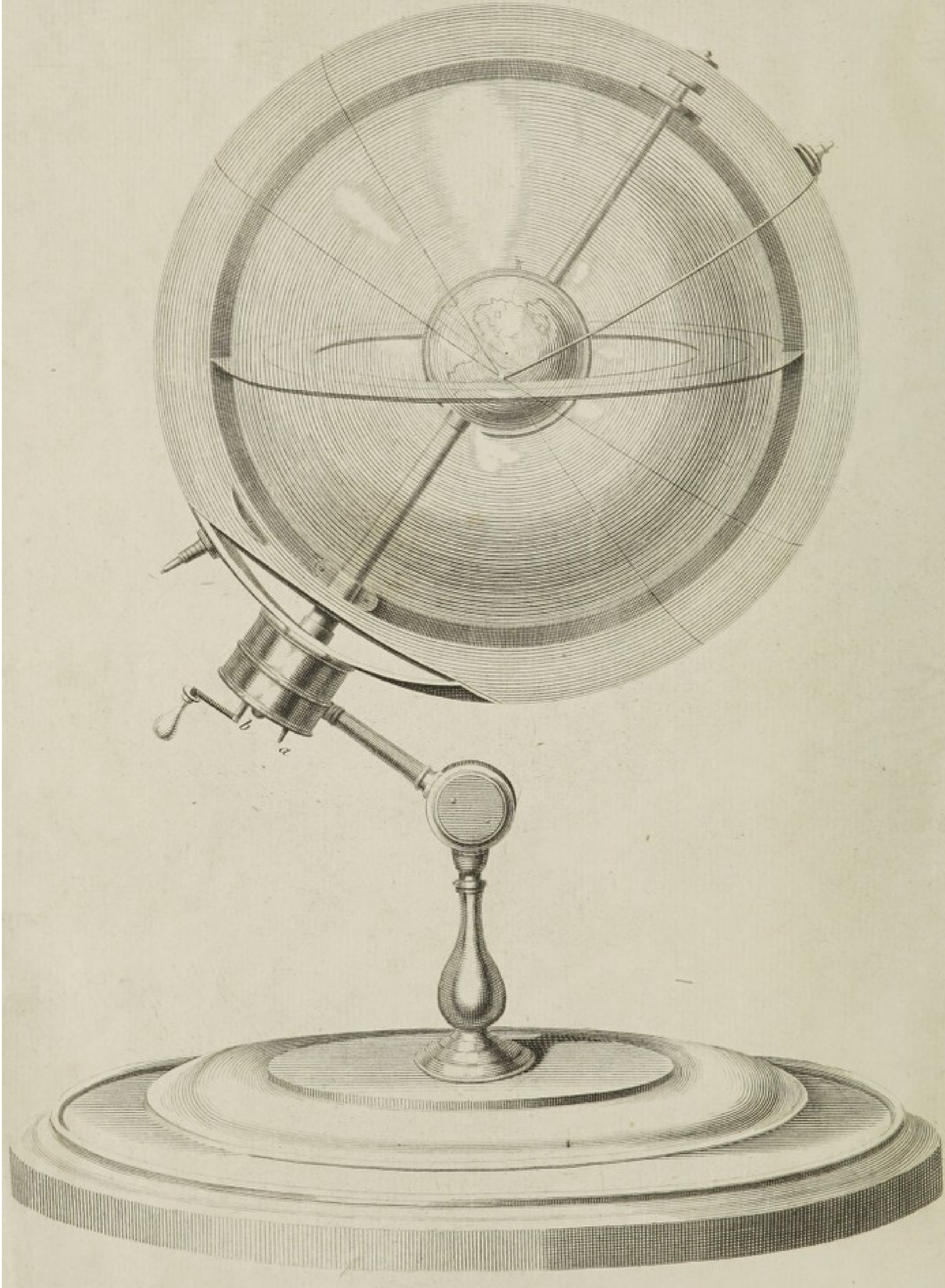

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ASTRONOMY,

IN FIVE BOOKS.

BY

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PREFACE.

ASTRONOMY is a ſcience which, in all ages and countries flouriſhing in arts and politeneſs, has engaged the attention of the curious: it has not only employed the pens of the moſt eloquent orators and embelliſhed the writings of poets of the moſt elevated genius; but has alſo been cultivated by the greateſt princes, the ableſt ſtateſmen, and the wiſeſt philoſophers; as will appear at large, when we come to look into the hiſtory of its riſe and progreſs in ſeveral parts of the world.

It ſhould not indeed be diſſembled, that the great inducement to ſearch into the nature and motions of the heavenly bodies with ſuch care and pains as many perſons have done was oftentimes the hopes they entertained of being thereby enabled to gratify a darling paſſion of human nature, the deſire of looking into futurity: how mankind came firſt to give into this opinion, and how groundleſs a fancy it is, will appear in ſeveral places of this work: not that I ſhall take the pains profeſſedly to ſhew the vanity of *judicial aſtrology*; this has already been done ſufficiently by ſeveral able hands[a]: I ſhall only make ſome ſhort remarks upon it as occaſion offers it ſelf.

It is not much to be wondred at, that among nations abandoned to idolatry and ſuperſtition, or immerſed in darkneſs and ignorance, it ſhould be believed that the ſtars are the diſpenſers of good and evil to the inhabitants of this lower world, and that by their configurations they point out to mankind which of theſe two is to be expected from their influences; but it ſeems ſtrange that ſo many of thoſe who had the light of revelation to guide them have embraced ſo abſurd opinions.

Idolatry and divination were of great antiquity among the Egptians[b]; *the Jews*, by their long ſtay among them when they were a rich and flouriſhing people, contracted a great fondneſs for their ſuperſtitions: after their going out of Egypt into the promiſed land they were to be ſurrounded by nations addicted to various kinds of idolatrous and ſuperſtitious practices; there was very good reaſon therefore why their law ſhould ſo expreſſly forbid, not only all idolatrous worſhip in general, and that of worſhipping the hoſt of heaven in particular, but all kinds of divination alſo, and particularly that of *obſerving times*[c], or enquiring after the lucky or unlucky moments of entring

a Cic. *de divinatione l.* 2. Favorinus *ap.* Gellium *l.* 14. *c.* 1. Sextus Empiricus *adverſus aſtrologos.* Auguſtin. *de civ. l.* 5. *c.* 1. *&c.* b Exod. 8. 26. Gen. 41. 8. c Lev. 19. 26. Deut. 18. 10, 14.

upon any action, which astrologers pretend to find out by the positions of the stars and planets. The sacred historians tell us, that, notwithstanding these prohibitions, the Jews frequently fell into the practice of the former of these abominations, and we have no reason to believe they did at those times keep clear of the latter: it is expressly recorded of *Manasseh* that in the beginning of his reign he was guilty of both, that he *worshipped the host of heaven, and observed times*[a]; and we may conclude the same of his people, from what we are told in general terms, that *he made Judah and the inhabitants of Jerusalem to do worse than the heathen*[b]. There is such a connection between star-worship and star-divination, that the latter of these has with great probability been thought to owe its origin to the former.

It has been observed by some, that the Jews were never guilty of idolatry after the Babylonish captivity: but it is certain that in after times they gave into the belief that the stars and planets have an influence upon the tempers and actions of men: to this purpose there are several passages in the *talmud*, wherein it is said what will be the disposition and circumstances of life of a man born under such or such a planet[c]: and though the wisest of them decry such notions, as indeed wise men of all times and places have done, yet we find one of their Rabbins[d] wrote a treatise of judicial astrology, and another[e] foretold the coming of their Messiah would be A.D. 1464, because then, as he pretended to find by his calculations, the heavenly bodies would be in the same state as they were at the time of the giving of the law. To mention no more, their attachment to this superstition sufficiently appears by a saying common among them to a proverb, *that every thing depends upon the stars*[f].

As to *the primitive Christians*, judicial astrology is by good interpreters thought to be one of those curious arts whereof some of the first converts shewed their detestation, by burning their books in great numbers, and to a considerable value[g]: however that be, it is condemned by some of the most ancient fathers[h]: afterwards, when the Christian religion had obtained the support of the secular power, we find astrologers, who had been banished Rome by some heathen Emperors[i], ranked in the same class with apostates, sacrificers to idols, magicians, enchanters and dealers in witchcraft; and together with them threatned by the canons of the church with excomunication[k]: and by the imperial laws with death[l]. This denunciation, we may suppose, for some time at least, very much discouraged the practice it was levelled at; but in

a 2 Kings 21. b 2 Chron. 33. 9. c Buxtorf. *florileg. Hebraic. tit. Sydera.* d Aben Ezra.
e Abraham *dictus Princeps apud* Picum *disput. in astrolog. l.* 5. *c.* 12. f Buxtorf. *ubi supra.* g Acts 19. 19.
h Tertullian. *de idololatr.* 9. Bardesanes & Origenes *ap.* Euseb. *præp. l.* 6. i Sueton. *in* Tiber. & Vitell.
k *Concil. Laodic. can.* 36. *v.* Photii *nomocan.* l *cod. l.* 9. *tit.* 18. *de maleficis et mathematicis.*

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the ſucceeding ages of barbariſm and ignorance, and eſpecially after the Europeans became acquainted with the learning of the Arabians, aſtrology prevailed ſo much that in the 14th century that great genius *Picus* Earl of Mirandola wrote againſt it, and that in a very maſterly manner; expoſing, with great learning, acuteneſs and ſtrength of reaſoning, the vanity of all the rules of that pretended art: the aſtrologers publiſhed anſwers to *Picus:* ſome of them boaſt, as a full evidence of the truth of their art, that the death of that incomparable perſon happened according to their predictions; one of them[a] is ſaid to have foretold that he ſhould dye in the 33d year of his age: another[b] tells us three aſtrologers had pronounced he would not live to ſix and thirty, and that this provoked him to write againſt them: the truth is this, *Picus* dyed in his 32d year; now if they really came thus near the fact as is pretended, and thoſe predictions were not trumped up after the event, which is often the caſe, it did not require any great ſagacity to gueſs that ſo extraordinary a perſon as *Picus*, of ſo much fire and ſo great application, would be ſhort lived: perhaps, if they had found he was likely to prove them falſe prophets, he might have been in ſome danger of having his life ſhortned by them; this is no more than what the famous *Cardan* is ſaid to have practiſed upon himſelf, who having, calculated his own nativity, and found in what year of his age he ſhould die, ſtarved himſelf to death, to verify the prediction[c].

That aſtrologer pretends to out do all that went before him in calculating nativities[d]; he tells us he beſtowed an hundred hours upon that of our *Edward* the 6th, from which he foretold ſeveral ſickneſſes which would attack him in the 34th and 55th year of his age; whereas that hopeful prince did not outlive his ſixteenth year. It is pleaſant enough to ſee how *Cardan* endeavours to bring himſelf off after this event: he ſays he will not, like ſome other aſtrologers, pretend that he knew what would happen, and kept it to himſelf only out of fear; but that he had omitted ſomething in his calculation, which, if he had gone through it, as he might have done in half an hour more, would have ſhewed him that the King would be in great danger of death in his 16th year: that he looked upon this omiſſion as a piece of good fortune to himſelf, on account of the great danger ſuch a prediction might have brought him into, when he was at the Engliſh court: and he mentions two aſtrologers to whom foretelling the untimely death of princes had pro-

a Bellantius *ap.* Gaſſendum *de ſyderum effectibus prope finem.* b Gauricus, *v. Elogia* Pici *ejus operib. prefixa.* c Gaſſendus *ubi ſupra.* d *comment. in* Ptolem. *et in lib. geniturar.* *Cardan* pretended to calculate the nativity of *Jeſus Chriſt*, and to deduce from thence the nature and duration of the Chriſtian religion: others have been guilty of the like preſumption: ſee *Bayle*'s dict. art. *Cardan.*

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ved fatal. This was not the only time *Cardan* was out in his predictions: I believe it would not do him much wrong, to apply to him what he ſays himſelf of the generality of aſtrologers, that *we ſhould be in the right to expect events juſt contrary to what they foretell.* In the laſt century judicial aſtrology was again attackt by the learned *Gaſſendus:* this was no unneceſſary work; for, notwithſtanding what *Picus* had written, it continued to be in great vogue, not only in Italy, where it was patronized by Popes, Cardinals, and many of the petty Princes; but in other parts of Europe alſo.

But, how vain ſoever their pretenſions be who would perſwade us they can read future events in the ſtars, aſtronomy ſtill deſerves to be cultivated with the greateſt application, as it is one of the nobleſt branches of natural philoſophy; whether we conſider the dignity of the ſubject, the certainty which we are able to arrive at in many parts of it, or its uſefulneſs in civil life.

As to the firſt of theſe, the aſtronomer has for the ſubject of his ſpeculations the whole univerſe of material beings: he conſiders the nature of matter in general, and enquires by what laws the ſeveral parts of matter act upon one another: but his thoughts are more particularly employed about thoſe great bodies that compoſe the viſible ſyſtem of the world, which are in common ſpeech comprehended under the appellation of *the ſun moon and ſtars.* He finds the magnitude of theſe to be vaſtly greater than is commonly imagined: he is able to demonſtrate, that very few of them are ſo ſmall in bulk as the earth we live upon; and that much the greater part of them far exceed it in dimenſions: that the ſun appears ſo ſmall as he does, by reaſon of his great diſtance from us; whereas in reality he is in magnitude equal to a million of our earths: he diſcovers that there are ſeveral other earths, ſome of them much larger than ours, which receive heat and light from the ſun, are carried round him with prodigious velocities, and may probably be inhabited by various creatures both rational and irrational: he knows that the ſtars which ſeem to be ſo thick ſown in the firmament are at immenſe diſtances from one another, as well as from us: he has proofs to ſhew, that, how ſmall ſoever they appear to us, they are really very large bodies, many of them not inferior to the ſun in magnitude; and that there is therefore reaſon to believe they may ſerve for the like uſes, of giving light and heat to habitable earths with which they are environed: his glaſſes ſhew him a prodigious number of ſtars which by reaſon of their vaſt diſtances from us are inviſible to the unaſſiſted eye: and, the better his glaſſes are, the greater is the number of ſtars thus diſcovered: this makes it reaſonable to conclude that there is ſtill an innumerable multitude of them diffuſed through the immenſity of ſpace, beyond the reach of any glaſſes that can ever be made. How magnificent

cent an idea does this give us of the univerſe, in compariſon of what it appears to an ordinary ſpectator, who looks upon the ſtars only as groupes of glittering ſpangles fixed by way of ornament in the vaulted roof of heaven, or as ſo many little lamps lighted up there, for no other uſe than to ſend a faint glimmering upon the earth, of leſs ſervice to the inhabitants thereof than the light which the moon alone furniſhes them with?

The pride of man is apt to make him fancy, that all things were made for his uſe: he has indeed a dominion given him over thoſe works of God which are within the limits of the earth and ſea[a], but it reaches no farther: the Pſalmiſt, when he contemplated the heaven, and the luminaries thereof, the ſun, moon, and ſtars, the handy work of the great Creator of all things, which he has diſpoſed and ſet in order in ſo much beauty and perfection, was ſo far from thinking that all theſe glorious beings were created for the ſervice of man only; that he is humbled into an admiration of the great condeſcenſion of the author of ſuch wonderful works, that he ſhould vouchſafe to caſt an eye of regard upon man, and make him the object of his favour[b].

It is an obſervation of a philoſopher[c] that mathematical ſciences have a tendency to purify the ſoul: the active principle within us muſt have ſome employment; if it be taken up with abſtruſe ſpeculations, it will be leſs attacht to ſenſual pleaſures: but, if we go no farther than that, we may fall very ſhort of acting up to the dignity of a reaſonable nature: in order to this, we muſt carry on our contemplations of the frame and conſtitution of the univerſe to their proper mark, ſo as, from beholding the wonders of the creation, to be brought to adore the wiſdom power and goodneſs of the Creator: there is indeed no part of the creation which does not diplay theſe attributes to an attentive mind; though *an unwiſe man doth not well conſider this, and a fool doth not underſtand it:* but *the heavens*, in a more eminent manner, *declare the glory of God, and the firmament ſheweth his handy-work*[d]*:* in this divine book, the moſt unlettered may find enough to excite their admiration, though it will diſplay the greateſt wonders to thoſe who peruſe it with the cloſeſt attention: but then we muſt take care always to approach it, as we ſhould the other book of God, the holy ſcriptures, with reverence and humility; not having too high an opinion of our own abilities, as if we could with the line of human reaſon fathom all the depths of the divine counſels; *but thinking ſoberly as we ought to think*: for want of theſe diſpoſitions, ſome men read the ſcriptures, and become teachers of new doctrines, departing from the ſimplicity of the primitive faith; others philoſophiſe about the viſible creation, till they forget the inviſible creator; till they become materi-

a Pſal. 8. 6, 7. b Pſal. 8. 4. c Hierocles *in aur. carm.* Pythag. d Pſal. 19. 1.

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alifts or epicureans; and fancy they can account for the formation and preſervation of this beautiful frame of the univerſe, by matter and motion: or, at beſt, only conſider it as a curious machine, without ever lifting up their thoughts to the adorable author and Lord of all things.

As to the *certainty* of this noble ſcience, there are many things therein which, though to an ordinary underſtanding they ſeem incredible, or beyond the reach of human ſkill to know, are capable of ſtrict demonſtration: when we are ſpeaking of the vaſt magnitude, the immenſe diſtance of ſome of the heavenly bodies, and the prodigious velocity of their motions, a man unacquainted with the methods by which we arrive at the knowledge of thoſe matters is apt to think it all conjecture; whereas we go a great way in theſe ſpeculations by the infallible ſteps of arithmetic and geometry.

The ignorant vulgar may think it a trifling and unprofitable employment, for a man to ſpend his time in enquiring into the nature and motions of the ſtars: but *the uſefulneſs of aſtronomy* will quickly appear, if we conſider what a dependance ſeveral other arts and ſciences have upon it: without aſtronomy, *chronology* and *geography* would be more imperfect than they are; and, in conſequence of that, *hiſtory* would be liable to greater uncertainty than it is. Without aſtronomy, we ſhould be ſo far from being able to meaſure time ſo accurately as we now do, by the help of ſundials, clocks, and watches; that we could not ſo much as divide the year into months, or know the length of the days and nights, or mark out the ſeaſons exactly enough even for the purpoſes of agriculture, and other uſes of common life. Without aſtronomy, all intercourſe and commerce with diſtant nations muſt ceaſe; the ſailor could neither know the ſituation of the place to which he is bound, nor be able to find the way to it. In ſhort, it is to this ſcience that we owe the firſt attempt to diſcover America, as well as the ſucceſs of that attempt: and it is to the ſame that we are beholden for the means of ſailing thither with ſafety and certainty, to fetch home the riches and rarities of that new world.

It is now time to give the reader *ſome account of the following treatiſe*, and in what manner I have handled the ſubject before me: my propoſals promiſed to make the ſtudy of aſtronomy eaſy to perſons unacquainted with mathematics; this, I hope, it will be thought is performed, if it be made much eaſier than was ever done before: in order to this, I have in the introduction explained ſuch mathematical terms as muſt be made uſe of, and ſet down ſeveral propoſitions to which reference is ſometimes made in the body of the work: ſome of theſe are very neceſſary to be previouſly known, and are eaſy enough; others, which are more difficult, and are inſerted either to make the introduction more methodical, or for the ſake of thoſe who have

have a mind to look farther into the ſubject, are diſtinguiſhed from the reſt by a full point placed before them, as may be ſeen page 12; 14, 15, &c, that they may be paſſed over by ſuch readers as deſire only to have a general view of aſtronomy: my intention at firſt was to have diſtinguiſhed the more difficult parts from thoſe eaſy to be underſtood, all along throughout the work; but, upon conſidering the great difference there muſt needs be in the capacities and attainments of my readers, I thought that improper: only I have in ſome places thrown the moſt abſtruſe mathematical demonſtrations into *the remarks*, where they may be paſſed by without breaking the connection: I muſt however take notice, that the remarks are not all of this ſort; for ſome of them are philological, as thoſe upon the names and characters of the ſun and planets, book 2 chap. 3; and thoſe upon the ſigns and their characters, book 2 c. 6: others are explanations of or additions to ſomething that went before, as in book 2 c. 14.

As for thoſe readers who are the leaſt prepared for ſtudies of this ſort, I would not have them diſcouraged by ſeeing ſchemes of lines and circles, and ſome of them of an appearance a little complicated; for they will often find them to be no more than pictures or perſpective views of the heaven, or of the routes which the heavenly bodies are ſuppoſed to take, or of the tracks wherein they appear to us to move. The line which an arrow or a bullet ſhot through the air deſcribes may be drawn upon paper, though neither of them leaves any viſible traces behind it; in the ſame manner, the aſtronomer repreſents the motions of the heavenly bodies: and, in order to this, he is not always confined to the earth, and the proſpects which he has from thence; but, one while, he ſuppoſes himſelf to be carried to the ſun, and conſiders in what manner our earth and the planets would from that point of ſight appear to go round him: at another time, he imagines himſelf to be an inhabitant of one of the planets, and from thence to view the ſun, our earth and the reſt of the planets: and ſometimes, when he has beheld the vaſt concave of the heaven, adorned with numberleſs ſtars, his imagination tranſports him out of the confines of this viſible ſyſtem, to ſome point at an immenſe diſtance from it, from whence he takes a view of the convex of this imaginary ſphere: *the common celeſtial globe* ſhews the heaven with the ſtars in their proper ſituations in this view: *the glaſs ſphere*, of which I have given a picture for the frontiſpiece, and a deſcription page 71, has a repreſentation of the ſame ſort, on its outſide; and the inner concave ſurface of it ſhews how the ſtarry heaven by which we are ſurrounded appears to us. This machine, which was invented by me above 20 years ago, as is well known to a great number of people, has ſince been imperfectly copied by ſeveral perſons, and by ſome

of them, ignorantly enough, called the ſphere of *Archimedes:* it ſeems they had heard of the glaſs ſphere of that great mathematician, but had not met with thoſe authors who give an account of it; if they had, they would have found it very different from mine. I have ſometimes conſidered the heaven as a ſphere of glaſs, that ſo any circles conceived to be drawn upon it might be exhibited entire; this will be found a great help to the imagination.

It will not be amiſs to inform thoſe who have not ſeen *my aſtronomical apparatus* at Pembroke Hall in the Univerſity of Cambridge, that I have there a large hoop about 20 feet in diameter, and 3 in breadth, whereon are delineated the conſtellations of the zodiac, with the ecliptic and ſuch other circles as I thought proper: ſitting in the midſt of this I have the ſame view of things as if I was looking at ſo much of the ſtarry heaven it ſelf. If a ſphere of theſe dimenſions were made to turn round a ſtage whereon the ſpectators were placed, with a *planetarium* or *Orrery* in the center; moſt of the appearances in aſtronomy might be exhibited thereby in a more eaſy and familiar manner than has ever yet been done by ſchemes or mechaniſm. I ſhould have been glad to have been enabled to erect ſuch a fabric, for the ſervice of the younger part of the univerſity whereof I have been many years a member; but have no great reaſon to expect to be aſſiſted and encouraged in ſuch an undertaking: however I intend, if I have time, to leave behind me a model of ſuch a machine; though I think the hint I have here given is enough to direct any ingenious perſon who underſtands aſtronomy and mechanicks, how to execute that deſign. What I have already done this way has helped to furniſh my book with ſeveral ſchemes which will be found entirely new. I have in ſome of my figures treſpaſſed upon the rules of perſpective, by ſhewing a little more than the eye takes in at one view; this is done but ſeldom, only when I thought I could thereby convey a more perfect idea of what I intended to repreſent. I have quoted authors, ſometimes as vouchers of facts, ſometimes to ſhew to whom I am beholden, and ſometimes for the ſake of the youth of the Univerſities, whom I had often in my thoughts, to let them know where they may find the ſubjects treated of more at large; though I have generally given the ſubſtance of what has been ſaid by former writers, where I thought it worth the while: ſuch of my notes are in latin, as I thought would be of no uſe to an engliſh reader; for whoſe ſake I have generally quoted thoſe authors in engliſh which I knew were tranſlated into that language, though I had them before me in the originals.

As my chief deſign was to make the knowledge of the heavenly bodies as eaſy as the nature of the thing will admit, I have taken all the care I was able to diſpoſe the ſeveral parts of my work in ſuch a manner, that what comes

comes firſt in order prepares the way for what is to follow; the want of which method is often an occaſion of great obſcurity in books that treat of any ſcience. In the ſtyle I have ſtudied conciſeneſs, as far as is conſiſtent with perſpicuity. The paragraphs or articles which have numbers prefixt to them I call *ſections*, and refer to them by the character §; though that mark as well as the word ſection is made uſe of by ſome authors to ſignify a larger diviſion. A ſhort view of the particulars treated of may be ſeen, by running over the heads of the chapters, and the words printed in *italic*, or by the table of *contents* at the end of this volume; I have made it very full, and marked the moſt difficult parts with an obeliſk or dagger.

Since the *addenda* were printed off, I have met with a farther confirmation of the *change of the obliquity of the ecliptic* mentioned p. 274 & 356: it is from the obſervations of the Chineſe aſtronomers, who are ſaid, in the year 66 before Chriſt, to have ſuppoſed the obliquity of the ecliptic 24°; and in the year 1280 after Chriſt, to have found it 23° 33′ 40″ 17‴ or 18‴. *v. Obſervations mathematiques & aſtronomiques &c tirees des anciens livres Chinoiſes par Souciet, Vol.* 2. *& act. eruditor. Lipſ. menſ. Auguſt. Ann.* 1732.

I ought now to make ſome apology to my ſubſcribers for my long delay: this, among other reaſons which it is not worth while to trouble the public with, has been owing in ſome meaſure to my enlarging my firſt plan: ſo that I hope I ſhall have their pardon, when they find I have given them a good deal more than I promiſed in my propoſals; as *the principles of navigation, the uſe of maps and globes*, and ſome other particulars which I thought would make the work more entertaining or uſeful; though no body would have had any reaſon to complain of me if I had omitted them: but an author that intends to content his readers muſt endeavour in the firſt place to pleaſe himſelf, it is in writing as in building; we are often drawn in farther than we at firſt intended: this has ſwelled my book into two volumes, and obliges me, contrary to my firſt deſign, to publiſh only the firſt at preſent: the public may be aſſured the ſecond ſhall follow with the utmoſt expedition I am able; great part of it being already printed in books I uſe to put into the hands of thoſe who attended the courſe of lectures in aſtronomy, which, for above 20 years I have been conſtantly reading in this Univerſity.

ERRATA.

Page 11. line 2. for AF read AE. p. 12. l. 5. f. DC r. CE. p. 19. l. 15. f. 1008 r. 1034. ibid. l. 19. f. 1016064 r. 1069156. f. 1008 r. 1034. p. 19. l. 1. f. twice r. four times. p. 21. l. 20. f. ACE r. ACB. p. 22. l. 22. f. verſed r. verſed ſine. ibid. l. 35. f. AC, is the verſed ſine r. AR, is the verſed ſine. p. 23. l. 11. f. BT r. BI. ibid. l. 15. f. DF r. BF. p. 31. l. 8. f. the center of the quadrant r. his eye. ibid. l. 9. f. it r. the quadrant. p. 37. in the margin f. 29 r. 92. p. 42. l. 33. f. 197474980 r. 197819550. p. 45. l. 20. f. D r. L. ibid. l. 23. f. 9. r. 1. ibid. l. 27. f. whether it be thinner, or more denſe than the firſt r. if it be thinner than the firſt. ibid. l. 30. f. different r. thinner. p. 48. in the margin dele 93 & 94. p. 49. l. 25. f. DCE r. FEG. ibid. l. 27. f. C r. E. p. 56. l. 26. for ab read na. for bc in one to bc read bc in one to mn. ibid. l. 27. for cd to cd read cd to ml. p. 57. l. 27. for g to f read g to h. for f to e read h to i. ibid. l. 28. for e to d read i to l. p. 59. l. 34. dele from g to h. ibid. l. ult. & in the margin f. 151 r. 152. p. 60. l. 2. dele na & gh. ibid. l. 4. insert gh, before hi, & na, after mn. ibid. l. 21. f. G r. I. p. 62. l. penult. ult. f. on the eaſt ſide of Spain r. round the cape of Good-hope. p. 63. l. 24. f. ſemidiameter r. diameter. ibid. l. 25. f. above r. about. ibid. l. 34. f. 273 r. 274. p. 64. l. 4. f. 274 r. 275. ibid. l. ult. f. 275 r. 276. p. 65. l. 18. f. A r. Z. p. 67. l. 2. for a read A. ibid. l. 17. f. over r. in the focus of. p. 72. l. 8. after epqs; inſert the plane of. p. 75. l. 21. for a read g. p. 76. l. 20. f. PGS r. PHS. ibid. l. 21. f. PHS r. PIS. ibid. l. 23. f. PES r. PFS. p. 81. l. 37. f. anſwer to 15″ r. anſwer to 1′. f. 15 thirds r. 1 ſecond. p. 84. l. 36. after London: inſert the third column ſhews the ſame in degrees, minutes, &c: p. 87. l. 21. for eq read ao. p. 88. l. 3. f. PHO r. PIO. for pho read pio. p. 97. l. penult. f. about one degree r. a little more than one third of a degree. p. 98. l. 8. f. 12th of december r. 11th of june. p. 105. l. ult. f. ſeveral r. ſome. p. 109. l. 7. after vertical inſert much. p. 110. l. 7, 8. f. moveable round its center, and with teleſcope ſights r. with a teleſcope moveable round its center. ibid. l. 30. f. 60° 30′ r. 62° 30′. ibid. l. 32. f. 40° 30′ r. 42° 30′. p. 112. l. 34. f. COP r. CPO. ibid. l. penult. f. other ſide r. other ſides. p. 114. l. 2. f. 213$\frac{1}{8}$ to 600; juſt the ſame as r. 600 to 209; a little different from what. p. 115. l. 9. f. eliptic r. ecliptic. ibid. l. ult. f. l. 2. r. l. 3. p. 116. l. ult. f. higher r. lower. p. 117. l. 19. f. § 419 r. § 412. p. 120. l. 27. f. 235. r. 435. p. 128. l. 27. f. 900 r. 9000. p. 131. l. 2. f. 5703 r. 57033. ibid. in the margin f. 58 r. 57. p. 134. l. 12. dele and then for every 10′, from 1°, to 2°: p. 136. l. 18. f. 2094655 r. 20949655. p. 146. l. 37. f. London r. Naples. ibid. l. penult. f. Naples r. London. p. 150. l. 13, 16, 22. dele E. p. 151. l. 17. after rhumb inſert except the eaſt and weſt. p. 154. l. 18. f. § 258 r. § 257. p. 157. l. 15. f. chap. 17 r. chap. 16. p. 158. l. 7. & in the margin dele 89. ibid. l. 33. f. extream meridians r. bounding lines. ibid. l. 37. f. extream parallels r. bounding lines. p. 160. l. 19. f. 180 r. 120. p. 165. l. ult. f. Plin. nat. hiſt. l. 4. c. 10. r. d Plin. nat. hiſt. l. 4. c. 12. p. 182. l. penult. f. 368 r. 369. p. 190. l. 12. dele certainly. p. 199. l. 2. after ſun, inſert ſome of them. p. 204. l. 12. f. § 339 r. § 340. p. 205. l. 2. f. S r. ☉. p. 218. l. 10. f. a planet r. mercury. ibid. l. 11. after orbit inſert proximè. ibid. l. 12. after L: inſert the greateſt poſſible elongation of venus is when the viſual line is a tangent to her orbit, and the earth is near her perihelion. p. 224. l. 28. f. 1608 r. 1708. p. 229. l. 12. f. P r. D. p. 231. l. 19. for n read a. p. 232. l. 16. f. § 670 r. § 620. p. 233. l. 13. f. § 706 r. § 711. p. 236. l. 4. f. lemma 3 r. lemma 4. ibid. l. 20. f. retrograde to direct r. direct to retrograde. ibid. l. 24. f. direct to retrograde r. retrograde to direct. p. 237. l. 37. f. c. 16 r. c. 6. ibid. l. ult. f. c. 10 r. c. 14. p. 240. l. 22. f. at A, fig. 47 r. at E, fig. 48. ibid. in the margin. f. 47 r. 48. p. 268. l. 3. f. EQ r. AQ. ibid. l. 25. f. NAS r. NDS. ibid. l. 27. f. E r. Q. p. 276. l. 12. f. § 802 r. § 805. p. 279. l. 17. f. 1700 r. 1692. p. 288. l. 32. f. DA r. PB. ibid. l. 33. f. DB r. PA. p. 301. l. 5. after by and by[a]: inſert what is ſaid here and in the remarks § 879 is true only of ſtars that are on the ſame ſide of the true pole as the apparent pole is when the ſtar paſſes through the zenith: by the true pole I mean the center of the circle deſcribed by the earth's axis extended, ſee § 829. p. 312. l. 1. f. quadrature r. conjunction or oppoſition. ibid. l. 2. f. A or C r. B or D. p. 319. l. 7. f. ABCD r. ABCH. p. 321. l. 14. after than inſert the north pole is.

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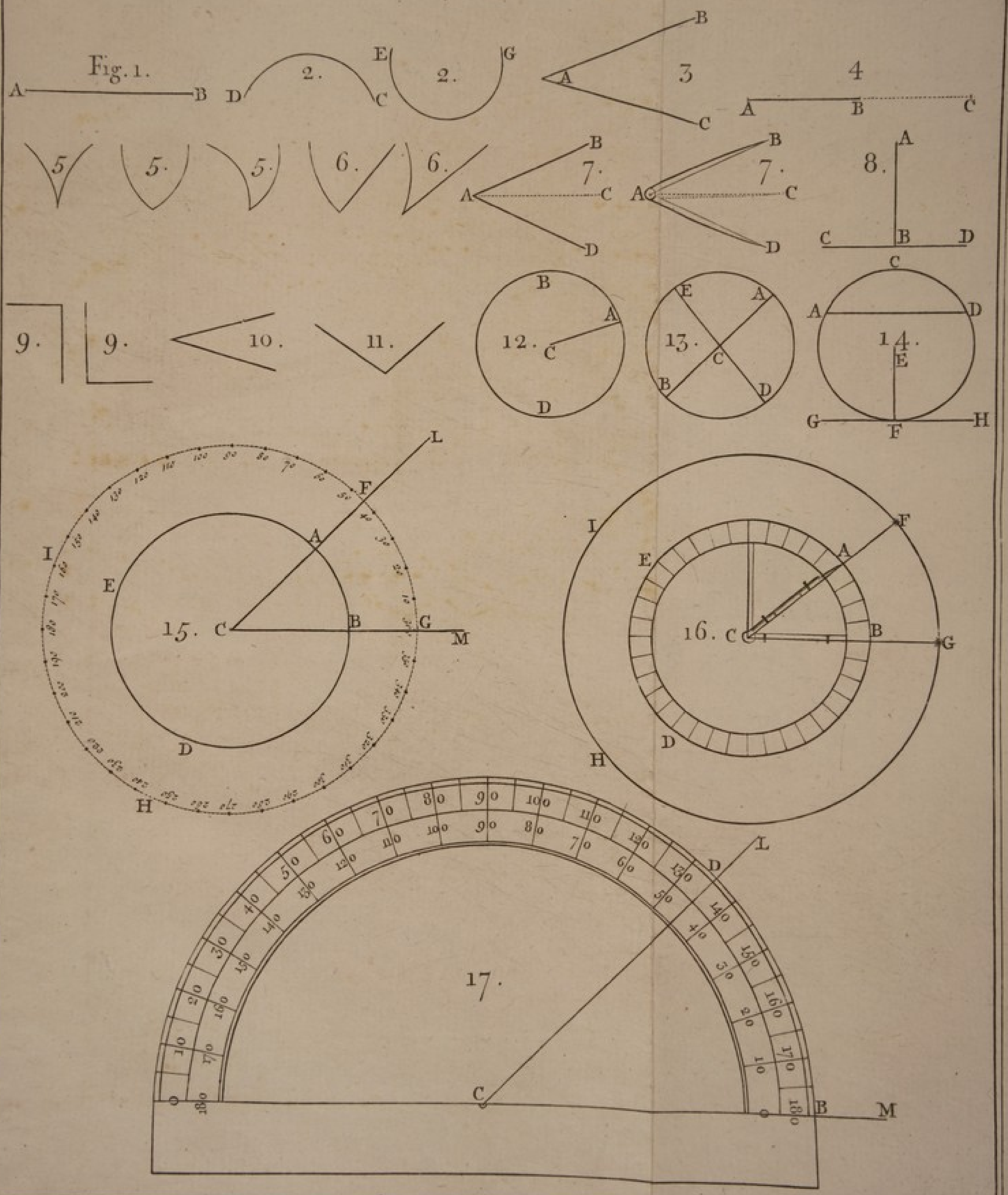
Introduction



INTRODUCTION.

§. 1. ASTRONOMY IS A SCIENCE WHICH TREATS OF THE HEAVENLY BODIES: by the heavenly bodies are meant the ſun, moon, ſtars, planets, and comets: the nature of theſe it is the buſineſs of an aſtronomer to ſearch into, to conſider their order, diſtance, magnitude, ſhape, motion, light, and other particulars which relate to them; their different appearance to the inhabitants of the earth, at different times, and in different places, and to enquire into the cauſes thereof: in this enquiry, the earth alſo upon which we live, being the place from whence we view all the appearances in the heaven, muſt of neceſſity be conſidered, with regard to its ſhape and magnitude, its ſituation in the univerſe, its motion, or reſt, and many other affections and properties. Among the ancient Greek and Latin writers aſtronomy and aſtrology were but different names for the ſame thing, but in modern language, an aſtrologer is one who pretends to be acquainted with the influences of the heavenly bodies upon our earth and its inhabitants, and would have it believed that, from their various poſitions, aſpects, and configurations, he can foretell future events.

FIG. 2 It is impoſſible to treat of aſtronomy without borrowing, ſeveral terms from that part of the mathematics which is called geometry, ſuch as a line, an angle, a circle, *&c:* theſe terms I ſhall, for the ſake of thoſe readers that are unacquainted with that ſcience, take care to define and explain, before I make uſe of them.

3 The object about which mathematical reaſoning is employed is *quantity*; that is, every thing concerning which we may enquire how great or how much it is: thus, magnitude, weight, number, duration, motion, and many other affections or properties which may be conceived to belong to material beings, may be conſidered as quantity.

4 *Magnitude* is that quantity which we conceive extended and diviſible into parts. There are three ſorts of magnitude, *viz.* a line, a ſurface, and a ſolid.

5 *A line* is that magnitude in which we conſider extenſion in length only, without breadth or thickneſs: thus, if I imagin a line drawn from one ſtar in the firmament to another, I conſider nothing but the length of that line, or the diſtance between the two ſtars; it is true, if I draw a line upon paper, it muſt have ſome breadth to make it viſible, and if I form the idea of a viſible line in my mind, I muſt give that ſome breadth likewiſe, to make it the object of my imagination; nevertheleſs, if I would conſider a line as mathematicians do, I muſt conſider the length of it only, without any regard to its breadth.

6 *A line* is either *ſtrait*, which is ſometimes called *a right line*, or crooked,
1 which is frequently called *a curve*; the line AB, fig. 1, is a ſtrait line; the lines
2 DC and EG, fig. 2, are curves.

7 A ſtrait line may be imagined to be continued or extended both ways as far as we pleaſe; when no bounds are ſet to this extenſion, the line is ſaid to be *infinite*, or more properly *indefinite*.

8 *A point* is underſtood to be without any extenſion at all: to make a point viſible upon paper, I muſt give it ſome magnitude, and when I form the idea of a viſible point in my imagination, I muſt give that alſo ſome magnitude, though the leaſt that is poſſible, as when I think of the point of a needle; nevertheleſs mathematicians conſider a point as without extenſion, without parts and indiviſible: thus the ends of a line are points, that is, they are conſidered only as bounds which terminate the line, or as places to which the line is extended; if the ends of a line were conceived as extended, and making parts of the line, they would be then ſhort lines and not points. By this time I ſuppoſe it appears that geometrical points and lines are objects of the underſtanding, not of the ſenſe or imagination; and our ideas of them are formed by abſtraction after this manner; from the idea of a viſible point the mind takes away every thing but place; from the idea of a viſible line the mind takes away every thing but extenſion in length only.

9 *A*

9 *A line* may be conceived to be *deſcribed* by the motion of a point: thus, I may imagin the line AB, fig. 1, to be deſcribed by the motion of the point A, from A to B. FIG. 1

10 *A ſurface* or *ſuperficies* is that magnitude in which we conſider extenſion in length and breadth only: thus, a piece of land is meaſured how long and how broad it is, without any regard to the depth of the earth: the ſhadow which is caſt upon the ground in ſunſhine by an opake body gives us a ſenſible image of a ſurface, for a ſhadow has no thickneſs or depth.

11 A ſurface is either plane or curve; the ſurface of a common looking-glaſs, or the ſmooth ſide of a marble ſlab made exactly flat and even, may repreſent *a plane ſurface:* a plane ſurface is uſually called *a plane.*

12 *A curve ſurface* is, either *convex*, that is, ſwelling out, as the outſide of an egg-ſhell, or *concave*, that is, hollow, as the inſide of an egg-ſhell.

13 *A ſurface* may be conceived to be *deſcribed* by the motion of a line, not directly endways; a ſtrait line deſcribes a plane; a curve deſcribes a curve ſurface: this will be illuſtrated when we come to conſider the formation of a circle, ſquare, or globe: if a line is moved directly endways, it will not deſcribe a ſurface, but only a line.

14 A plane ſurface may be imagined to be extended every way as far as we pleaſe: when no bounds are ſet to this extenſion, the ſurface is ſaid to be infinite, or rather indefinite.

15 Any ſurface terminated or encloſed every way is called *a figure:* a plane ſurface terminated or encloſed every way is called *a plane figure:* a plane figure may be formed by one curve, or by two, or by a curve and a ſtrait line; but a plane ſurface cannot be encloſed by fewer ſtrait lines than three.

16 *The area* of a plane figure is the quantity of ſurface contained therein.

17 *An angle* is the opening of two lines which touch one another in a point, and do not lie directly one againſt the other endways: thus, fig. 3, let the line 3
AB touch the line AC in the point A, the opening between theſe two lines is called an angle.

Some define it thus, an angle is the inclination towards each other of two lines which meet in a point, &c: the difference between this definition and the former is that in this, we conſider the relation between the lines, as they come towards the point where they touch, in the other, as they go from it.

It is mentioned in both definitions, that the lines, in order to form an angle, muſt not lie directly endways, becauſe two ſtrait lines which lie ſo and touch, will not form an angle, but make one ſtrait line: thus, fig. 4, the lines AB and 4
BC form one ſtrait line, AC: two curves alſo, which lie directly one againſt the other endways and touch, will not make an angle, but form one curve; thus, fig. 13, the curves AE and EB make one curve, AEB. 13

FIG. 18 An angle is rectilinear, curvilinear, or mixt. *A rectilinear angle* is formed
3, 5 by two ſtrait lines, as in the third figure; *a curvilinear angle* by two curves, as
6 in the fifth figure; *a mixt one* by a ſtrait line and a curve, as in the ſixth figure. I am at preſent treating of rectilinear angles.

3 19 The lines which form an angle, are called its *legs:* the point A, fig. 3, where they touch one another, is the *vertex* of the angle, or *the angular point.*

20 An angle is uſually marked with three letters of the alphabet, or other marks, one placed at the vertex, the other two at the other ends of the legs; in expreſſing an angle, the letter or mark at the vertex is always named in the
3 ſecond place: thus, the angle, fig. 3, may be called BAC or CAB; by this means, ſeveral angles which touch in one point may be diſtinguiſhed from one ano-
7 ther; thus, fig. 7, there are three angles touch in the point A, *viz.* BAC, CAD, and BAD. Sometimes, when it can be done without the danger of occaſioning any miſtake or ambiguity, an angle is expreſt by one letter or mark only: thus I may
3 call the angle which is drawn in the third figure, the angle A.

21 *The quantity of an angle* does not depend upon the length of the lines which form it, but upon the wideneſs of their opening: imagin the two lines
7 AB and AC, fig. 7, to be faſtened together at A, as with a joint, ſo as to be moveable like the legs of a pair of compaſſes; the wider you open them aſunder, the larger angle will they form, the nearer you bring them together, the leſs will
7 the angle be between them: thus, fig. 7, the angle BAD is greater than the angle BAC. How the quantity of an angle is meaſured, will be ſhewn when a circle is treated of, § 30.

8 22 If one ſtrait line AB, fig. 8, ſtands exactly upright upon another CD, between the ends of it, there will be formed at the point B two angles, *viz.* ABC and ABD, which will be equal, becauſe the line AB is ſuppoſed to ſtand upright, and not lean one way more than another: ſuch are called *right angles*, and the line AB is ſaid to be *perpendicular* to CD. Two lines may alſo be perpendicular
9 to each other, and form a right angle, when they touch at one end, as fig. 9.

10 23 Any angle leſs than a right one is called *an acute angle*, as fig. 10; any
11 angle greater than a right one is called *an obtuſe angle*, as fig. 11: and both acute and obtuſe are called *oblique angles.*

12 24 If a ſtrait line CA, fig. 12, be fixt at one end C, and the other end A be carried round, it will deſcribe a figure called *a circle*: the curve ABD is *the circumference*, the point C at the immoveable end of the line is *the centre* of the circle; any ſtrait line drawn through the centre and terminated at each end by
13 the circumference is *a diameter* of the circle: thus, fig. 13, AB and DE are diameters. Every diameter divides a circle into two equal parts, which are called
13 *ſemicircles:* any ſtrait line drawn from the centre to the circumference, as CA, CB, CD, CE, is *a ſemidiameter* or *radius* of a circle.

25 All

25 All ſemidiameters of the ſame circle are equal; this is evident from the manner of drawing a circle; for the deſcribing line AC, fig. 12, is ſuppoſed to continue of the ſame length, all the while it is carried round; and if a circle be drawn with a pair of compaſſes, the feet of the compaſſes are all the while kept at the ſame diſtance the one from the other. FIG. 12

26 A circle is properly the whole figure, § 24; however, when we name a circle, we frequently mean the circumference only; ſometimes by a circle is meant only the ſurface contained within the circumference, but this is properly *the area of a circle:* the ſame is to be obſerved in ſpeaking of a ſemicircle.

27 A piece of the circumference, is called *an arch*, or rather *an arc of a circle*, thus, fig. 14, the line AD divides the circle into two arcs, ACD and AFD: a ſtrait line drawn from one end of an arc to the other is called *the chord* of that arc: thus the line AD is the chord of the arc ACD, or of the arc AFD. 14

28 A ſtrait line is ſaid to be *a tangent to a circle* when it only touches it in a point, in ſuch a manner, that, if it were extended both ways from the point of contact, it would not enter into the circumference, or cut any part of it: thus, fig. 14, GH is a tangent to the circle ACDF: geometers demonſtrate that a radius of a circle drawn to the point of contact is perpendicular to the tangent: thus, fig. 14, the radius EF is perpendicular to GH: *Eucl. l.* 3. *prop.* 18. 14 14

29 Every circle may be imagined to be divided into 360 equal parts, which are called *degrees* of a circle: every degree into 60 equal parts, which are called *minutes*, every minute into 60 *ſeconds*, every ſecond into 60 *thirds*, &c: the mark for a degree is°, for a minute ′, for a ſecond ″, *&c:* forty four degrees ſeven minutes fifty two ſeconds are thus expreſt, $44^\circ\,7'\,52''$.

30 The quantity of an angle is found, by taking its vertex for a centre, drawing a circle which ſhall cut the legs of the angle, and meaſuring the arc contained between the legs: thus, to meaſure the angle LCM, fig. 15, ſet one foot of a pair of compaſſes in the vertex C, and open them to any diſtance at pleaſure, ſo that the other foot of the compaſſes may draw a circle cutting ſomewhere the two legs of the angle, as the circle ABDE does at the points A and B, let the circumference be divided into 360°, and obſerve how many degrees are contained in the arc AB, for of ſo many degrees is the angle ſaid to be: in the preſent example the arc AB is 45°, therefore the angle LCM is an angle of 45°. 15

31 The quantity of an angle will be found the ſame, of what ſize ſoever the circle be drawn that meaſures it: thus, if inſtead of ABDE, which for diſtinction, may be called the *black circle*, the angle LCM be meaſured by a larger one, as the *pointed circle* FGHI, divided into 360°; I ſay the arc FG will contain the ſame number of degrees as the arc AB does, and conſequently give you the ſame meaſure of the angle LCM: for if you imagin the line LC to be carried 15

round

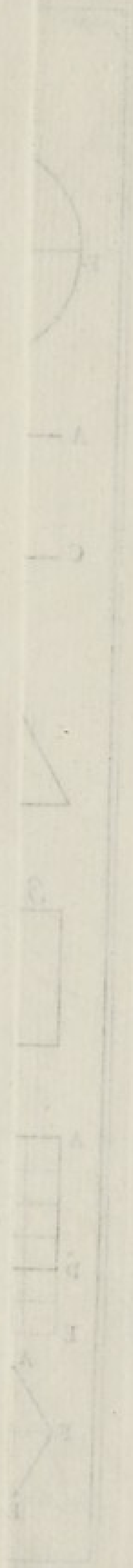
FIG. round the point C, according to the order of the letters FGHI, it is manifeſt 15 that the point F will deſcribe the whole pointed circle, in the ſame time that the point A deſcribes the whole black circle: therefore when the line LC is carried any part of its round, as into the ſituation MC, the point F will have deſcribed juſt as great a part of the pointed circle, as the point A will have deſcribed of the black circle; that is, the arcs FG and AB ſhall each of them bear the ſame proportion to its reſpective circle: ſo that if FG is an eighth part of the pointed circle, AB will be an eighth part of the black circle: if one of theſe arcs be 45°, the other ſhall be likewiſe of the ſame number of degrees.

32 It is in conſequence of this laſt propoſition, that we are able with a ſmall circle, or piece of a circle, of braſs or wood, to meaſure arcs in thoſe vaſt circles which we imagin in the ſtarry heaven it ſelf: for let ABDE, fig. 16, be a
16 circle of braſs, whoſe circumference is divided into 360°, let F and G be two ſtars, whoſe diſtance from one another is to be meaſured: if the ſtar G be viewed through two ſights placed in the line CB, the eye being at C, and at the ſame time the ſtar F be viewed through two ſights in a moveable ruler, whoſe edge lies upon the line CA, then will the number of degrees in the arc AB of the braſs circle, which in the preſent example is 40°, ſhew the number of degrees in FG, an arc of a circle imagined to be drawn in the heaven through the ſtars F and G; and the diſtance of thoſe ſtars is ſaid to be 40°.

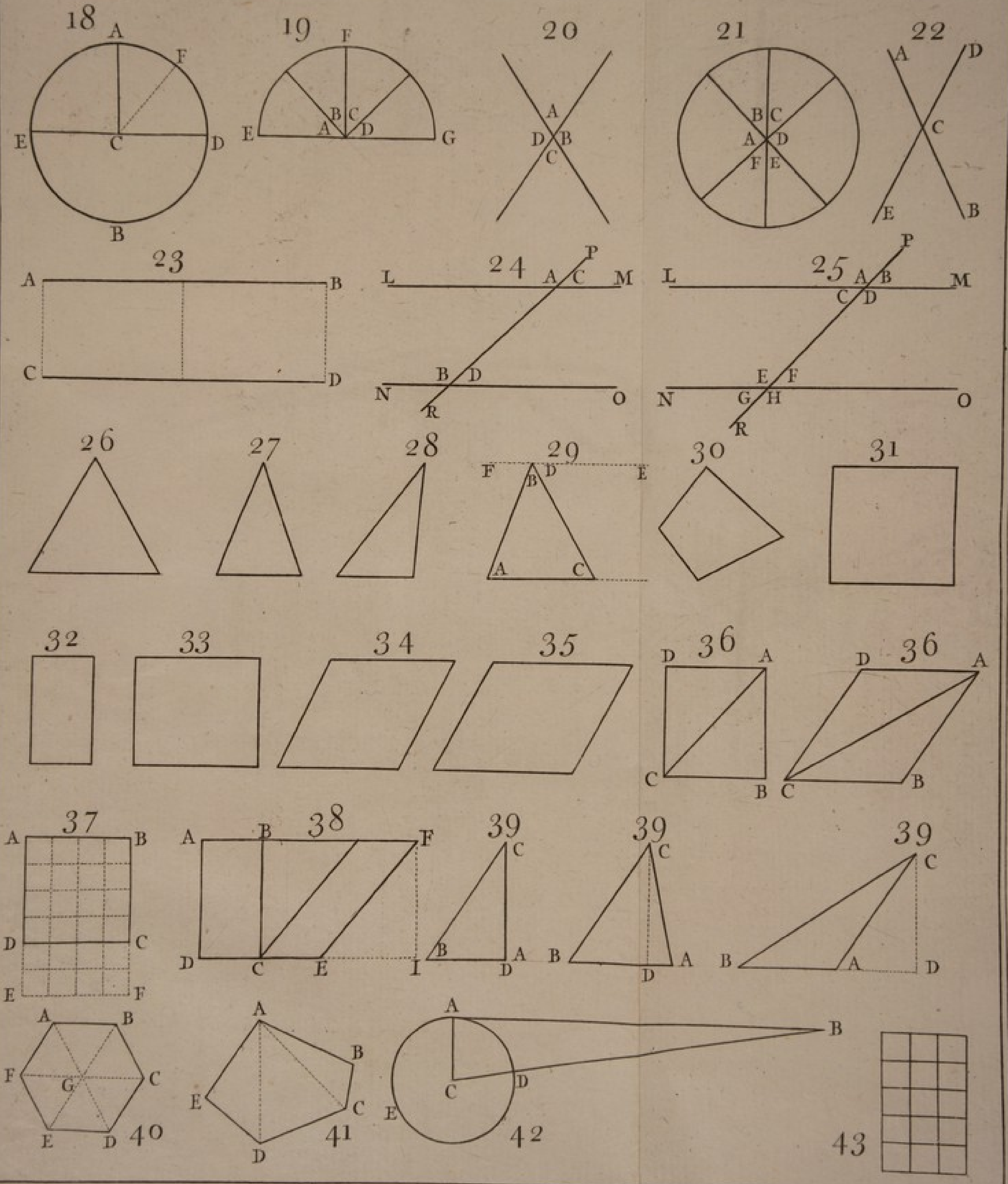
33 To ſave the trouble of dividing a circle into 360°, in order to meaſure the degrees of an angle, you may make uſe of an inſtrument called a *protractor*, which is a ſemicircle of ſilver or braſs divided into degrees, and, if it be large enough to admit of ſuch diviſion, into halves and quarters of a degree: the ſeventeenth figure gives the picture of the protractor, the manner of uſing it is
17 as follows: if it be required to meaſure the angle LCM, fig. 17, lay the central point of the protractor upon C, the vertex of the angle, with the ſemidiameter of the protractor CB upon CM, one of the legs of the angle; the arc of the protractor DB contained between the legs of the angle ſhews the number of degrees the angle LCM contains, which in the preſent example is 45°.

34 By the ſame inſtrument may an angle be drawn of any number of de-
17 grees required: thus, to lay down an angle of 45°; draw a ſtrait line at pleaſure CM, lay upon it the ſemidiameter of the protractor CB, ſo that its central point may fall upon one end of the line, as C, make a mark D with a pen, cloſe to the circumference of the protractor, at the diviſion of 45°, take off the protractor, and draw a line from C through D, as CDL: the angle LCM will be of 45°, as was required.

35 *An axiom* is a ſelf evident propoſition: ſuch are theſe that follow; Axiom 1, The ſum of all the parts is equal to the whole. 2 If equal quantities



Introduction



ties be added to equal ones, the ſums thereby produced will be equal. 3 If FIG.
from equal quantities equal ones be taken, the remainders will be equal. 4 If any two quantities are equal to a third quantity, they are equal to one another. 5 Thoſe quantities which having a third quantity added to them or taken from them are equal, are equal themſelves.

36 Thoſe angles which are meaſured, or as they ſometimes ſpeak, *ſubtended* by equal arcs of the ſame circle, are equal: thus, if the arc AD, fig. 18, be equal 18
to the arc AE, the angles ACD and ACE are equal; this is evident from the way of meaſuring angles, which is taught, § 30.

37 If one ſtrait line AC falls upon another, ED, any where between the ends of it, fig. 18, there will be formed two angles ACD and ACE, which have one 18
leg AC common to them both: ſuch may be called *conſequent angles.*

38 The meaſure of any two conſequent angles ACD and ACE is a ſemicircle, 18
or 180°; for if from their common vertex C you draw a circle ADBE, cutting their legs in the points A, D, and E, then DE ſhall be a diameter, and EAD a ſemicircle, by § 24; but EAD is the meaſure of the angles ACD and ACE; § 30.

39 Any two conſequent angles ACD and ACE are equal to two right ones: for 18
if AC be perpendicular to DE, then the angles ACD and ACE are right ones, by the definition of a right angle, § 22: if FC be drawn oblique to ED, then I ſay the oblique angles FCD and FCE are equal to the two right angles ACD and ACE by the foregoing propoſition, becauſe they have the ſame meaſure as they have, *viz.* the ſemicircle EAD.

40 If two conſequent angles be divided into a greater number of angles, by more lines drawn to the vertical point, fig. 19, the ſum of all theſe angles A, B, C, D, is 19
equal to two right angles; for a ſemicircle EFG meaſures them all, and it is ſtill the ſame quantity of two right angles, divided into a greater number of parts.

41 If two ſtrait lines cut one another, fig. 20, the four angles A, B, C, D, round 20
the point of interſection are equal to four right angles: *demonſtration,* A and B are equal to two right angles, becauſe they are conſequent, § 39; D and C are equal to two right angles, for the ſame reaſon, being alſo conſequent; therefore the ſum of A, B, C, D, is equal to four right angles; which was the thing to be proved.

42 Since a ſemicircle meaſures two right angles, § 38 and 39, a quarter of a circle 90°, or, as it is frequently called, *a quadrant,* is the meaſure of one right angle; a whole circle 360° is the meaſure of four right angles.

Corollary. If more than two ſtrait lines croſs one another in a point, fig. 21, 21
all the angles A, B, C, D, E, F, formed round the point are equal to four right ones: for the meaſure of them all is a circle, as appears by the figure.

43 If two ſtrait lines AB and DE, fig. 22, interſect one another, there will be 22
formed round the point of interſection C, four angles, whereof any two oppo-

ſite

FIG. ſite to each other at the vertex are called vertical: in the figure before us, the
22 two acute angles ACD and BCE conſidered together are called *vertical angles*, in like manner the two obtuſe angles ACE and BCD are vertical.

22 44 All vertical angles are equal: in the figure laſt mentioned, the two acute angles are equal, the two obtuſe angles are alſo equal: ·*demonſtration*, ACD and ACE are equal to two right angles, being conſequent, § 39; ACE and ECB are equal to two right angles, for the ſame reaſon: therefore, § 35 *axiom* 5, ACD and ECB are equal; which was to be proved.

23 45 Two *lines* as AB and CD, fig. 23: are ſaid to be *parallel*, when they are in every part at equal diſtances from one another: the diſtance between parallel lines is meaſured by other lines drawn perpendicular to them, as the pointed lines are in this figure; if theſe pointed lines are all equal, the lines AB and CD are parallel: the oppoſite edges of a flat ruler, which is made throughout of the ſame breadth, will ſerve very well to repreſent parallel lines.

46 Parallel lines, to what length ſoever they be extended, will never meet, but continue ſtill equidiſtant from each other.

24 ·47 If a ſtrait line PR croſſes two parallel lines LM and NO, fig. 24, it will have the ſame inclination to both; if it is perpendicular to one, it will be ſo to the other; if it croſſes one obliquely, it will croſs the other with the ſame obliquity: that is, the angle A will be equal to B, and the angle C to D; this is evident from conſidering the interſecting line as inflexible, which therefore cannot bend from or towards one line more than the other, if they are parallel, as is ſuppoſed in the propoſition.

25 ·48 If a ſtrait line PR cuts two parallel lines LM and NO, fig. 25, it makes with them eight angles: four of which, A, B, H, G, are *external*; the other four C, D, E, F, are *internal*. The angles D and E conſidered together, are called *alternate*, as are alſo C and F. The angles E and A conſidered together, are called *oppoſite angles on the ſame ſide*, as are alſo B and F. The angles C and E conſidered together, are called *internal angles on the ſame ſide*, as alſo are D and F.

25 ·49 The alternate angles C and F, fig. 25, are equal; *demonſtration*, C is equal to B, becauſe they are vertical, § 44, B is equal to F, by § 47, therefore C is equal to F; which was to be proved. In the ſame manner, D and E may be proved equal to one another, as being both equal to A.

25 ·50 The internal angles on the ſame ſide D and F are equal to two right ones: *demonſtration*, F is equal to C by the preceding propoſition, being alternate; C and D are equal to two right angles, being conſequent, § 39; therefore by § 35, *axiom* 5, D and F are equal to two right angles; which was to be proved.

·51 One propoſition is called *the converſe* of another, when after a concluſion is drawn from ſomething ſuppoſed, in the converſe propoſition, that concluſion

cluſion is firſt ſuppoſed, and then that which was before ſuppoſed, is drawn FIG.
from it as a concluſion: for example, in this propoſition, if two parallel lines are croſſed by a third, the alternate angles will be equal; the ſuppoſition is, that the lines are parallel, the concluſion, that the angles are equal: the converſe of this propoſition is, if the alternate angles are equal, the lines are parallel; here the ſuppoſition is, the angles are equal, and the concluſion, that the lines are parallel. In geometry wherever the inſeparable and incommunicable property is found, there is the thing itſelf; and every propoſition about ſuch properties infers the truth of its converſe.

52 *A triangle* is a plane figure encloſed by three lines, which meet and form three angles. The lines which form a triangle are called its *ſides*; if the ſides are all ſtrait lines, it is a *plane triangle*; if they are all curves, it is a *curvilinear* one; if they are of both kinds, it is a *mixt triangle:* we are at preſent treating of plane triangles: in every triangle *an angle* may be ſaid to be *oppoſite* to a ſide, or *a ſide oppoſite* to an angle: thus fig. 29, the angle C is oppoſite to the ſide BA, 29
the angle B is oppoſite to the ſide CA, and the angle A to the ſide BC: in the ſame figure, the ſide BA is oppoſite to the angle C, the ſide BC is oppoſite to the angle A, and the ſide CA to the angle B.

53 A triangle may have all its ſides and all its angles equal, as fig. 26; or 26
only two ſides and two angles equal, as fig. 27; or all the ſides and all the an- 27
gles may be different, as fig. 28. *A right-angled triangle* is that which has one 28
of its angles a right one: an *obtuſe-angled triangle* is that which has one obtuſe angle: an *acute-angled triangle* is that which has all its angles acute.

54 Sometimes we call one ſide of a triangle *the baſe*, and then the other two ſides are called its *legs:* any ſide of a triangle may be conſidered as its baſe; but we commonly call that ſo which lies neareſt to us, when we view the triangle: thus, fig. 29, AC is the baſe of the triangle ABC.

55 In every triangle ABC, fig. 29, the three angles A and B and C, taken to- 29
gether, are equal to two right ones: *demonſtration*, if through the vertex of the angle B the line FE be drawn parallel to the baſe AC, the lines BA and BC may be conſidered as falling upon theſe two parallel lines; and then the angles A and ABE are equal to two right ones, being internal oppoſite on the ſame ſide, § 50: now the angle ABE contains the two angles B and D; therefore A and B and D are equal to two right ones, but D and C are equal, becauſe alternate, § 49; therefore A and B and C added together are equal to two right angles; which was to be proved. *Eucl. l.* 1. *p.* 32. This propoſition is ſaid to have been invented by *Pythagoras*, and is brought by *Ariſtotle* and others as an example of a perfect demonſtration: many corollaries or concluſions may be drawn from it, among which theſe that follow are the moſt uſeful.

FIG. *Cor.* 1, The ſum of the angles of any one triangle is equal to the ſum of the
angles of any other triangle; *viz.* 180°, or two right angles. 2, The quantity
or number of degrees, of any one angle of a triangle being given or known, the
quantity of the other two angles may be known: thus, in the preceding figure,
if the angle A be 70°, the ſum of the angles B and C will be 110°: for 70° ad-
ded to 110° is 180°. 3, The quantity of two angles of a triangle being given,
29 the quantity of the remaining angle may be known: thus, in fig. 29, if the ſum
of the angles B and C be 110°, the quantity of the angle A is 70°. 4. If two an-
gles in one triangle are equal to two angles in another triangle, the remaining
angles are equal. 5, In every right-angled triangle one acute angle is *the com-
plement* of the other to 90°. 6, If one angle in a triangle be a right one, the
other two angles are acute. 7, If any right-angled triangle has one acute angle
equal to one of the acute angles of another right-angled triangle, thoſe trian-
gles are equiangular.

56 *Trigonometry* is the art of meaſuring triangles; to meaſure a triangle is
to find out the quantity of every angle of it, and the length of every ſide:
ſometimes, by meaſuring a triangle we mean finding out the area of it, the
way of doing this ſee below, § 64. There are in every triangle ſix things chiefly
to be conſidered, *viz.* three angles and three ſides; trigonometry teaches us how
we may, if ſome of theſe are given, find out all the reſt: the corollaries im-
mediately preceding point out to us ſome of the firſt ſteps to be taken in tri-
gonometry; before any further progreſs therein is attempted, ſeveral things are
to be premiſed; and firſt it is neceſſary to treat of *quadrilateral figures*, or ſuch
as have four ſides.

57 If a quadrilateral figure has either its oppoſite ſides or its oppoſite an-
30 gles unequal, it is called a *trapezium*, fig. 30. If a quadrilateral figure has its
oppoſite ſides parallel, it is called *a parallelogram*, as figg. 31, 32, 33, 34, 35, 36.
If a parallelogram has all its angles right ones and all its ſides equal, it is call-
31 ed *a ſquare*, fig. 31. If a parallelogram has all its angles right ones and only
32 its oppoſite ſides equal, it is called *a rectangled parallelogram*, or more uſually
33 *a rectangle*, figg. 32, 33. If a parallelogram has all its angles oblique and all
34 its ſides equal, it is called *a rhombus*, fig. 34. If all the angles of a parallelogram
35 are oblique, and only the oppoſite ſides equal, it is called *a rhomboid* fig. 35.

58 A parallelogram is named by ſetting down the four letters or other marks
placed at the four corners of it, and ſometimes by mentioning only two letters
36 or marks placed at two oppoſite corners; thus the 36th figure may be called the
parallelogram ABCD, or the parallelogram AC, or BD.

59 *The generation* or formation *of a parallelogram* may be conceived in the
following manner: let it be ſuppoſed that a right line AB, fig. 37, which may
be

be called *a describent*, is carried or moved, so as to be all the while parallel to itself in its first situation, along another line AE, which will be *a dirigent*; when the describent has moved from its situation AB, and is come into the situation EF, the surface it has passed over or described is the parallelogram ABFE. FIG. 37 AE

60 *The mensuration of squares and rectangles* is easily understood, from considering the manner in which they are generated: let it be supposed that the describent AB is, before its motion, divided into any number of equal parts, 37
as 4, and the dirigent, which in order to generate a rectangle or square must stand at right angles to the describent, into as many of the like parts as it contains: for example, let the length of the describent be 4 inches, and the length of the dirigent 6; when the describent has moved one inch upon the dirigent, the surface described by it will be 4 square inches; when it has moved 2 inches upon the dirigent, it will have described 4 more, in all 8 square inches &c; when it has moved upon the dirigent a length equal to its own, *viz.* 4 inches, it will then have described a square ABCD, which contains an area 4 times 4, that is 16 square inches: let this motion of the describent be continued till it has moved upon the dirigent the whole 6 inches, and it will then have described a rectangle ABFE, whose area is six times 4, that is 24; square inches.

61 From hence it appears, that the way to find the area of any rectangle AF, 37
is to measure two contiguous sides of it, as AB and AE, and see what number of feet, inches, or tenths of an inch, or any other known measure, each side contains, and to multiply the number of feet, inches, &c of one side by the number of feet, inches, &c. of the other side: thus, if AB is 4 inches and AE 6, multiply those numbers 4 and 6 together, and the product 24 is the number of square inches contained in the rectangle AF: since all the sides of a square are equal, the area of a square is found by multiplying any one of its sides by itself: thus if a room is square, and has each side 12 feet long, the area of the floor is 12 times 12, that is 144 square feet.

62 Not only squares, and rectangles, but all other kinds of plane figures, as circles, triangles, &c have the quantity of their areas exprest, by saying how many square feet, square inches, &c, they contain; the same way of measuring is also applicable to convex or concave surfaces, as well as plane ones; thus, I may find how many square feet &c. are contained in the surface of a mountain or valley, or even of the whole earth it self. I shall now shew the method of measuring the areas of such plane figures, as we may have occasion to consider in the following work; the demonstrations, which are here omitted, may be seen in the common books of geometry.

63 All parallelograms, whether oblique-angled ones or rectangles, having equal bases and equal perpendicular heights are equal: *Eucl.* I. 35. thus, fig. 38, 38

 the

FIG. the rectangle AC and the oblique parallelogram CF are equal, if their baſes DC
38 and CE are equal, and if they have the ſame perpendicular height AD and FI, ſo
that both of them can ſtand between the ſame parallel lines AF and DI: from
hence it follows, that the way *to find the area of any oblique-angled parallelo-*
CE *gram* as CF, fig. 38, is this; multiply the baſe ~~DC~~ by the perpendicular height
FI, and the product is the area.

64 A ſtrait line drawn from any corner of a parallelogram to the oppoſite
36 one is called *a diagonal:* thus, fig. 36, AC is a diagonal. Every diagonal divides
36 a parallelogram into two equal triangles: thus, fig. 36, ABC and ADC are equal,
as is eaſy to demonſtrate, *Eucl. l.* 1. *p.* 34: and therefore, every triangle is half
a parallelogram which has the ſame baſe and the ſame perpendicular height:
39 therefore, *to find the area of any triangle* BAC, fig. 39, multiply the baſe AB by
the perpendicular height CD, and half the product is the area.

65 *A polygon* ſignifies a plane figure with many angles: no figure is called
by that name which has not more than four angles: many polygons are called
by particular names, expreſſing the number of angles they contain, which is
always the ſame with the number of their ſides; thus if a polygon has five an-
gles or ſides, it is called *a pentagon:* if ſix, *an hexagon:* if ſeven, *an heptagon:*
if eight, *an octagon:* &c. theſe are all called *regular*, when their angles and ſides
are all equal, and are underſtood to be regular when nothing is ſaid to the con-
40 trary. Any polygon, fig. 40, may be divided into as many triangles as it has
ſides, if any where within the polygon, you take a point G, and from thence
draw a line to every angle A,B,C,D,E,F: *the area of any polygon* is the ſum of
the areas of the ſeveral triangles into which it is thus divided.

41 66 *To find the area of any irregular plane figure* ABCDE, fig. 41, let it be di-
vided into triangles by drawing lines from one angle to another, as is here done,
find the area of each of thoſe triangles, by § 64, the ſum of them is the area
of the whole figure.

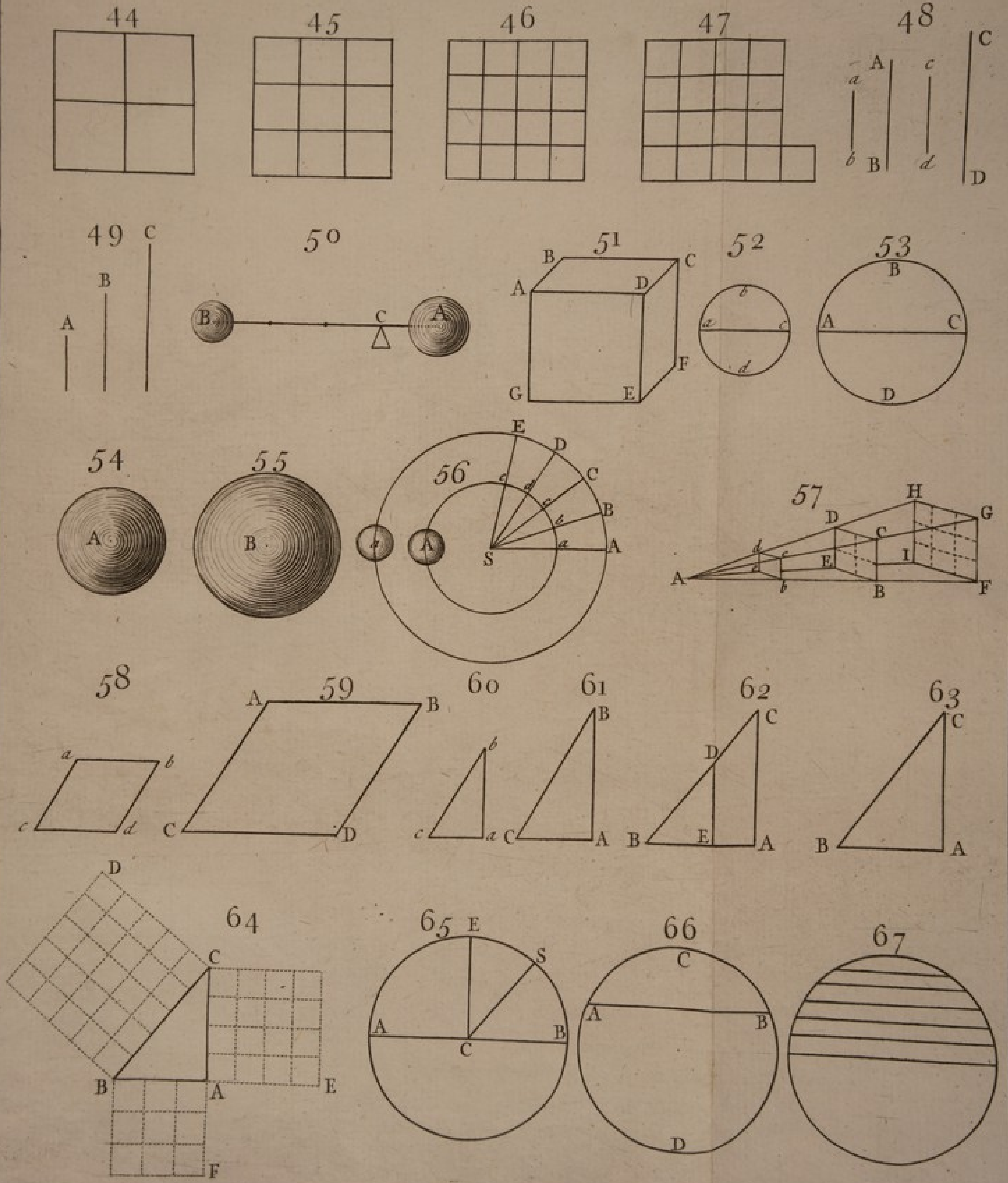
67 To find the area of a circle is the ſame thing as to find the quantity of
its ſurface in ſquare meaſure, which is commonly called, *to ſquare the circle*;
this may be done, if we can find a ſquare, triangle, or any other rectilinear plane
figure, equal to the circle; becauſe the area of any ſuch figure may be found,
by § 64 and 66; for this purpoſe, the following propoſition is demonſtrated
by geometers,[a]

42 The area of any circle ADE, fig. 42, is equal to the area of a right-angled
triangle BAC, which has one leg AC equal to the radius, and the other leg AB
equal to the circumference of the circle.

Scholium, the only difficulty here is to find a ſtrait line equal to the circum-
ference, the radius being given, or, which is the ſame thing, to find the ratio
between the diameter and circumference; this can never be done exactly, though
we

[a] *Tacquet's Geometria practica l.* 2. *cap.* 12. *Pardie Geometr. l.* 4. *p.* 31.

Introduction



we may come as near exactneſs as we pleaſe: we ſay in groſs, and inaccurately, that the diameter of a circle is to its circumference as 1 is to 3; ſo that if the diameter of a circle is one foot, the circumference of it will be about 3 feet: but theſe numbers are fit only for ſuch uſes as do not require much exactneſs. *Archimedes* found the diameter of a circle to be to the circumference as 7 to 22; this is exact enough for many uſes: *Ludolf van Ceulen*, by a laborious calculation, found the ratio between the diameter of a circle and its circumference, in numbers of 36 places each; this was looked upon to be ſo conſiderable a performance, that the numbers ſtand engraved upon his tombſtone, to perpetuate the memory thereof: His numbers are theſe

if the *diameter* be 100000, 000000, 000000, 000000, 000000, 000000,
the *circumference* will be 314159, 265358, 979323, 846264, 338327, 950288,

in theſe numbers, that by which the circumference is expreſt is too ſmall; and yet if inſtead of (8), the firſt figure upon the right-hand, we were to put the figure (9), the number expreſſing the circumference would then be too great; with either of theſe figures, it is ſo near the truth, that the diameter of the earth being given, we might from thence compute the number of ſands equal to the ſolid content of the whole earth, ſo near as not to differ one grain of ſand from the truth. *Van Ceulen*'s numbers have been doubled by that induſtrious arithmetician *Mr Abraham Sharp*; this has carried the affair to an accuracy almoſt beyond belief; ſufficient, if the diameter of the ſphere of the fixt ſtars were given, in grains of ſand to compute the number of grains of ſand which might be contained in the concavity thereof.

68 We ſhall be exact enough for moſt purpoſes, if we take theſe numbers only as far as the four laſt places on the left hand, and ſay the diameter of a circle is to its circumference, as 1000 to 3141: with theſe numbers, by the help of the golden rule, the diameter of a circle being given, the circumference may be found: or the circumference being given, the diameter may be found, very near the truth. See this whole affair treated of more at large, by *Tacquet*, in his *Geometria practica*, *l.* 2. *c.* 12, & *ſelecta theoremata ex Archimede*, *prop.* 6: ſee alſo *Sherwin*'s *tables p.* 53.

Example 1, If the circumference of a circle be 138204 feet, how many feet is its diameter? the anſwer is 44000 feet; for by the golden rule,

$$3141 :^{circumf.} 138204^{feet} :: 1000 :^{diam.} 44000^{feet}.$$

Example 2, If the diameter of a circle be 2000 feet, how many feet is the circumference of it? the anſwer is 6282 feet; for

$$1000 :^{diam.} 2000^{feet} :: 3141 :^{circumf.} 6282^{feet}.$$

the diameter and circumference of a circle being thus found, by either of them being given, multiply half the diameter by half the circumference, the product is the area of the circle, by § 64 and 67.

FIG. ·69 *A plane number* is that which may be produced by the multiplication
of one number by another: thus, 6 is a plane number, becauſe it may be pro-
duced by the multiplication of 3 by 2, for two times 3 is 6; again, 15 is a plane
number, becauſe it is the product of 5 multiplyed by 3. Thoſe numbers which
multiplyed by each other produce a plane number, are called *the ſides of the
plane:* thus 5 and 3 are the ſides of the plane 15. If we ſuppoſe the units of
which any plane number conſiſts, to be repreſented by little ſquares, thoſe
ſquares may be placed in the form of a rectangle; thus, the number 15 may
43 be repreſented by a rectangle, one of whoſe ſides is 3, the other 5: fig 43.

·70 *A ſquare number* is a plane number whoſe ſides are equal; the product of
any number multiplyed by it ſelf is therefore always a ſquare number: thus, 4
44 is a ſquare number, becauſe it may be produced by multiplying 2 by 2, fig. 44;
45 again, let 3 be multiplyed by 3, the product is 9, a ſquare number, fig. 45; let 4
46 be multiplyed by it ſelf, the product will be the ſquare number 16, fig. 46, &c.
The ſide of a ſquare is called *the ſquare root* of that number, thus 4 is the ſquare
root of 16. Every ſquare number may be ranged in form of a ſquare; and
the converſe of this is true, *viz.* that every number which can be ranged in
the form of a ſquare is a ſquare number; ſee the three figures immediately pre-
ceding. We are taught in the common books of arithmetic how to find out
the ſides, or, as it is uſually called, to extract the ſquare root of any number
given; if a number is a ſquare, its root may be found exactly in whole num-
bers; thus the ſquare root of 16 is 4: if a number is not exactly ſquare as 17,
47 fig. 47, its root cannot be found exactly in whole numbers, but inſtead there-
of it is uſual to take the root of the next ſquare number below it, as 16, and
make uſe of it with ſome fraction.

·71 By comparing lines and numbers together, we ſee that a rectangle in geometry is the ſame to the lines by which it is generated, as the product in arithmetic is to the numbers from the multiplication whereof it ariſes: the ſquare of a number is the product of that number multiplyed by it ſelf, and the ſquare of a line is the ſquare produced by the multiplication of the line into itſelf, that is, by imagining a deſcribent to be carried along a dirigent equal to itſelf, as already has been explained § 60.

·72 One kind of quantity is frequently expreſt by another: numbers will ſerve to expreſs all kinds of quantity; thus, if I compare two cannon balls together, and find the weight of one double to the weight of the other, I may expreſs the weight of the heavieſt ball by the number 8, and the weight of the other by the number 4: in the ſame manner may different quantities of motion, of heat, light, &c. be expreſt by numbers: all kinds of quantity may be alſo expreſt by lines; thus, I may expreſs the time of one hour by a line of

a deter-

a determinate length, and the time of two hours by a line twice as long as the former: different quantities may be alſo expreſt by rectangles or ſquares of different magnitude; by this means, geometry as well as arithmetic is uſeful in computing all ſorts of quantity: for when quantities are repreſented by numbers, lines, or ſquares, we may proceed to compute with thoſe numbers, lines, or ſquares, and thereby diſcover the proportions of thoſe quantities which they repreſent.

·73 *An aliquot part* of any quantity is that which repeated a certain number of times, (*aliquoties*,) exactly meaſures that quantity; *an aliquant part* of any quantity is that which does not meaſure it: thus, in numbers, 2 is an aliquot part of 8, becauſe 2 repeated 4 times is equal to 8: but 3 is an aliquant part of 8, becauſe if repeated twice, it is leſs than 8, if repeated thrice, it is more than 8: thus, a line 2 inches long is an aliquot part of a foot, a line 5 inches long is an aliquant part of a foot.

·74 Any two *quantities* are *commenſurable*, or, as they are ſometimes called, *rational*, when a third quantity can be found which is a common meaſure to them both: thus 2 is a common meaſure to 4 and 12: and 3 is a common meaſure to 9 and 15: all numbers are commenſurable; becauſe an unit is their common meaſure; and all commenſurable quantities may be expreſt by numbers.

·75 *Incommenſurable, irrational*, or *ſurd quantities* are ſuch as have no common meaſure, and cannot be expreſt by numbers: thus geometers demonſtrate, that the diagonal and ſide of a ſquare are incommenſurable.[a]

·76 When we compare two quantities together, as to more or leſs, and enquire whether they be equal or not, and, if unequal, how much one is greater or leſs than the other, we are ſaid to conſider the *ratio* or *reaſon* of thoſe quantities, and we ſay one is in ſuch a ratio to the other: in ſuch compariſons the firſt quantity is called *the antecedent*, the ſecond *the conſequent:* if the antecedent and conſequent are equal, they are ſaid to be in *a ratio* of *equality*; if unequal, in *a ratio of inequality:* when the antecedent is greater than the conſequent, as in the numbers [8 : 4,] it is in *a ratio of majority:* when the antecedent is leſs than the conſequent, as [4 : 8,] it is in *a ratio of minority:* in ratio's of inequality the leſs number is either an aliquot part of the greater, as in the numbers [12:3,] or an aliquant part of it, as [10:3.] The names of ſome of thoſe ratios of inequality that moſt frequently occur, are theſe that follow.

·77 In a ratio of majority, when the antecedent contains the conſequent twice preciſely, as [8:4,] the antecedent is ſaid to be in a *duple ratio* to the conſequent: when it contains it three times, as [9:3,] it is in a *triple ratio:* when four times, as [12:3,] in a *quadruple ratio* &c: when the antecedent con-

a *Tacquet Euclid. edit. Cantabrig. Schol. in lib.* 1. *prop.* 47.

tains

FIG. tains the conſequent once, and a half of the conſequent, as in theſe numbers, [3:2,] it is in a *ratio ſeſquialtera:* when it contains the conſequent once and a third part, as in theſe numbers, [4:3,] it is in a *ratio ſeſquitertia* &c.

·78 In ratios of minority, the ſame terms are uſed as before, with the addition of *ſub*; thus, when the antecedent is contained in the conſequent twice, as [4:8,] the *ratio* is *ſubduple:* when three times, as [3:9,] it is *ſubtriple*: when four times, as [3: 12,] it is *ſubquadruple:* when once and a half, as [2:3,] it is *ſubſeſquialtera:* when once and a third part, as [3:4,] it is *ſubſeſquitertia*, &c.

·79 When we conſider four quantities together, and compare them by pairs, two with two, and find that the ratio between one pair is equal to the ratio between the other pair, we call this equality or ſimilitude of ratios *proportion*; and thoſe four *quantities* are ſaid to be *proportional.* Proportion is either direct or reciprocal; *direct proportion* is where the firſt antecedent is to the firſt conſequent, as the ſecond antecedent is to the ſecond conſequent: thus, in theſe four numbers, 4, 6, 8, 12, if I compare the pair [4:6,] with the pair [8:12,] I ſhall find that 4 is in the ſame ratio to 6, as 8 is to 12; which is uſually thus ex-
48 preſt, 4:6::8:12; thus, in the four lines of fig. 48, ſo that *ab*: AB::*cd*:CD: that is, the line *a b*: is in the ſame ratio to AB, as *c d* is in to CD. If the quantities are expreſt by numbers, in direct proportion more requires more, or leſs requires leſs; the greater the third number is, the greater muſt the fourth number be; or the leſs the third number is, the leſs muſt the fourth number be: thus, in this example, if one degree of a great circle upon the earth, is equal to 60 Italian miles, to how many ſuch miles will 360°, the whole circumference of the earth, be equal? here more degrees require more miles; the anſwer is 21600 miles; thus expreſt, $1^\circ : 60^{miles} :: 360^\circ : 21600^{miles}$.
2^{d} *Example*, if the moon goes through a great circle in the heaven, or 360° in 27 days, how many degrees will ſhe go in one day? here leſs requires leſs, that is, in leſs time the motion will be of fewer degrees; the anſwer is 13°: with a fraction or piece of a degree, thus expreſt, $27^{days} : 360^\circ :: 1^{day} : 13^\circ \frac{9}{27}$. In numbers directly proportional, three numbers being given the fourth is found by the ſingle golden rule direct.

·80 When three quantities are ſuch that the firſt quantity is in the ſame ratio to the ſecond as the ſecond is to the third, the ſecond quantity is called *a mean proportional* between the firſt and the third: thus, in numbers, 12 is a
49 mean proportional between 6 and 24; for 6:12::12:24: thus, in lines, fig. 49, B is a mean proportional between A and C; for A:B::B:C.

·81 *Reciprocal proportion* is where more requires leſs, or leſs requires more; that is, the greater the third quantity is, the leſs will the fourth be, or the leſs the third quantity is, the greater will the fourth be; thus, if I would poiſe two

two unequal heavy bodies A and B, fig. 50, fixed at the two ends of a beam AB, FIG. ſo as to make them reſt *in æquilibrio*, or to be of equal weight, I muſt place 50 *the fulcrum* or ſupport C under the beam in ſuch a manner, that the diſtances of the centers of the heavy bodies from it may be reciprocally as their weights; that is, if the weight of A be triple the weight of B, the diſtance of B from C muſt be triple the diſtance of A from C: here greater weight requires proportionally leſs diſtance, and leſs weight requires proportionally greater diſtance from the fulcrum; the point C, where the fulcrum muſt be placed to ſupport the bodies A and B in æquilibrio, is called *the center of gravity* of thoſe bodies. In numbers reciprocally proportional, three numbers being given, the fourth is found by the ſingle golden rule inverſe.

·82 Any quantity conſidered as capable by multiplication, of producing, or being produced by, another quantity, is called *a power:* the product or *factum* of any quantity multiplyed by it ſelf is called the *ſecond power*, or *ſquare* of the ſimple quantity ſo multiplyed: if that ſquare is multiplyed by the firſt ſimple quantity, the product is called the *third power*, or *cube*, &c: in all theſe caſes, the ſimple quantity, to which the reſt owe their origin, is called *the firſt power*, *the root*, and in geometry *the ſide* of the ſquare, or cube, *&c:* thus, in numbers, let the root be 4, the ſquare number produced by 4 multiplyed by 4, is 16; the ſquare 16 multiplyed by the root 4, produces the cube number 64: thus, in lines, fig. 51, the line AB, multiplyed by it ſelf gene- 51 rates the ſquare ABCD: this ſquare multiplyed by the ſide AB, or carried parallel to it ſelf, in its firſt ſituation, along a line AG, perpendicular to its plane, and equal to the ſide AB, generates the cube ACEG.

·83 *Quantities* that being multiplyed into themſelves produce equal ſquares, equal cubes *&c*, are ſaid to be *equal in power*: in latin, *æquipoſſe*.

·84 Ratios may be conſidered not only between ſimple quantities, but alſo between their powers: the ratio between two ſquares or ſecond powers is called *a duplicate ratio:* the ratio between two cubes or third powers is called *a triplicate ratio:* the ratio between a ſquare and a cube, or between the ſecond and third power is called *a ſeſquiplicate ratio.*

·85 *Firſt example* of direct proportion of powers; the areas of any two circles *abcd* and ABCD, fig. 52 and 53, are in a duplicate ratio of their diameters, 52 or as the ſquares of their diameters: thus, let the diameter *ac* be 12, and the 53 diameter AC be 20; the ſquare of 12 is 144, the ſquare of 20 is 400; then I ſay, the area of *abcd*: area of ABCD::144:400. *Euclid. lib.* 12. *prop.* 2.

86 *Second example*; the ſurfaces of any two ſpheres A and B, fig. 54 and 55, 54 are as the ſquares of their diameters[a]: thus, let the diameter of A be 6, and 55

a *Archimedes de ſphæra & cylindro, Tacquet ſelecta ex Archimede theoremata.*

FIG. the diameter of B 8, the ſquare of ſix is 36, the ſquare of 8 is 64; I ſay then
54 that the ſurface of A is to the ſurface of B, as 36 is to 64.
55 ·87 *Third example*; the ſolid contents of two ſpheres, A and B, of different
54 magnitude, fig. 54 and 55, are in a triplicate ratio of their diameters, or as the
55 cubes of their diameters: thus, let the diameter of A be 6, and the diameter of
B 8; the cube of 6 is 216, the cube of 8 is 512, I ſay then the ſolid content of
A is to the ſolid content of B, as 216 is to 512. *Eucl.* 12, 18.

·88 *Fourth example*; of reciprocal proportion of powers; the intenſeneſs of
all corporeal qualities or powers which are diffuſed every way in ſtrait lines
from any natural body, as from a center, ſuch as light, heat, ſmell &c, is re-
ciprocally as the ſquares of the diſtances of the acting body from the bodies acted
upon. To give an inſtance in light; it is evident that the intenſeneſs of the
ſuns light, falling upon any given ſurface, is greater or leſs, according as his
rays fall upon it in greater or leſs quantity; or in other words, any ſurface is
more or leſs illuminated, according as the light falls thicker or thinner upon it;
now that this denſity of the ſuns light is reciprocally as the ſquares of the
diſtances of the illuminated bodies from the ſun, is thus demonſtrated: let S
56 be the ſun ſending forth rays of light every way round, in the ſtrait lines SA,
SB, SC, SD, &c, all theſe rays, at the diſtance S*a*, are ſpread uniformly over
the ſpherical ſurface *abcde*; at the diſtance SA, the ſame rays are ſpread uni-
formly over a larger ſpherical ſurface ABCDE; the light then muſt be as much
thinner upon this larger ſpherical ſurface than it is upon the ſmaller one, as the
larger ſpherical ſurface is greater than the ſmaller one: now the ſurfaces of
ſpheres are as the ſquares of their diameters, by § 86; that is, the ſpherical ſur-
face ABCDE is to the ſpherical ſurface *a b c d e*, as the ſquare of SA is to the
ſquare of S*a*: therefore the light at A is to the light at *a*, as the ſquare of S*a* is
to the ſquare of SA: which was to be proved. The following experiment, taken
out of *Smith*'s *Optics pag.* 17, may ſerve for a further illuſtration of this matter.
57 ·Let the light which flows from a point A, and paſſes through a ſquare
hole *bcde*, be received upon a plane BCDE, placed parallel to the plane of the
hole; if the diſtance of the plane BCDE from the point A be twice as great
as the diſtance of the hole from that point, the light will then be ſpread over
a ſurface which is four times as large as the aperture of the hole, as appears
by the figure, where BCDE is divided into four ſquares, each of which is e-
qual to the ſquare *b c d e*; if the diſtance of the plane which receives the
light coming through the hole be three times the diſtance of the hole from the
point A, the light will then fall upon a ſquare ſurface FGHI, nine times as
large as the ſquare aperture of the hole, as is evident alſo from a view of the
figure; ſo that at double the diſtance, the plane illuminated by the point A is
twice

~~twice~~ as large; at three times the diſtance, it is nine times as large; at four FIG.
times the diſtance, the illuminated ſurface is ſixteen times as large, *&c*; the ſurfaces illuminated increaſing as the ſquares of their diſtances from the illuminating point: thus, let there be two bodies of equal ſurfaces A and *a*, fig. 56, 56
at different diſtances from the ſun, let the diſtance of A from the ſun be as 4, and the diſtance of *a* as 8; then will the quantity of the ſuns light falling upon A, compared with his light which falls upon *a*, be in the ſame ratio as 64, the ſquare of 8, is to 16, the ſquare of 4: by this method, the ſeveral diſtances of the planets from the ſun being given, the force of the ſuns heat or light upon them reſpectively may be compared: thus, if the diſtance of Mercury from the ſun be as 4, and the diſtance of the earth as 10; the heat upon Mercury ſhall be to the heat upon the earth, as 100, the ſquare of 10, is to 16, the ſquare of 4. By this method alſo the different force of the ſuns heat upon the earth, ariſing from her different diſtances from the ſun, may be found: thus, let the diſtance of the earth from the ſun in ſummer, be as ~~1008~~, her diſtance in winter, 1034
as 1000; then, if no other cauſe of the difference of the ſuns heat were to be conſidered, but the difference of his diſtance from the earth, ſummers heat would be to the winters heat, as 1000000 the ſquare of 1000, the winters diſtance, is to ~~1016064~~, the ſquare of 1008, the ſummers diſtance. 1069156

·89 *Fifth example*; the gravitation of the ſeveral primary planets towards the ſun is reciprocally as the ſquares of their diſtances from him: *Newt. princ. p.* 362. *ed.* 2. Thus, let the diſtance of the earth from the ſun be 10, the diſtance of Mercury 4; the ſquare of 10 is 100, the ſquare of 4 is 16; I ſay then, Mercury's gravitation is to the earths gravitation in the ſame ratio as 100 is to 16: the gravitation of Jupiters ſatellits towards Jupiter, and of Saturns ſatellits towards Saturn, is in the ſame proportion, *viz.* reciprocally as the ſquares of their diſtances from their primary; and may be compared by this method.

·90 *Sixth example*, of proportion between different powers; if the periodical times in which the planets go round the ſun be compared with their middle diſtances from the ſun, the proportion ſtands thus; their periods are in a ſeſquiplicate ratio of their diſtances, or in other words, *the ſquares of their periods are as the cubes of their diſtances*: thus, if we conſider Venus and the earth together, we ſhall find that the ſquare of the period of Venus is to the ſquare of the earths period, as the cube of the diſtance of Venus is to the cube of the earths diſtance. The periodical times of the ſecondary planets motion round their primaries are likewiſe in the ſame ratio of their diſtances from their primaries. *Præfat. in edit.* 2. *Newtoni Princip.* & *lib.* 3. *pag.* 259. & 360.

The ſix following ſections, are uſeful for the underſtanding the way of making tables of ſines, &c, *but may be paſſed over by thoſe who are not deſirous to look into that affair.*

FIG. 91 *Similar plane figures* are ſuch as have their correſponding parts proportional.

92 *All circles are ſimilar:* the circumference of any one circle is in the ſame ratio to its diameter, radius, or arc of a given number of degrees, or chord of a given arc, as any other circle is to its diameter, radius, or arc of a like number of degrees, or chord of a like arc. § 31 and 32.

93 *Similar parallelograms* are ſuch as have their correſponding ſides proportional, and their correſponding angles equal: thus, the two parallelograms
58 AD and *ad*, fig. 58 and 59, are ſimilar, if the ratio between the ſides is ſuch
59 that, *ab*: AB :: *ac*: AC, and if the angle *a* is equal to A, and the angle *b* to B.

60 94 Triangles which are equianglar are ſimilar: *Eucl.* 6. 4. thus, fig. 60 and
61 61, if the angle *a* is equal to A, the angle *b* to B, and *c* to C, thoſe triangles are ſimilar, and their correſponding ſides are proportional; that is, *ab*: AB :: *ac*: AC. and *ab*: AB :: *cb*: CB. and *ac*: AC : *cb* : CB.

62 95 If any triangle BAC, fig. 62, has a line DE drawn in it parallel to one of its ſides CA, the other two ſides of it BC and BA will be cut proportionally; and there will be formed another triangle BED, ſimilar to BAC : ſo that, BE : BA :: BD : BC. and BE : BA :: ED : AC, &c. *Eucl.* 6. 2. *this propoſition is of great uſe in making the tables of ſines, tangents, and ſecants.*

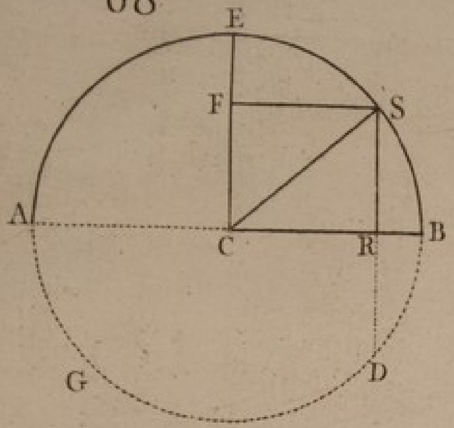
96 If one acute angle in one right-angled triangle is equal to one acute angle in another right-angled triangle, thoſe triangles are ſimilar; § 55, *Cor.* 7, and § 94. We may now reſume the doctrine of trigonometry, ſo much of it as we ſhall have occaſion to conſider in the preſent work.

63 97 In every right-angled triangle BAC, fig. 63, the longeſt ſide BC, which is always that oppoſite to the right angle A, is called the *hypotenuſe*; the other ſides AB and AC, are called *the legs.*

98 *In every right-angled triangle, the ſquare of the hypotenuſe is equal to the ſquares of the legs.* This propoſition is ſometimes thus expreſt, in every right-angled triangle the hypotenuſe is *equal in power* to the legs: thus, take the triangle BAC, fig. 64, upon the hypotenuſe BC erect the ſquare BD, upon
64 the leg AC erect the ſquare CE, upon the leg BA, erect the ſquare BF; I ſay the area of the ſquare BD will be equal to the ſum of the areas of the other two ſquares CE and BF. This propoſition, the demonſtration of which may be ſeen in the common books of geometry, *Eucl.* 1, 47, is of great uſe in trigonometry, for thereby, the meaſure of any right-angled triangle is eaſily found, if we have ſome *data*, or things known to go upon: thus, in the right-angled triangle,
63 fig. 63, the length of the hypotenuſe BC and one leg AC being given, the other leg may be found in the following manner; let the length of the hypotenuſe be 10 feet, yards, or miles, or any other known meaſure, in the preſent example we

Introduction .

68



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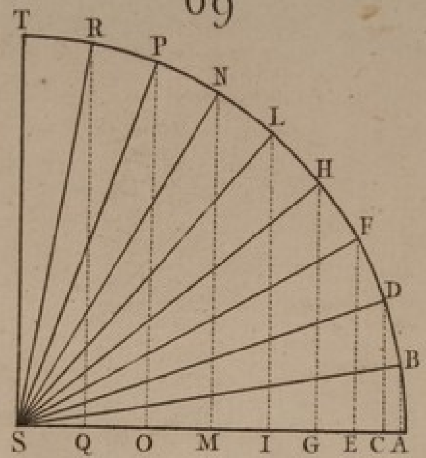

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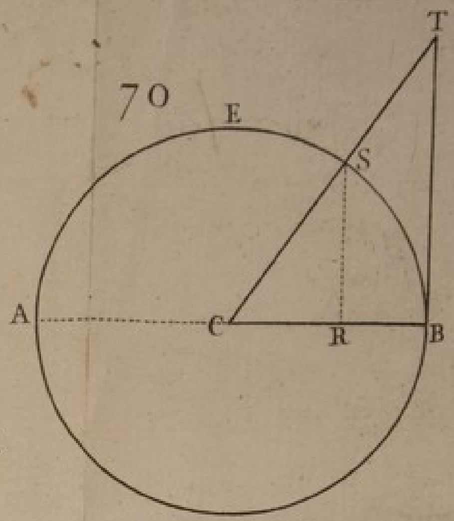

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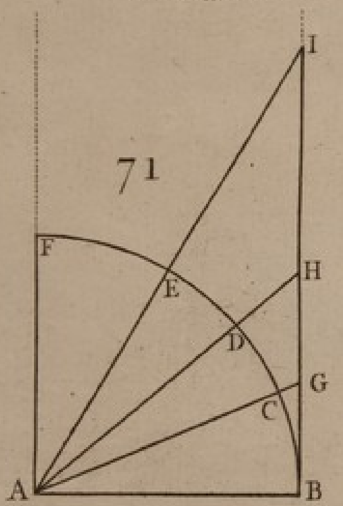

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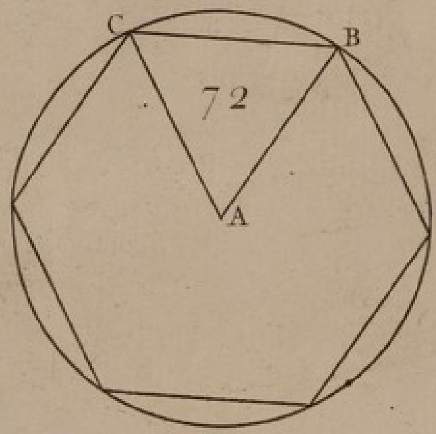

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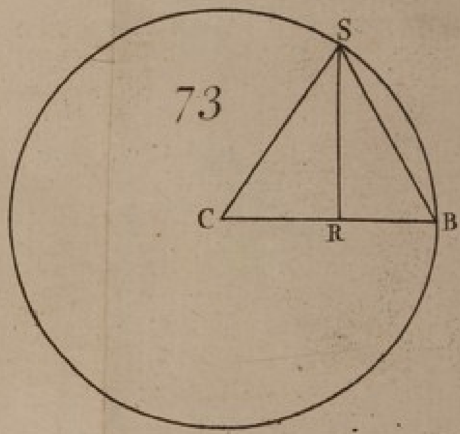

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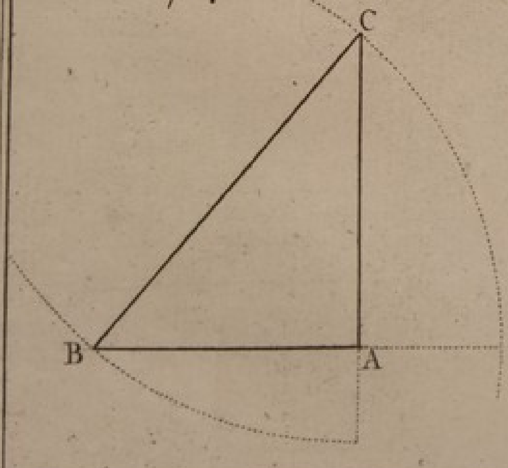

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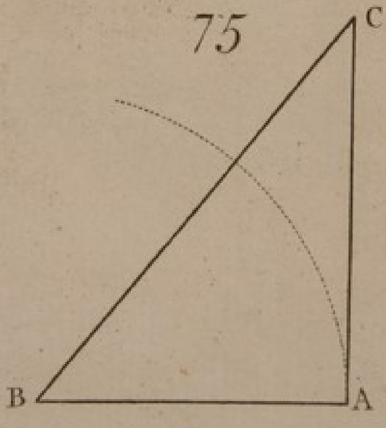

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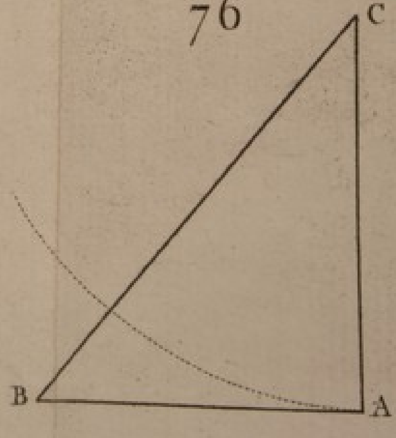


we will ſuppoſe feet; the ſquare of 10 is 100: let the length of the leg AC be 8 FIG.
feet, the ſquare of 8 is 64: let the ſquare 64, be taken from 100, the remainder is 36, the ſquare of the other leg AB; find the ſquare root of 36, *viz.* 6, and you 63
have the length of the leg AB, 6 feet. In like manner the two legs being given, the hypotenuſe may be thus known; find the ſquares of the legs and add them together, the ſum is the ſquare of the hypotenuſe: *example,* let the leg BA be 6 feet, the leg AC 8 feet, the ſquare of 6 is 36, the ſquare of 8 is 64, the ſum of 36 and 64 is 100, the ſquare of the hypotenuſe: the ſquare root of 100 is 10, the length of the hypotenuſe therefore is 10 feet; which was to be found. *This propoſition is another of the ſources of the tables of ſines, tangents, and ſecants,* which for the ſake of ſome of my readers I ſhall now explain.

·99 *The complement of an arc* is ſo much as it wants of a quarter of a circle: thus, fig. 65, the arc SE is the complement of the arc SB; and the arc SB is 65
the complement of the arc SE.

·100 *The ſupplement of an arc* is ſo much as it wants of a ſemicircle: thus, fig. 65. SEA is the ſupplement of the arc SB, and SB is the ſupplement of the 65
arc SEA: ſome writers call this the complement to a ſemicircle.

·101 *A chord* or *ſubtenſe*, AB, fig. 66, is a ſtrait line drawn within a circle, 66
terminated at each end by the circumference: every chord as AB divides the circumference of the circle into two arcs, ACB and ADB: the chord is ſaid to ACB
be the chord of either of thoſe arcs: a chord is ſaid to ſubtend its arc, becauſe it is ſtretched under it, being as a ſtring to a bow.

·102 The larger any arc is, the longer is the chord, till the arc is a ſemicircle, and the chord a diameter; which is the longeſt ſtrait line that can be drawn within a circle, as appears by the ſixty ſeventh figure. 67

·103 *A right ſine*, or as it is generally called, *a ſine of an arc*, is a ſtrait line drawn within a ſemicircle, from one extreme of an arc, perpendicular to a diameter drawn from the other extreme of that arc: in the black ſemicircle AEB, fig. 68, let the arc whoſe ſine is to be found be SB, from S one extreme of 68
the arc, draw SR, perpendicular to AB the diameter which is drawn from B, the other extreme of the given arc; SR is the right ſine of it: and ſince the arc SB meaſures the angle SCB, § 30, the line SR is called the ſine alſo of the angle SCB. Sine is a relative term, and is indifferently referred either to the angle, or to the arc which meaſures the angle; in trigonometry it is generally called the ſine of an angle.

·104 If we compleat the circle, as is done in the preceding figure by the 68
pointed ſemicircle AGB, and take an arc BD equal to SB, and continue the line SR to D, it is obvious, by *Eucl.* 3.3, that the ſine SR, is half SD, the chord of the arc SBD, which is double to the arc SB; this propoſition is commonly thus expreſt,

FIG. preſt, *the ſine is half the chord of a double arc:* thus it appears that a ſine is the
ſame in a ſemicircle that a chord is in the whole circle.

·105 As a chord is referred to both parts of the circumference of a circle, as
well that which exceeds a ſemicircle as that which falls ſhort of it, § 101; ſo
a ſine is referred to both parts of a ſemicircle, as well the arc greater than a
68 quadrant as that which is leſs than a quadrant: thus SR the ſine of the arc SB,
is alſo the ſine of the arc SEA, the ſupplement of SB: if we conſider the angles,
inſtead of the arcs, we may then ſay, that the ſine of every acute angle SCB, is
alſo the ſine of the obtuſe angle SCA, the ſupplemental angle to SCB, which
added to it makes two right angles: for this reaſon, tables of ſines are never
computed for angles that exceed 90°; but if the ſine of any obtuſe angle be re-
quired, we take for it the ſine of the acute angle which added to it makes 180°:
thus, for the ſine of 160°, we take the ſine of 20°; for the ſine of 110°, we take
the ſine of 70°.

69 ·106 The larger any angle or arc is, the greater will the ſine be, till the arc
is a quadrant, and the angle a right one; and then the ſine is the radius of the
circle; which being the largeſt ſine poſſible, and all other ſines being taken
out of it, is called *the whole ſine:* in fig. 69, the pointed lines are ſines of angles
or arcs increaſing from 10°, to 90°, thus, AB is the ſine of an angle or arc of 10°,
CD the ſine of 20°, EF of 30°, &c.

68 ·107 *A verſed ſine* of an arc is a ſtrait line drawn from one extreme of that arc
to the right ſine of it, perpendicular to the right ſine: thus, RB is the verſed sine
of the arc SB, drawn from B to R, making the angle BRS a right one: thus
alſo, AR is the verſed ſine of the arc AES, drawn from A to R, and making ARS
a right angle.

68 ·108 The point R, where the right ſine SR falls upon the diameter AB, di-
vides the radius CB into two parts, CR and RB, that part RB next the circum-
ference is the verſed ſine, called by ſome the *ſagitta* of the arc SB; the other
part *viz.* CR next the center is called *the ſine of the complement*, becauſe, by *Eucl.*
1, 34, equal to FS, which is in reality the ſine of the arc SE, the complement
of the arc SB. Verſed ſines are ſeldom inſerted in tables[a], becauſe eaſily found
by knowing the radius and ſine complement; thus, for any arc SB leſs than a
quadrant, take the ſine complement CR from the radius CB, the remainder RB
is the verſed ſine: for any arc AES greater than a quadrant, add the ſine com-
plement CR to the radius AC, and the ſum of both, *viz.* AC, is the verſed ſine. AR

·109 *A tangent of an arc* is a ſtrait line perpendicular to the diameter, drawn
out from one extreme of the arc, till it meets with the radius continued
70 through the other extreme of the arc: thus, in fig. 70, BT is the tangent of

a *Verſed ſines are in Sr* Jonas Moor's *and* Sherwin's *tables.*

the

the arc SB, perpendicular to the diameter AB, drawn out from the point B, till it meets with the radius CS continued, in T. FIG. 70

·110 *A ſecant of an arc* is the radius continued through one end of the arc, till it meets the tangent drawn from the other end: in fig. 70, CT is the ſecant of the arc SB. The ſecant or tangent of any arc is, as was ſaid of the ſine, the ſecant and tangent alſo of the ſupplement of that arc; thus, TB is the tangent, and TC the ſecant, of the arc SEA, the ſupplement of SB.

·111 The larger any angle or arc is, the longer will the ſecant and tangent 71
be, till the arc is a quadrant, and the angle a right one; and then they are ſaid to be infinite; becauſe, fig. 71, the ſecant will be the radius AF continued, as 71
by the pointed line, to which the tangent ~~BT~~ is parallel, and therefore they can BI
never meet, § 46. The ſeventy firſt figure ſhews how the ſecants and tangents grow longer, as the arcs are larger; thus, of the arc BC, the tangent is BG; the ſecant AG: of the arc BD, the tangent is BH; the ſecant AH: of the arc BE, the tangent is BI; the ſecant AI: of the arc ~~DF~~ the tangent is BI; the ſecant AF: BF
both infinitely extended.

·112 The ſine, tangent, or ſecant, of the complement of a given arc or angle, is frequently called *the coſine*, *cotangent*, and *coſecant* of that arc or angle.

·113 To find the ſine, tangent, or ſecant, of an arc or angle, is to find what proportion it bears to the radius; that is, ſuppoſe the radius were divided into a certain number of equal parts, as 10000000 parts, to find how many of ſuch parts the ſine, ſecant, or tangent, is equal to: for this purpoſe, tables have been made, wherein an angle or arc being given, we may find the ſine, tangent, or ſecant thereof, or the ſine tangent or ſecant being given, we may find the angle or arc.

·I ſhall now give the Reader, for a ſpecimen, the firſt two pages of a table of ſines, &c. together with directions for the manner of uſing it.

·114 The table is divided into ſix columns, the firſt of which is the column of minutes: the ſecond, of ſines: the third, of tangents: the fourth, of ſecants: the fifth, of logarithms of ſines: the ſixth, of logarithms of tangents.

·115 At the top of each page, except the firſt and the third, after the word *grad.* is ſet down a number which ſignifies whole degrees: and in the firſt column under the word minutes are the minutes which added to thoſe degrees expreſs the quantity of any angle whoſe ſine, tangent, &c, may be found in that page. The firſt and third pages of the table contain only minutes from 1′ to 60′, and therefore at the top of thoſe two pages is put *grad.* 0.

Minut.	Grad. 0. Sinus	Tang.	Secant.	Log. Sin.	Log. Tang.
0	0	0	100000.00	0	0
1	29.09	29.09	100000.00	6.4637261	6.4637261
2	58.18	58.18	100000.02	6.7647561	6.7647562
3	87.27	87.27	100000.04	6.9408473	6.9408475
4	116.36	116.36	100000.07	7.0657860	7.0657863
5	145.44	145.44	100000.11	7.1626960	7.1626964
6	174.53	174.53	100000.16	7.2418771	7.2418778
7	203.62	203.62	100000.21	7.3088239	7.3088248
8	232.71	232.71	100000.27	7.3668157	7.3668169
9	261.80	261.80	100000.34	7.4179681	7.4179696
10	290.89	290.89	100000.42	7.4637255	7.4637273
11	319.98	319.98	100000.51	7.5051181	7.5051203
12	349.06	349.07	100000.61	7.5429065	7.5429091
13	378.15	378.16	100000,72	7.5776684	7.5776715
14	407.24	407.25	100000.83	7.6098530	7.6098566
15	436.33	436.33	100000.95	7.6398160	7.6398201
16	465.42	465.42	100001.08	7.6678445	7.6678492
17	494.51	494.51	100001.22	7.6941733	7.6941786
18	523.60	523.60	100001.37	7.7189966	7.7190026
19	552.68	552.69	100001.53	7.7424775	7.7424841
20	581.77	581.78	100001.70	7.7647537	7.7647610
21	610.86	610.87	100001.87	7.7859427	7.7859508
22	639.95	639.96	100002.05	7.8061458	7.8061547
23	669.04	669.05	100002.24	7.8254507	7.8254604
24	698.13	698.14	100002.44	7.8439338	7.8439444
25	727.21	727.23	100002.65	7.8616623	7.8616738
26	756.30	756.32	100002.86	7.8786953	7.8787077
27	785.39	785.41	100003.08	7.8950854	7.8950988
28	814.48	814.50	100003.31	7.9108793	7.9108938
29	843.57	843.60	100003.55	7.9261190	7.9261344
30	872.65	872.69	100003.80	7.9408419	7.9408584

Pag. 2.

Minut.	Grad. 89. Sinus	Tang.	Secant.	Log. Sin.	Log. Tang.
60	10000000	Infinit.	Infinit.	10.0000000	Infinit.
59	99999.99	343774667.	343774682.	9.9999999	13.5362739
58	99999.98	171887319.	171887348.	9.9999999	13.2352438
57	99999.96	114591530.	114591574.	9.9999998	13.0591525
56	99999.93	85943630.	85943689.	9.9999997	12.9342137
55	99999.89	68754887.	68754960.	9.9999995	12.8373036
54	99999.84	57295721.	57295809.	9.9999993	12.7581222
53	99999.79	49110600.	49110702.	9.9999991	12.6911752
52	99999.73	42971757.	42971873.	9.9999988	12.6331831
51	99999.66	38197099.	38197230.	9.9999985	12.5820304
50	99999.58	34377371.	34377516.	9.9999982	12.5362727
49	99999.49	31252137.	31252297.	9.9999978	12.4948797
48	99999.39	28647773.	28647948.	9.9999974	12.4570909
47	99999.28	26444080.	26444269.	9.9999969	12.4223285
46	99999.17	24555198.	24555402.	9.9999964	12.3901434
45	99999.05	22918166.	22918385.	9.9999959	12.3601799
44	99998.92	21485762.	21485995.	9.9999953	12.3321508
43	99998.78	20221875.	20222122.	9.9999947	12.3058214
42	99998.63	19098419.	19098680.	9.9999940	12.2809974
41	99998.47	18093220.	18093496.	9.9999934	12.2575159
40	99998.30	17188540.	17188831.	9.9999927	12.2352390
39	99998.13	16370019.	16370325.	9.9999919	12.2140492
38	99997.95	15625908.	15626228.	9.9999911	12.1938453
37	99997.76	14946502.	14946837.	9.9999903	12.1745396
36	99997.56	14323712.	14324061.	9.9999894	12.1560556
35	99997.35	13750745.	13751108.	9.9999885	12.1383262
34	99997.13	13221851.	13222229.	9.9999876	12.1212923
33	99996.91	12732134.	12732526.	9.9999866	12.1049012
32	99996.68	12277396.	12277803.	9.9999850	12.0891062
31	99996.44	11854018.	11854440.	9.9999845	12.0738656
30	99996.19	11458865.	11459301.	9.9999835	12.0591416

·116 If an angle is given, whose quantity is expreſt in degrees and minutes, and the ſine, tangent, or ſecant thereof required; find the number of degrees on the top of the page, and the number of minutes in the column of minutes in the ſame page, and on the ſame line with the number of minutes, you have the ſine, in the column of ſines: the tangent, in the column of tangents: the ſecant, in the column of ſecants.

·117 *Example*, To find the ſine, *&c* of 89° 45′; in the ſecond page of the table, which has on the top *grad.* 89, look in the column of minutes for the number 45; on the ſame line, you have the ſine of 89° 45′, *viz.* 99999.05: the tangent 22918166: the ſecant 22918385.

·118 When an angle is given of a number of minutes only, find that number in the firſt or third page of the table, in the column of minutes; and on the ſame line, in its proper column, you have the ſine, tangent, and ſecant of the angle given.

·119 *Example*, To find the ſine, tangent, or ſecant of an angle of 14′; look in the firſt page of the table, in the column of minutes, for the number 14; and on the ſame line in the column of ſines, you have the ſine 407.24: in the column of tangents, you have the tangent 407.25: in the column of ſecants, the ſecant 10000083.

·120 If the ſine, tangent, or ſecant be given, and the angle correſponding to it required, proceed thus; find the ſine in the column of ſines, or the tangent in the column of tangents, *&c*, and in the column of minutes, on the ſame line, you will find the minute, which with the number of degrees on the top of the page is the angle required: thus, if the ſine 99999.58 be given, find that number in the column of ſines, which in the ſpecimen before us is in the ſecond page; and on the ſame line is the number 50, in the column of minutes: add 50′ to 89°, the number of degrees at the top of the page, and you have the angle required; *viz.* 89° 50′.

·121 The numbers are ſo placed in theſe two pages, which in the common books of tables face one another, that the degree and minute in one page, is the complement to the degree and minute on the ſame line, in the other page; ſo that ſine and coſine, tangent and cotangent, ſecant and coſecant are ſeen at one view: thus, on the ſame line with 10′, in the left hand page, together with its ſine, tangent, and ſecant, we have in the right hand page its complement, 89° 50′, with its ſine, tangent, and ſecant.

·122 Sometimes a ſine, tangent, or ſecant is given, of a number which is not to be found in the table; this often happens when the ſine, *&c* given is the fourth number in an operation by the golden rule; in this caſe, inſtead of the number given, take the number neareſt to it in the table: *example*, if the

ſine

ſine given whoſe angle is required be 8699567, inſtead of this number, which FIG.
is not in the table, take the neareſt to it *viz.* 86992.56, and the correſponding angle 60° 27′ is the angle required.

·123 In the column of ſines there is all along placed a point amongſt the figures by which every ſine is expreſt, in ſuch a manner, that every number has two places on the right hand of the point: there is a point alſo among the figures by which every tangent, or ſecant is expreſt, and for the greateſt part of the table, every number by which any tangent or ſecant is expreſt, has two places on the right hand of the point: but when the numbers riſe ſo high as to have more figures than can conveniently ſtand in the column, it is uſual to omit one or two of thoſe figures, which were to be placed on the right hand of the point, whoſe places muſt always be ſupplyed with as many cyphers, in order to have the true tangent or ſecant: thus, the tangent of 89° 56′ is ſet down in the table 85943630, without any figure or cypher on the right hand of the point; two cyphers therefore are to be added, and then you have the true tangent, *viz.* 85943630.00.

·124 In ſome tables we have the ſines, tangents, and ſecants, for angles of leſs than 1′: the table publiſhed with *Oughtred's trigonometria* gives them for centeſmes of a degree: by *Pitiſcus's or Sherwin's* tables, they may be found for an angle of any number of ſeconds from 1″ to 60″.

· 125 Though the labour of computing a table of ſines &c need not now ·be undertaken, becauſe it has been already gone through by others with in·credible induſtry and patience; yet ſome readers may be deſirous to ſee ſome·thing of the method which they proceeded in, who calculated the tables we ·have: the eleven following ſections are for that purpoſe.

· 126 Sines are either primary, or ſecondary; *primary ſines* are ſuch as are ·found out by an immediate calculation; *ſecondary ſines* are ſuch as are deduced ·from the primary ones.

· 127 The firſt primary ſine is the radius or whole ſine, which we may ſup·poſe divided into any number of parts; for the eaſe of calculation, the num·ber aſſumed for it is an unit with a certain number of cyphers, as 10000000.

· 128 The radius is equal to the ſide of an hexagon inſcribed in a circle; ·*Eucl.* 4. 15: thus, let an hexagon be inſcribed in a circle, fig. 72, I ſay any 72
·ſide thereof CB is equal to the radius: *demonſtration*, draw the radius's AC ·and AB, theſe are equal, by § 25, therefore in the triangle ABC the angles C ·and B are equal, *Eucl.* 1. 5; the ſum of the angles A, C, B, is 180, § 55, where·of the angle at A is a third part, *viz.* 60°, by the work, which ſuppoſes CB ·to be the chord of a ſixth part of the whole circumference 360°; therefore ·the angle A is equal to B or C: and then the ſide CB is equal to the radius AC ·or AB, *Eucl.* 1. 6.

·129 The

FIG. 129 The radius being given, the ſine of 30° may be known; for the radius is the chord of 60°, by § 128, and the ſine of 30° is half the chord of 60°, by § 104; thus, the radius being 10000000, the ſine of 30° is 5000000.

130 The ſine of an arc being given, its coſine may be found by this propoſition; *the ſine of an arc and its coſine are in power equal to the radius: demonſtr.* the ſine SR of an arc SB together with its coſine CR and radius CS, fig.
68 68, form a right-angled triangle, in which the radius CS is the hypotenuſe, by the definitions, § 67, 103, 108: but in every right-angled triangle the hypotenuſe is in power equal to the legs, § 98: therefore &c: thus the ſine of 60° is found in the following method: SR the ſine of 30° is 5000,000, § 129, let the ſquare thereof 25000,000,000,000, be ſubſtracted from 100,000,000,000,000 the ſquare of the radius, and the remainder 75000,000,000,000, is the ſquare of the coſine, the ſquare root of which *viz.* 8670254 is the ſine of 60°.

131 The right ſine and the verſed ſine of an arc are in power equal to the
73 chord of that arc: *demonſtr.* in fig. 73. let the given arc be SB, the ſine thereof SR together with the verſed ſine RB and the chord SB, form a right-angled triangle, whereof the chord SB is the hypotenuſe, by the definitions, § 97, 103, and 107: but in every right-angle triangle the legs are equal in power to the hypotenuſe, by § 98: therefore &c.

132 *Coroll.* 1. The ſine of an arc being given, the chord of that arc may be found, in this manner; find the verſed ſine of the given arc by § 108, and add the ſquare thereof to the ſquare of the ſine; the ſquare root of the ſum of them is equal to the chord required.

133 *Cor.* 2. The ſine of an arc being given, the ſine of half that arc may be found, in this manner; find the chord of the arc by the preceding corollary, and half that chord is the ſine of half the given arc, by § 104.

134 This is ſufficient to ſhew ſomething of the method of inveſtigating ſines; a primary ſine is firſt found, and the ſecondary ſines are derived from it, by finding the ſine of half the given arc, by § 133; and then the complement of that half, by § 130; and then again the half of that complement, by § 133; and thus we may proceed as far as is required: thus, from the ſine of 30°, are found the fifteen following ſines.

Sine of 30° and its halves	Complements,	Halves of the Complements.	Complements.	Halves of the Comp.	Complements.
30° 0'	60° 0'				
15° 0'	75° 0'	(37° 30'	52° 30'	26° 15'	63° 45'
		(18° 45'	71° 15'		
7° 30'	82° 30'	41° 15	48° 45'		
3° 45'	86° 15'				

135 When

135 When the ſines are found by the preceding propoſitions, the tangents and ſecants are eaſily found by the golden rule: thus, let the given arc be SB, fig. 70; the ſine thereof RS together with the coſine CR and radius CS, form a right-angled triangle CRS, by the definitions § 103 and 108; the radius CB together with the tangent BT and ſecant CT, form another right-angled triangle, CBT, by the definitions § 109 and 110: theſe triangles having one acute angle at C common, are ſimilar, by § 96: therefore to find the tangent, ſay, CR:RS::CB:BT. that is, as the coſine CR is to the ſine RS, ſo is the radius CB to the tangent BT. FIG. 70

136 To find the ſecant, ſay thus. CR : CS : : CB : CT. that is, as the coſine CR is to the radius CS, ſo is the radius CB to the ſecant CT. 70

137 What ever number is aſſumed for the radius, almoſt all the ſines tangents and ſecants are incommenſurable to it, as being found either by extracting the ſquare root, or by the golden rule; in the firſt of theſe operations, the root extracted is often a ſurd number, as being extracted out of a number not exactly ſquare; in the ſecond operation, *viz.* that by the golden rule, the 4th number is often a whole number with a fraction; for theſe reaſons tables of ſines, tangents, and ſecants cannot be made perfectly accurate: but they may be made ſo nearly accurate, that no number in them ſhall differ from the true one ſo much as one of thoſe parts into which the radius is ſuppoſed to be divided in the tables; thus, in the common tables, where the radius is aſſumed of 10000000 parts, no ſine or tangent differs from the true number ſo much as a 10000000th part of the radius: to make the tables thus near the truth, it was neceſſary for authors either to conſider fractions in their calculations of ſines *&c*, which would have made them exceedingly operoſe; or elſe to aſſume the radius of a much greater number of parts in the calculation, than it is ſaid to conſiſt of in the tables after they are made: the latter method as the more eaſy has been made uſe of: thus, *Rheticus* in order to compute a table of ſines, *&c*, to a radius of 1000000,0000, aſſumed a radius of 100000,00000,00000 parts; and after the calculation, cut off from each number 5 figures on the right hand: *Pitiſcus* for ſome ſines at the beginning of his table, aſſumed the radius of 100000,00000,00000,00000,00000 parts, *Pitiſc. trigonometr. l.* 2. *n.* 26. For the reſt, ſee *Tacquets geometr. pract. l.* 1. *c.* 2. *and the Authors there cited: Lansberg. triangulorum geometria: Newton's compendium of trigonometry: Sherwin's tables p.* 44: *Keils trigonometria*, &c.

138 By the definitions § 103 and 108; the ſine SR, of any acute angle SCR, fig. 68, together with the coſine CR, and the radius CS form a right-angled triangle, CRS: the converſe of this is true, *viz.* that in every right-angled triangle CRS, the ſides are radius, ſine, and coſine of one of its acute angles. 68

139 By

FIG. ·139 By the definitions § 109 and 110, the tangent TB, of any acute angle
70 TCB, together with its ſecant CT, and the radius CB, form a right-angled tri-
angle TBC: the converſe of this is true, *viz.* that in every right-angled trian-
gle TBC, the ſides are radius, tangent, and ſecant of one of its acute angles.

74 ·140 In every right-angled triangle, BAC fig. 74, any ſide may be made ra-
dius, and then each of the other ſides will be either ſine, tangent, or ſecant of
one of the acute angles: *caſe* 1. If the hypotenuſe BC be made radius, the legs
will be ſines of their oppoſite angles; that is, CA is the ſine of its oppoſite an-
gle ABC, and BA is the ſine of the angle ACB: *caſe* 2. If one of the legs be made
radius, then ſhall the other leg be tangent of the angle oppoſite to it, and the
75 hypotenuſe ſecant of the ſame: thus, fig. 75, if the leg BA be made radius, the
other leg CA will be tangent of its oppoſite angle B, and the hypotenuſe BC
76 ſecant of the ſame: again, fig. 76, if the leg CA be made radius, the other leg
BA will be tangent to its oppoſite angle C, and the hypotenuſe BC ſecant.

·141 All the angles of a right-angled triangle being given, the ratio between
any two of its ſides may be found: for every ſide may be conſidered either as
radius, or ſine, or tangent, or ſecant of a given angle, § 138 and 139; and the
ratio between the radius, and the ſine, tangent, or ſecant of a given angle, may
74 be found by the table, § 113: thus, fig. 74, the ſide BC being conſidered as
radius, is 10000000; the leg BA as ſine of the angle C, ſuppoſe of 50°, is found
in the table 76604.41: the leg CA as coſine, or ſine of the angle B of 40° the
complement of 50°, is 64278.76: and the ratios between the ſides ſtand thus;

BC : AB :: 10000000 : 76604.41. and BC : CA :: 10000000 : 64278.76.

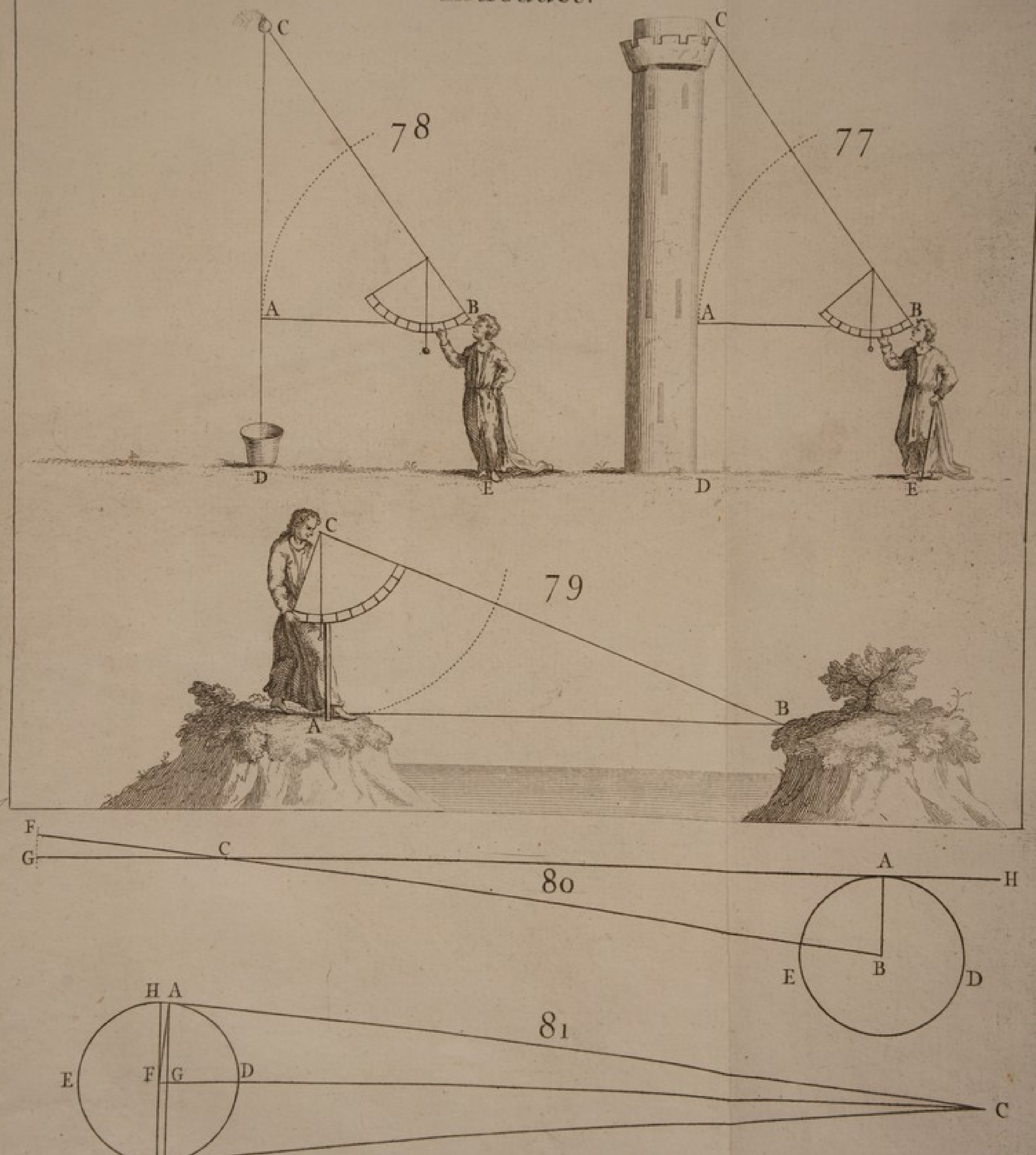
·142 If the ratio between any two quantities, and the real meaſure of one of
them be given in numbers, the meaſure of the other quantity may be found
74 by the golden rule: thus, fig. 74, if in the triangle BAC I find the ratio be-
tween the ſides BC and BA is ſuch that BC:BA::100:76, and that the actual
meaſure of BC is 200 feet, then I may be aſſured that BA is 152 feet; for
$100 : 200^{feet} :: 76 : 152^{feet}$.

·143 This propoſition then in trigonometry is univerſally true, that *in every right-angled triangle, if one acute angle and the length of one ſide be given, the whole triangle may be known:* that is, we may find the quantity of every angle, and the length of every ſide.

·144 This propoſition being here once demonſtrated, will be referred to as an axiom, in other parts of this work: in the mean time it will not be amiſs to give the reader a taſte of the uſefulneſs thereof, and of the tables of ſines *&c*, in the following examples; wherein the method will be ſeen in which we may proceed by trigonometry, not only to meaſure the heights and diſtances of ſuch objects upon the earth as are inacceſſible, but alſo to diſcover the diſtances and magnitudes of the heavenly bodies.

·145 *Ex-*

page 31.



·145 *Example* 1; ſuppoſe DC is an upright tower whoſe height is required, it may be found in this manner; with a chain or ſtaff of a known length, meaſure a diſtance at pleaſure from D the foot of the tower, to E where the ſtation of the obſerver is to be, in the preſent inſtance let DE be taken 100 feet; let the obſerver ſtanding at E look firſt, through the ſights of a quadrant held horizontally, at the tower, and where the viſual ray terminates make a mark A, which will ſhew the height of his eye above D the bottom of the tower, then keeping ~~the center of the quadrant~~ in the ſame place B, let him turn ~~it~~, till through the ſights he can ſee the top of the tower C: here is a triangle BAC, made by theſe three lines, *viz.* BA the diſtance of the obſerver's eye from the tower, CA the height of the tower above his eye, and BC a line drawn from his eye to the top of the tower; in this triangle, the angle A is a right one by the ſuppoſition, the angle at B is found by the quadrant, ſuppoſe it 60°, and the meaſure of one ſide AB is known, *viz.* 100 feet: from theſe *data* we may find, firſt, the ratio between AB and AC, after this manner; make BA radius, and AC, will, by § 140, be tangent of the angle B, which is by obſervation found 60°; now in a table where the whole ſine or radius is 10000000, the tangent of 60° is 173205.08; therefore BA : CA :: 10000000 : 173205.08. Secondly, the real meaſure of BA being 100 feet, AC will by the golden rule be found 173 feet with a fraction or part of a foot, which after reduction comes to a little more than two tenths of a foot. The operation in numbers ſtands thus, 10000000 : 100^{feet} :: 173205.08:

FIG. 77

his eye
the quad

$$\times 100$$

$$1\,|\,0000000)\ 173\,|\,2050800\ (\ 173\ \tfrac{2}{10}\Big|\tfrac{050800}{000000}.$$

AC being thus found 173 feet $\frac{2}{10}$, add thereto AD, equal to BE the height of the obſervers eye from the ground, which ſuppoſe to be 5 feet, and you have the whole height of the tower CD, 178 feet $\frac{2}{10}$.---I have in this example ſuppoſed E the ground upon which the obſerver ſtands and D the bottom of the tower to be upon a level; if one of theſe is higher than the other, allowance muſt be made for the difference between them, in aſſuming the height of the obſervers eye.---By the ſame method may the utmoſt height of a bomb or rocket thrown up perpendicularly be found, by an obſerver ſtanding at E, fig. 78, a known diſtance, ſuppoſe 100 yards, from D the place where it is diſcharged, and looking at it through the ſights of a quadrant when at its utmoſt height C: a view of the figure is ſufficient, if compared with the laſt, for the triangle BAC is meaſured in the ſame manner as in the laſt figure; *viz.* the angle A is a right one by the work, the angle B is found by the quadrant, and the diſtance AB equal to DE is given in real meaſure, *viz.* 100 yards: ſo that if BA be made radius, AC will be tangent of the angle at B, &c. 78

·146 *Ex-*

FIG. ·146 *Example* 2; let it be required to meaſure the diſtance AB, which may
79 be the breadth of a river or valley fig. 79; ſet up perpendicularly a ſtick CA of a known length, ſuppoſe it 4 feet two inches, in all 50 inches long; place the center of your quadrant at C the top of the ſtick, and look through the ſights of it till the viſual ray points at the object B, whoſe diſtance from A the place of the obſerver is to be meaſured: here is a right-angled triangle BAC, with one of its acute angles and one of its ſides given; for the angle A is a right one by the ſuppoſition, the ſide AC is 50 inches by the ſame, the angle C is found by the quadrant, ſuppoſe it 89° 30′: make CA radius, and AB will be tangent of the angle at C, of 89° 30′, § 140 *caſe* 2: ſay then, as radius CA is to 50 inches, ſo is the tangent of 89° 30′ to the number of inches contained in AB: now in a table where the radius is 10000000, the tangent of 89° 30′ is 11458865.00, ſo that for an operation by the golden rule we have three numbers given, by means whereof the fourth number required, *viz.* 5729 inches and 4 tenths, the length of AB, is eaſily found; the work in natural numbers ſtands thus,

$$10000000 : 50^{inches} : : 1145\ 8865.00$$

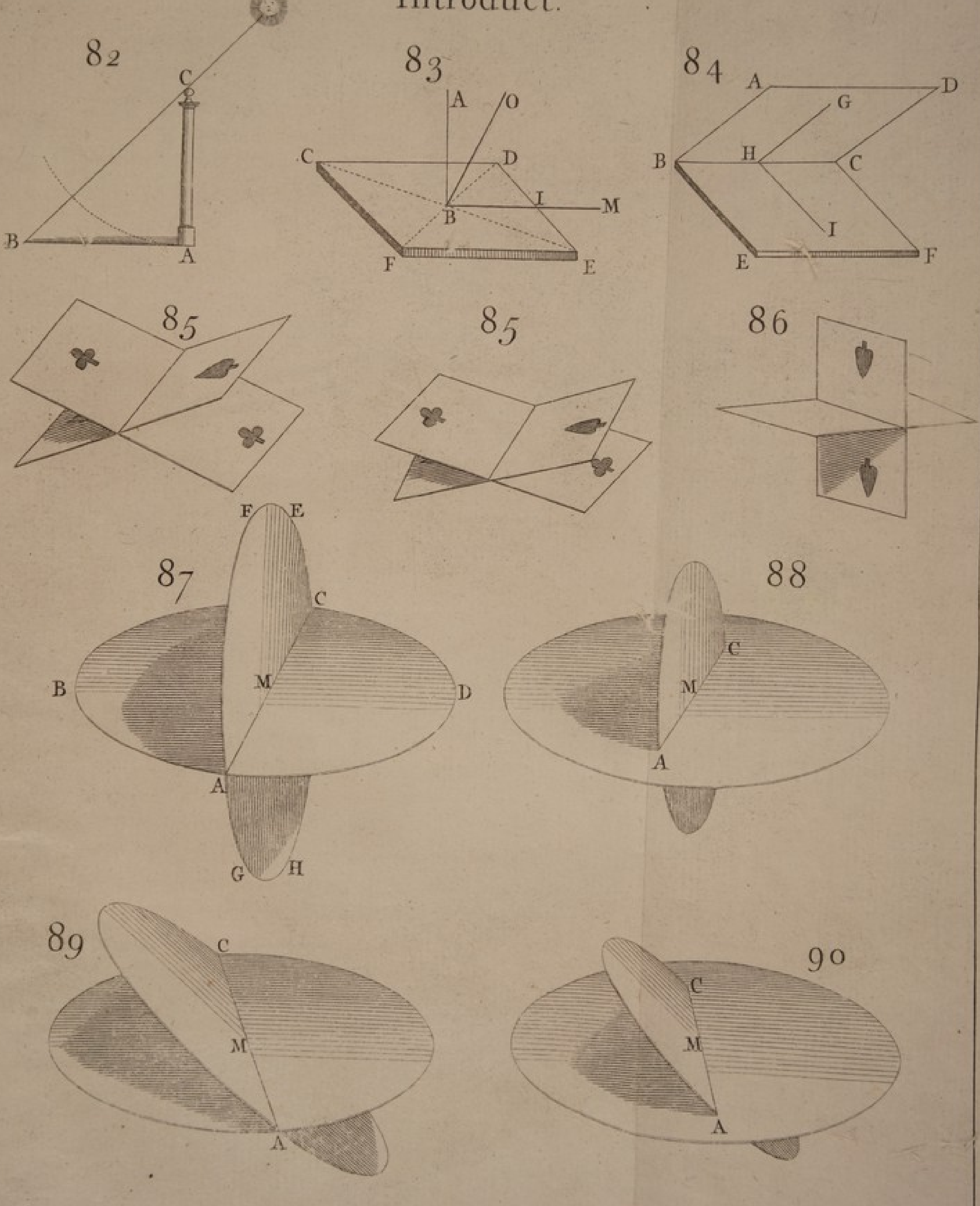
$$\underline{\qquad\qquad 50}$$

$$1 \mid 0000000\ )\ 5729 \mid 4325000\ \left(5729\ \tfrac{4}{10} \,\Big|\, \tfrac{325000}{000000}\right.$$

theſe 5729 inches reduced to feet or yards, will give the diſtance of B from A 477 feet, or 159 yards, and 5 inches 4 tenths. I have in this example, to make it more eaſy, ſuppoſed the points A and B to be upon a level, as they muſt be if we would have the angle at A a right one: to ſhew how to find a diſtant point upon the ſame level with one that is near us, would I think be foreign to my preſent deſign.

80 . 147 *Example* 3; *to find the moons diſtance from the earth*; let ADE fig. 80, repreſent the earth, C the moon, A the place of the ſpectator obſerving the moon in his ſenſible horizon HC: here is a triangle BAC, made by AB a ſemidiameter of the earth, BC a line drawn from the center of the earth to the moon, and AC a line drawn from the place of the ſpectator to the moon; in this triangle the angle BAC is a right one, by § 28, *Eucl.* 3. 18: the angle ACB is the angle of the moons parallax, which, by methods hereafter to be taught, has been found to be 57′; the ſide AB, by finding the circumference of the earth, the manner of doing which will alſo hereafter be ſhewn, is found to be in round numbers, 4000 miles: make BC radius, and then AB, will be ſine of the angle C; ſay then, as BA ſine of 57′ is to 4000 the number of miles contained in the earths ſemidiameter, ſo is BC radius to a 4th number, *viz.* 241255, the number of miles contained in BC, the moons diſtance from the center of the earth; the ſine of 57′ is 165799; the proportion then ſtands thus,

165799


82
C
B
A
83
A
O
C
D
B
I
M
F
E
84
A
D
G
B
H
C
I
E
F
85
85
86
87
F
E
C
B
M
D
A
G
H
88
C
M
A
89
C
M
A
90
C
M
A

165799^{sine} of $57'$: 4000^{miles} :: 10000000^{rad} : 241255^{miles} FIG.
in round numbers we may ſay the diſtance of the moon from the earth is 240000 miles.

·148 *Example* 4; to find the diameter of the moon; let ADBE be the moon, fig. 81, let her be viewed by a ſpectator upon the earth at C, her apparent di- 81
ameter is meaſured by the angle ACB, which, by methods hereafter to be taught, is found to be 30′; half of this, *viz.* the angle ACF is therefore 15′: here then is a triangle CAF whoſe angle CAF is a right one, *Eucl.* 3. 18, the angle ACF is 15′ by obſervation, and the ſide CF the moons diſtance from the earth is known by § 147: from theſe *data* the ſemidiameter of the moon AF is thus found; in the triangle ACF make the hypotenuſe CF radius, and AF will be the ſine of the angle ACF, of 15′: ſay then, as radius 10000000 to 240000, the number of miles contained in CF the moons diſtance from the earth, ſo is 43633 the ſine of 15′ to the number of miles contained in AF, the moons ſemidiameter: from theſe three numbers given, the fourth *viz.* 1047 miles is eaſily found by the golden rule: for 10000000 : 240000^{miles}. :: 43633 : 1047^{miles}. 1047 miles is then the moons ſemidiameter, and the double thereof 2094 miles her diameter.

·149 *Scholium*; by the figure before us it appears that we do not ſee an en- 81
tire hemiſphere of the moon HDI at one view from C, but only the ſegment ADB which is a little leſs than an hemiſphere; notwithſtanding this the preceding calculation helps us to the true diameter of the moon HI: for the viſual angle ACB and the half of it ACF being found, we do not proceed to find the meaſure of the chord AB or of its half AG; what we deduce from thence is the meaſure of the line AF, which is a ſemidiameter of the moon, and conſequently equal to half the line HI the moon's true diameter. I need not here add that the diſtance of the moon from us is ſo great that the ſegment of the moon ſeen by us differs not ſenſibly from an hemiſphere as will be obſerved § 241.

·I have in theſe examples, to make the computation more eaſy, made uſe of round numbers inſtead of the true ones, *viz.* 4000 miles for the earths ſemidiameter, to find the moons diſtance, and 240000 miles for the moons diſtance, to find her diameter; for this reaſon the diſtance and diameter of the moon here found are a little different from the true ones: but that difference is not conſiderable, and I ſhall in the proper place give the true diſtance and diameter of the moon, deduced from the true ſemidiameter of the earth.

·150 *Example* 5; let it be enquired how far the ſhadow of an upright pillar will be extended at noon, upon a level pavement, the meridian altitude of the ſun and the height of the pillar being given; ſuppoſe the meridian altitude of the ſun is 50°, and the height of the pillar 100 inches: here is a triangle CAB 82

FIG. whoſe angle at A is a right one by the ſuppoſition; the angle at B is 50° by the
82 ſuppoſition alſo; therefore the angle C the complement of B is 40° § 55 *Cor.* 5; in this triangle if CA be made radius, AB will be the tangent of the angle C of 40°, § 140 caſe 2; we may ſay then, as radius to tangent of 40°, ſo CA is to AB: the tangent of 40° is 8390996, therefore 10000000 : 8390996 :: CA : AB; but the meaſure of CA is given 100 inches; from theſe three numbers given, the 4th, *viz.* the length of AB in inches, is eaſily found by the golden rule to be 83 inches: for 10000000 : 100$^{\textit{inches}}$ :: 8390996 : 83$^{\textit{inches}}$.

151 In the foregoing examples I have made uſe of natural ſines *&c*; it remains to ſhew the uſe of the other part of the tables; *viz.* the logarithms of the ſines and tangents. Logarithms are numbers ſo contrived that by making uſe of them, the difficult operations of arithmetic may be performed by the help of more eaſy ones: thus, inſtead of multiplication in natural numbers, we may work by addition in logarithms; inſtead of diviſion, by ſubſtraction; inſtead of ſquaring or cubing a number, or raiſing other powers, we work by multiplication; inſtead of extracting the root of a ſquare, cube, or other power, we uſe diviſion.

152 There is uſually at the end of the table of ſines, another table in which any number within the compaſs of the table being given, its logarithm may be found; or the logarithm being given, its number may be found.

If two numbers are to be multiplied together, add together the logarithms of the given numbers; and the ſum of them is the logarithm of the product.

If one number is to be divided by another, ſubſtract the logarithm of the diviſor from the logarithm of the dividend; the remainder is the logarithm of the quotient.

From whence it follows, that in the direct golden rule, if you add the logarithms of the ſecond and third terms together, and from the ſum of them ſubſtract the logarithm of the firſt, the remainder is the logarithm of the fourth term.

The calculation of ſpherical triangles and of ſome oblique-angled plain triangles is made more eaſy, if we make uſe of logarithmic ſines, and tangents inſtead of natural ones; I have ſaid ſo much of them in this place, to explain the tables of which I gave a ſpecimen: for a fuller account of logarithms ſee *Wallis's Algebra, c.* 12. *Halley Philoſ. tranſ. N.* 216. *Pardie's Geometr. l.* 5. *Keil de Logarithmis. Sherwin's tables.* &c.

153 If a ſtrait line ſtands exactly upright upon a plane, as an upright pillar does upon a level pavement; that *line* is ſaid to be *perpendicular to the plane:*
83 thus, the line AB, fig. 83, is perpendicular to the plane CDEF, if it makes right angles with all the lines, as CE or DE, which can be drawn upon the plane through

Introduct.

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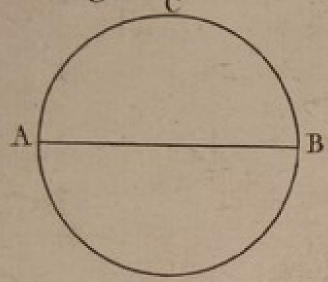

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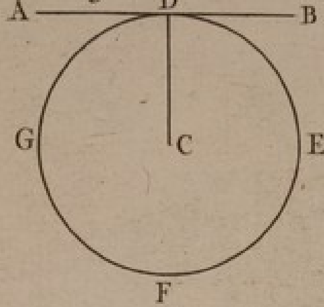

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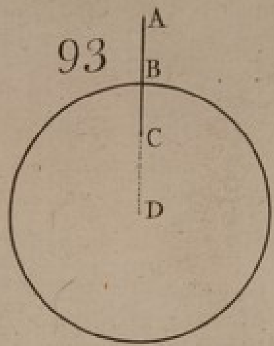

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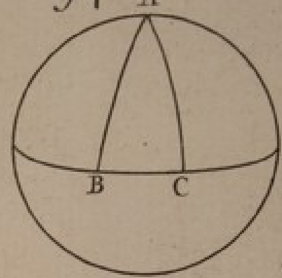

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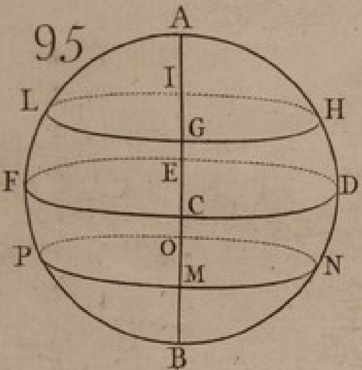

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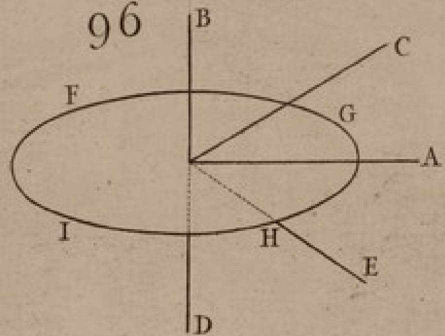

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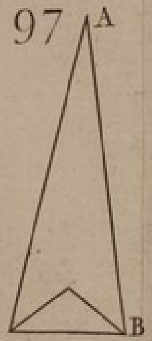

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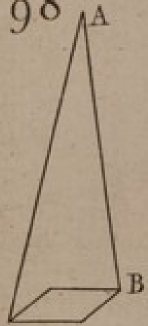

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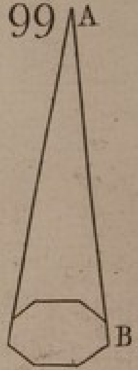

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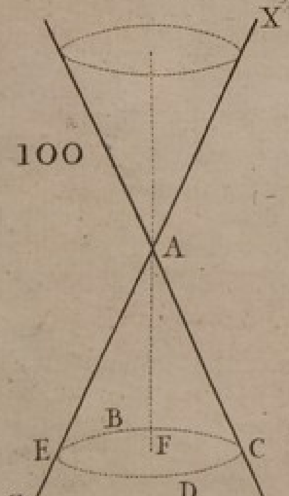

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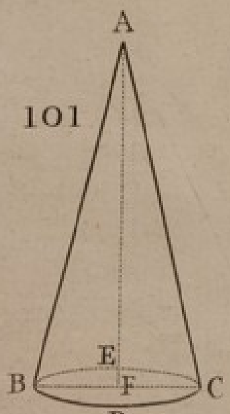

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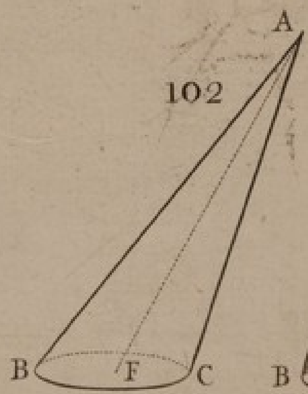

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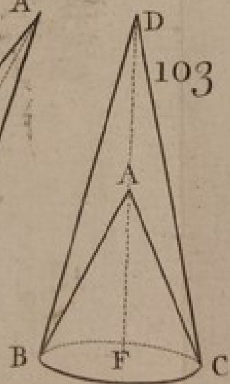

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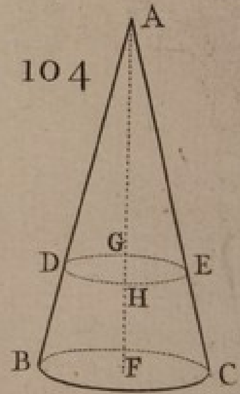

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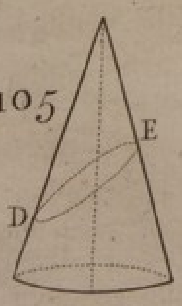

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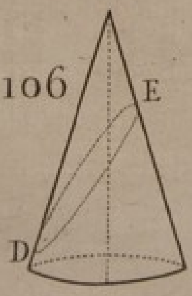

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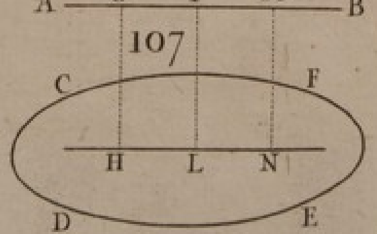

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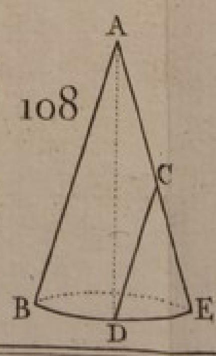

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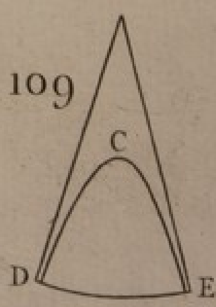


through the point B: a thread with a bullet at the end of it, hung over a table FIG.
that ſtands exactly level, will be perpendicular to the ſurface of the table.

154 If a ſtrait line ſtands obliquely upon a plane, as a pillar that leans does upon a level pavement; that *line* is ſaid to be *inclined to the plane*, and the acute angle contained between the plane and the line where they approach neareſt to one another is *the angle of the lines inclination:* thus, fig. 83, the line OB 83
is inclined to the plane CDEF, and the angle of its inclination is OBI.

155 *A ſtrait line* AB is *parallel to a plane* CDEF, and *the plane* CDEF is *parallel to a ſtrait line* AB, fig. 107, when every part of the line is equally di- 107
ſtant from the plane: that is, when all the lines which can be let fall from the line, perpendicular to the plane, as GH, IL, MN, are equal.

156 *A point* is ſaid to be *in a plane produced*, when the plane continued or extended would paſs through that point: *a point* is ſaid to be *elevated above a plane*, when a line drawn from the point to the center of the plane, is either perpendicular or inclined to the plane: thus, fig. 83, the point M is in the 83
plane CDEF produced, but the points A and O are elevated above that plane: thus alſo, fig. 96, let FGHI be a circle viewed obliquely, the point A is in the 96
plane of this circle produced, but the points, B, C, D, E, are all elevated above the plane of the circle: *viz.* B and C above one ſide of the plane, and D and E above the other ſide of it.

157 *Parallel planes* are ſuch as, how far ſo ever they be extended, will never meet, but continue ſtill equidiſtant: the diſtance between parallel planes is meaſured by ſtrait lines drawn from one plane to the other, ſo as to be perpendicular to both of them; if theſe perpendiculars are all equal, the planes are parallel: thus, if a coach glaſs be throughout of the ſame thickneſs, the two ſurfaces of it are parallel planes; the oppoſite ſides of a die are alſo parallel planes.

158 If one plane ſtands exactly upright upon another, as an upright wall does upon a level pavement, thoſe *planes* are ſaid to be *perpendicular* to one another, or to interſect each other at right angles. See fig. 86. 86

159 If one plane ſtands obliquely upon another, as a wall that leans does upon a level pavement, it is ſaid to *incline* to it, and the angle contained between thoſe two ſurfaces of the planes which are neareſt to each other, is called 84
the angle of their inclination. See fig. 84 and 85. 85

160 Any two planes ABCD and BEFC, fig. 84, which are not parallel, will, 84
if both of them be extended, interſect each other in a right line BC, which is called *their common ſection.*

161 The inclination of two planes is meaſured by an angle contained between two right lines which are drawn upon the planes, perpendicular to

 their

FIG. their common ſection, and meet in a point of it: thus, fig. 84, let there be two
84 planes ABCD and BEFC, whoſe common ſection is BC; from any point thereof as H draw upon the planes the lines HG and HI perpendicular to BC; the angle GHI is the angle of inclination of thoſe planes.

162 If two planes interſecting one another be imagined to move upon their common ſection, as the lid of a ſnuff box does upon its hinge, the wider the planes are opened aſunder, the greater is the angle of their inclination, till they are opened ſo wide that one is perpendicular to the other. If two cards, or pieces of ſtiff paper be cut, each half through, and let one into the other, you
85 may by opening them more or leſs repreſent the different inclinations of two
86 planes: ſee the eighty fifth and eighty ſixth figures.

163 Any two circles deſcribed upon parallel planes with their centers exactly oppoſite to one another, ſo that if a line were drawn perpendicularly to the planes through the center of one circle, that line if extended would paſs through the center of the other circle, are *parallel circles:* circles drawn upon the oppoſite ſides of a die with their centers exactly oppoſite are parallel. Circles may be parallel whether they be equal to each other or not.

164 Any two *circles* are ſaid to *incline* to each other which are drawn from the ſame center upon inclining planes, and the angle of their inclination is the ſame as that of the planes upon which they are drawn. Two *circles* are *perpendicular* which are drawn from the ſame center upon perpendicular planes: two circles may be perpendicular or inclined, whether they be equal
87 or not: the 87th figure gives a view of two equal circles, ABCD and EFGH,
88 having the ſame center M, drawn upon planes perpendicular to each other: the
89 88th figure ſhews two unequal and perpendicular circles: the 89th figure repre-
90 ſents two circles equal and inclined: and the 90th figure two circles unequal and inclined: in every one of theſe figures, AC is the common ſection of the planes of the interſecting circles, and M is their common center. Circles having different centers may alſo be drawn upon inclining planes; but theſe fall not under our preſent conſideration.

165 A *ſolid* or *ſolid figure* is that magnitude in which we may conſider threefold extenſion, *viz.* length, breadth, and thickneſs: every piece or particle of matter, of what ſhape ſoever, is a ſolid, becauſe it is conceived as having this threefold extenſion, and it may be enquired how long, how broad, and how thick or deep it is; but we need at preſent conſider only two or three of the regularly ſhaped ſolids, as a ſphere, a cone, a cylinder, and a cube.

166 When geometers ſpeak of a ſolid, they do not always mean that it ſhould conſiſt of groſs material parts, as the word ſolid may ſeem to imply; pure ſpace it ſelf, though it be conceived perfectly empty and void of all matter, has

has this threefold extenſion; and any part of infinite ſpace, when we imagin FIG.
it of any determinate largeneſs and figure, is a ſolid in geometry: thus, the inſide of a veſſel, whatever its ſhape be, may be called a ſolid, whether the veſſel be full or empty; becauſe it may be meaſured in length, breadth, and thickneſs, and its capacity found how much it may contain: ſo that when we ſpeak of a ſphere, cone, or cube, we may only conſider a figure having threefold extenſion, of ſuch a ſhape and ſize, without regarding whether it conſiſts of matter or of pure ſpace.

167 *A ſphere* or *globe* is a ſolid every way perfectly round: the ivory balls uſed at a billiard table, and the marbles children play with are ſpheres or globes. A ſphere and a globe ſignify originally the ſame thing, *viz.* a round body, in different languages; but cuſtom has prevailed ſo, that when we ſpeak of the bodies of the ſun, moon, earth, planets, or ſtars, which we ſuppoſe to be round bodies, we call them globes; but when we ſpeak of the heaven, in the concave ſurface of which the ſun, moon, ſtars, and all the heavenly bodies appear to be placed, we call it *the ſphere of the heaven*, or *of the fixt ſtars:* geometers alſo when they conſider a round ſolid abſtractedly, and the circles or other lines which may be imagined to be drawn upon the ſurface of it, whether conſidered as convex or concave, are ſaid to treat of the ſphere. We may imagin as many circles as we pleaſe drawn upon the convex ſurface of the globe of the earth, or upon the concave ſurface of the ſphere of heaven: the circles of both theſe kinds, are called in books of aſtronomy *the circles of the ſphere*, and an explanation of the nature and uſe of them in aſtronomy or geography is called *the doctrine of the ſphere.*

168 The *formation of a ſphere* is commonly thus explained; imagin a ſemicircle ACB, fig. 91, to turn round upon its diameter AB, till it comes to its firſt 91
ſituation, and it will deſcribe a ſphere: the center of this ſemicircle will alſo be the center of the ſphere thus deſcribed by it. Any ſtrait line drawn through the center of a ſphere, and terminated at each end by the ſurface of it, is called *a diameter.* Any ſtrait line drawn from the center to the ſurface, is *a radius*, or *ſemidiameter of the ſphere.* All radius's or ſemidiameters of the ſame or equal ſpheres, are equal; as are alſo all their diameters: this is evident from § 25.

169 *A great circle* is that which divides the ſphere into two equal parts: *a leſs circle* is that which divides the ſphere into two unequal parts: fig. 95. 95

170 Any ſtrait line which touches a ſphere on its convex ſurface, in ſuch a manner that the line, if extended both ways, would not enter into the ſphere, is called a *tangent to the ſphere.* Any radius of a ſphere drawn to the point of contact, is perpendicular to the tangent: in fig. 92, AB is a tangent to the 29 92
ſphere DEFG; and CD drawn to the point D is perpendicular to AB. Any tangent to a great circle of a ſphere is a tangent to that ſphere.

171 Any

FIG. 171 Any ſtrait line AB or CB, fig. 93, ſtanding exactly upright either upon the
93 concave or convex ſurface of a ſphere, is ſaid to be *perpendicular to the ſphere:* ſuch a line continued through the ſphere would paſs through the center of it; and the converſe of this is true, that any ſtrait line drawn from the center to the ſpherical ſurface, or through it, will be a perpendicular.

172 If the arcs of three great circles be drawn upon the ſurface of a ſphere, ſo as to meet in three points, they will form *a ſpherical triangle*, as ABC, fig. 94.

94 173 The meaſure of a ſpherical angle BAC, fig. 94, is the arc BC of a great
94 circle deſcribed from the angular point A, intercepted between the ſides AB and AC continued to quadrants.

174 The common *terreſtrial globe* repreſents very well the earth and ſea, the ſituation of mountains, rivers &c, with the extent of kingdoms, and ſtates; and has beſides ſeveral circles drawn upon it, to repreſent ſuch as we may conceive to be drawn upon the ſpherical ſurface of the earth it ſelf.

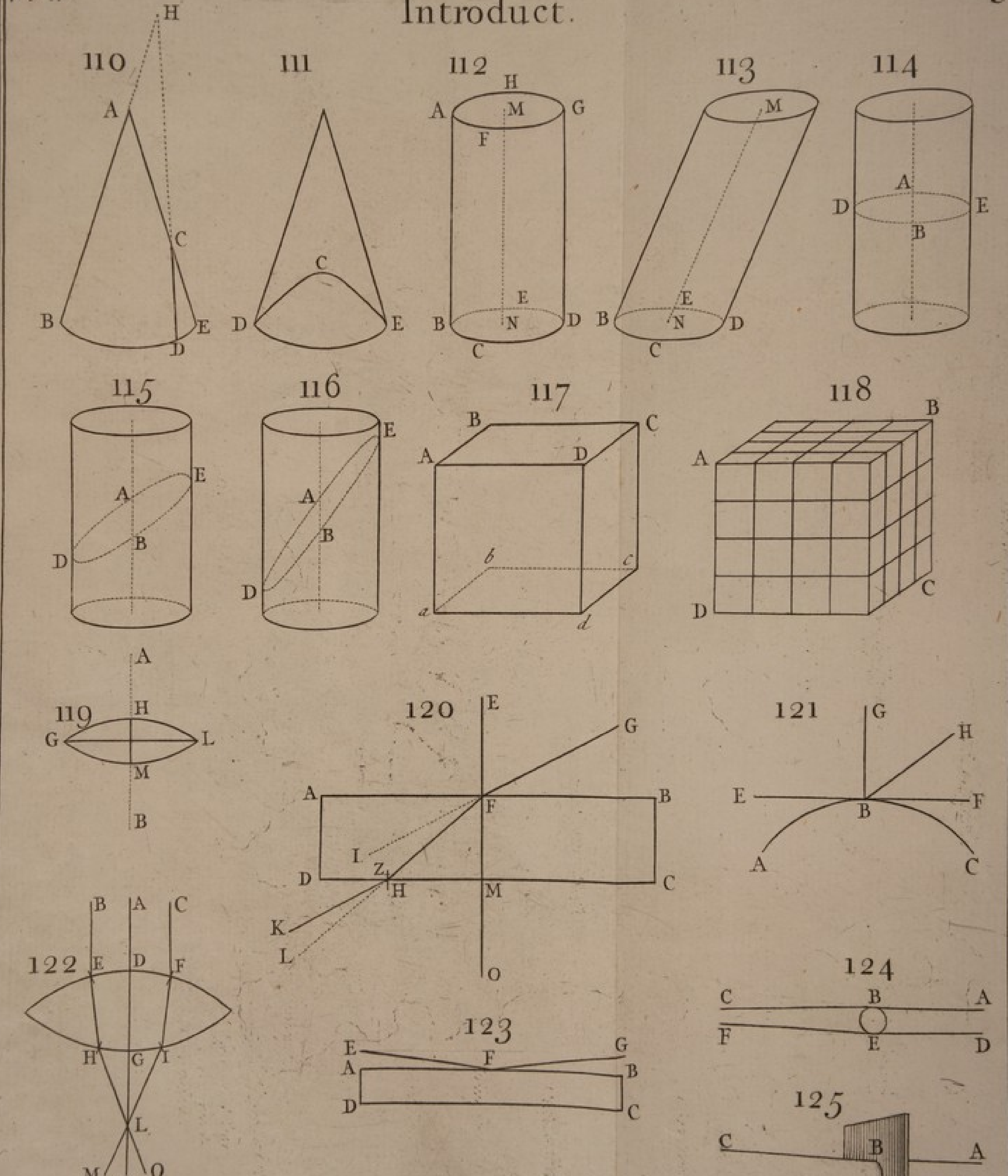
175 The common *celeſtial globe* repreſents the convex ſurface of the ſphere of the heaven, ſuch as it would appear to us, if we were placed without, at an immenſe diſtance from it; and has ſeveral circles drawn upon it, to repreſent ſome which may be imagined to be drawn upon the ſphere of the heaven. *An artificial ſphere* is a machine which has the principal circles of the ſphere drawn upon hoops, or repreſented by rings of braſs or other metal. The circles of the ſphere may alſo be drawn upon the ſurface of a hollow ſphere made of glaſs: ſuch an one I have for many years made uſe of in reading lectures.

176 A ſphere ADBF, fig. 95, may be conſidered as put into ſuch a whirling
95 motion round one of its diameters AB, as boys give a top; this motion is called *a rotation*, becauſe it is like the turning of a wheel round its axletree: the diameter AB, round which the rotation of the ſphere is made, is called *the axis:* the two extreme points of the axis A and B, terminated by the ſurface of the ſphere, are *the poles of the ſphere:* by this rotation, every point of the ſpherical ſurface, except the poles, deſcribes a circle; thus, the point G deſcribes the circle GHIL, the point C deſcribes the circle CDEF, the point M deſcribes the circle MNOP: the circle CDEF deſcribed by a point C equally diſtant from both poles, is a great circle; to this the other circles are all parallel: every parallel grows leſs, the nearer the point deſcribing it is to either of the poles. Any circle may be conceived as a great circle drawn upon a ſphere, and to have its axis and its poles. I have in the figure ſuppoſed the ſphere to be tranſparent, that the circles drawn upon it might be ſeen entire.

177 Any two great circles of the ſame ſphere which interſect each other, will divide one another into two equal parts. *Theodoſ. Sphæric. l.* 1. *prop.* 11.

178 If a plane be imagined to paſs through a ſphere, *the ſection of the ſphere*, that

Introduct.



that is, the curve deſcribed upon the plane by the ſurface of the ſphere paſſing FIG.
through it, will be a circle: if the plane which cuts through a ſphere paſſes through the center of it, the ſection of it is a great circle of that ſphere; if the plane does not paſs through the center, the ſection is a leſs circle: a plane that cuts through a ſphere, and paſſes through the center, divides it into two equal parts, which are called *hemiſpheres*, or half ſpheres: a plane that cuts through a ſphere, and does not paſs through the center of it, divides it into two unequal parts, either of which, eſpecially the leaſt, is called *a ſegment of a ſphere*: thus, 95
fig. 95, AHGLI is a ſegment of the ſphere ADBF.

179 If we imagin a ſtrait line AB, figg. 97, 98, 99, one end of it A being 97
fixt, to be carried round, all the while touching the ſides of a triangle, ſquare, 98
or polygon, above whoſe plane the point A is elevated; it will deſcribe a 99
ſolid called *a pyramid: the vertex* of the pyramid is the immoveable point A, *the baſe* of it is the triangle, ſquare, or polygon, round which the line is ſuppoſed to be carried.

180 If we take an immoveable point A elevated above the plane of a circle 100
BCDE, and ſuppoſe a ſtrait line XZ drawn through the point, and extended both ways from it to an indefinite length, to be carried quite round the circle, all the while touching its circumference, and continuing ſtill fixt to the immoveable point, the line by this motion will deſcribe two *conic ſurfaces*, which are *vertical*, or oppoſite, having their common vertex at the immoveable point A, fig. 100.

181 The ſolid contained within the conic ſurface, between the immoveable point A and the circumference of the circle BCDE, is *a cone*. fig. 100: the 100
immoveable point A is *the vertex:* the circle BCDE, is *the baſe:* and a ſtrait line AF drawn from the vertex to the center of the baſe, is *the axis of the cone:* all ſtrait lines drawn from the vertex to the circumference of the baſe, as AB, AC, AD, AE, &c. are *ſides of the cone*.

182 If the axis of a cone be perpendicular to its baſe, it is called *a right cone*, ſuch as is repreſented, fig. 101: if the axis be inclined to the baſe, it is 101
called *a ſcalenous* or *oblique cone*, ſuch as is drawn, fig. 102: a right cone is al- 102
ways underſtood when the contrary is not expreſt.

183 The formation of a right cone may be conceived in another manner, by the revolution of a right-angled triangle round one of its legs, as upon an axis: thus, fig. 101, let there be a right-angled triangle BFA, let one of its legs 101
AF be fixt, and let the triangle revolve round it; there will then be deſcribed the cone ACB, whereof AF the fixt leg of the triangle will be the axis, and the circle BECD deſcribed by the other leg BF will be the baſe.

184 A cone deſcribed as in the preceding ſection will be more or leſs acute,

FIG. cute, according as the acute angle BAF adjoining to AF the immoveable leg
103 of the deſcribing triangle is more or leſs acute: thus, fig. 103, the cone BDC
deſcribed by the revolution of the triangle BFD is more acute than the cone
BAC deſcribed by the revolution of the triangle BFA; becauſe the angle BDF
is leſs than the angle BAF.

185 The acuteneſs of a cone may alſo be thus eſtimated; from the extreme
101 points of any diameter of the baſe, as BC, fig. 101, draw ſtrait lines to the
vertex A, as BA and CA, theſe will form a triangle BAC, by whoſe angle at
the vertex A, the acuteneſs of the cone is meaſured: if two cones of equal baſes
are of different length, the longer is ſaid to be more acute than the other: thus,
103 fig. 103, the cone DBC is more acute than the cone ABC, becauſe the angle
BDC is leſs than the angle BAC.

186 *Similar cones* are ſuch as have their axes and the diameters of their baſes
proportional: all right cones having the ſame acuteneſs are ſimilar: and con-
104 ſequently, if any right cone ABC, fig. 104, be cut through by a plane DE pa-
rallel to the baſe, the ſegment ADE will be a cone ſimilar to the cone ABC.

187 Vertical cones whoſe baſes are parallel, are ſimilar: this is evident
100 from a view of the 100th figure, and needs not be demonſtrated.

188 If a plane be imagined to paſs through all or part of the ſides of a cone,
the curve line deſcribed upon the plane by the ſides is called *a conic ſection.*

189 If all the ſides of a cone are cut through by a plane, to which the axis
104 is perpendicular, the ſection of the cone is *a circle:* thus, fig. 104, if the cone
BAC be cut through by a plane DE to which the axis AF is perpendicular, the
ſection is the circle DGEH.

105 190 If all the ſides of a cone are cut through by a plane to which the
106 axis is inclined, the conic ſection is called *an ellipſis.* fig. 105, and 106.

An ellipſis made by the ſection of the ſame cone, or of two cones that are
ſimilar, is more oblong, the leſs the angle is which the axis of the cone makes
106 with the interſecting plane: thus, the ellipſis DE is more oblong in fig. 106,
105 than the ellipſis DE in fig. 105.

191 If a cone is cut through by a plane to which one of the ſides of the
108 cone is parallel, the ſection is called *a parabola*: thus, fig. 108, let the cone ABE
be cut through by a plane DC to which the ſide AB is parallel, the ſection will
109 be a parabola, ſuch as is repreſented, fig. 109, by the curve DCE.

192 If a cone is cut through by a plane to which one of the ſides of the
cone is inclined in ſuch a manner, that the plane and the ſide extended both
ways from the baſe of the cone would meet in a point beyond the vertex of
110 it, the ſection is called *an hyperbola:* thus, fig. 110, let the cone ABE be cut
through by the plane DC to which the ſide BA is ſo inclined, that both of them
extended

extended both ways from the baſe would meet ſomewhere beyond the vertex, FIG.
in the point H, the ſection will be an hyperbola, ſuch as is repreſented, fig. 111
111, by the curve DCE.

193 If a ſtrait line, which is either perpendicular or inclined to the plane of a circle BCDE, fig. 112, be carried round the circle, all the while continuing 112
parallel to itſelf in its firſt ſituation, and touching with one end B the circumference of the circle, the line will deſcribe *a cylindrical ſurface:* the circle BCDE is *the baſe*; to this the point A at the other end of the line will deſcribe another circle equal and parallel, *viz.* AFGH, which may be alſo called a baſe: the ſolid contained between the cylindrical ſurface and the planes of theſe two baſes, is called *a cylinder:* a ſtrait line MN drawn from the center of one baſe to the center of the other, is *the axis of the cylinder:* the deſcribing line AB in every different ſituation as AB, GD, &c is *a ſide of the cylinder.*

194 If the axis of a cylinder is perpendicular to the baſe, it is *a right cylinder*, fig. 112: rolling ſtones uſed in gardens are right cylinders. If the axis 112
of a cylinder is inclined to the baſe, it is *a ſcalenous* or *oblique cylinder.* fig. 113. 113

The formation of a right cylinder is by ſome explained, by imagining a rectangle to revolve round one of its ſides: thus, fig. 112, if we imagin the rect- 112
angle ABMN to turn round the ſide MN, that ſide being all the while fixt, there will be deſcribed the cylinder ABDG.

195 If a plane DAEB to which the axis is perpendicular cuts through all 114
the ſides of a cylinder, the ſection ariſing from thence is a circle. fig. 114.

196 If a plane to which the axis is inclined cuts through all the ſides of 115
a cylinder, the ſection is an ellipſis, figg. 115, 116: this ellipſis is more oblong, 116
the leſs the angle is which the axis makes with the interſecting plane: thus, the ellipſis DAEB in fig. 116, is more oblong than the ellipſis DAEB in fig. 115.

197 *A Cube* is a ſolid terminated by ſix ſides, every one of which is an exact ſquare: ſuch is a well made die, called in Greek *cubos*, from whence the word cube is derived.

198 The formation of a cube may be thus conceived; imagin a ſquare 117
ABCD, fig. 117, to be carried parallel to it ſelf, the length of one of its ſides, as along the line A*a* equal to AD, when this ſquare has paſſed from its firſt ſituation ABCD, and is come into the ſituation *abcd*, it will have deſcribed the cube ABC*cda*. The ſide or root of the ſquare by which the cube is generated is called alſo *the root of the cube.*

199 If every ſide of a cube is a foot ſquare, the cube is called a cubic foot: if a ſide is an inch ſquare, it is a cubic inch, &c: the meaſure of any cube is expreſt by ſaying how many cubic feet, cubic inches, &c it may be divided into.

200 To find how many cubic feet, inches, &c are contained in a cube, find

FIG. how many ſquare feet, inches &c are contained in one of the ſides, and mul-
118 tiply that number by the ſquare root; thus, let a ſide of the cube ABCD, fig. 118, be 16 inches ſquare, the root or ſide of the ſquare 16 is 4, multiply 16 by 4, the product 64 is the number of cubic inches in the cube ABCD.

201 If a ſquare number be multiplied by its ſquare root, the product is *a cube number*; which is ſo called, becauſe if we imagin every unit of which the product conſiſts to be repreſented by a little cube, the whole product may be repreſented by a larger cube containing all thoſe little ones: thus, if the number 16 the ſquare of 4 be multiplied by 4 the ſquare root of it, the product
118 64 may be repreſented by the cube ABCD, fig. 118, containing 64 little cubes.

202 As a ſquare is the meaſure of all ſurfaces, § 62, ſo a cube is the meaſure of all ſolids, the dimenſions of which are expreſt by ſaying how many cubic feet, cubic inches, or cubic tenths of an inch, &c they contain: thus, I may conſider and expreſs how many cubic feet are contained in a mountain, or in the globe of the earth, or in the ſun or moon, or in any planet or ſtar.

203 How to meaſure either the ſuperficial or ſolid content of a cone, cylinder, or any other regular ſolid, may be ſeen in the common books of geometry [a]; a ſphere or globe is the only ſolid, beſides the cube, whoſe menſuration we ſhall have occaſion to conſider at preſent: the way to meaſure the cube has already been ſhewn, § 200; how to find the dimenſion of the globe will be ſeen in the two following ſections.

204 *To find the ſuperficial content of a globe, the circumference or diameter being given*; find the area of a great circle of the globe by § 68, and multiply that area by the number four, the product is the ſuperficial content required: thus, ſuppoſe the circumference of the earth to be 24930 engliſh miles, the diameter 7935, § 457; the area of a great circle upon the earth will be 49454887$\frac{1}{2}$ miles: the product of this number multiplied by 4 is 197819550, which is the number of ſquare engliſh miles contained in the ſurface of the earth.

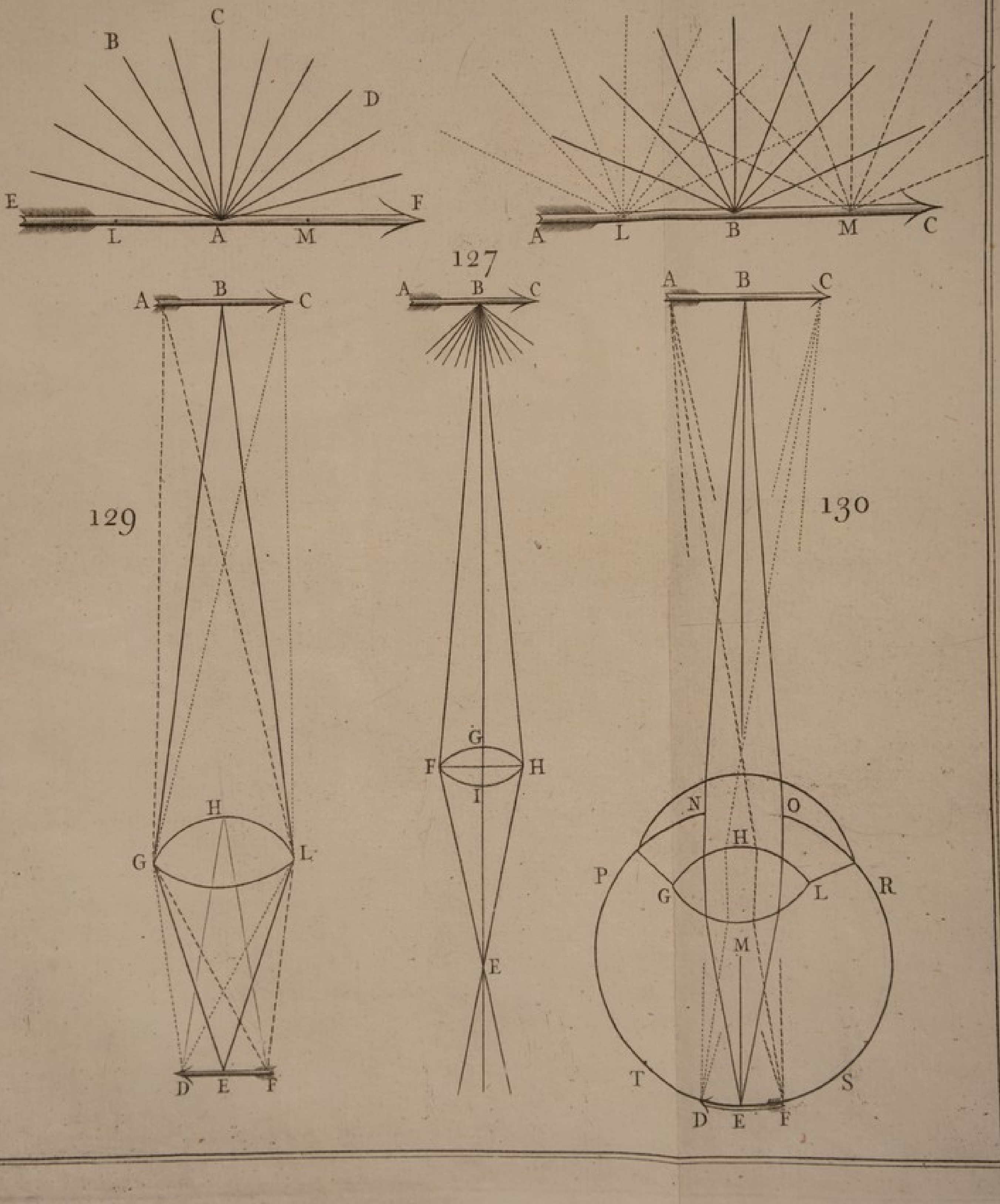
205 *To find the ſolid content of a globe, the ſuperficial content being given*; multiply the ſuperficial content by a ſixth part of the diameter of the globe, the product is the ſolid content required: thus, ſuppoſe the ſuperficial content
197,819,550 of the globe of the earth be found 197474980 ſquare engliſh miles, by the preceding ſection; multiply this number by 1322$\frac{1}{2}$ the ſixth part of 7935, the number of engliſh miles the diameter of the earth amounts to, and the product 261616354875, is the number of cubic engliſh miles contained in the globe of the earth.

The following propoſitions about the nature of light, refraction, and viſion are ſo uſeful in aſtronomy, that I ſhall make no apology for inſerting them in this place.

a *Tacquet Geometria practica l. 3. c. 18, Pardie Geometr. l. 5.*

206 Light

126 128 127 129 130



206 *Light* consists of exceedingly small distinct parts of matter[a], which moving with a prodigious swiftness enter our eyes, and impress upon the internal parts of them that motion which excites in our minds the sensation we call seeing: light either comes directly from a luminous body, as the sun, a star, fire, &c; or else being emitted from a luminous body, and falling upon an opake one, is from thence reflected, or thrown back, and scattered every way: luminous bodies are incessantly streaming out these particles of light; opake bodies continue to reflect light no longer than they receive it from luminous ones. FIG.

207 Though the progressive motion of light be exceedingly swift, yet it is not instantaneous, but it spends some time in passing from one place to another: what the velocity of light is, will be shewn in a proper place.

208 Light may be considered either as contemporary or successive[b]: the *light* which falls upon an object all at once, in the same instant, is *contemporarary*; the *light* which from time to time continues to fall upon an object, is *successive*, consisting of parts following one another, as the parts of water do that are forced in a continued stream out of the spout of an engin.

209 The least light or part of light which can be conceived to act or be acted upon alone by itself, is called *a ray of light*.

210 Empty space, or any body that is transparent, that is, through which any rays of light can pass, as air, water, oil, &c, is called *a medium*.

211 *A lens* is a solid, convex on both sides, shaped like a lentil, from whence it has its name: each side of a lens is a segment or piece of a sphere: the sides of a lens may be segments of equal spheres, or of unequal ones: when we speak of a lens in optics, we generally mean a piece of glass of this figure; such as a burning-glass, or a spectacle-glass: a lens may be made of water, or any other transparent liquor, by inclosing it between two thin concave pieces of glass: the chrystalline humour in the eye is a lens formed of that liquor which constitutes it, inclosed between the coats of the eye. If a circular plane be imagined to divide the segments of spheres which form a lens, that plane may be called *the section of the lens: the axis of a lens* is a line drawn from the middle point of one of its convex surfaces to the middle point of the other: the axis of a lens extended both ways would pass through the centers of the spheres whereof the convex surfaces of the lens are segments: a lens is turned directly towards an object, when its axis if extended would fall upon the middle point of the object: in fig. 119, GHLM is a lens; HM the axis: GL the 119
section, A and B the centers of the spheres whereof the surfaces of the lens are segments: in fig. 127, the lens FGHI is turned directly towards the object ABC. 127

a *Newt. Optics p.* 345. b *Newt. Opt. p.* 2.

FIG. 212 The rays of light, in paſſing through a medium that is throughout of
the ſame denſity, go in ſtrait lines. If a ray of light goes out of one medium into
another of a different denſity, as out of air into glaſs, or out of glaſs into air,
if it falls perpendicularly upon the ſurface of the ſecond medium, it will con-
tinue to go on in a ſtrait line, in the ſame direction as through the firſt medium:
120 thus, fig. 120, let A B C D be a ſolid piece of glaſs, a ray of light E F coming
out of air, and falling perpendicularly upon the ſurface of the glaſs A B, will
go on in a ſtrait line E F M; in like manner, the ray going out of glaſs into air
at M, in the direction F M, perpendicular to the ſurface of air C D, will go
ſtrait on in the direction F M O.

213 If a ray of light, coming out of one medium into another of a different
denſity, falls obliquely upon the ſecond medium, it will be bent at the point
of incidence, and go through the ſecond medium in a different direction: this
bending of the rays is called *refraction*. The laws of refraction are theſe; if
a line be drawn perpendicular to the ſurface of the ſecond medium, a ray go-
ing out of a thinner medium into a more denſe one, is refracted towards the
perpendicular; but a ray going out of a denſer into a thinner medium, is re-
120 fracted from the perpendicular: thus, fig. 120, a ray G F falling obliquely upon
A B, will be refracted at F, and ſince glaſs is denſer than air, it will be bent
towards the perpendicular F M, and inſtead of the ſtrait line F I, will go on in
the refracted line F H; again, at H is its point of incidence out of glaſs into
air, out of a denſer into a thinner medium, there it will be bent from the per-
pendicular H Z, and inſtead of going on in its former direction F H L it will
go in the refracted line H K.

214 In the foregoing example, the ſurface of the ſecond medium was ſup-
poſed to be a plane, when it is a curve ſurface, we conſider it in the following
manner; a line which, being drawn to the point of contact, is perpendicular
to the tangent of a curve, is perpendicular to that curve; a line which, being
drawn to the point of contact, makes oblique angles with the tangent, makes
121 the like angles with the curve: thus, fig. 121: let the line E F touch the curve
A B C in the point B, if G B is perpendicular to the tangent, it will be alſo
perpendicular to the curve; let the line H B fall obliquely upon the tangent, it
will fall upon the curve with the ſame obliquity; that is, the mixt angle C B H
is equal to the rectilinear angle F B H. *See Molyneux dioptr. p. 6.*

215 A ray of light paſſing out of one medium into another of a different
denſity, when the ſurface of the ſecond medium is curve, is ſubject to the ſame
general laws of refɹaction, as when it is a plane: if it falls perpendicularly
upon the ſurface of the ſecond medium, it will continue to go on in a ſtrait
line, in the ſame direction as through the firſt medium; if it falls obliquely
upon

upon the ſurface of the ſecond medium, it will be refracted at the point of in- FIG. cidence, ſo as to be bent towards the perpendicular, when it paſſes out of a thinner medium into a more denſe one; and from the perpendicular, when it paſſes out of a denſer into a thinner medium: thus, fig. 122, let EFIH be a 122 lens of glaſs, upon the middle point D of its convex ſurface, let the line AD fall perpendicularly, it will then paſs on in a ſtrait line DG coinciding with the axis of the lens, and again at G, where it leaves the glaſs, falling perpendicularly upon the ſurface of the air HGI, it will continue to go on in the ſame direction, in the line GL; ſo that the paſſage of this ray, firſt out of air into glaſs, and then out of glaſs into air, will be in the ſtrait line ADGL.

Let other rays BE, CF, parallel to AD, fall upon the ſame lens at the points 122 E and F, theſe will fall obliquely upon the convex ſurface of the glaſs, the denſer medium, and therefore will be bent towards the perpendiculars, which are here expreſt by ſhort dotted lines, and inſtead of going ſtrait on in their firſt direction, will go through the glaſs in the directions EH and FI; at H and I falling obliquely upon the concave ſurface of the air, they will be again refracted and bent from the perpendicular, ſo as to go in the directions HL and IL.

216 From hence it appears, that parallel rays, as BE, AD, CF falling upon a lens EFIH turned directly towards them, will be refracted ſo as to *converge* or draw nearer to one another, till they meet in a point D, fig. 122: there they 122 L will croſs, and from thence proceed *diverging*, or ſpreading further aſunder, as is expreſt by the lines LM, LN, LO. *Molyn. dioptr. p. 6. For the phyſical cauſe of theſe refractions, See Newt. Optics, p.* 248. 320. 324. *Smith's Optics, l. 9. c. 7.*

217 When a ray of light, in paſſing out of one medium into another of a different denſity, falls very much inclined to the ſurface of the ſecond medium, that is, makes a very ſmall angle with it, it will not enter the ſecond medium, whether it be thinner, or more denſe than the firſt; but it will be reflected, if it be thinner in ſuch a manner, that the angle of reflection ſhall be equal to the angle of in- or first cidence: thus, fig. 123, let a ray EF fall at the point F upon AB the ſurface of 123 a different medium, ſo as to make the angle EFA a very ſmall one, the ray thinner then will not enter the ſecond medium ABCD, but will be reflected in the line FG, ſo that the angle of reflection GFB ſhall be equal to the angle of incidence EFA.

218 I here conſider refraction and reflection of light at large and in a general view, as if all the rays of light were alike affected in paſſing through different mediums, which accurately ſpeaking they are not; for with the ſame angle of incidence ſome rays are more refracted, that is, bent further from the ſtrait line than others, and when they fall very much inclined to the ſecond medium ſome are ſooner reflected than others, that is, with the ſame angle of incidence

FIG. incidence ſome rays ſhall be reflected and others not, but they will require to have the the angle of incidence ſtill leſs, to make them reflected; this is the meaning of this propoſition, *the light of the ſun conſiſts of rays differently refrangible: Newt. Opt. p.* 21: and of theſe propoſitions, *the ſuns light conſiſts of rays differing in reflexibility*; and *thoſe rays are more reflexible than others which are more refrangible:* theſe and many other curious particulars relating to the nature of light, I ſhall not dwell upon here, as not pertinent to my ſubject; it is ſufficient juſt to mention ſome of the moſt remarkable ones.

219 Light is not refracted or reflected by impinging upon the ſolid parts of the refracting or reflecting medium, but by a power uniformly diffuſed through the medium, which acts upon the particles of light, without immediate contact, in a direction perpendicular to the ſurface of the medium: *Newt. Opt. p.* 237.

220 Light in paſſing cloſe by the ſides of bodies is bent out of the way, in ſuch a manner, that parallel rays paſſing on each ſide any body, converge; and
124 paſſing between two bodies, diverge: thus, fig. 124, let BE repreſent an hair viewed endways, parallel rays of light AB and DE paſſing by the ſides of the hair will not go on in ſtrait lines, but will be bent, and made to go on in the
125 converging lines BC and EF: again, fig. 125, let BE be an hole in a plate of braſs, parallel rays paſſing through the hole will not go on in ſtrait lines, but will be bent, and made to go on in the diverging lines BC and EF. *Newt. Opt. p.* 293 *& ſeqq.* & 313. *Qu.* 2.

221 Rays of light of different degrees of refrangibility, reflected from opake bodies to our eyes, excite in us ſenſations of different colours: when thoſe rays which are leaſt refrangible are reflected by any body, alone, or in much the greateſt quantity, the reſt being totally or in a great meaſure abſorbed, that body appears red; when the moſt refrangible rays are reflected alone, or in the greateſt quantity, the other rays being abſorbed, the reflecting body appears of a violet colour; we ſay then, that the red-making rays are leaſt refrangible and the violet-making rays are moſt refrangible, and the rays which produce intermediate colours, orange, yellow, green, blew, are of intermediate degrees of refrangibility: probably the particles which conſtitute the red-making rays are the largeſt, and thoſe which conſtitute the violet-making ones the ſmalleſt, and the intermediate ones are of intermediate magnitudes, whereby different vibrations are excited in the retina, which give us ſenſations of different colours: *Newt. Opt. p.* 319, and 320.

222 The ſeveral *colours* juſt now mentioned are called *primary*, and the *rays* which produce a primary colour are called *homogeneal* or *ſimilar:* all other colours ariſe out of different mixtures of the primary colours: whiteneſs is a mixture of all colours; and light the mixture of all the ſeveral ſorts of rays which

which are capable of producing the different primary colours. *Newt. p.* 217. FIG.

223 Every point of a viſible object ſends from itſelf, as from a center, rays of light in ſtrait lines, every way through an hemiſphere: thus, fig. 126, the 126
rays of light are diffuſed every way from the point A in ſtrait lines AB, AC, AD, *&c* through the hemiſphere EBCDF; this is evident from hence, that wherever a ſpectator is placed within this hemiſphere, ſo that a ſtrait line can be drawn from A to his eye, the point A will be viſible to him; it is for this reaſon the ſame object may be viſible to an hundred people at the ſame time: we are here to underſtand by a point of an object, not a mathematical but *a phyſical point*; that is, the leaſt imaginable part of an object, or the leaſt part that can reflect light enough to make itſelf viſible: the light is in like manner diffuſed from all other points of the object as L and M. See fig. 128. 128

224 An object is ſaid to be diſtant from a lens, when the ſurface of the lens which is towards the object is ſmall, compared with the diſtance of the object: an object is diſtant from the eye, when the aperture of the pupil is ſmall, compared with the diſtance of the object: as ſuppoſe the diameter of the pupil is but about an hundred and fiftieth part of the diſtance of the object.

225 All the *rays* which can be drawn from any one point B, fig. 127, of an 127
an object ABC, diſtant from a lens FH, to that ſurface of it FGH which is towards the object, may be looked upon as *phyſically parallel:* thus, the rays BF and BH are ſo near being parallel, that they will be refracted in the ſame manner as if they were exactly parallel: from hence, and from § 216, it follows, that,

226 The rays which come from the ſame point of an object, and fall upon the ſurface of a lens turned directly towards the object, unite in a point beyond the lens: thus, fig. 127, let the object be ABC, the lens FGHI the rays 127
which come from the point B, and fall upon the ſurface of the lens FGH, will be ſo refracted at their paſſage out of air into glaſs, and out of glaſs into air, that they will be made to converge ſo as to meet ſomewhere at a point, as at E.

227 The whole parcel of rays which thus coming from any point B fall 127
upon the ſurface of the lens, and paſſing through it are united in a point E, are called *a pencil of rays:* a pencil of rays is a double cone of rays, the common baſe whereof is the ſection of the lens FH: the vertex of one cone is B the radiating point of the object, the vertex of the other cone is E *the tip of the pencil: the axis of a pencil rays* is a line BE drawn from one vertex to the other: the axis may be conſidered as a ſtrait line. *Molyneux dioptr. p.* 8.

228 The rays of light coming from different points of the ſame object croſs each other in the manner repreſented fig. 128, this they do in innumerable 128
places, without hindring one anothers progreſs, by reaſon of the inconceivable

ſmallneſs

FIG. ſmallneſs of the particles of light: this may be looked upon as one of thoſe
93 many wonders which we meet with, in our ſearches after natural knowledge.

229 An object is ſeen when the rays of light coming from all parts of it enter the pupil of the eye, and paint its picture upon *the retina* [a], which is a thin membrane at the bottom of the eye: the following experiments are proofs of this, *exper.* 1, take out the eye of an ox or ſheep new killed, and ſtrip off
94 carefully the ſkin and fat from the back part of it, till only a thin film is left
94 there; upon this film the picture of any object placed before the pupil of the eye will be painted in little.

230 *Exper.* 2. Having made a room dark, make a ſmall hole in the door or window-ſhutter, hold a white paper over againſt the hole at a proper diſtance from it, within the room, and there will be painted upon the paper the picture of thoſe objects without doors which are within view of the hole: this experiment ſucceeds beſt when the ſun ſhines upon that ſide of the objects which is towards the hole: the picture will be more ſtrong and lively if a lens be placed in the hole: the proper diſtance for the paper is found by tryal, by moving it nearer the hole or further from it, till the picture is in its greateſt perfection.

231 In both theſe experiments, the picture of the object is inverted, as it is alſo in the eye of a living perſon; this leads us to this enquiry, how does an inverted image make us ſee the object erect? to which it may be anſwered, that in viſion, as in the perceptions by our other ſenſes, there is no likeneſs between the impreſſion made by the ſenſible object upon the bodily organ and the ſenſation thereby excited in the ſoul; there is only a connection between theſe two, ſo that ſuch an impreſſion ſhall always excite ſuch a ſenſation; in the caſe before us, ſuch an impreſſion upon the retina as is always uſed to be made by an erect object will always make us perceive the object erect; this impreſſion is always made, when the rays of light coming from that part of the object which is neareſt the earth fall upon that part of the retina which is furtheſt from the earth, and the rays of light coming from that part of the object which is furtheſt from the earth, fall upon that part of the retina which is neareſt to the earth. *v. Molyneux dioptr. p.* 105. *Smith's Optic. p.* 38 and 49.

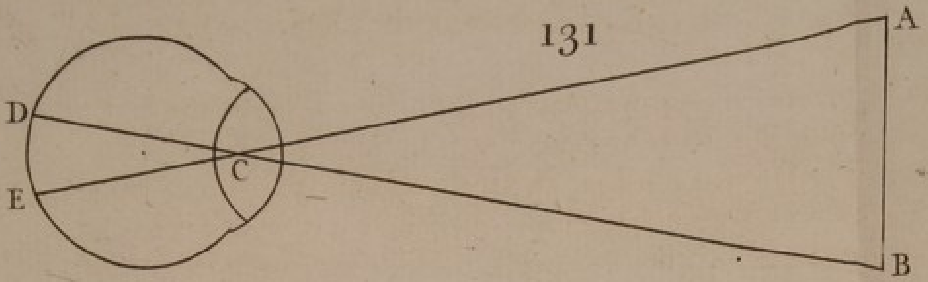
129 232 Let GHL fig. 129, be a lens placed in a hole of a ſhutter to a dark room, and turned directly towards an object ABC; from each point of the object will come a pencil of rays: thus, from the point B comes the pencil BGEL, expreſt by black lines, terminating in E; and from the point C comes the pencil CGDL, expreſt by dotted lines, terminating in D; from the point A comes the pencil AGFL, expreſt by daſhed lines, terminating in F. A plane DEF

a *Newt. Opt. p.* 319.

paſſing

Introduct.

131



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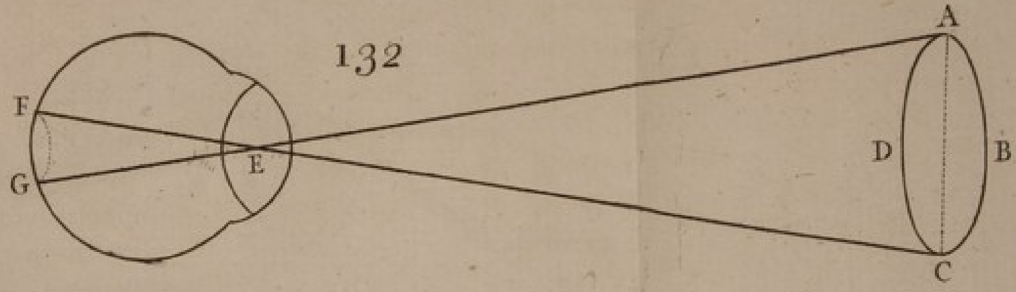

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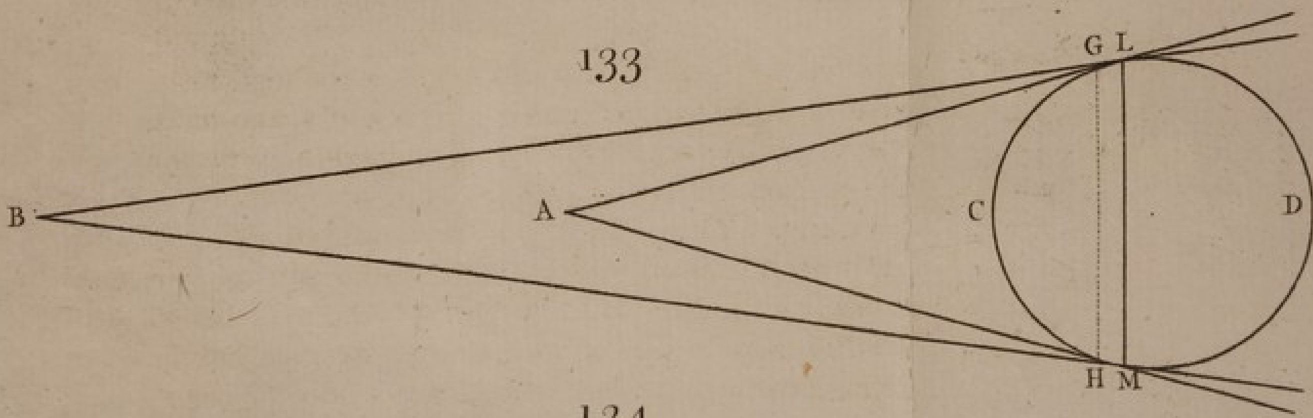

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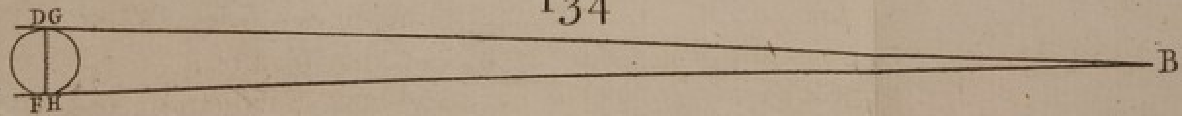

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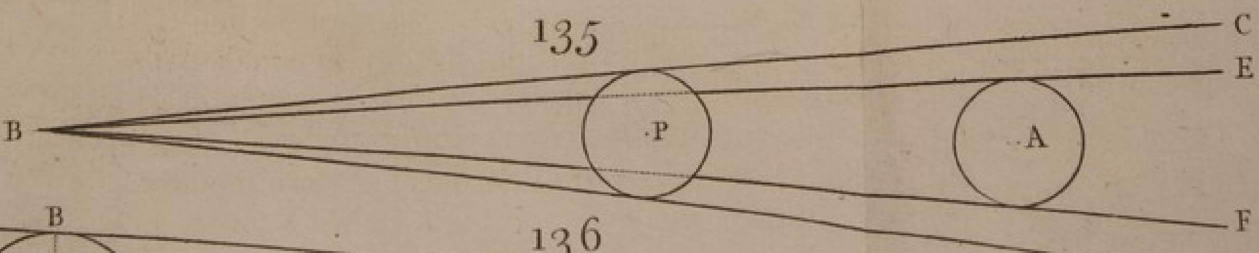

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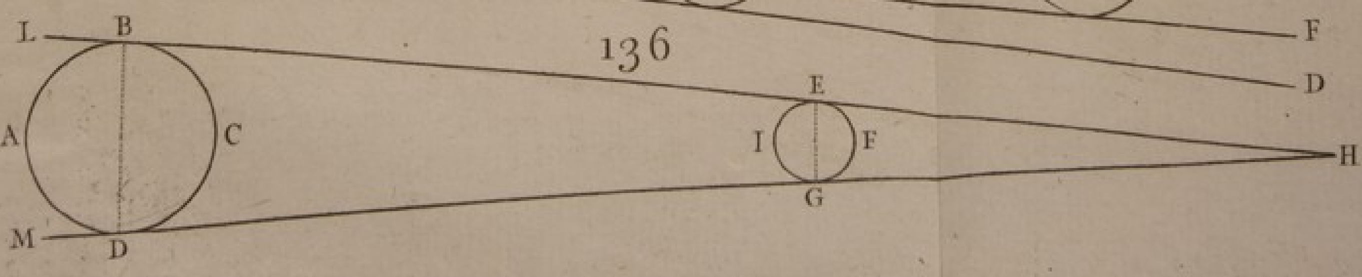


paſſing through the tips of the pencils, is called *the diſtinct baſe*; becauſe a FIG.
paper held there will have painted upon it the diſtinct picture of the object; if the paper be held nearer the lens, or further from it, the picture will be confuſed. [a]

233 In the ſame manner *viſion* is performed; fig. 130, let PRST be the globe 130
of the eye with its coats and humours, whereof we conſider chiefly the chryſtalline humour, which forms a lens GHLM; by this lens, the rays coming from the ſeveral points of the object through the pupil of the eye NO, are ſo refracted, that the pencils terminate upon the retina DEF, and make there a diſtinct picture of the object. *Molyneux dioptr. p.* 103.

234 The pencils of rays have here been conſidered, only to ſhew how an object comes to appear diſtinct or confuſed: in ſpeaking of the apparent magnitude of objects, we conſider only the axis of each pencil, and of thoſe pencils in particular which come from the extreme points of the object: we may ſay then, that the magnitude of the picture upon the retina is determined by ſtrait lines drawn from the extreme points of the object, through the pupil to the retina: thus, fig. 130, the length of the picture DF is determined by the lines 130
AF and CD. See § 227.

235 *The apparent magnitude of a ſtrait line* AB, fig. 131, is the angle form- 131
ed by two ſtrait lines drawn from the extreme points of it A and B, and meeting at a point in the eye at C: *the optic* or *viſual angle*, under which the line AB is ſeen, is the angle ACB. *Tacquet. optic. l.* 1. *deſinit.* 4.

236 Suppoſe an object were a circular plane ABCD, viewed directly, fig. 132
132, imagin ſtrait lines to be drawn from every point of it through the pupil, theſe will croſs and form two ſimilar cones, one of which, DCE has its FEG
baſe upon the retina; the other, which is called *the optic* or *viſual cone*, has the object for its baſe; the common vertex C of theſe two cones is near the center E
of the chryſtalline: the viſual cone is formed by ſtrait lines drawn from every point of the object to a point in the eye. It is obvious, that if inſtead of a circle, the object were a triangle, ſquare, or polygon, the lines drawn from it would have formed a viſual pyramid inſtead of a cone; but a circle is the more ſimple figure, and therefore more proper for our preſent conſideration.

237 *The apparent magnitude of a circle* is the apparent magnitude of its diameter: thus, fig. 132, the apparent magnitude of the circle ABCD is the 132
angle AEC; and we ſay its *apparent diameter* is ſo many ſeconds, minutes, or degrees, as that angle contains: to this angle the angle FEG is equal. §. 44.

a If a lens be held directly to the ſun, the place of the diſtinct baſe is called the *focus*, or burning point of the lens; becauſe there the pencils of rays from every point of the ſuns body terminate, paint his image moſt ſtrongly, and excite a violent heat, ſo as to inflame combuſtible bodies.

FIG. 238 If an opake globe be at a moderate diſtance from the eye, the picture of it upon the retina is a circle, properly diverſified with light and ſhade, ſo as to excite in the mind the ſenſation of a globe: if a globe be at a great diſtance from the eye, the difference between thoſe lights and ſhades which form the picture of a globe will not be perceptible, and then the globe will appear like a circular plane: thus, the moon viewed with the naked eye, and the planets viewed through a teleſcope appear like circular planes. A luminous globe, though at a moderate diſtance from the eye, appears like a luminous plane: the eye cannot diſtinguiſh a globe of iron heated ſo hot that it is almoſt ready to run, from a flat circular piece, at the diſtance of a few yards; much leſs can the eye diſtinguiſh a luminous globe from a plane, when the diſtance of it is very great, as is that of the ſun from us: ſuch a globe appears luminous, becauſe the rays emitted from it are of all ſorts mixed together § 222; and it appears a flat circular plane, becauſe the rays of light come from all parts of it, as to ſenſe, with equal fullneſs and ſtrength, without any ſhades, or difference of colour: for this reaſon, the ſun, though really a globe, appears to us a circular plane, whether we receive his picture upon a piece of white paper in a dark room, or look at him through a ſmoaked glaſs.

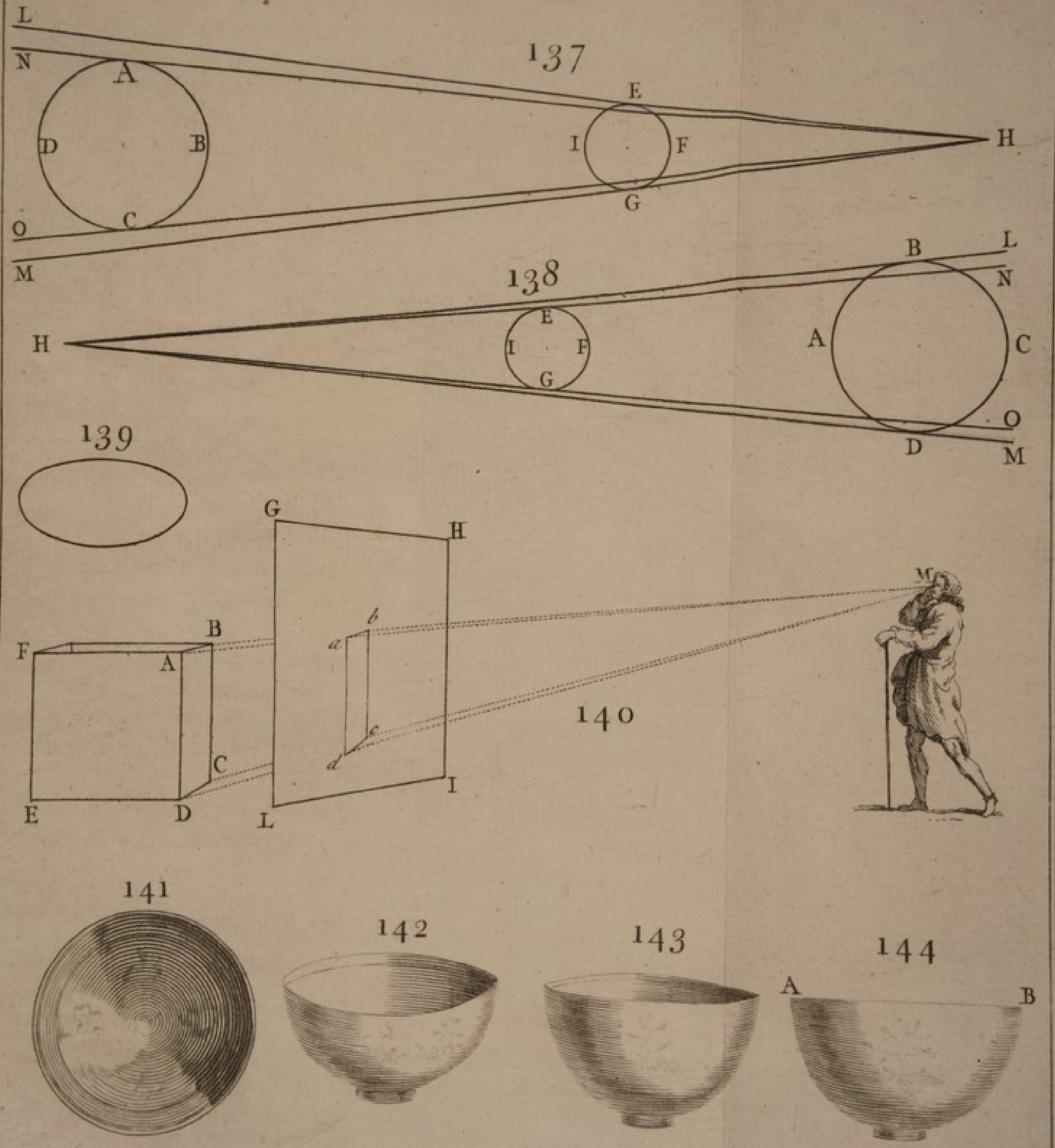
239 When we conſider the ſun, moon, or planets in this view, we call them the *diſks* of the ſun, moon, or planets; the apparent diameters of which I ſhall ſhew how to meaſure, in a proper place: the apparent diameter of the diſk of the ſun differs not ſenſibly from the apparent diameter of the globe of the ſun: § 149: the ſame may be ſaid of the diſk of the moon, or any of the planets.

·240 The nearer a globe is to the eye, the leſs ſegment of it is viſible; the
133 further off it is, the greater is the viſible ſegment: thus, fig. 133, let the globe be C G D H, let the eye be at A, from A draw tangents to the globe which will touch it at G and H; if theſe lines be imagined to be carried round, ſtill touching the globe, the point A being immoveable, they will then include the ſegment of the globe, G C H, which is viſible at A: if the eye be further off as at B, from B draw tangents B L and B M, theſe carried round, as before, will include a larger ſegment of the globe, *viz.* L C M, which is viſible at B.

·241 If a globe is at a very great diſtance from the eye, ſo as to appear under a very ſmall angle, which is the caſe of the ſun, moon, ſtars, and planets, the viſible ſegment of the globe will not be ſenſibly leſs than half the globe: and
134 then fig. 134, the line G H which ſubtends the viſual angle, differs not ſenſibly from D F the diameter of the globe. *Tacquet. Optic. l.* I. *prop.* 37 *& ſeqq.*

·242 The nearer a globe is to the eye, the greater is its apparent diameter; that is, under the greater angle will it appear; the further off a globe is, the leſs

page 51.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leſs is its apparent diameter; that is, the leſs is the optic angle under which FIG.
the diameter is viewed: thus, fig. 135, ſuppoſe the eye is at B, the moon at P 135
is ſeen under the angle CBD; let the moon be further from the eye, as at A, the moon will then be ſeen under the angle EBF, leſs than CBD: the converſe of this is true, *viz.* the larger the apparent diameter of the ſame globe is, the nearer is that globe to the eye: from hence we know, the ſun, moon, and planets are ſometimes nearer to us than they are at other times; becauſe their apparent diameters are ſometimes larger than at other times, if they be meaſured with inſtruments proper for that purpoſe.

·243 Two globes of different magnitude may appear under eqūal angles, if their diſtances are in a direct proportion to their diameters: for this reaſon, if the ſun be as much further from us than the moon, as the ſuns diameter is greater than the moons, their apparent diameters will be equal: thus, fig. 136. 136
let ABCD be the ſun, EFGI the moon, let the eye be at H, they will both appear under the ſame angle LHM: if the larger globe is further off than according to this proportion, the leſs globe will be ſeen under the greateſt angle: thus, fig. 137, let ABCD be the ſun, EFGI the moon, let the eye be at H; the ſun 137
will then be ſeen under the angle NHO, leſs than the angle LHM, under which the moon is ſeen.

·244 The apparent diameters of the ſun and moon are always nearly equal: the diſtance of each of them is ſo varied, that ſometimes their apparent diameters are exactly equal, as in fig. 136: ſometimes the apparent diameter of 136
the ſun is a very little leſs than the apparent diameter of the moon, as in fig. 137: and ſometimes the apparent diameter of the moon is a very little leſs 137
than the apparent diameter of the ſun, as in fig. 138: from hence it comes to 138
paſs, that in a central eclipſe of the ſun, the ſun is ſometimes juſt covered by the moon, ſometimes he is a little more than covered, and ſometimes the moon does not quite cover the ſun, but a ring of his light appears round the moon.

·245 If an object, whoſe real magnitude is known, is ſeen alone, without any intermediate objects to compare it with, we judge of its diſtance by its apparent magnitude: thus, we judge the diſtance of a crow flying in the air to be greater, the leſs the crow appears: the greater the apparent magnitude of an object is, the larger is the picture of it upon the retina; pictures of different magnitude excite different ſenſations in us; it is matter of experience, that when ſuch objects have excited ſuch ſenſations, they have been at ſuch diſtances, and therefore whenever the ſame objects excite the ſame ſenſations, we make the ſame judgment of their diſtance, as well as of other circumſtances of them, which we have often experienced to be true; juſt as we judge a piece of iron to be hot, when we ſee it of ſuch a colour, as we have often ſeen iron to have, which we otherwiſe knew to be hot.

246 Another way by which we judge of the diſtance of a known object, is by the diſtinctneſs or confuſedneſs of its appearance: we have a thouſand times experienced, that we can diſtinguiſh the ſeveral parts of an object better, the nearer it is to us, and that at ſuch a diſtance it appears with ſuch a degree of diſtinctneſs: colour is another circumſtance that ſuggeſts to the mind the idea of diſtance: thus we judge a mountain to be at a great diſtance, when it appears of a faint blewiſh colour; ſuch as painters for that reaſon uſe, when they would repreſent the diſtant parts of a landſkip.

247 As for an object that is ſeen with other objects, as is uſually the caſe, the diſtance of it from our eye, beſides the circumſtances already mentioned, is alſo ſuggeſted to us, by the apparent magnitude of other adjoining objects, obliquely extended either beyond the object in view, or between it and our eye: thus, we judge an houſe to be further off, the more ground we ſee between it and the place where we ſtand to view it: *See Smith's Optics l. 1.c. 5.* It is matter of experience, that in perſpective, lines that are really parallel will appear to converge towards a point, which is of the height of the ſpectators eye, and is called *the point of ſight* by writers of perſpective: thus, the furtheſt parts of a cieling ſeem to deſcend; the furtheſt parts of a level pavement appear to riſe higher; a walk of trees ſet in parallel lines, viewed at one end, ſeems to grow narrower as the trees are more diſtant from the eye: and converſely, ſince the ſame ideas always accompany the ſame impreſſions upon the organ, we judge that part of a level pavement to be the furtheſt off, which appears higheſt; and we judge that part of the cieling to be furtheſt off, which appears loweſt; and when we look along through a walk of trees ſet in parallel lines, we judge that part of the walk to be furtheſt off which appears narroweſt. *Tacquet. opt. l. 1.prop. 24 & 25.*

248 Without ſome of theſe circumſtances, the eye does not enable us to judge of the diſtance of an object: the moſt proper for our preſent conſideration are luminous objects: let a number of lamps be placed irregularly, at different diſtances from the eye, in a dark night; here being no ſenſible difference of colour, no intermediate objects to be ſeen, no converging towards the point of ſight, the eye perceives no difference in their diſtance, and they will therefore ſeem all to be equally diſtant from the ſpectator; for the ſame reaſon, the ſun, and moon, ſtars and planets, ſeem all to be at the ſame diſtance from us: it is indeed very probable, that ſome of the ſtars are many millions of miles further from us than others; the diſtance of the ſun is demonſtrated to be much leſs than the diſtance of any ſtar; the moon and ſome of the planets, we know by ocular proof, are nearer to us than the ſun, becauſe they ſometimes come between the ſun and our eye, and hide his whole diſk or part of

it

it from our view: this the moon does every time the ſun is eclipſed: neverthe- FIG.
leſs the ſenſe perceives no difference, in the diſtances of the heavenly bodies; to us they appear to be all equally diſtant, and to be placed in the ſurface of a ſphere whereof our eye is the center: the heaven therefore may very well be repreſented by the glaſs ſphere, or by the common celeſtial globe.

249 The concave ſurface in which the ſtars appear to be placed, is called *the ſphere of the fixt ſtars:* this ſphere is ſo immenſely large, that our eye would ſeem to be in the center of it, and we ſhould find no ſenſible difference in the apparent places of the ſtars, though we were removed many millions of miles from our preſent ſituation; becauſe ſuch a diſtance, though great in it ſelf, dwindles to nothing, and becomes inſenſible, when compared with the vaſtly greater diſtance of the ſtars from us: this may be illuſtrated by this eaſy experiment; let any perſon look at two or three objects that are at a pretty large diſtance from him, but appear near to one another, a ſmall removal of the eye will not alter the proſpect of thoſe objects: thus, ſuppoſe a man ſtanding in a certain place, looks at two or three churches that are three or four miles diſtant from him, but appear near to one another, he will ſee them in a certain poſition; let him remove two or three feet from his firſt ſtation, and they will ſtill appear, as to ſenſe, in the ſame ſituation as before; becauſe the diſtance of two or three feet bears an exceedingly ſmall proportion to the diſtance of three or four miles; in ſo ſmall a difference of ſtations, the difference of the pictures of ſo diſtant objects upon the retina, is too ſmall to be perceptible.

The following propoſitions in perſpective are very uſeful to help the imagination, in conceiving the repreſentations of ſeveral appearances in the heavenly bodies: they are diſtinguiſhed by points, that the reader may if he pleaſes paſs them over for the preſent, and read them hereafter, when they are referred to, as they will be in proper places.

·250 *Perſpective* is the art of deſcribing upon a plane the repreſentation of any object, or in other words of drawing the picture of it: a picture drawn in the utmoſt perfection, and placed in a proper poſition, ought ſo to appear to the ſpectator, as not to be diſtinguiſhable from the object it repreſents: in order to produce this effect, the rays of light ought to come from the ſeveral parts of the picture to the eye of the ſpectator, in the ſame direction, and with the ſame ſtrength of light, ſhadow, and colour, as they would do from the correſponding parts of the object it ſelf, ſituated in the place wherein the picture repreſents it to be: thus, fig. 140, if we ſuppoſe a ſpectator whoſe eye is at M to be 140
looking at a picture of a cube *abcd*, and the original cube ABCDEF to be actually placed behind the picture, at the ſame diſtance from his eye, and in the ſame ſituation as the picture repreſents it to him; the light from any point *a*
of

FIG. of the picture, ought to come to the ſpectators eye M by the ray *a* M, in the
140 ſame direction, with the ſame colour, and ſtrength of light and ſhadow, as it would do from the correſponding point A of the original cube, by the ray AM.

·251 The plane upon which the picture is drawn may be called *the glaſs*, becauſe it may be imagined tranſparent, as glaſs is, for the rays of light coming from the object to the eye to paſs through.

·252 If we imagin lines drawn from every point of an object to the eye, through the glaſs, they will form a plane figure upon the glaſs, ſimilar to the picture of the object upon the bottom of the eye: the out lines of the figure thus formed upon the glaſs are called *the projection* of the object.

·253 When the eye is at a moderate diſtance from an object, the *projection* of it is called *ſcenographic:* in this manner the ſcenes of a theater are deſigned, as are alſo pictures of buildings, gardens, *&c* drawn in perſpective: I call that *a moderate diſtance* where the apparent magnitude of the object bears a ſenſible proportion to the diſtance of it from the eye of the ſpectator.

·254 When the eye is at an infinite diſtance from the object, the *projection* of it is call *orthographic:* in this caſe, all the lines which may be imagined drawn from the ſeveral points of the object to the eye, though they really converge and meet in a point in the eye, yet may be conſidered as phyſically parallel; becauſe they have the ſame effect, are projected in the ſame manner upon the glaſs, and form the ſame picture upon the retina, as if they were really parallel: that is commonly called *an infinite diſtance*, which is immenſely great, where the apparent magnitude of the object is exceedingly ſmall compared with the diſtance of it from the eye of the ſpectator; where conſequently the object appears under a very ſmall angle: this is the caſe with regard to the ſun, which, though really of a great magnitude, by reaſon of his vaſt diſtance from us, appears under a ſmall angle, of no more than about $30'$: for this reaſon, all the rays of light which come from the ſun to our earth may be looked upon as phyſically parallel; and therefore if any plane or ſolid figure be held in the ſun, the ſhadow of it, caſt upon a plane held perpendicular to the rays of the ſun, will be the orthographic projection of that figure: thus, the ſhadow of a circle held directly to the ſun, ſo that his rays fall upon it perpendicular to the plane of it, will be a true circle, if projected upon a plane perpendicular to the rays of the ſun: thus alſo, a circle held obliquely to the ſun, ſo that his rays fall inclined to the plane of it, will be a true ellipſis, if projected upon a plane perpendicular to the rays of the ſun. The orthographic projection is of greateſt uſe in aſtronomy, and therefore principally to be conſidered: I ſhall firſt explain as much of that as is neceſſary in the twelve following propoſitions, and then ſay ſomething of the ſcenographic projection.

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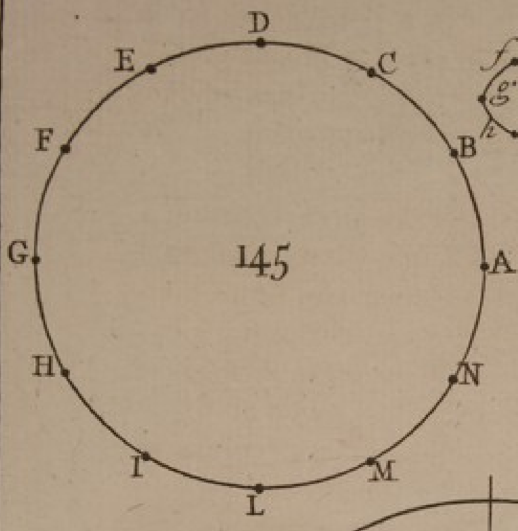
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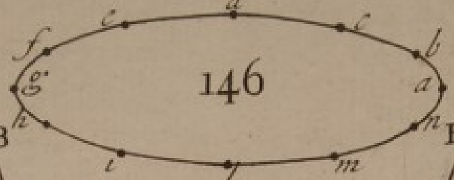
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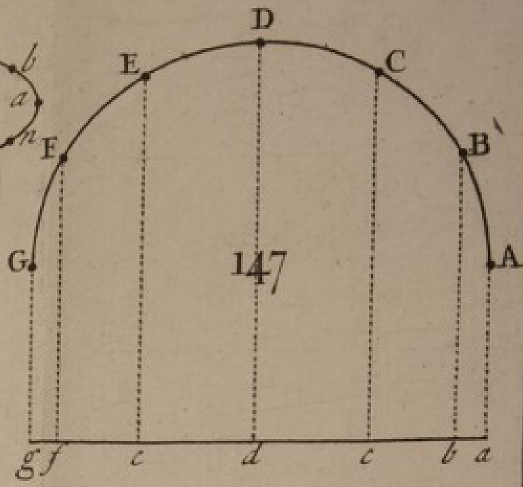
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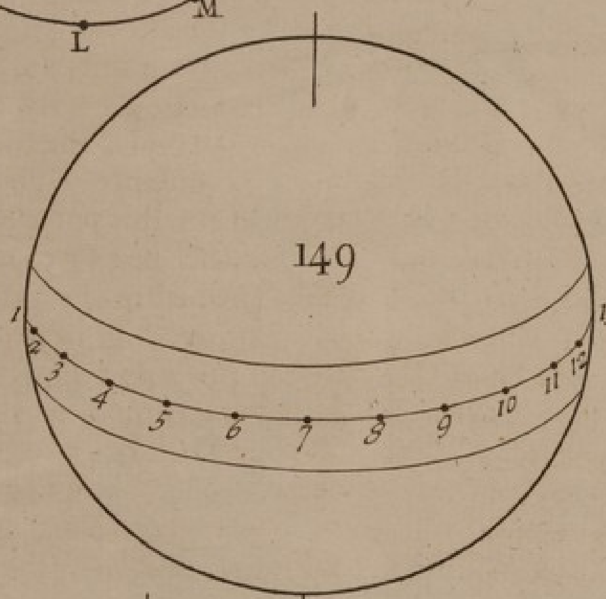
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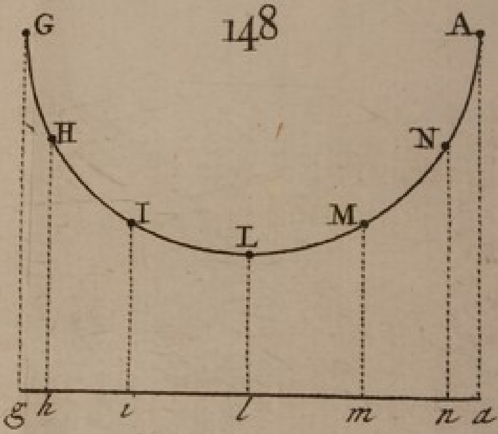
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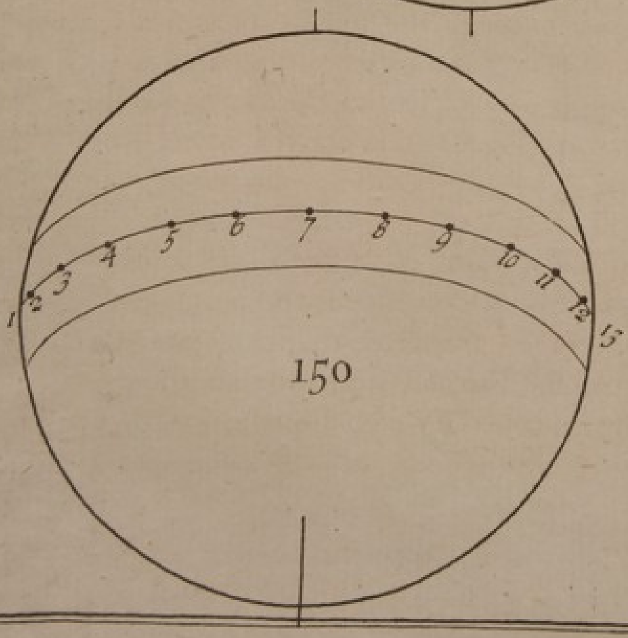
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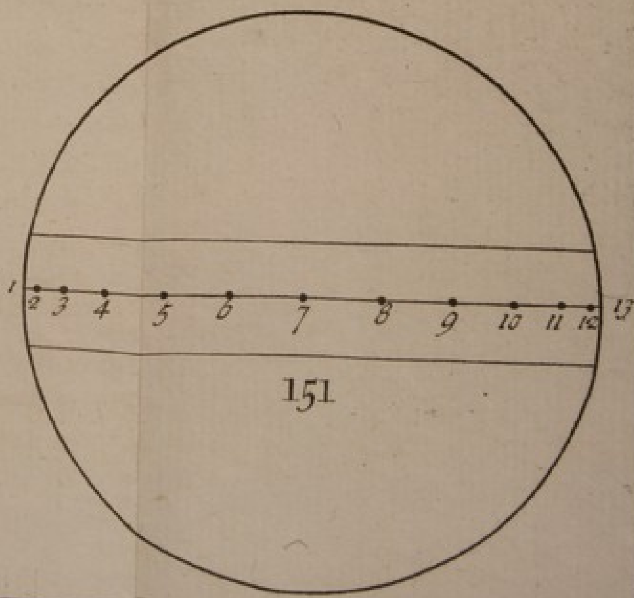
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FIG.

·255 The projection of a globe is a circle, ſee § 236 and 238.

·256 The projection of a circle viewed directly, ſo that a line drawn from the eye to the center of it would be perpendicular to the plane of it, is a circle.

·257 The projection of a circle viewed obliquely, ſo that a line drawn from the eye to the center of it would make an acute angle with the plane of the circle, is an ellipſis.

·258 A circle viewed in ſuch a poſition that the plane of the circle continued would paſs through the eye, appears a ſtrait line: theſe three laſt propoſitions may be illuſtrated by the different appearances of the circular rim of a china baſin: look directly into the baſin, and the rim will appear a circle, as fig. 141: 141
look obliquely upon it, and it will appear an ellipſis, more or leſs oblong, as it is viewed more or leſs obliquely: fig. 142 repreſents the baſin viewed oblique- 142
ly; fig. 143 ſhews the ſame viewed more obliquely; and fig. 144 repreſents 143
the baſin, as it appears viewed with the eye in the plane of the circular rim of 144
it produced; in which caſe the projection or view of it is a ſtrait line AB.

·*Scholium*, In this experiment, in order to make the projection nearly orthographic, and the curve not ſenſibly different from a true ellipſis, the baſin muſt be placed at a good diſtance from the ſpectator; the diſtance of about 100 diameters of the circular rim from his eye is ſufficient for this purpoſe.

·259 In all projections of a circle, except the direct one deſcribed § 256, the parts which are equal in the original circle will appear unequal in the projection of it: thus, ſuppoſe a circle is divided into 12 equal parts, fig. 145, if it 145
be viewed ſo obliquely that the projection of it is the ellipſis *adgl*, fig. 146, 146
the points ABCDEFGHILMN, equally diſtant in the original circle, fig. 145, 145
will appear unequally diſtant in the projection, fig. 146; *viz.* in the ſituation 146
abcdefghilmn.

·260 When a circle is viewed obliquely, or with the eye in the plane of it continued, one half of it is nearer to the eye than the other: thus, if you look obliquely at fig. 145, or with your eye in the plane of the paper continued, 145
the book being held in its proper ſituation a little diſtance from you, the ſemicircle GHILMNA will be nearer to your eye than the ſemicircle ABCDEFG: the neareſt of theſe I call *the convex ſemicircle*, becauſe it is convex towards the eye: that which is furtheſt from the eye I call *the concave ſemicircle*, becauſe it is concave towards the eye.

·261 If a concave ſemicircle divided into any number of equal parts be viewed obliquely, or with the eye in the plane of it continued, the points equally diſtant in the original ſemicircle will be ſo projected, that thoſe neareſt the middle of the projection will appear the furtheſt from one another: thus, if the concave ſemicircle ABCDEFG, fig. 145, be viewed obliquely, ſo that 145
the

FIG. the projection of it is the ſemiellipſis $abcdefg$, fig. 146, the arcs cd and de
146 are greater than bc, or ef; and the arcs bc and ef are greater than ab, or fg: and
145 if a concave ſemicircle ABCDEFG, fig. 145, be viewed with the eye in the
147 plane of it continued, ſo as to be projected into the ſtrait line ag, fig. 147, then cd and de will be longer than bc, or ef; and bc or ef will be longer than ab, or fg.

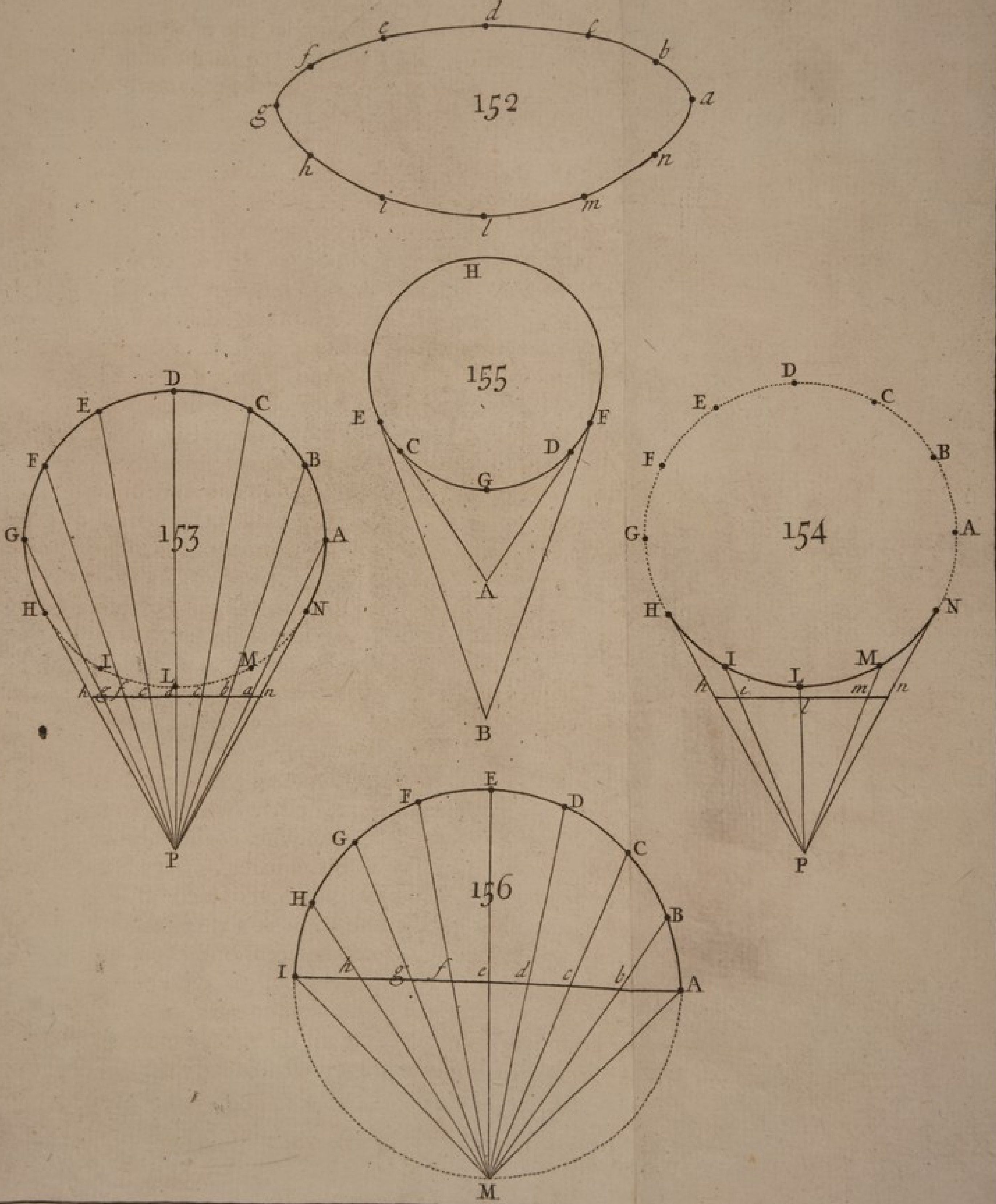
262 If a convex ſemicircle divided into any number of equal parts be viewed obliquely, or with the eye in the plane of it continued, the points equally diſtant in the original ſemicircle will be projected in ſuch a manner, that thoſe neareſt the middle of the projection will appear to be moſt diſtant from one
145 another: thus, if the convex ſemicircle GHILMNA, fig. 145, be viewed ſo
146 obliquely that the projection of it is the ſemiellipſis $ghilmna$, fig. 146, the arcs il and lm are greater than hi or mn, the arcs hi and mn are each of them greater than gh or na: again, if the ſame convex ſemicircle GHILMNA, be viewed with the eye in the plane of it produced, ſo that the projection of it
148 is the ſtrait line $ghilmna$, fig. 148, the lines il and lm are longer than hi or mn, and the lines hi and mn are each of them longer than gh or na.

263 In the orthographic projection of a circle, the projections of the convex ſemicircle and the concave one are ſimilar, whether the projection be an
146 ellipſis or a ſtrait line: thus, fig. 146, the ſemiellipſis $abcdefg$ is ſimilar to the ſemiellipſis $ghilmna$; and the largeſt arcs in one are equal to the largeſt arcs in the other; as are alſo the ſmalleſt arcs in one to the ſmalleſt in the other, and the intermediate arcs in one to the correſponding intermediate ones in the other: that is, ab is equal to na, as is alſo bc to mn, and cd to lm &c; thus
147 alſo, the line ag, fig. 147, is ſimilar to the line ag, fig. 148, that is ab in one
148 is equal to ab in the other of theſe lines, as is alſo bc in one to bc in the other, and cd to cd &c.

n a — m l.

264 *Corollary.* From hence it follows, that a body moving in a circle regularly, with the ſame velocity through all the parts of the circle, will appear to move irregularly, to a ſpectator who views the circle obliquely, or has his eye
145 in the plane of the circle produced: thus, fig. 145, let A be a body moving uniformly, equal arcs in equal times, in the circle ABCDE, &c. that is, moving from A to B, in the ſame time that it moves from B to C, or from C to D, or from D to E, &c. If this circle be viewed ſo obliquely, that the projection of it is the ellipſis $abcdef$, &c, fig. 146, the apparent motion of the body will be unequal; for it will appear to move from a to b, in the ſame time that it moves from b to c, or from d to e &c: this apparent inequality in the motion is ſuch, that both in the concave and convex ſemicircle, the moving body appears to go quickeſt neareſt the middle: for in the projection of the concave ſemicircle, cd and

Introduct.


152
a b c d e f g h i l m n
155
H E F C D G A B
153
D E C F B G A H N I M L h g f e d c b a n P
154
D E C F B G A H N I M L h i l m n P
156
E F D G C H B I h g f e d c b A M

and *de* are greater than *bc* or *ef*; and *bc* and *ef* are greater than *ab* or *fg*; and FIG.
in the projection of the convex ſemicircle, *il* and *lm* are greater than *hi* or 146
mn, and *hi* and *mn* are greater than *gh* or *na* &c: again, let the projection of circle in which the body moves uniformly, be a ſtrait line; equal diviſions in the concave ſemicircle will appear as in fig. 147, therefore the moving body 147
will appear to move from *a* to *b* in the ſame time as from *b* to *c*, &c, that is, quickeſt near the middle of the line: and equal diviſions in the convex ſemicircle will appear as in fig. 148, therefore the moving body will appear to 148
deſcribe the line *gh* in the ſame time as it does the line *hi* or *il*, or *lm*, &c: which apparent motion is alſo quickeſt, neareſt the middle of the line.

·265 The following examples will ſerve to illuſtrate, as well as ſhew the uſefulneſs of the propoſition now before us, and are therefore brought in this place by way of anticipation; *the firſt example*; the orbits of the ſatellits of Jupiter and Saturn are at ſuch a diſtance from us, that the projection of them is orthographic, when our eye is elevated above any one of their planes, the elevation is ſo little, that the projection of the orbit is a very oblong ellipſis, ſuch as is drawn fig. 146, ſo that the ſatellit appears to move unequally, going 146
according to the order of the letters unequal arcs in equal times; *viz.* from *a* to *b* in the ſame time as from *b* to *c*, or from *c* to *d*, &c, firſt in one ſemiellipſis *abcdefg*, from the right hand towards the left, and then in the other ſemiellipſis *ghilmna*, from the left hand towards the right: ſometimes our eye is in the plane of a ſatellits orbit produced, ſo that the projection of it is a ſtrait line, in which caſe alſo the ſatellit appears to move unequally, going, whilſt in its concave ſemicircle, according to the order of the letters, in a ſtrait line from *a* to *b*, in the ſame time that it does from *b* to *c*, or from *c* to *d*, &c, fig. 147; and whilſt in its convex ſemicircle, going back again with the ſame un- 147
equal motion, moving in the ſame time from *g* to *f*, as it does from *f* to *e*, or from *e* to *d*, &c, fig. 148. 148

·266 *The ſecond example*; the ſun has a rotation round his axis, as will be be more at large ſhewn hereafter; if we imagin a great circle, which may be called *the ſuns equator*, to be drawn upon the globe of the ſun, equally diſtant from both his poles, with other circles parallel to his equator, § 176, ſince only half the ſuns globe can be ſeen by us at a time, only half of each of theſe circles, *viz.* the convex ſemicircles, would be viſible to us at a time, and the projection of theſe ſemicircles would appear differently, according as our eye is differently ſituated with regard to the ſuns equator: thus, if the eye be a little elevated above the north ſide of the plane of the ſuns equator, it will be likewiſe elevated above the north ſide of the planes of all the parallels, and the projections of them will be ſuch ſemiellipſes as are repreſented fig. 149: if the 149

FIG. eye be elevated above the ſouth ſide of the plane of the ſuns equator, it will be
in like manner elevated above the ſouth ſide of the planes of all the parallels,
150 and the projections of them will be ſuch ſemiellipſes as are drawn, fig. 150: if
the eye be in the plane of the ſuns equator produced, it will likewiſe be in the
planes produced of all the parallels, § 254, and then the projections of them will
151 be ſtrait lines, as fig. 151, now if we imagin theſe circles drawn upon the ſuns
globe to be divided into equal parts, by viſible points, theſe points will appear
unequally diſtant in theſe three ſeveral projections; as they are repreſented in
149 150 fig. 149, 150 and 151: from whence it follows, that a ſpot upon the ſpherical
151 ſurface of the ſun, being viſible only whilſt that hemiſphere upon which it is
placed is towards our earth, will, by the really uniform rotation of the ſun
round his axis, appear to move unequally upon the ſuns diſk, ſo as to go quicker,
the nearer it is to the middle of the diſk, and ſlower the nearer it is to the
edges; and this will be the caſe, whether the eye be elevated above the plane
of the ſuns equator, ſo as to make the projections of that circle and its parallels
149 very oblong ellipſes, as in fig. 149, and 150, or the plane of the ſuns equator
150 continued, paſſes through the eye, ſo as to make the projections of that circle
151 and its parallels ſtrait lines, as in fig. 151: a view of theſe figures is ſufficient
to ſhew the inequality of the apparent motion of a ſolar ſpot; the numeral
figures ſhew the apparent place of a ſpot every day for 13 days, which is a-
bout half the time in which a ſpot appears to us to revolve round the ſun:
149 150 thus, fig. 149, 150, and 151, if any day at noon we obſerve the apparent place
151 of a ſpot at 1, the next day at noon it will be at 2; the third day from the firſt
obſervation it will be at 3; the fourth day it will be at 4; *&c.*

·267 The ſcenographic projection of the out-lines of a figure may be made
by caſting the ſhadow of it upon a wall with a candle; thus, a circle of wire
held obliquely between a candle and a wall will caſt a ſhadow of an elliptic
152 form, ſuch as is repreſented fig. 152; where *g l a* the lower part of the proje-
ction is the half of a wider ellipſis than the upper part *a d g* is; but the moſt
accurate as well as the eaſieſt way of taking the projections of all kind of fi-
gures, is by the *camera obſcura*, or dark room, which is now ſo commonly
known, that I need add nothing to the ſhort deſcription already given of it,
§ 230, but this, that when a lens is made uſe of, the projection will be larger,
the longer the focus of the lens is; that is, the flatter the lens is, or the larger
the ſpheres are whereof the ſides of the lens are ſegments; and that with the
ſame lens you may project the object of different magnitudes, according as you
place it at different diſtances from the lens.

·268 In the ſcenographic projection of a circle, the projections of the con-
cave and convex ſemicircles are not ſimilar, whether the projection be an el-
liptic

liptic curve or a ſtrait line; for though in both theſe the parts which are e- FIG.
qual in the original circle appear larger in the projection, the nearer they are
to the middle of it, equal parts in the original ſemicircles will be more une-
qual in the projection of the convex, than in that of the concave ſemicircle: thus,
if a circle divided into 12 equal parts, fig. 145, placed at a little diſtance from 145
the eye, be viewed with the eye a little elevated above the plane of it, ſo that
the projection of it is the elliptic curve, fig. 152, the points A B C D E &c, e- 152
qually diſtant in the original will be projected into the points *a b c d e f* &c, un-
equally diſtant, in ſuch a manner that in the lower and convex ſemiellipſis
g h i l m n a, there will be a greater difference between the ſmalleſt and greateſt
arc, than there is between the ſmalleſt and greateſt arc in the upper and con-
cave ſemiellipſis *a b c d e f g*, again, if the ſame circle placed at a little diſtance
from the eye, be viewed with the eye in the plane of it continued, the concave
ſemicircle will be projected into the ſtrait line *n h*, fig. 153, where the points 153
N, A, B, C, D, &c equally diſtant in the original, are projected into the points une-
qually diſtant *n, a, b, c, d, e, f, g, h*: but the convex ſemicircle will be projected into
the ſtrait line *h n* fig. 154, in which the points H, I, L, M, N, equally diſtant in the 154
original, are projected into points ſtill more unequally diſtant, *viz. h, i, l, m, n.*

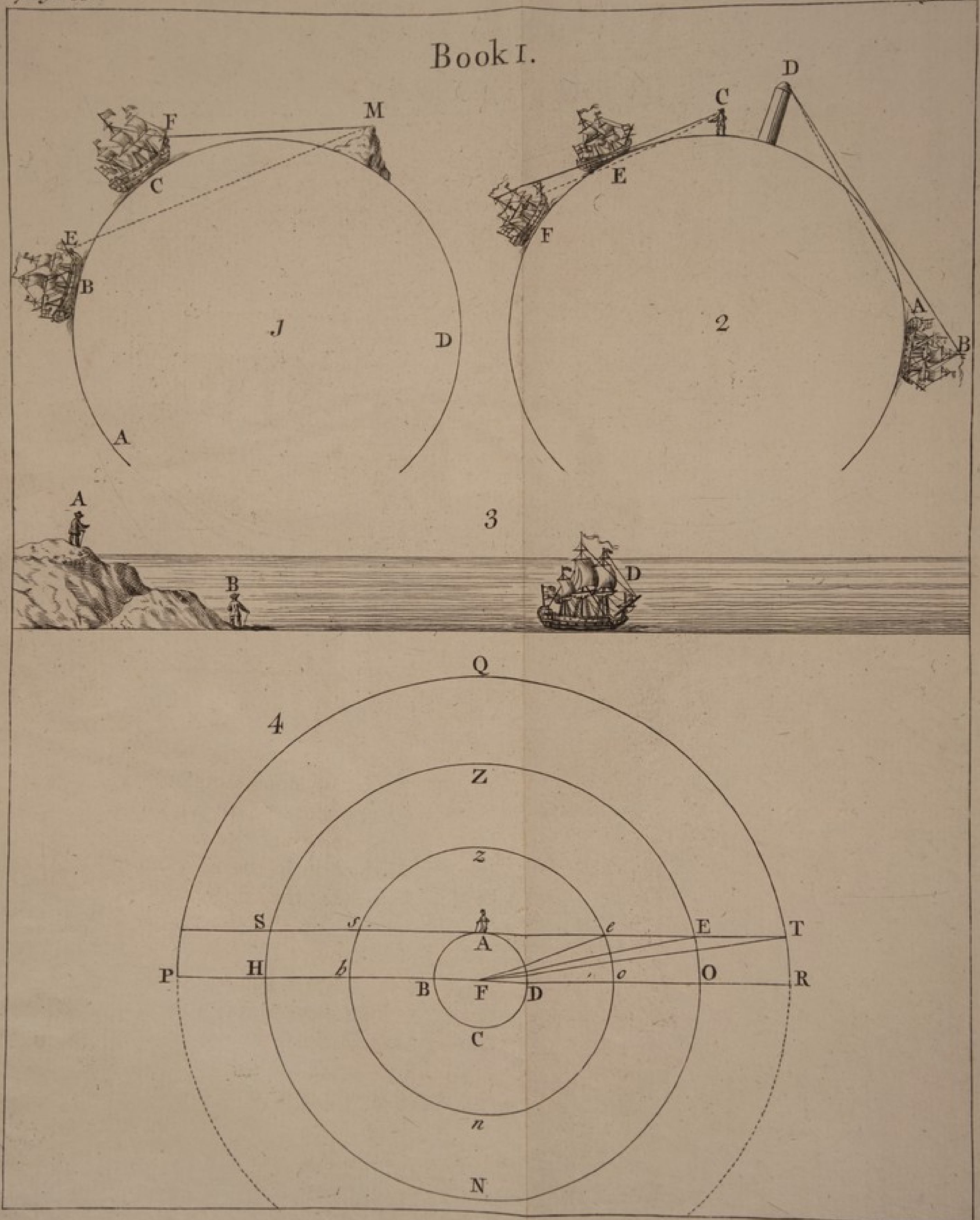
269 *Corollary*; if a body moving uniformly round in a circle, at a moderate
diſtance from the eye, be viewed with the eye a little elevated above the plane
of the circle, it will appear to move unequally throughout the whole circle,
but moſt unequally whilſt it is in its convex ſemicircle: for let fig. 152 be the 152
projection of the circle in which the body moves, it will appear to move in e-
qual times from *a* to *b*, from *b* to *c*, from *c* to *d*, from *d* to *e*, from *e* to *f*, &c;
if the ſame body moving uniformly round in a circle, at a moderate diſtance
from the eye, be viewed with the eye in the plane of the circle continued, it
will appear to move unequally in ſtrait lines, but moſt unequally whilſt in
its convex ſemicircle: thus, fig. 153, let the body A move round in the circle 153
A B C D &c, according to the order of the letters, the eye being in the plane of
the circle continued at P; whilſt it is in its concave ſemicircle, it will ap-
pear to move unequally, going in equal times from *a* to *b*, from *b* to *c*, from
c to *d*, from *d* to *e*, &c; but whilſt the body is in its convex ſemicircle, fig.
154, it will appear to move more unequally, going the contrary way to the 154
former, in equal times ~~from *g* to *h*~~, from *h* to *i*, from *i* to *l*, &c;------ this may
be illuſtrated by the following example, which is alſo brought in here by way
of anticipation, and will be better underſtood hereafter; ſuppoſe the diſtance of
our eye from the orbit of Mercury, and its elevation above the plane of it were
ſuch, that the projection of this orbit ſeen from our earth would be the curve
a b c d &c, fig. 151; the figure ſhews what the apparent motion of Mercury 151 152.

 round

FIG. round the ſun would be, ſeen from our earth, if the earth were all the while to
152 continue at reſt; namely, in equal times the unequal arcs *na*, *ab*, *cd*, *de*, *ef*, *fg*, *gh*,
from the right hand towards the left, whilſt he is in his concave ſemicircle,
and more unequal arcs *hi*, *il*, *lm*, *mn*, in equal times, from the left hand to-
wards the right, whilſt he is in his convex ſemicircle: in like manner, if the
153 orbit of Mercury were repreſented by the circle A B C D &c, fig. 153, and 154,
154 and the eye were at reſt in the plane of it continued at P, the apparent une-
qual motion of Mercury whilſt in his concave ſemicircle, would be in equal
times in the unequal ſtrait lines from *n* to *a*, from *a* to *b*, from *b* to *c*, &c,
fig. 153, from the right hand towards the left; and whilſt Mercury is in his
convex ſemicircle, his apparent motion would be in equal times in more un-
equal ſtrait lines from *b* to *i*, from *i* to *l*, &c, fig. 154, in a direction contrary
to the former, from the left hand towards the right.

·270 *Scholium*, although I have in this and the preceding ſection uſed the
word ſemicircle, it is to be obſerved, that when a circle at a moderate diſtance
from the eye is viewed, the convex part of it is not quite ſo much as a ſemi-
circle, and the concave part of it is a little more than a ſemicircle; for if we
imagin the lines P H and P N to be drawn from the eye at P tangents to the
153 circle, fig. 153 and 154, they will touch the circle at H and N; ſo that the con-
154 cave part of the circle will be N A B C D E F G H, greater than the convex part,
which is H G L M N; and the nearer the eye is to the circle, the greater is the
difference between the concave and convex part of it: thus, if the circle E G D H
155 fig. 155, be viewed, the eye being at B, the concave part of it is E H F, the con-
vex E G F; if the eye be nearer the circle as at A, the concave part of it is then
C H D, and the convex part is C G D.

·271 In the ſcenographic projections hitherto explained, the eye is ſuppoſed
to be placed a greater diſtance from the center of the circle whoſe projection
is to be found, than the ſemidiameter of the circle: there is another kind of
projection of a circle into a ſtrait line, in which the eye is ſuppoſed to be in the
plane of the circle, at a diſtance of a ſemidiameter from the center of it: in
this projection, which takes in only the concave ſemicircle, equal parts in the
original ſemicircle will appear ſmaller in the ſtrait line, the nearer they are to
156 the middle of it: thus, fig. 156, the eye being at M, the equidiſtant points
A, B, C, D, E, F, G, H, I, will be projected into the unequally diſtant points
A, *b*, *c*, *d*, *e*, *f*, *g*, *h*, I, where the lines *de* and *ef* are ſhorter than *cd* or *fg*; the
lines *cd* and *fg* are ſhorter than *bc* or *gh*; the lines *bc* and *gh*
are ſhorter than A*b* or *h*I.



J. Mynde Sc.

ASTRONOMY. BOOK I.

CHAP. I. OF THE SHAPE OF THE EARTH.

§ 272. THE EARTH is the place from whence we view the heavenly bodies, the appearance of theſe bodies is different to the inhabitants of different parts of the earth, this is evident from the experience of all who have travailed into far diſtant countries: the ſun, moon, and ſtars riſe and ſet in Greenland, in a manner very different from what they do in the Eaſt Indies; and in both theſe places they appear differently from what they do in England: the cauſe of this difference is the ſhape of the earth; this therefore is one of the firſt things into which an aſtronomer ought to enquire.

273 *The earth is ſpherical:* by the earth is meant the earth and ſea; now that the earth and ſea together conſtitute a body of a figure every way round, we have ſeveral proofs, ſome of which ſhall be here produced, the reſt being reſerved for a more proper place. 1. When we are at ſea on board a ſhip, we may be out of ſight of land, when the land is near enough to be viſible, if it were

FIG. were not hid from our eye by the convexity of water; thus, fig. 1, let ABCD
1 repreſent a piece of the globe of the earth; let M be the top of a mountain,
this cannot be ſeen by a perſon on board a ſhip at B, becauſe a line drawn
from M to his eye at E is intercepted by the convexity of water: but let the
ſhip come to C, and then the mountain will be viſible, becauſe a line may be
drawn from M to his eye at F. 2. The higher the eye is, the further will the
view be extended: it is very common for ſailors from the top of the maſt of a
ſhip to diſcover land or ſhips at a greater diſtance, than they can do when
2 they ſtand upon deck: thus, fig. 2, the top of the tower D may be ſeen from
B the top of the maſt, when it cannot be ſeen from A, by reaſon of its being hid
by the convexity of the water. 3. When we ſtand upon the ſhore, the higheſt
part of a ſhip is viſible at the greateſt diſtance: if a ſhip is going from us out to
ſea, we ſhall continue to ſee the maſt after the hull or body of the ſhip diſ-
appears, and the top of the maſt will continue to be ſeen longeſt; if a ſhip is
coming towards us, the top of the maſt comes firſt into view, and we ſee more
2 and more of it, till at laſt the hull appears: thus, fig. 2, let the eye be at C, when
a ſhip is as far off as at F, only the top of the maſt is viſible, the hull is hid be-
hind the water, when the ſhip is nearer, as at E, the hull may alſo then be
3 ſeen. If the ſurface of the ſea were a flat, fig. 3, a line might be drawn from any
object ſituate upon it, as the ſhip D, to the eye, whether placed high or low,
at A or at B: in this caſe, any object upon the earth, or ſea, would be viſible
at any diſtance which was not ſo great, as to make the appearance of it, too
faint, or the angle under which it appears too ſmall, to be ſeen by us: an
object would be viſible at the ſame diſtance, whether the eye were high or low:
not the higheſt but the largeſt objects would be viſible, to the greateſt di-
ſtance, ſo that we ſhould be able to ſee the hulk of a ſhip further off than the
maſt: all which is contrary to experience. 4. The convexity of the water may
be ſeen upon any ſtill water, as upon a river which is extended in a ſtrait line,
a mile or two in length; a little boat upon the water may be ſeen at a mile
diſtance, by a man whoſe eye is any height above the water: but if he ſtoops
down, and lays his eye near the water, he will find the ſurface thereof ri-
ſing up in ſuch a manner as to cover the boat, and intercept his view of it.
5. Several navigators have ſailed quite round the globe; not in an exact cir-
cle, for this the winding of the ſhores, the land running out in many places
into the ſea, would not admit of; but going in and out, as the ſhores happen
to lie, they have held on the ſame courſe, and come home on a different ſide
from that they firſt ſet out from: thus, *Ferdinand Magellan* ſetting out on the
weſt ſide of Spain, continued ſailing weſtward till he returned home ~~on the~~
pe of Good Hope ~~eaſt ſide of Spain~~; our S^r *Francis Drake*, Capt. *Dampier* and others have done
the

the like; the courſe they have ſome of them run is marked upon ſome maps and globes: theſe proofs are ſufficient to evince the roundneſs of the water; that the earth is alſo round is evident, if we conſider, that the ocean is diffuſed all over the globe, ſo as to divide the earth as it were, into large iſlands; and that the ſurface of the earth is no where very much higher than the ſea, as is evident from the courſe of rivers, which are at a moderate eſtimate computed not to have above one mile fall, in running a thouſand miles, and have their ſhores pretty much of the ſame height[a]; as alſo from the height of mountains, which are none of them found to be above 3 or 4 miles higher than the ſurface of the ſea: theſe experiments prove the earth and ſea to have a convex ſurface every where. 6. All the appearances in the heaven, both at land and ſea, are the ſame, as they would be, if the earth were a globe, which proves it to be of that ſhape; and laſtly, in eclipſes of the moon, which are cauſed by the ſhadow of the earth falling upon the moon, as will appear when eclipſes are treated of, this ſhadow is always circular, whatever ſituation the earth is in at that time: now a body can be no other than a globe, which in all ſituations caſts a circular ſhadow: it is true the ſurface of the earth is not an exact geometrical globe, becauſe it ſinks into valleys in ſome places, and riſes into mountains in others, but theſe inequalities upon its ſurface are as inconſiderable, when compared with the magnitude of the earth, as the little aſperities upon the rind of an orange are to the bulk of the orange; and accordingly we find that mountains and vallies upon the ſurface of the earth, cauſe no irregularities in its ſhadow, in a lunar eclipſe, but the circumference thereof is even and regular, as if it were caſt by a body exactly globular: the ſemidiameter of the earth is above 8000 Engliſh miles, the higheſt mountain is not 4 miles, higher than the ſurface of the ſea, which is but a 2000th part of the earths diameter: thus it appears that the higheſt mountain bears no greater proportion to the bulk of the earth, than a grain of duſt does to a common globe.[b]

We may imagin as many circles as we pleaſe to be deſcribed upon the earth, or upon the ſphere of the heaven: we may alſo, when we have imagined a circle to be deſcribed upon the earth, conceive the plane of that circle to be extended every way, till it marks a circle concentric to itſelf, upon the ſphere of the heaven.

273. The horizon is either ſenſible or rational: *the ſenſible horizon* is a circle, the plane whereof is ſuppoſed to touch the ſpherical ſurface of the earth, in the place of the ſpectator whoſe horizon it is, and to be continued to the heaven: thus, if I imagin the plane of the floor upon which I ſtand to be extended every way, till it reaches the ſtarry heaven, this plane is my ſenſible

a *Kepler epit. Aſtronom. l.* 1. *pag.* 21. b *Varenius Geograph. l.* 1. *c.* 9.

horizon:

FIG. horizon: *the rational horizon* is a circle whose plane passes through the center of the earth, parallel to the plane of the sensible horizon, and is continued to the heaven.

274 The earth is so small in comparison of the immense largeness of the sphere of the heaven, that the planes of the sensible and rational horizon coincide; that is, the distance between them, when measured in the sphere of heaven, is insensible, not great enough to be discovered by any observation: in fig. 4,
4 let ABCD represent the earth, *zhno* the sphere of the starry heaven, if an inhabitant of the earth stands upon the point A his sensible horizon is *se*, his rational horizon *ho*, the distance between the planes of these two is AF the semidiameter of the earth, which is measured in a great circle upon the sphere of the heaven, by the angle *eFo* or by the arc *eo*, this arc in so small a circle as *zhno* would amount to several degrees, and consequently the difference between the sensible and rational horizon would be great enough to be easily discovered by observation: but this circle in the figure is a great deal too small to represent the sphere of the heaven, proportional to such an earth as is here supposed of the magnitude ABCD; let us then represent the sphere of the heaven by a larger circle ZHNO, here the same semidiameter of the earth AF measured in this larger circle amounts to fewer degrees, for the arc EO is of fewer degrees than the arc *eo* and the angle EFO is less than *eFo* but this angle also may amount to several degrees or minutes, and be large enough to be measured by astronomical observation: if we imagin the sphere of the heaven to be still larger in proportion to the earth, so that half of it may be represented by the semicircle PQR, the distance between the planes of the sensible and rational horizon measured by the angle TFR less than the angle EFO, or by the arc TR, less then the arc EO, is now of a fewer degrees than in the last supposition, but still may be large enough to be observed with instruments: from a view of this scheme it appears, that the larger the sphere of heaven is, in proportion to the globe of the earth, the less sensible is the difference between the sensible and rational horizon, as being measured by a less angle; we may go on further, and suppose the sphere of the heaven larger; so large, that the angle which should measure the distance of the sensible from the rational horizon does not amount to a few seconds, or perhaps not so much as one second of a minute, and consequently is too small to be measured by any astronomical observation: this is in fact the case, and therefore the difference between the sensible and rational horizon is insensible; just as it would be if the earth were a point of no sensible magnitude; and this is meaning of that common expression, that *the earth is but a point* compared with the starry heaven.

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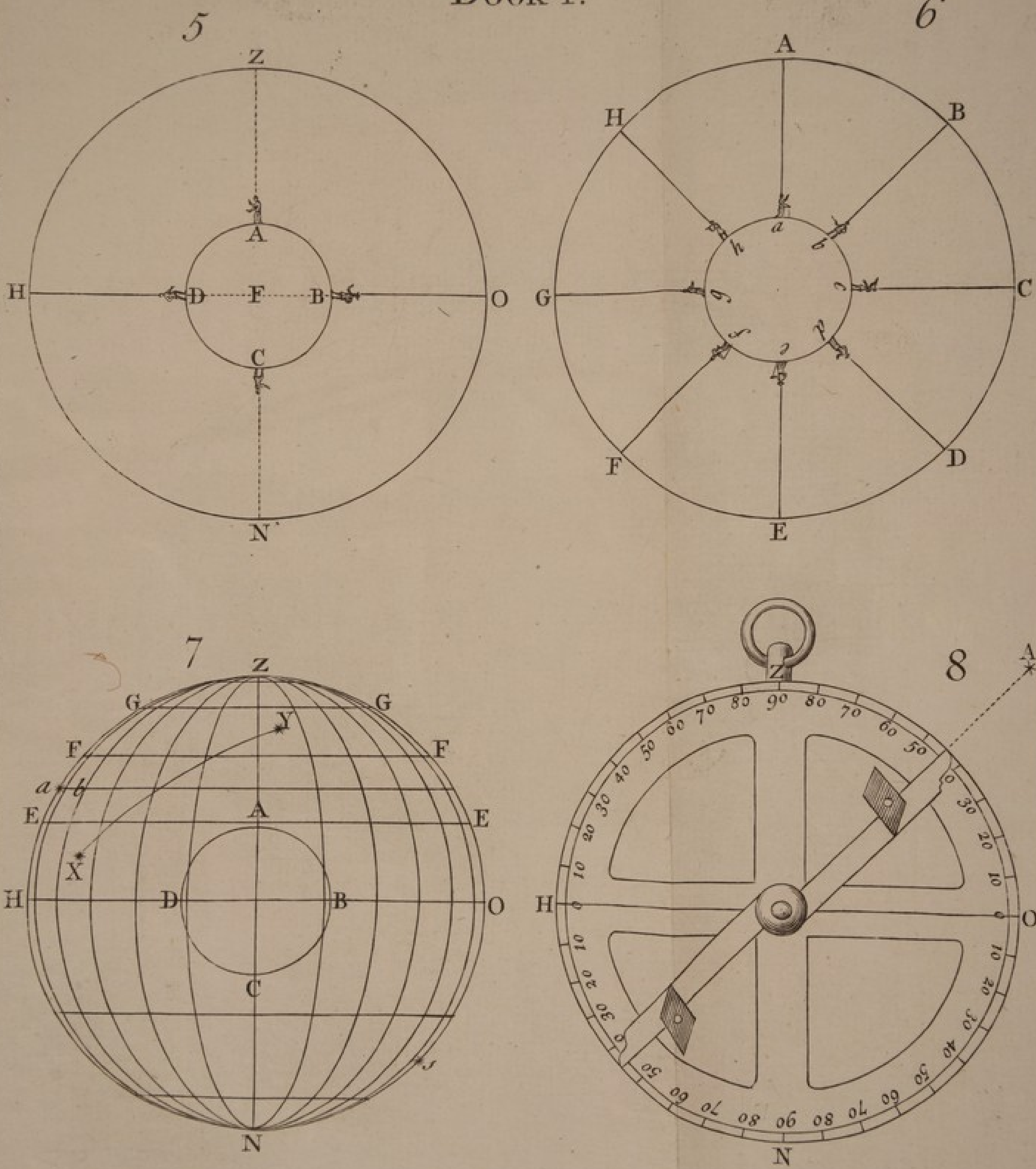

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276 The plane of our horizon continued to the heaven divides it into two FIG.
hemiſpheres, one *viſible* to us, the other *inviſible*; as being hid from us by the interpoſition of the earth: thus, fig. 5, let Z O N H repreſent the heaven, A B C D 5
the earth, the horizon of an inhabitant of the earth at A, is H O, his viſible hemiſphere is H Z O, his inviſible hemiſphere H N O; let another inhabitant of the earth be placed at C, on a part of the earth oppoſite to A, his horizon is H O, his viſible hemiſphere H N O, his inviſible hemiſphere H Z O; the viſible hemiſphere is often called alſo *the upper hemiſphere*; and whatever ſtars or other objects in the heaven are within it, they are ſaid to be *above the horizon*; as whatever is in the inviſible hemiſphere is ſaid to be *below the horizon*, or *in the lower hemiſphere:* this way of ſpeaking may, without due caution, lead us into a vulgar error; to avoid which we are to remember, that no part of the heaven is abſolutely in itſelf above or below, but only relatively, and in reſpect of us; for that which is above with regard to one part of the earth, is below with regard to another: thus, if a man is placed upon the earth at A, the point 5
Z in the heaven is over his head, the oppoſite point N is under his feet; on the contrary, if a man be placed upon the earth at C, the point N is over his head, and the point A under his feet.

277 What has now been mentioned may be ſufficient to ſatisfy thoſe who think it impoſſible there ſhould be any *antipodes*, or *inhabitants of the earth with their feet oppoſite to ours*, and imagin that, if there were any ſuch, they would fall downwards, as they call it, into the ſky which is under us: but to take away this prejudice more effectually, we may conſider *the earth* as *a large round loadſtone*, whoſe attractive power cauſes all heavy bodies upon the ſurface of it to tend towards its center, and that the earth is alike on all ſides ſurrounded by the heaven; and then the reaſon will be eaſily ſeen why the inhabitants of all parts of the earth ſtand equally upright upon it, with their feet towards F, the center of it; namely, becauſe towards that the weight or tendency of every mans body is directed, whether he lives at A or at B, at C or D, fig. 5; and 5
therefore a man living at A has no more reaſon to imagin that a man who lives at C would fall towards N, than he has to fear that he himſelf is in danger of falling towards Z.

278 The horizon is the firſt circle which offers itſelf to the conſideration of an aſtronomer, and may be thus defined: *the horizon* is that circle which any one upon a large plain obſerves, terminating his view every way round him, where the heaven and earth ſeem to meet: this definition, though it ſeems chiefly to regard the ſenſible horizon, is applicable to the rational one, becauſe that is coincident with the ſenſible, as has been already ſhewn, § 275; in

FIG. aſtronomy and geography, whenever the horizon is mentioned, the rational horizon is uſually underſtood, when nothing is ſaid to the contrary.

279 Since the horizon is a great circle of the ſphere of the heaven, dividing it into two equal parts, § 276, it muſt alſo divide into two equal parts every great circle of that ſphere, which is interſected by it, § 177; and ſince the horizon, as will appear hereafter, divides every ſuch great circle into two equal parts, this is a proof that the horizon is a great circle, § 51.

280 By reaſon of the earths roundneſs, *every place upon the ſurface of the*
6 *earth has a different horizon:* this is eaſily underſtood by fig. 6; if a man lives at *a*, his horizon is GC; if he lives at *b*, his horizon is HD; if at *c*, it is AE; *&c.* this difference of horizons in different parts of the earth is another proof that the earth is ſpherical: if the earth were a flat, all the inhabitants thereof would have the ſame horizon.

281 *The poles of the horizon,*[a] are called the zenith and nadir; they are called alſo the *vertical points*; *the zenith* of any inhabitant of the earth is that point in the heaven which is over his head: *the nadir* is the oppoſite point in
6 the heaven, directly under his feet: thus, fig. 6, if a man lives at *a*, his zenith is A, his nadir E; if he lives at *b*, his zenith is B, his nadir F; *&c.*

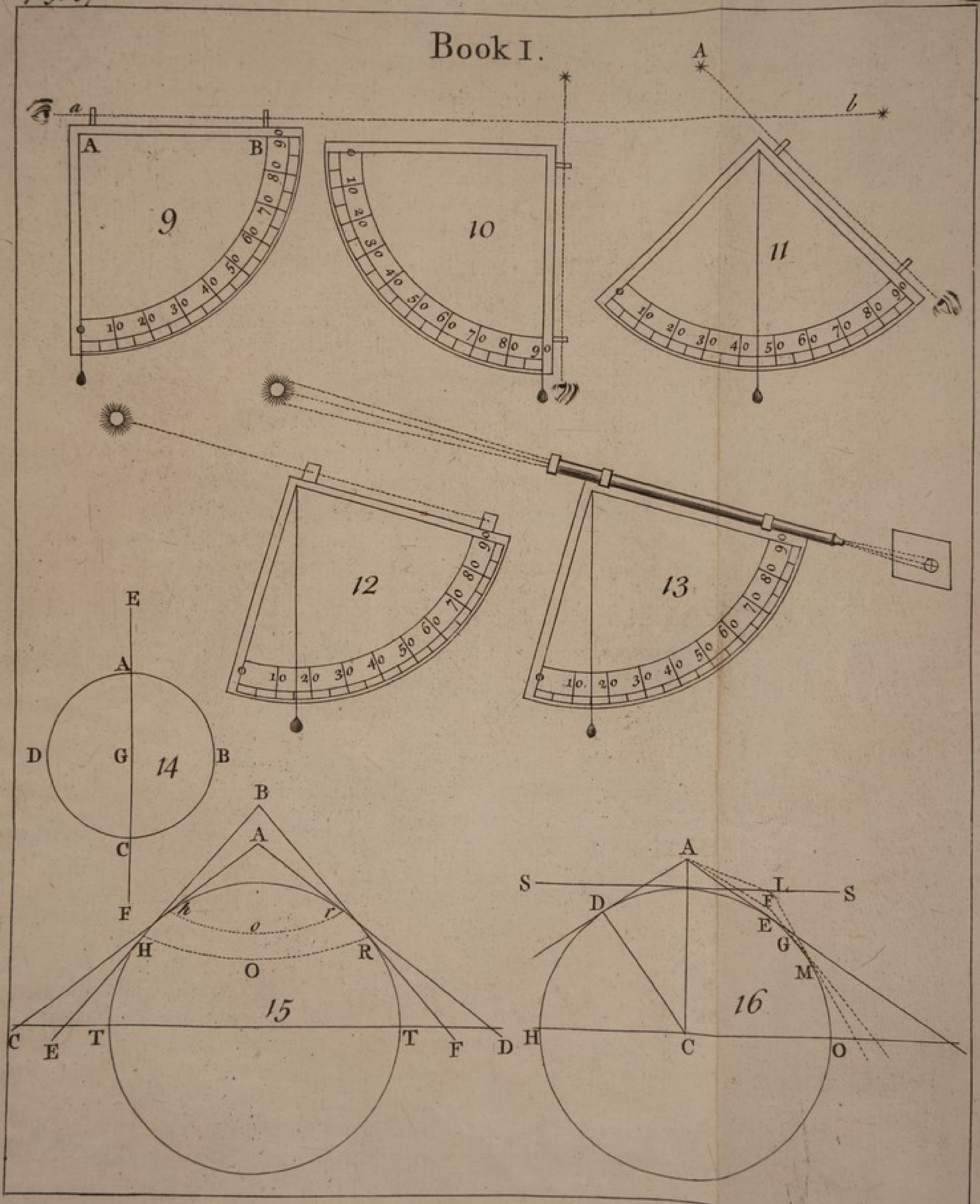
282 We may imagin as many great circles as we pleaſe to be deſcribed upon the ſphere of the heaven, ſo as to interſect each other in the two vertical points; theſe are called *vertical circles* or *verticals*; they are alſo called *azi-*
7 *muths:* in fig. 7, let ABCD repreſent the earth, ZONH the ſphere of the heaven, if an inhabitant of the earth lives at A, his horizon is HO, his zenith Z, his nadir N, the ſemiellipſes terminated at Z and N are projections or pictures of his vertical circles, whereof only one half of each vertical as Z*a*HN, or Z*b*N, *&c* is here drawn, to avoid confuſion: verticals are ſometimes called *ſecondaries of the horizon*; and in general, any great circles which are imagined to be drawn through the poles of another great circle, are called ſecondaries of that circle.

283 *The altitude of any point of the heaven above the horizon,* or *its depreſſion below the horizon,* is the arc of a vertical intercepted between that point and the horizon: thus, if it be enquired what is the height of the ſtar
7 *a* above the horizon HO, fig. 7; imagin a vertical circle ZONH to be drawn through the ſtar, the arc *a*H contained between the ſtar and the horizon is 30°, the height of the ſtar *a* then is 30°: the ſame figure ſhews the ſtar *s* is 45° below the horizon.

284 *The way of meaſuring the height of any of the heavenly bodies* will be
8 underſtood, by an explanation of fig. 8; let ZONH be a circle of braſs divided into 360°, ſuſpended in ſuch a manner, that the plane of it is perpendicular, and the line HO parallel to the horizon; then will HO always repreſent the

a § 176.

page 67.



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the horizon, and whenever the circle is turned ſo, that the plane of it continued FIG.
would paſs through a ſtar *a*, the graduated edge will repreſent a vertical 8
drawn through that ſtar; let there be a ruler with ſights, moveable about the
center of the circle, turn the ruler about, till you can ſee the ſtar through the
ſights, and the number of degrees intercepted between the edge of the ruler
and the horizontal line H O, will ſhew the height of the ſtar above the hori-
zon: thus, in the figure before us the height of the ſtar A is 40°[a].

285 The zenith, which is the higheſt point in the heaven, is but 90° a-
bove the horizon; we may therefore inſtead of a whole circle, make uſe of
a quadrant, having a ſmall thread with a plummet at the end of it, to meaſure
the altitude of any ſtar, the ſun, moon, *&c:* a quadrant may be either furniſhed
with *plain ſights*, which are two thin pieces of braſs pierced through with
two very ſmall holes, and placed ſo, that a line *ab* drawn through the centers of
the two holes is parallel to the quadrants radius A B, fig. 9; or elſe a teleſcope is 9
fixed to the quadrant, in ſuch a manner, that a line drawn from the center of
the eye-glaſs to the center of the object-glaſs is parallel to the radius; there 13
are then uſually two fine hairs ſtretched over the eye-glaſs, ſo as to croſs each
other at the center of it, by means whereof the teleſcope is directed more ac-
curately towards any object: thus, if a ſtar is to be viewed with theſe *teleſcopic
ſights*, in order to take its altitude, the quadrant muſt be held ſo that the point
of interſection of the croſs hairs may cover the ſtar. *The limb* or margin of a
quadrant is divided into 90°, every degree into halves or quarters, and ſome-
times, if the inſtrument be large enough to admit of it, into minutes: the way
of uſing it will eaſily be underſtood by what followeth.

286 If when a ſtar is viewed through the ſights of a quadrant, the thread
falls upon (0) in the limb of the quadrant, the ſtar has then no altitude, but
is in the horizon, fig. 9: if the thread falls upon (90), the ſtar is in the zenith, 9
fig. 10: if a ſtar is in any intermediate place between the zenith and the hori- 10
zon, when it is viewed through the ſights of a quadrant, the thread will lye
upon that degree in the limb which ſhews its altitude: thus, fig. 11, the alti- 11
tude of the ſtar A is 45°: in uſing the quadrant to obſerve the height of a ſtar,
care muſt be taken that the thread juſt touches the limb of the quadrant, ſo as
to play freely without preſſing upon it, and then the plane of the graduated
face of the inſtrument will be coincident with the plane of a vertical drawn
through that ſtar.

287 When *the ſuns altitude* is to be obſerved *by a quadrant with plain ſights*,
it is ſufficiently exact for common uſes to let the ſun ſhine through the hole
of one ſight, and turn the quadrant, till the little round bright ſpot made by
his rays, falls with its center upon the middle of the hole of the other ſight;

a *See* § 31 & 32.

FIG. ſee fig. 12: if *teleſcopic ſights* are made uſe of, we may receive the ſuns image
12 through the teleſcope upon a piece of white paper, held ſo that his rays may
fall perpendicular upon it, and form thereon a luminous circle, with the ſha-
13 dows of the croſs hairs interſecting each other in the center of it; ſee fig. 13.

288 If we would take *the altitude of the ſun more accurately*, it may be done
by two obſervers, taking at the ſame time, with different inſtruments, one, the
height of the upper edge, the other, the height of the lower edge of the ſuns
diſk; the middle height between theſe two is the height of his center: thus,
14 fig. 14, let ABCD be the ſun, if the height of the upper edge A be 40°, the
height of the lower C 39° 30′, the difference between them is 30′, take half
thereof, 15′ from 40°, the height of the upper edge, or add it to 39° 30′, the
height of the lower edge, and you have the height of the center G, 39° 45′.

289 *The ſuns altitude* may alſo be taken *accurately by one obſerver*, his apparent diameter being given, after this manner; the height of the upper edge of the ſuns diſk being found by the quadrant, take from it half his diameter, the remainder is the height of his center: or the height of the lower edge being found, add thereto the ſuns ſemidiameter, the ſum of both is the altitude of his center. Whenever we look at the ſun, whether through plain ſights or a teleſcope, it is neceſſary to hold a piece of *glaſs ſmoaked* over a lamp or a candle, before the eye, to prevent its being injured by the glare of his beams.

290 Sometimes, that an inſtrument of a large radius may not be unweildy, *a ſextant*, or a ſixth part of a circle, and ſometimes, *an octant*, or eighth part of a circle is made uſe of, inſtead of a quadrant.

291 We may imagin as many *circles* as we pleaſe to be drawn upon the
ſphere of the heaven, *parallel to the horizon*; theſe are called *almicantarahs*;
and grow leſs and leſs, as they come nearer to either of the poles of the ho-
7 rizon: in fig. 7, the horizon is repreſented by H O, the almicantarahs, by the
lines E E, F F, G G, &c, parallel to H O.

292 If we are *to meaſure the apparent diſtance between any two points in the*
ſphere of the heaven, we muſt imagin a great circle to be drawn through them,
and find how many degrees, minutes, &c are contained in that arc of it which
is intercepted between thoſe points; this great circle is called *a circle of di-*
7 *ſtance:* thus, if I am to meaſure the diſtance between two ſtars X and Y, fig. 7,
I muſt find how many degrees, minutes, &c are contained in the arc X Y[a].

The apparent diameter of the ſuns diſk is *meaſured* by a circle of diſtance
14 drawn through the center of it: thus, fig. 14, let A B C D be the ſuns diſk, E A C F
a piece of a great circle drawn through the center of it, the arc A C contain-
ed between two oppoſite points in the circumference of the diſk is the mea-
ſure of the ſuns diameter; and of ſo many minutes of a degree as that con-
tains,

a See § 32.

tains, is the ſuns diameter ſaid to be: the apparent diameter of the ſun may FIG.
be found by two obſervers, one of them taking the height of the upper, the other, the height of the lower edge of his diſk, at the ſame time; the difference between the heights of theſe two is the ſuns diameter: thus, if the height of the upper edge A be obſerved 40°, and the height of the lower edge C, 39° 14
30′, the difference between theſe two, *viz.* 30′, is the apparent diameter of the ſun: the ſeveral methods of meaſuring the apparent diameters of the heavenly bodies, or the diſtance between any two points in the heaven, will be ſhewn more at large in the proper place, it is ſufficient for the preſent to know in general what is meant by meaſuring them.

293 Sometimes the ſenſible, or rather viſible horizon is conſidered, only with regard to ſuch objects as are upon the earth, and may be thus defined; *the viſible horizon* is a leſs circle upon the ſurface of the earth, comprehending all objects upon it, which are within our view: *the higher the eye is, the farther is the viſible horizon extended:* thus, fig. 15, let H *hr* R repreſent a part of the 15
ſpherical ſurface of the earth, if the eye be at A, draw A *h* and A *r* tangents of the globe of the earth, imagin one of theſe A *h*, the point A continuing immoveable, to be carried round, all the while touching the ſurface of the earth, the point *h* will deſcribe the viſible horizon, part of which is here ſhewn by the pointed curve *hor:* if the eye be placed higher, as at B, the tangents B H and B R will reach farther off, and the viſible horizon will be larger, *viz.* HOR: what the extent of the viſible horizon is, and how it may be found, will be ſhewn, after the dimenſion of the earth has been treated of.

294 The viſible horizon is moſt accurately obſerved upon the ſea, and is therefore ſometimes called *the horizon of the ſea*; it may be obſerved, by looking through the ſights of a quadrant at the moſt diſtant part of the ſea within view; in making this obſervation, the viſual rays AD and AE, fig. 16, will, by 16
reaſon of the ſpherical ſurface of the ſea, always point a little below the true ſenſible horizon S S, before deſcribed, in § 274, and conſequently below the rational horizon H O, which is parallel to it, and coincident with it, § 275: how much *the depreſſion of the horizon of the ſea* is below the true horizon, is ſeen by the quadrant, which gives the meaſure of the angle DAC. It is obvious, from fig. 15, that the higher the eye is, the greater is the depreſſion of the 15
horizon of the ſea; for the tangents B E and B F point lower, or are more depreſt below the true horizon T T, than the tangents A C and A D.

295 *The depreſſion of the horizon of the ſea is variable* [a], ſo as to be ſometimes a little greater than at other times, though the height of the eye be the ſame, in the ſeveral obſervations; this difference is but ſmall, amounting only to a

[a] *Obſervations aſtronomiques faites par Caſſini en divers endroits du Royaume, pag.* 16.

few

FIG. few ſeconds, and is owing to the difference in the air, which, at different times, refracts the viſual rays more or leſs, according as it is of a greater or leſs den-
16 ſity: in fig. 16, without refraction, the viſual ray is AE, and E is the moſt diſtant point which could be ſeen; but by refraction, the ray FG, coming from the point G may be bent at F, ſo as to go on from thence in the line FA, and then the view is extended as far as G, and the depreſſion of the horizon of the ſea is in the line AF; which points higher than AE, but extends the view farther: a view of the figure is ſufficient to ſhew that if the refraction were greater, the view would be extended ſtill farther, as to M; though the depreſſion of the horizon of the ſea would then be leſs; as is ſhewn by the line ALM: from hence it appears, that our viſible horizon is, by the different refraction of the air, ſometimes extended farther than at other times.

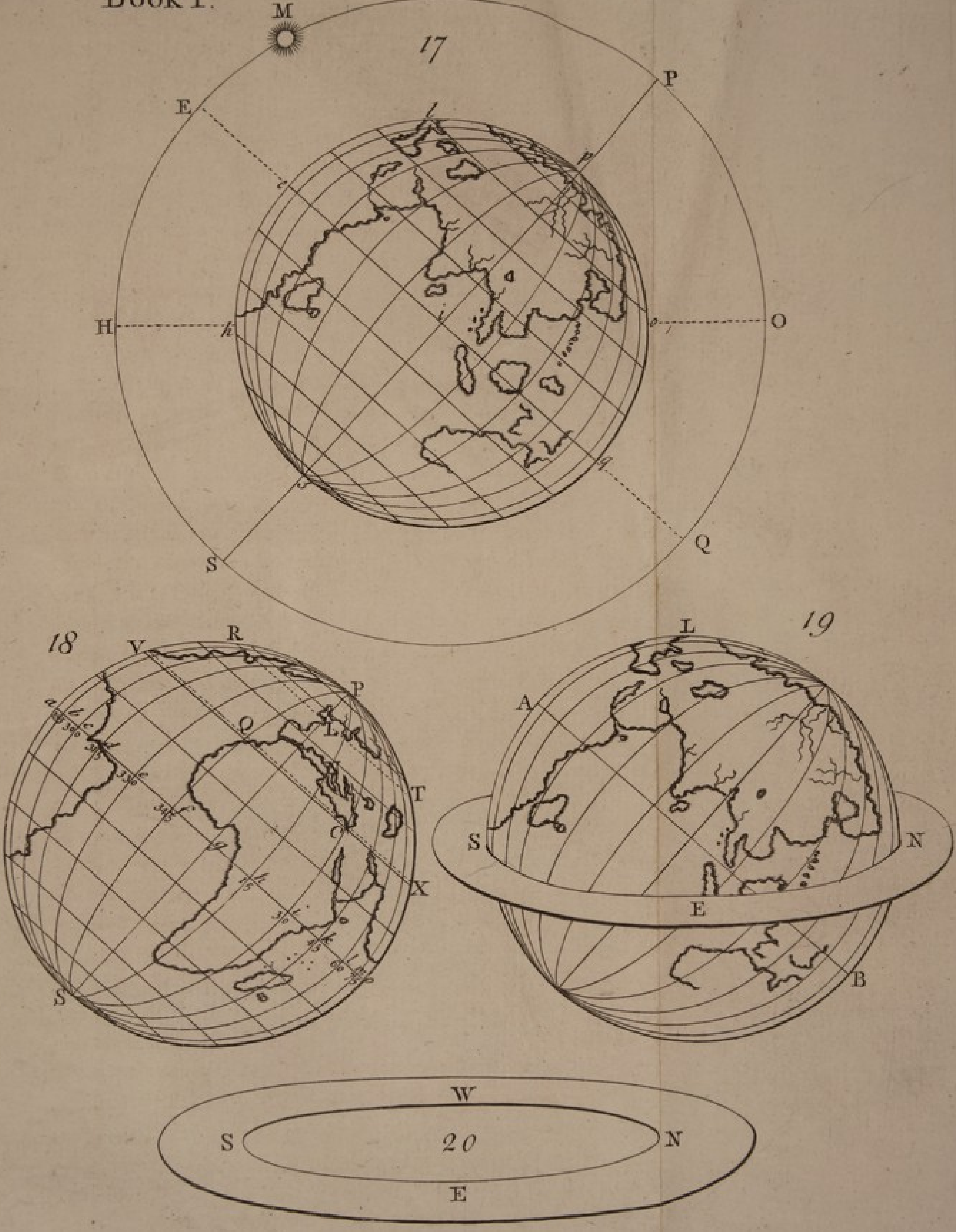
CHAP. 2. THAT THE EARTH TURNS ROUND ITS AXIS.

296 THE ſphere of the fixt ſtars, together with all the heavenly bodies, which by reaſon of their diſtance ſeem to be placed therein, appears to revolve round us in the ſpace of 24 hours; this is a fact, of the truth of which every body may be convinced, with a very little attention; if the ſun's place in the heaven be obſerved any day at noon, he will appear to go round in a circle, and return to the ſame place the next day at noon; the ſame is obſervable with regard to the ſtars, though they are not ſo generally taken notice of: obſerve the place of any ſtar at any hour of the night, look at it ſome hours after, and you will find it has changed its place; continue to obſerve it, and you will find that in 24 hours it deſcribes a circle in the ſphere of the heaven, and returns to its place wherein you firſt obſerved it to be: this apparent motion of the heavenly bodies is called *the firſt*[a], and *the diurnal motion*, and can be accounted for, but one of theſe two ways, either they revolve round in the manner they appear to do, and our earth ſtands ſtill; or they ſtand ſtill, and our earth revolves round, the contrary way to the apparent motion of the heaven: which of theſe opinions is moſt probable, will be conſidered in another place; it is enough at preſent to ſhew, that the ſenſes alone cannot determine the point, becauſe every thing will appear in the ſame manner to them, whether it be the earth or the heaven that moves: ſuppoſe a man were in a boat, in the middle of a large lake of water, the banks whereof were in ſome places covered with trees, and in other places with buildings; if his boat were, unknown to him, without any noiſe or ſhock, turned evenly round one way,

a Either becauſe this motion of the heavenly bodies is moſt obvious, and therefore firſt taken notice of; or becauſe it is ſuppoſed to owe its riſe to the motion of the *primum mobile*.

by

Book I.



J. Mynde sc.

by a diver underneath it, or by ſprings and wheels, the trees and buildings FIG.
would appear to him to move round his boat the contrary way; nor would it be poſſible for him, by his ſenſes alone, to determine whether this apparent motion of the trees and buildings were owing to the real motion of them, or of his boat: in like manner, if the earth, which we conſider as always in the center of the ſphere of the heaven, has a rotation round its axis, ſuch a motion will cauſe to all the inhabitants of the earth an apparent revolution of the ſphere of the heaven, the contrary way, round the axis of the earth produced.

297 The cut which I have choſen for the frontiſpiece to this work is a picture of *my glaſs ſphere*, on the ſurface of which the figures of the conſtellations, ſome of the principal ſtars, and ſuch circles of the ſphere as were neceſſary are engraved with a diamond; ſo that this glaſs repreſents the ſphere of the heaven; within, in the middle of it, is placed a little globe of the earth, ſupported by a ſteel axis, the ends of which go through the ſphere in the places of the celeſtial poles; *a* and *b* are two ſquare ſteel *arbors*, upon either of which a little winch may be put, to turn it round with; if the winch be put upon the arbor *a*, and turned round the ſame way the key of a watch is uſually turned in order to wind it up, it will, by means of ſome wheel-work encloſed in the braſs box *c d*, carry the little globe round within the ſphere, the ſame way we ſuppoſe our earth to revolve; if the winch be put upon the arbor *b*, as it is drawn in the cut, and turned round the contrary way to the former, the glaſs ſphere will go round the globe, the ſame way that the heaven appears to us to move. Thus, by this machine, the real motion of the earth round its axis within the ſphere of the heaven, or the apparent motion of the heaven round the earth, may be repreſented; a view of it is ſufficient to take off the prejudice of ſenſe, and to ſhew that the appearances of the heavenly bodies would be the ſame to us, whether they moved round our earth, as they appear to do, and our earth ſtands ſtill; or they ſtand ſtill, and our earth is carried round the contrary way: I ſhall explain the other parts of this ſphere, as occaſion offers, ſome of the following figures are repreſentations of ſo much of it as is neceſſary for our preſent purpoſe: *the rotation of the earth having been conſidered, ſeveral aſtronomical terms occur, which it is now proper to explain; I ſhall firſt treat of thoſe which more immediately reſpect the earth.*

298 *The axis of the earth* is an imaginary line, paſſing through the center of the earth, round which its revolutions are made: *the poles of the earth* are the two points in the ſurface thereof, which terminate the axis; one of theſe, *p*, fig. 17, is called *the north pole*, the other *s*, *the ſouth pole*: *the equator* is a great 17
circle upon the earth, every part of which is equally diſtant from either of the

poles;

FIG. poles; in fig. 17, *e q* is the equator: by ſailors the equator is frequently called
17 *the line*, and when they ſail over it, they are ſaid to croſs the line.

299 *The meridian* of any place is a great circle upon the earth drawn through the place, and through the poles of the earth: the meridian of any place cuts the horizon at right angles, and marks upon the plane of it the *north* and *ſouth points*, and divides the globe of the earth into two *hemiſpheres*, the
17 *eaſtern* and the *weſtern*: thus, fig, 17, let the point *l* be London, the meridian of London is *e p q s*; the horizon is H O, the north point of the horizon is *o*, the ſouth point of it *h*; all that part of the globe which is ſhewn in the figure, is the eaſtern hemiſphere, in reſpect of London, and all parts of the earth that are in the hemiſphere oppoſite to this, which is not here deſcribed, but may be imagined, or may be ſeen upon a common globe, are in the weſtern hemiſphere.

300 The meridian of any place is by the poles of the earth divided into two ſemicircles; one of which is drawn through the place whoſe meridian it is, the other paſſes through the point in the earth which is oppoſite to that place: by the meridian of any place, writers in geography and aſtronomy, very often mean the ſemicircle which paſſes through the place: this therefore may be called *the geographical meridian:* all places lying under this ſemicircle are ſaid to have the ſame meridian; the ſemicircle oppoſite to this is then
17 called *the oppoſite meridian*, or the oppoſite part of the meridian: thus, fig. 17, *plebs* is the geographical meridian of London, and alſo of all the parts of the earth lying under that ſemicircle; the oppoſite meridian to this is *poqs*.

301 The meridian of any given place is, by the definition thereof in the two laſt ſections, immoveably fixt to that place, ſuppoſing the place to keep its ſituation upon the earth, and the poles of the earth to keep their places alſo; the meridian therefore of any place muſt be carried round along with it, by the rotation of the earth.

302 When the geographical meridian of any place is by the rotation of the earth brought to point at the ſun, it is *noon* or *midday* in that place: thus,
17 in fig. 17, if we ſuppoſe the ſun to be at M, the geographical meridian of London *plebs* points at the ſun, ſo that if the plane of that ſemicircle were extended to the ſun it would paſs through his center; in ſuch a ſituation of the earth as this, it is noon at London, and at all places which lye under the ſemicircle *plebs*.

303 The plane of the meridian of any place may be imagined to be extended to the ſphere of the fixt ſtars: when by the rotation of the earth the plane of the meridian comes to any point in the heaven, as the ſun, moon, or a ſtar, *&c*; that point appears to come to the meridian: according to this explanation

tion, I would always be underſtood, when I uſe the common expreſſions, as FIG.
I often ſhall do, and ſay the ſun, a ſtar, &c comes to, or paſſes through the meridian.

304 *The rotation of the earth is from weſt to eaſt:* eaſt and weſt are relative terms; ſo that a place may lye eaſt with regard to one place, and weſt with regard to another: thus, let fig. 18 repreſent the globe of the earth, with 24 18
geographical meridians drawn upon it, at equal diſtances from one another; let P L *g* S, be the meridian of London, paſſing through London at L; let N be Naples, P N *b* S is then the meridian of Naples; let Q be Canaria, P Q *f* S is the meridian of Canaria: it is evident, from a view of the figure and from § 299, that the meridian of London, is weſt from the meridian of Naples, and eaſt from the meridian of Canaria.

If we were to go round the earth upon the equator *a o* eaſtward, we ſhould go according to the order of the letters *a b c d* &c from *a* to *b*, from *b* to *c*, 18
from *c* to *d*, &c: the rotation of the earth being eaſtward is therefore according to the order of the letters *a b c d e f* &c; and is the cauſe that *the heaven and heavenly bodies appear to move* the contrary way *from eaſt to weſt*.

The true *eaſt* and *weſt* points in any place are thoſe where the horizon of that place is interſected by the equator: thus, fig. 19, let L be London, A B 19
the equator, S E N part of the plane of the horizon of London; E is the eaſt point for London; and the point oppoſite to this in the horizon, which cannot be ſeen in this figure, but may eaſily be imagined, is the weſt point: in fig. 20, I have given an oblique view of the horizon of London, ſimilar to that in 20
the preceding figure, only in this the picture of the globe of the earth is omitted, that the horizon may be ſeen entire, with *the four cardinal points*, as they are called, eaſt, weſt, north, and ſouth; which are here marked with their initial letters, E, W, N, S: in a looſer and more general way of ſpeaking, we may call that half of the horizon, S E N, in the middle of which the eaſt point (E) is, *the eaſt ſide of the horizon*; becauſe the ſun, moon, ſtars &c, appear to riſe on this ſide[a]: in the ſame way of ſpeaking, we may call the other half of the horizon, S W N, which has the weſt point (W) in the middle of it, *the weſt ſide of the horizon*; becauſe below this the heavenly bodies appear to ſet[b].

305 The time which paſſes between the noon of any one day, in a given place, and the noon of the day following, in the ſame place, is called *a natural day:* thus, if when the earth is in the ſituation deſcribed, § 302, it is noon at 17
London; the time that the earth takes up in turning once round its axis, ſo as to return into the ſame ſituation, and make it noon again at London, is a natural

a, b, The eaſt is, in our own and ſeveral other languages, expreſſed by a word which ſignifies *riſing*; and the weſt by a word which denotes *ſetting*: ſee the words eaſt and weſt, in the index.

FIG. tural day[a]: the natural day comprehends the day and night, and is divided into 24 *hours*, every hour into 60 *minutes*, every minute into 60 *ſeconds*, every ſecond into 60 *thirds*, *&c:* minutes and ſeconds of time are expreſt by the ſame characters as minutes and ſeconds of a degree are: 9 hours 56 minutes 44 ſeconds are thus ſet down, $9^{h}.\ 56'.\ 44''$:

306 Noon is the beginning of the natural day, and therefore all places which lye under the ſame meridian, and have noon at the ſame time, have alſo every other hour of the natural day at the ſame time: thus, when it is one in the afternoon at London, is is alſo one in the afternoon at every place under the meridian of London; when it is two at London, it is two every where under the ſame meridian; when it is three at London, it is three there; *&c.*

CHAP. 3. THE LONGITUDE OF PLACES: THE FIRST MERIDIAN.

307 All places under the ſame meridian are ſaid to have the ſame *longitude:* all places that lye under different meridians are ſaid to have different longitude: this difference of longitude may be eaſtward or weſtward: *the difference of longitude between any two places* is the diſtance of their meridians, meaſured in degrees, minutes, and ſeconds, upon the equator: thus, if the meridian of any place cuts the equator in a point which is diſtant 15° eaſt from the point where the meridian of London cuts the equator, we ſay that place differs from London in longitude 15° eaſtward: if the meridian of any place cuts the equator in a point which is 30° diſtant weſtward from the point where the meridian of London cuts the equator, that place differs from London in longitude 30° weſtward, *&c:* thus Naples marked with N, fig. 18, differs in longitude
18 from London 15° eaſtward; and Canaria, marked with Q, differs from London 15° weſtward; Grand Cairo in Egypt marked with the letter C, differs 30° from London eaſtward.

308 It is uſual for geographers to pitch upon the meridian of ſome remarkable place for *the firſt meridian*: and to reckon the difference of longitude of any other place, by the diſtance of its meridian from the firſt meridian, meaſured upon the equator eaſtward. The ancient Greek geographers[b] placed the firſt or great meridian in Hera or Junonia, one of the Fortunate iſlands, as they were then called; this is ſuppoſed to be the iſland Teneriff, one of the Canaries, and was the moſt weſtern part of the earth then diſcovered: the Arabian geographers,

a If we would expreſs it according to the apparent motion, we may ſay, the natural day in London is the time which paſſes between the ſuns leaving the meridian of London and returning to it again.

b *Ptolem. Geogr.* l. 1. *ex Marino*; v. *Gregorii poſthuma*, p. 266. a treatiſe about the uſe of the globes; *Chriſtmanni Comment. in Alfragan. Aſtron.* cap. 11. *præcipue vero Ricciol. Geographiæ reformat.* l. 9. cap. 2,

ambitious

ambitious of having the beginning of the longitude taken from them, choſe to FIG.
fix the great meridian upon the utmoſt ſhore of the weſtern ocean: ſome later geographers made it to paſs through the iſland Corvo, one of the Açores[a], becauſe on that iſland the magnetic needle, at that time, pointed directly north, without any variation; and it was not then known that the variation of the needle is it ſelf ſubject to variation, as has ſince been diſcovered: *Bleau* in his mapps and globe replaced the firſt meridian in Teneriff; and to aſcertain the place of it more exactly, made it to paſs through the middle of a mountain in that iſland famous for its great height, and called, from the ſmallneſs of its top, *el pico*[b]: it is now grown a cuſtom amongſt geographers, for every one to make the firſt meridian paſs through the principal city of that country to which he belongs; thus the Engliſh, in their mapps and globes, make the firſt meridian to paſs through London; the Dutch theirs through Amſterdam; the French theirs through Paris; and particularly through the royal obſervatory there. I ſhall all along take the meridian of London for the firſt meridian, as Mr *Senex* has done in his globes, the moſt correct, I believe, that have yet been publiſhed.

309 *The longitude of any place* is the number of degrees, minutes and ſeconds, upon the equator, which can be reckoned eaſtward from the firſt meridian to the meridian of that place: thus, fig. 18, if we take the meridian of 18
London P L *g* S for the firſt, and draw meridians through every 15° of the equator, beginning at that point of it *a*, through which the meridian of London paſſes, and go round eaſtward; we ſhall have the globe divided as it appears in the figure before us, which is a picture of half of it, as much as can be ſeen at one view: then I ſay, all places under the meridian P L *g* S are in the ſame longitude as London is; all places under the meridian marked P 15 S are in 15° of longitude; all places under the meridian P 30 S are in 30° of longitude; all places under the meridian P 45 S are in 45° of longitude; &c ſo that the numeral figure placed upon the equator at the point where each meridian cuts the equator, ſhews the longitude of any place which lyes under that meridian: thus fig. 18, N Naples is in 15° of longitude, C Cairo is in 30° of longitude, Q Canaria is in 345° of longitude[c].

310 If we imagin 12 great circles, one of which is the meridian of a given place, to interſect each other at the poles of the earth, and divide the equator into 24 equal parts, theſe are *the hour-circles* of that place: theſe circles are by

a So called from the Goſhawks there: *açor* in ſpaniſh is a Goſhawk. b *El pico* ſignifies a birds beak.

c Theſe places, Naples, Cairo, and Canaria, which laſt is a ſmall iſland that took its name from the large dogs bred there, *Canariam vocari a multitudine canum ingentis magnitudinis ſcribit Plin. l. 6. c. 32*, and gave the name to the reſt of the Canary iſlands, are all of them ſome few minutes and ſeconds different in longitude from what is here ſet down, as appears by the table of the longitude and latitude of places; I have however, to make the examples the eaſier, ſuppoſed the meridians drawn upon the 20 figure 15° or one hour diſtant from one another, to paſs through theſe places, though ſpeaking exactly they do not, but only very near them.

the

FIG. the poles divided into 24 ſemicircles; an arc of the equator contained between any two of theſe *hour-ſemicircles* which are neareſt to one another, is 15°, for 15° is a 24th part of 360°; by the rotation of the earth, the plane of every hour-ſemicircle points at the ſun, an hour after the ſemicircle which is next it towards the eaſt has pointed at the ſun; and thus they ſucceſſively point at the ſun every hour, ſo that the planes of all the 24 hour-ſemicircles extended, paſs
18 through the ſun in a natural day: fig 18 is a picture of the globe of the earth, upon which the hour-ſemicircles of London are drawn, as many as can be ſeen at one view of the earth; let P*g*S be the meridian of London, imagin the ſun to be in the place where your eye is when you look directly at the figure, the meridian of London then points at the ſun, ſo that it is noon at London; imagin the earth to revolve round, according to the order of the letters, *abcdef*, and you will eaſily ſee, that in one hours time, the next meridian P*f*S will point at the ſun, and then it will be one in the afternoon at London; in another hour, the meridian P*e*S will point at the ſun, and then it will be two in the afternoon at London; &c, ſo that at the end of 24 hours, the earth will return into the ſame ſituation, and the meridian P*g*S will point at the ſun again; and make it noon at London for the next day.

18 311 From a view of the figure thus explained, we may obſerve, that a meridian P*g*S, 15° eaſt from London, comes to point at the ſun, one hour ſooner than the meridian of London does; a meridian P*h*S, 30° eaſt from the meridian of London, comes 2 hours to the ſun, before the meridian of London does, &c; a meridian P*e*S, 15° weſt from London, points at the ſun, one hour later than the meridian of London does: and ſo agreeably to this proportion of 15° for an hour, the meridian of any place comes to point at the ſun, a longer or ſhorter time, ſooner or later than the meridian of London does, according as that meridian is more or leſs diſtant from London, eaſtward or weſtward: for this reaſon, the difference of longitude between any two places is ſometimes expreſt in time, *viz.* hours, minutes, and ſeconds; inſtead of degrees, minutes, and ſeconds: thus, ſuppoſing the meridian of London the firſt meridian, *the longitude of any place in time* is the number of hours, minutes, and ſeconds, by which the meridian of that place comes to the ſun, ſooner or later than the meridian of London does: thus, the meridian of Naples is diſtant from the meridian of London one hour, the meridian of Cairo two hours, eaſtward; the meridian of Canaria is diſtant from the meridian of London one hour, weſtward.

312 From the two preceding ſections it appears, that they whoſe meridian is 15° eaſt from London have noon, and conſequently every other hour of the natural day, an hour ſooner than they have it at London; they whoſe meridian is 15° weſt from London have noon and every other hour of the natural

ral day an hour later than at London: the converſe of this is true, that they who have noon and every hour of the natural day an hour ſooner than they have at London, have their meridian 15° eaſt from the meridian of London; as alſo that every place which has noon and every other hour of the day an hour later than London, differs from London in longitude 15° towards the weſt, and ſo on in the ſame proportion, ſo that one hour difference in time is 15° difference in longitude.

313 From hence it follows, that *by any inſtantaneous appearance in the heaven*, ſeen at two places which lye under different meridians, *the* difference of their *longitude may be found*, if the hour of the day be known at each place: thus, the beginning of a lunar eclipſe, when the moon firſt touches the ſhadow of the earth, is an inſtantaneous appearance, as is alſo the end of a lunar eclipſe, when the moon leaves the ſhadow of the earth; theſe appearances are viſible to all the inhabitants of that half of the globe of the earth which at that time is turned towards the moon; ſuppoſe, that when a lunar eclipſe begins, I find it is exactly 12 at night at London, and an obſerver from Naples writes me word, that in that place it was one in the morning, when the ſame eclipſe began; I may from thence conclude, that the meridian of Naples is 15° diſtant from the meridian of London, eaſtward; if another perſon ſends me word, that he obſerved the ſame eclipſe at Canaria, and that there the beginning of it was at 11 at night, I may be aſſured Canaria differs in longitude from London 15° weſtward.

314 I have in the preceding examples, to make them the more eaſy, ſuppoſed a whole hour difference in time, which anſwers to 15°; but ſince one minute of time anſwers to 15′ of a degree, and one ſecond in time anſwers to 15″ of a degree, &c; the difference in longitude between any two places may be found in minutes or ſeconds of a degree: thus, if at the beginning of an eclipſe of the moon, it is 12 at night at London, and at the ſame moment, it is $1^h. 55'. 55''$. in the morning at Conſtantinople, then the meridian of Conſtantinople is 28°. 58′. 45″. eaſt from the meridian of London.

315 There is alſo another conſequence which follows from § 312, proper to be mentioned in this place, which is this; *if a man goes round the earth eaſtward, he will reckon one day more* to have paſſed during the time of his voiage, than they do who live at the place from whence he ſet out; and be one day forwarder in the week than they are, at his return thither; ſo that he will count their monday to be tueſday; their tueſday to be wedneſday: &c. On the other hand, *if a man goes round the earth weſtward, he will* at his return *count one day leſs* to have paſſed, than they do who have continued all the while at the place from whence he began his voiage; and be one day in the week later than

they:

FIG. they; ſo that it will be tueſday with him, when it is wedneſday with them; and monday with him, when it is tueſday with them; &c. the reaſon of this will
18 eaſily be ſeen, if we conſider the 18th figure as a picture of the globe of the earth, in the following manner; ſuppoſe a man begins his tour from L London eaſtward, on a tueſday, when he is got to the meridian of Naples P*b*S, 15° from the meridian of London, it will be noon with him one hour ſooner than with thoſe who live at London; when he is got to the meridian of Cairo, P*i*S, 30° eaſt from the meridian of London, he will have noon two hours ſooner than they at London; and ſo on in this proportion, every meridian he arrives at 15° further eaſt from London, it will be noon, that is, the beginning of the natural day with him, one hour more, ſooner than at London: ſo that when he has gone quite round, and is returned to London again, he will have gone 360° eaſt from the meridian of London, and it will be noon with him, 24 hours, or a whole day, ſooner than to thoſe who ſtaid at London: that is, it will be tueſday noon with him, when it is but monday noon with them, &c. On the other hand, if a man ſets out from London weſtward, when he comes to the meridian of Canaria P*f*S, 15° weſt from the meridian of London, his noon will be an hour later than at London; when he comes to a meridian P*e*S 30° weſt from the meridian of London, it will be noon with him two hours later than at London; ſo that when he is got quite round to the meridian of London again, he will have gone through the 24 meridians deſcribed § 310, and therefore his noon will be 24 hours, or a whole natural day, later than at London; ſo that it will be monday noon in his account, when they who ſtaid all the while at London reckon it tueſday noon, &c: in this affair, it is not neceſſary that a man ſhould go round the globe upon the equator, or any of its parallels; it is ſufficient if he paſſes through the ſeveral meridians, as all navigators muſt do who go round the globe eaſtward or weſtward. And thus much may ſuffice at preſent, to give a general view of the nature of the longitude of places; the more particular conſideration of it is reſerved to another part of this work.

316 The two following tables are taken out of one of the almanacks publiſhed yearly by the order of the royal academy of ſciences at Paris, under the title of *conoiſſance des temps*; one uſe of theſe tables is, when the difference of longitude of places is expreſt in time, as hours, minutes, ſeconds, &c, to reduce it to meaſure, in parts of the equator, as degrees, minutes, ſeconds: or converſely, when it is expreſt in meaſure, to reduce it to time.

a *Conoiſſance des temps pour l'annee* 1727. *au meridien de Paris, publiee par l'ordre de l'Academie Roiale des* Sciences, & *calculee par* M. Lieutaud *de la meme Academie.*

THE FIRST TABLE

By which the longitude expreſt in hours, minutes, and ſeconds, &c, may be reduced to degrees, minutes, and ſeconds, &c.

Hours	Degrees	Min. / Sec. / Thirds	Deg. Min. / Min. Sec. / Sec. Th.	Min. / Sec. / Thirds	Deg. Min. / Min. Sec. / Sec. Thirds.
1	15	1	0 15	31	7 45
2	30	2	0 30	32	8 0
3	45	3	0 45	33	8 15
4	60	4	1 0	34	8 30
5	75	5	1 15	35	8 45
6	90	6	1 30	36	9 0
7	105	7	1 45	37	9 15
8	120	8	2 0	38	9 30
9	135	9	2 15	39	9 45
10	150	10	2 30	40	10 0
11	165	11	2 45	41	10 15
12	180	12	3 0	42	10 30
13	195	13	3 15	43	10 45
14	210	14	3 30	44	11 0
15	225	15	3 45	45	11 15
16	240	16	4 0	46	11 30
17	255	17	4 15	47	11 45
18	270	18	4 30	48	12 0
19	285	19	4 45	49	12 15
20	300	20	5 0	50	12 30
21	315	21	5 15	51	12 45
22	330	22	5 30	52	13 0
23	345	23	5 45	53	13 15
24	360	24	6 0	54	13 30
		25	6 15	55	13 45
		26	6 30	56	14 0
		27	6 45	57	14 15
		28	7 0	58	14 30
		29	7 15	59	14 45
		30	7 30	60	15 0

THE SECOND TABLE

By which the longitude expreſt in degrees, minutes, and ſeconds, &c, may be reduced to hours, minutes, and ſeconds.

Deg.	H.	M.	Deg.	H.	M.	Degrees.	Hours.	
Min.	M.	S.	Min.	M.	S.			
Sec.	S.	T.	Sec.	S.	T.			
1	0	4	31	2	4	70	4	40
2	0	8	32	2	8	80	5	20
3	0	12	33	2	12	90	6	0
4	0	16	34	2	16	100	6	40
5	0	20	35	2	20	110	7	20
6	0	24	36	2	24	120	8	0
7	0	28	37	2	28	130	8	40
8	0	32	38	2	32	140	9	20
9	0	36	39	2	36	150	10	0
10	0	40	40	2	40	160	10	40
11	0	44	41	2	44	170	11	20
12	0	48	42	2	48	180	12	0
13	0	52	43	2	52	190	12	40
14	0	56	44	2	56	200	13	20
15	1	0	45	3	0	210	14	0
16	1	4	46	3	4	220	14	40
17	1	8	47	3	8	230	15	20
18	1	12	48	3	12	240	16	0
19	1	16	49	3	16	250	16	40
20	1	20	50	3	20	260	17	20
21	1	24	51	3	24	270	18	0
22	1	28	52	3	28	280	18	40
23	1	32	53	3	32	290	19	20
24	1	36	54	3	36	300	20	0
25	1	40	55	3	40	310	20	40
26	1	44	56	3	44	320	21	20
27	1	48	57	3	48	330	22	0
28	1	52	58	3	52	340	22	40
29	1	56	59	3	56	350	23	20
30	2	0	60	4	0	360	24	0

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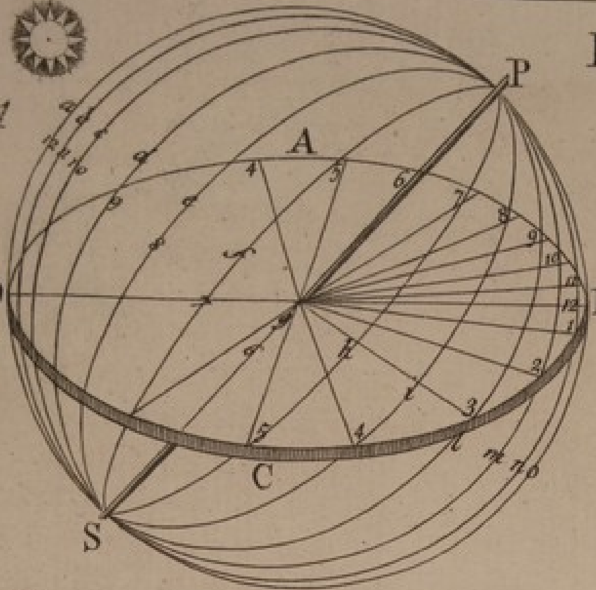

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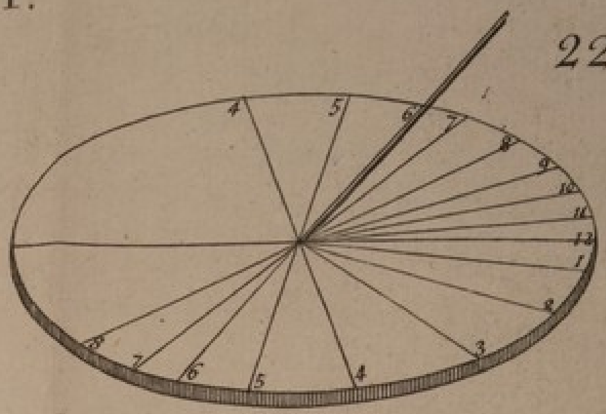

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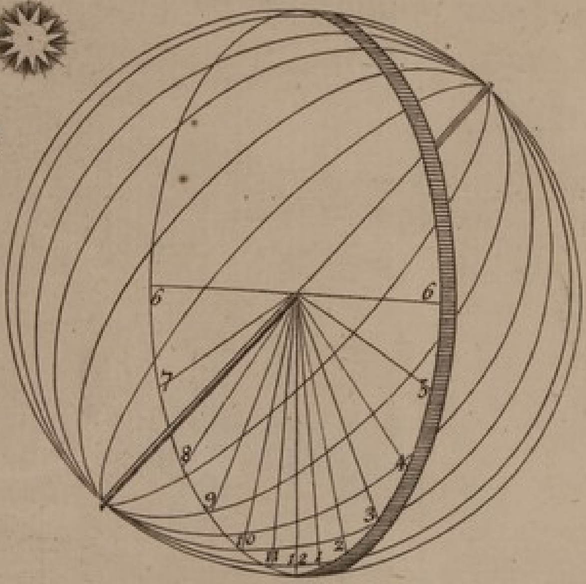

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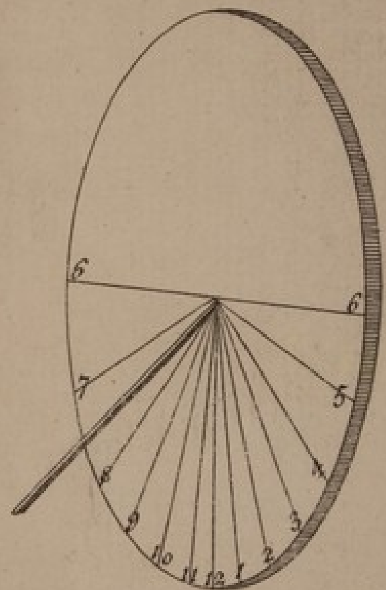

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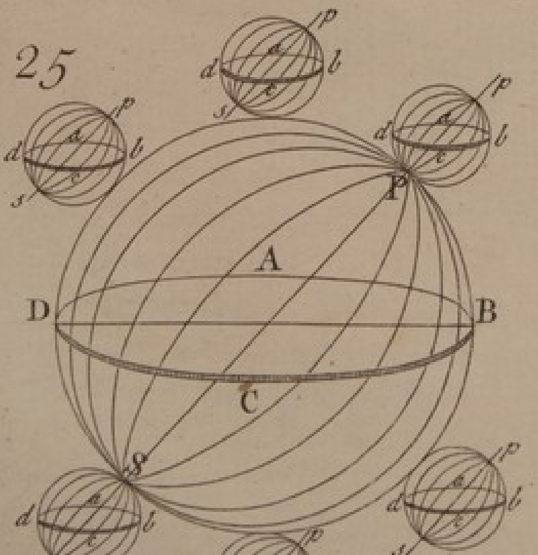

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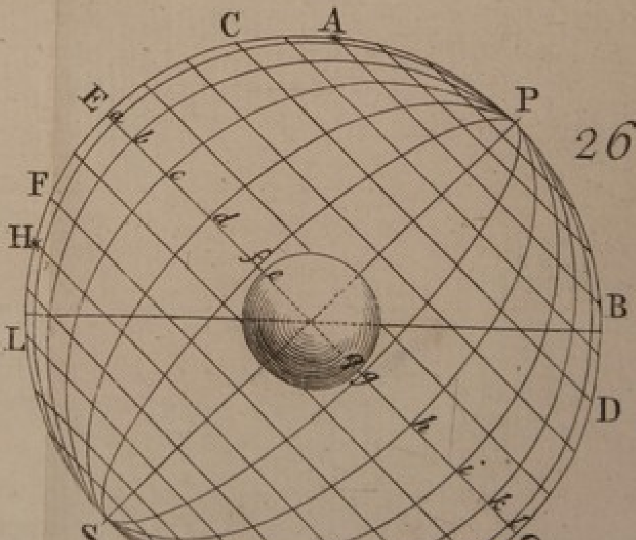

J. Mynde sc.

317 *The first table explained*; the first column contains whole hours, from 1 to 24; the second column has the number of degrees which answer to each number of hours: thus, to 4 hours the corresponding number of degrees is 60; to 9 hours 135° are equivalent: in the third column are minutes, or seconds, or thirds of an hour, from 1 to 30; and in the fourth column are the corresponding degrees, minutes, seconds, or thirds of a degree: here it is to be observed, that if a number in the third column be understood to signify minutes of an hour, the numbers on the same line in the fourth column signify degrees, and minutes; if a number in the third column signifies so many seconds of time, the corresponding numbers in the fourth line signify minutes, and seconds of a degree; if the number in the third column signifies thirds of time, the numbers of the fourth column which answer to it are so many seconds, and thirds, of a degree: the fifth column is a continuation of the third, from 31 to 60; and the sixth column is a continuation of the fourth.

Example; the difference in longitude between the meridian of the Royal Observatory at Paris and that of Pekin in China is $7^h\ 37^m\ 6^s$; if it be enquired what this difference is in parts of the equator, the answer is 114° 16′ 30″; which is thus found by the table; to 7^h in the first column, 105° answer in the second; to 37^m in the fifth column, the corresponding numbers in the sixth are 9° 15′; if 6 seconds be found in the third column, the equivalent parts of the equator in the fourth column are 1′ 30″, add these together,

	105°	0′	0″
	9	15	0
		1	30
the sum is	114	16	30.

318 *The second table explained*; the first column contains degrees, minutes, and seconds of the equator, from 1 to 30; the numbers in the second column express the time corresponding to each number in the first column, in hours, minutes, seconds, and thirds: here it must be observed, that if the number in the first column be understood to mean so many degrees, the numbers in the second column on the same line are hours, and minutes; if the number in the first column be minutes of a degree, the numbers in the second are minutes of an hour, and seconds; if the number in the first column expresses seconds in measure, the corresponding numbers in the second column are seconds, and thirds in time: thus, 1° is equivalent to $0^h.\ 4^m$; one minute of a degree to 4″ in time; one second in measure to four thirds in time: thus also, 15° answer to 1^h; 15′ of a degree answer to 15″ of an hour; 15″ in measure to 15 thirds in time: the third and fifth columns are continuations of the first; and the fourth and sixth are continuations of the second.

 Example;

FIG. *Example*; the meridian of Siam is diſtant $98^\circ\ 30'$ eaſt, from the meridian of
the R. Obſervatory at Paris: if it be enquired how much this difference is in time,
the anſwer will be $6^h\ 34^m$; for to 90° in the fifth column, 6^h anſwer in the
ſixth; to 8° in the firſt column, $0^h.\ 32^m$ are ſet down as equivalent, in the
ſecond column; and to $30'$ in the firſt column, 2^m correſpond in the ſecond:
add together 6^h and 32^m and 2^m, the ſum is $6^h.\ 34^m$,

CHAP. 4. THE GENERAL GROUNDS OF DIALLING.

319 If we imagin the hour-circles of any place, as London, to be drawn
upon the globe of the earth, and ſuppoſe this globe to be tranſparent, and to
revolve round a real axis, which is opake, and caſts a ſhadow; whenever the
plane of any hour-ſemicircle points at the ſun, the ſhadow of the axis will fall
21 upon the oppoſite ſemicircle: thus, fig. 21, if the ſemicircle *pas* points at the
ſun, the ſhadow of the axis *ps* will fall upon the ſemicircle *pos*.

320 If we imagin any plane to paſs through the center of this tranſparent
globe, the ſhadow of half the axis will always fall upon one ſide or other of
21 this interſecting plane: thus, fig. 21, let ABCD be the plane of the horizon
of London; ſo long as the ſun is above the horizon, the ſhadow of the upper
half of the axis *pg* will fall ſomewhere upon the upper ſide of the plane ABCD:
when the ſun is below the horizon of London, then the ſhadow of the lower
half of the axis *gs* falls upon the lower ſide of the plane ABCD.

321 When the plane of any hour-ſemicircle points at the ſun, the ſhadow
of the axis marks the reſpective hour-line upon the interſecting plane; *the
hour-line* therefore is a line drawn from the center of the interſecting plane to
the point where the interſecting plane is cut by the ſemicircle oppoſite to the
21 hour-ſemicircle: thus, fig. 21, let ABCD the horizon of London be the inter-
ſecting plane; when the meridian of London P*as* points at the ſun, as in the
figure before us, the ſhadow of the half axis P*g* falls upon the line *g*B, which
is drawn from *g* the center of the horizon, to B, the point where the hori-
zon is cut by the oppoſite ſemicircle PBS: therefore *g*B is the line for the
hour of 12 at noon.

322 By the ſame method the reſt of the hour-lines are found, by drawing
for every hour a line from the center of the interſecting plane, to that ſemi-
21 circle which is oppoſite to the hour-ſemicircle: the 21 figure ſhews the hour-
lines drawn upon the plane of the horizon of London, ſo many as are neceſ-
ſary, which are only for thoſe hours during which the ſun is above the hori-
zon of London, the longeſt day in ſummer: the hour-lines being thus found
by the interſecting points of the hour-ſemicircles, let the ſemicircles be taken
away,

away, as the ſcaffolding is when the houſe is built, and what remains, as in fig. 22, will be *an horizontal dial* for London. FIG. 22

323 If inſtead of 12 hour-circles as above deſcribed we take twice that number, we may, by the points where the interſecting plane is cut by them, find the lines for every half hour; if we take four times the number of hour-circles, we may find the lines for every quarter of an hour, *&c.*

324 I have here taken the horizon for the interſecting plane, by which the method is ſeen of making an horizontal dial; if we take any other plane for the interſecting plane, and find the points where the hour-ſemicircles paſs through it, and draw lines from the center of the plane to thoſe points, we ſhall have the hour-lines for that plane: the 23d figure ſhews how the hour-lines are 23
found upon a ſouth plane perpendicular to the horizon; and the 24th figure 24
ſhews *a ſouth dial* with its hour-lines, without the ſemicircles by means whereof they are found. *The gnomon of every ſundial repreſents the axis of the earth*, and is therefore always placed parallel to it, whether it be a wire, as in the figures before us, or the edge of a plate, as in the common braſs horizontal dials.

325 If a little tranſparent globe with hour-ſemicircles and an axis be ſo placed upon the ſurface of the earth, that the axis is parallel to the axis of the earth, all things mentioned in the preceding ſections will be the ſame in this globe as in the globe of the earth itſelf, ſuppoſed tranſparent; or as they would be in this little globe placed in the center of the earth: becauſe, by § 274, the earth may be conſidered as a point, and conſequently in every ſuch little globe, the plane *a b c d* being parallel to the plane A B C D, fig. 25, may 25
be looked upon as coincident with it, and the axis *p s* being in every ſuch globe parallel to P S, may be conſidered as coincident with it: for this reaſon, a dial placed upon the ſurface of the earth ſhews the hour as truly, as if it were placed at the center of the earth: in fig. 25, let the large dial in the 25
middle repreſent a dial made upon the plane of the rational horizon, let the little dials round this be pictures of dials made upon horizontal planes, placed upon the ſurface of the earth; the ſun, by reaſon of his immenſe diſtance, ſhines in the ſame manner upon all theſe, all his rays which fall upon theſe ſeveral dials are phyſically parallel, have the ſame effect as if they were exactly parallel; and therefore, ſince by the rotation of the earth the plane *abcd* of every one of theſe little dials is carried parallel to the plane of the horizon A B C D, they will ſhew the hours in the ſame manner as the large dial does.

And thus much is enough to ſhew the general grounds and principles of dialling, which conſiſt in finding where the ſhadow of a ſtrait wire parallel to the axis of the earth will fall upon a given plane, every hour, every half hour, *&c:* the hour-lines are found by the hour-ſemicircles as deſcribed above:

 there

FIG. there are ſeveral ways of finding the interſecting points of the hour-ſemicircles, for all ſorts of planes, either by calculation, or by mechanical operations, but theſe are to be learned from thoſe writers who profeſſedly treat of dialling.

CHAP. 5. THE LATITUDE OF PLACES: THE ELEVATION OF THE POLE: THE COMPLEMENT OF LATITUDE, OR HEIGHT OF THE EQUATOR.

326 *The equator* divides the globe of the earth into two *parts*, the *northern* and *ſouthern*: all places upon the earth lying under the equator, are ſaid to have no latitude: all other places upon the earth are ſaid to be in *north* or *ſouth latitude*, according as they are ſituated on the north or ſouth ſide of the equator, towards the north or ſouth pole.

327 *The latitude of any place* is its diſtance from the equator, meaſured in
17 degrees, minutes, and ſeconds, upon the meridian of that place: thus, fig. 17, let *l* be London, *p* the north pole, *eq* the equator, *ples* is the meridian of London, the latitude of London is the arc *el*, this arc is $51^\circ\ 31'$; London is then in $51^\circ\ 31'$ of north latitude.

328 *The complement of latitude* in any place is the number of degrees, minutes, and ſeconds which, added to the latitude, make up 90°: thus, the complement of the latitude of London is $39^\circ\ 29'$; for $39^\circ\ 29'$ added to $51^\circ\ 31'$ make 90°. *The complement of latitude ſhews the height of the equator*, or the angle the
17 plane of it makes with the plane of the horizon: thus, fig. 17, let *l* be London, the latitude of London is the arc *el*; the complement of latitude is the arc *eh*, which meaſures the height of the equator, or the angle *eih* contained between the planes of the equator *eq* and the horizon of London *ho*.

329 *The elevation of the pole* in any place is the leaſt diſtance of that pole from the horizon, meaſured in degrees, minutes, and ſeconds, upon the meri-
17 dian[a] of the place: thus, fig. 17, let *l* be London, *p* the north pole, *ho* the horizon of London; the elevation of the north pole above the horizon of London is the arc *po*.

330 *The elevation of the pole in any place is equal to the latitude* of that
17 place: thus, fig. 17, the arc *elp* is 90°, by § 298, and the arc *lpo* is 90°, by § 274; take from each of theſe the arc *lp*, and the remaining arcs *le* and *po* will be equal, by § 35, *axiom*. 3.

331 Here follows *a table of the longitudes and latitudes* of ſome remarkable places; the ſecond column ſhews the difference of their meridians from the meridian of London, in hours, minutes, and ſeconds; (E) ſhews the place to lye eaſt, and (W,) weſt from London: the laſt column contains the latitude or elevation of the pole: all the places here ſet down, except the Cape of good hope, are in north latitude.

a The meridian is here taken for the whole circle, as defined § 299.

	Difference from the meridian of London							Lat. or height of the pole.		
	H.	M.	S.		D.	M.	S.	D.	M.	S.
*Alexandria in Egypt	2	1	27	E	30	21	45	31	11	20
Aracta	2	59	41	E	44	55	15	36	0	0
*Bologna	0	46	46	E	11	42	15	44	30	0*
Cairo	2	6	6	E	31	31	30	30	2	30*
Cambridge	0	16	11	E	4	2	45	52	17	0
*Cape of G. hope	1	20	39	E	20	9	45	34	15	0*
*Cayenne	3	32	19	W	53	4	45	4	56	0*
Dantzic	1	14	25	E	18	36	15	54	22	0†
Dublin	0	26	0	W	6	30	0	53	12	0
Edinburgh	0	12	0	W	3	0	0	55	57	0
*Florence	0	45	39	E	11	24	45	43	46	30*
*Goa	4	55	21	E	73	50	15	15	31	0
Jerufalem	2	21	41	E	35	25	15	31	50	0
Ifpahan	3	31	41	E	52	55	15	32	25	0
Lifbon	0	33	19	W	8	19	45	38	45	0*
London	0	0	0		0	0	0	51	31	0*
†Madrid	0	12	19	W	3	4	45	40	26	0†
*Marfeilles	0	22	9	E	5	32	15	43	19	30*
Mexico	6	54	19	W	103	34	45	20	0	0†
Mofcow	2	41	41	E	40	25	15	55	36	0
Naples	0	59	1	E	14	45	15	40	48	0
†Nuremberg	0	44	37	E	11	9	15	49	26	0†
Oxford	0	5	0	W	1	15	0	51	43	0
*Paris R. obferv.	0	9	41	E	2	25	15	48	50	10*
*Pekin	7	46	47	E	116	41	45	39	54	0*
Peterfburg	2	7	41	E	31	55	15	60	0	0
Pic of the Açores	1	52	19	W	28	4	45	38	35	0
Pic of Teneriff	1	2	19	W	18	0	0	28	30	0
*Rome	0	51	1	E	12	45	15	41	54	0*
*Siam	6	43	41	E	100	55	15	14	18	0*
Stockholm	1	18	1	E	19	30	15	59	20	0†
Venice	0	51	1	E	12	45	15	45	25	0
Vienna	1	7	51	E	14	57	45	48	14	0*
Uraniburg	0	51	51	E	12	57	45	55	34	5
York	0	4	0	W	1	0	0	54	0	0

Tables of the longitude and latitude of places are to be found in many books of geography; *Ricciolus* has a very large one, in his *geographia reformata*; l. 9. c. 4. *Souciet* has another, at the end of his *obſervations mathematiques, aſtronomiques*, &c, *tirees des anciens livres Chinois, ou faites nouvellement aux Indes et a la Chine, par les peres de la C. de J. Lieutaud* gives us one of four pages, in the *conoiſſance des temps*: him I have chiefly followed in the foregoing ſpecimen; in which thoſe longitudes or latitudes that are marked with a ſtar, are ſuch as have been verified by the aſtronomical obſervations of ſome of the members of the Royal Academy of ſciences at Paris; thoſe marked with a croſs, are from the obſervations of other aſtronomers.

332 *A table of the longitude of places for one meridian being given, we may make a table for any other meridian*, if the difference between thoſe meridians be alſo given: thus, in *Lieutaud*'s table, the longitudes are from the R. Obſervatory at Paris; thoſe in my ſpecimen were from thence computed for the meridian of London, by the following method. I find in *Lieutaud*'s table, that the meridian of London is diſtant from the meridian of the Royal Obſervatory at Paris, $0^h\ 9^m\ 41^s$ in time, or $2°\ 25'\ 15''$ in meaſure, weſtward: every place therefore that lyes eaſt from Paris, is ſo much further eaſt from London; and muſt have $0^h\ 9^m\ 41^s$, or $2°\ 25'\ 15''$, added to its longitude from Paris, if we would have its longitude from London: on the other hand, every place that lyes weſt from Paris, is $0^h\ 9^m\ 41^s$, or $2°\ 25'\ 15''$, leſs diſtant from London, weſtward; and muſt have ſo much taken from its longitude reckoned from the meridian of Paris, if we would have its longitude from the meridian of London: thus, the longitude of Rome from Paris is $0^h\ 41^m\ 20^s$ eaſtward; add to this, $0^h\ 9^m\ 41^s$, and you have the longitude of Rome from London, $0^h\ 51^m\ 1^s$: thus again, Mexico is $106°\ 0'\ 0''$ weſt from Paris; take from that number of degrees, $2°\ 25'\ 15''$, and there remains $103°\ 34'\ 45''$, the longitude of Mexico weſt from London.

333 Another uſe of the table is this, *if the time of the day be given at one place, the time of the day at any other place, may be known*, if the different longitude of thoſe places be alſo given: thus, ſuppoſe it is now 2 in the afternoon at London, what is it o' clock at Jeruſalem? I find by the table, that the meridian of Jeruſalem is $2^h\ 21^m\ 41^s$ eaſt, ſo long therefore it comes ſooner to the ſun than the meridian of London, and conſequently ſo much more of the day is ſpent at Jeruſalem than at London: add then $2^h\ 21^m\ 41^s$ to the time of the day at London, and you have the time of the day at Jeruſalem, $4^h\ 21^m\ 41^s$ in the afternoon.

Another example; ſuppoſe, I find by an almanack, that the beginning of an eclipſe of the moon will be this preſent night, 4 minutes after 9 at London; if

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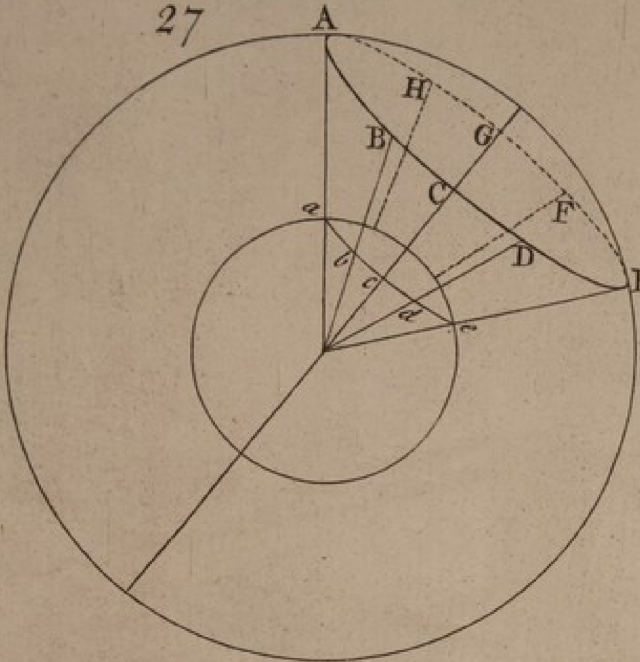

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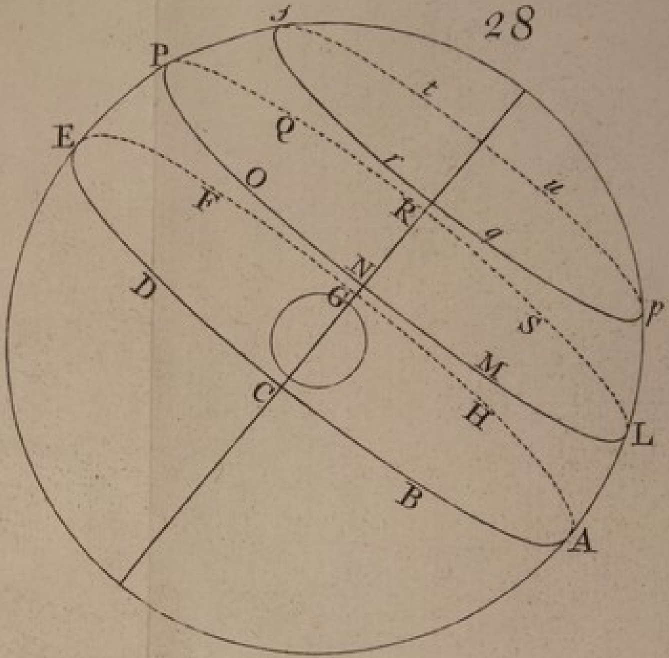

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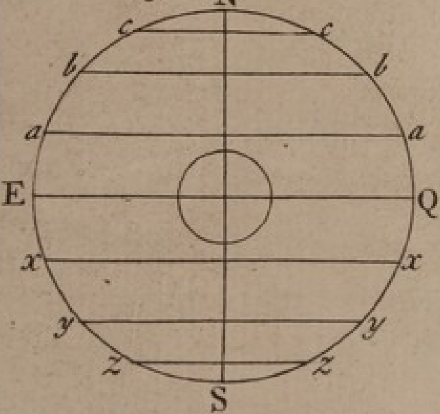

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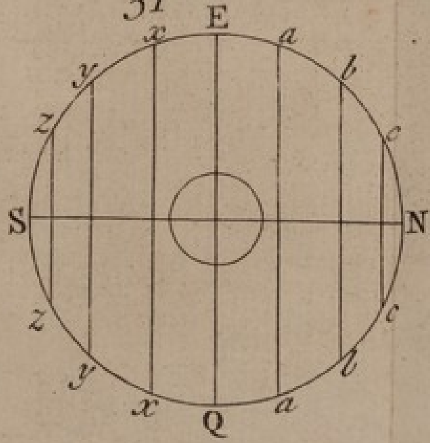

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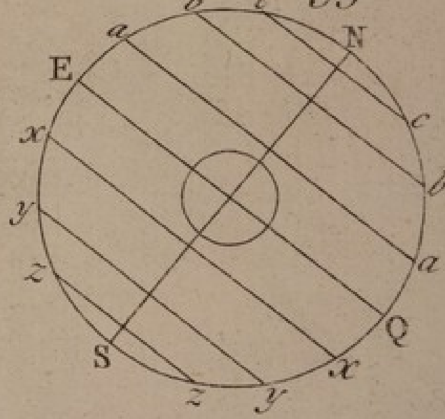

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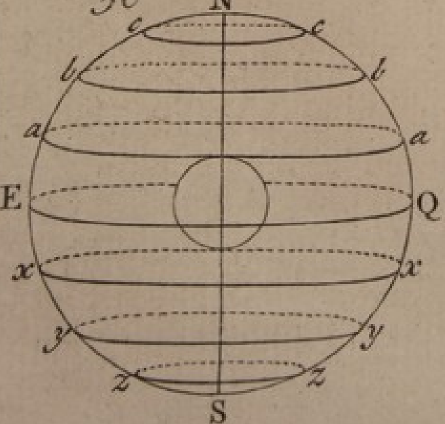

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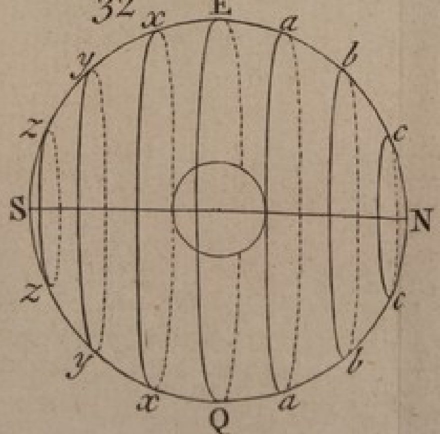

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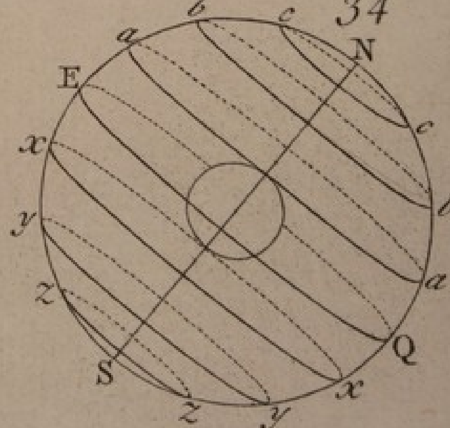

if it be enquired what time of the night it will then be at Liſbon, the anſwer FIG.
is thus found; Liſbon is $0^h\ 33^m\ 19^s$ weſt from London, therefore ſo much leſs of the natural day will be then paſt there, than at London; take $0^h\ 33^m\ 19^s$ from $9^h\ 4^m\ 0^s$, the time at London, and the remainder $8^h\ 30^m\ 41^s$ is the time of the night at Liſbon.

Another example; when it is noon at Iſpahan, what o' clock is it at London? I find by the table, Iſpahan is $3^h\ 31^m\ 41^s$ eaſt; ſo much further then is the day advanced there than at London: take $3^h\ 31^m\ 41^s$ from $12^h\ 0^m\ 0^s$ there remains the time of the day at London, $8^h\ 28^m\ 19^s$ in the morning: other uſes of theſe tables will be ſhewn, as occaſion offers itſelf.

334 *The different longitude and latitude of different places* upon the earth, *is a proof that the earth is ſpherical:* for that different meridians come ſucceſſively to point at the ſun, as has been deſcribed § 310, is a proof that the earth is round from eaſt to weſt; and the different elevation of the pole in different places under the ſame meridian, ſhews it to be round from north to ſouth.

335 We may imagin as many circles as we pleaſe to be drawn upon the earth, parallel to the equator; theſe grow leſs and leſs as they are nearer to either of the poles of the earth; ſuch circles are called *parallels*, or parallels of latitude: all places having the ſame latitude lye under the ſame parallel; and converſely, all places under the ſame parallel have the ſame latitude: in fig. 18, 18
theſe parallels are expreſt by ſtrait lines, parallel to the equator *e q*; amongſt which R L T is the parallel of London; V C X the parallel of Cairo.

The aſtronomical terms which ariſe from conſidering the rotation of the earth, and relate more immediately to the heaven, are next to be explained.

CHAP. 6. THE CELESTIAL POLES, EQUATOR, PARALLELS: CIRCLES OF DECLINATION: DECLINATION OF THE SUN, STARS, &c.

336 *The celeſtial poles* are two points in the ſphere of the heaven, through which the axis of the earth infinitely extended both ways would paſs: one of theſe, P, fig. 17, through which the north end of the axis would paſs, is 17
called *the arctic pole*, from the greek word *arctos*, which ſignifies a bear, becauſe this pole is near the conſtellations of the great and little bear; the other celeſtial pole S, being oppoſite to P, is called the *antarctic pole*: the celeſtial poles are often called the north and ſouth pole.

337 The elevation of the pole may be conſidered in the ſphere of the heaven, and then it is the arc of a vertical, contained between the celeſtial pole and the plane of the horizon extended: thus, the height of P the celeſtial pole, 17

fig.

FIG. fig. 17, is the arc P O: the height of the pole is of the ſame number of degrees,
minutes, and ſeconds, whether we conſider the terreſtrial or celeſtial pole: for,
S P being a ſtrait line, the angle P *h* O muſt be equal to the angle *pho*; and the
arc P O to the arc *po*: § 30, and 31.

338 We may imagin the plane of the equator upon the earth to be extend-
ed every way, till it reaches the ſtarry heaven, and to mark upon it *the cele-
ſtial equator*. We may imagin as many *circles* as we pleaſe to be drawn *in the
ſphere of the heaven, parallel to the celeſtial equator*; theſe parallels grow leſs
26 and leſs, the nearer they are to the celeſtial poles; in fig. 26, *eq* is the equator
upon the earth, and E Q the celeſtial equator; the parallels to the celeſtial e-
quator are A B, C D, F G, &c.

339 We may imagin as many great circles as we pleaſe to be drawn upon
the ſphere of the heaven, interſecting each other in the celeſtial poles; theſe
will cut the equator at right angles, and are called *circles of declination*, and
26 ſometimes, ſecondaries of the equator, § 282: in fig. 26, ſome of the circles of
declination are repreſented by the ſtrait line PS, and the curves PES, P*a*S, P*b*S,
P*c*S, &c, interſecting each other in the poles P and S.

340 *The declination of any point in the heaven*, as the ſun, moon, a ſtar &c,[a] is
its diſtance from the celeſtial equator, in degrees, minutes, and ſeconds, meaſur-
ed upon a circle of declination drawn through that point; *declination* is either
26 *north* or *ſouth*: thus, fig. 26, E Q is the celeſtial equator, P the north pole, S the
ſouth; the ſtar A is in north declination, ſo much as the arc A E amounts to;
in the ſame figure, the ſouth declination of the ſtar H is meaſured by the arc H E.

341 We may imagin any parallel upon the earth to have a correſponding
27 parallel in the ſphere of the heaven; thus, fig. 27, *abcd &c* is the parallel of
London, and A B C D E F G H the correſponding parallel in the heaven: we may
imagin any parallel in the ſphere of the heaven to have a correſponding parallel
drawn upon the globe of the earth; thus, A B C D E F G H is a parallel in the
heaven, the correſponding parallel to which upon the earth is *abcd &c*: *cor-
reſponding parallels* are ſuch where the celeſtial parallel is the ſame number of
degrees, minutes, and ſeconds diſtant from the celeſtial equator, as the parallel
upon the earth is from the equator upon the earth.

342 If we imagin a line to be drawn from the center of the earth through
any place, till it reaches the ſphere of the heaven, it will mark there the zenith
27 of that place: thus, fig. 27, a line drawn from the center of the earth through
London at *a*, marks the zenith of London A: by the rotation of the earth, the
zenith of every place which is not exactly under one of the poles, perpetu-

a By the declination of the ſun, moon, &c, is meant the declination of their centers.

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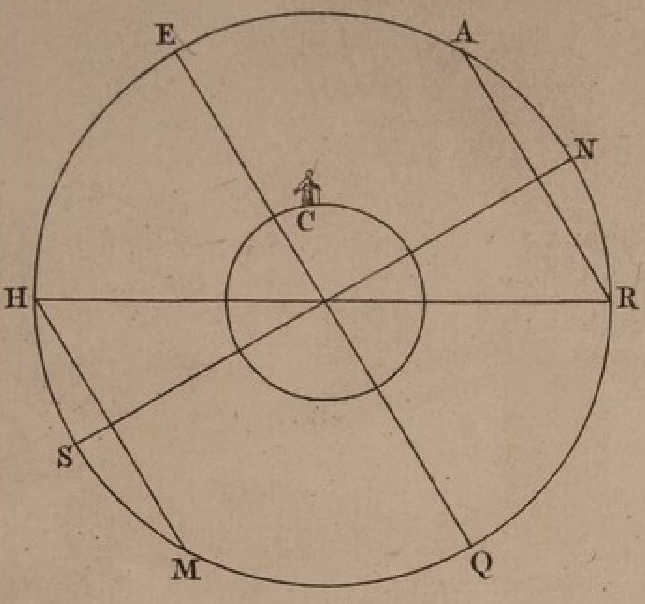

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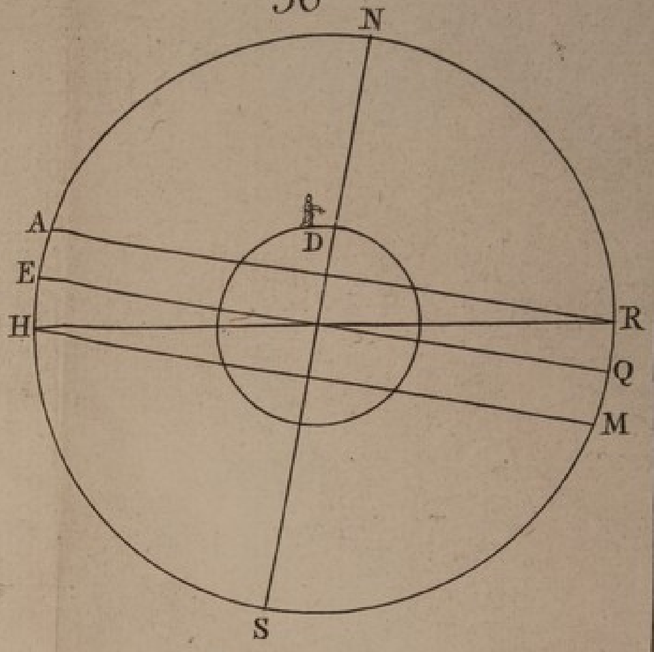

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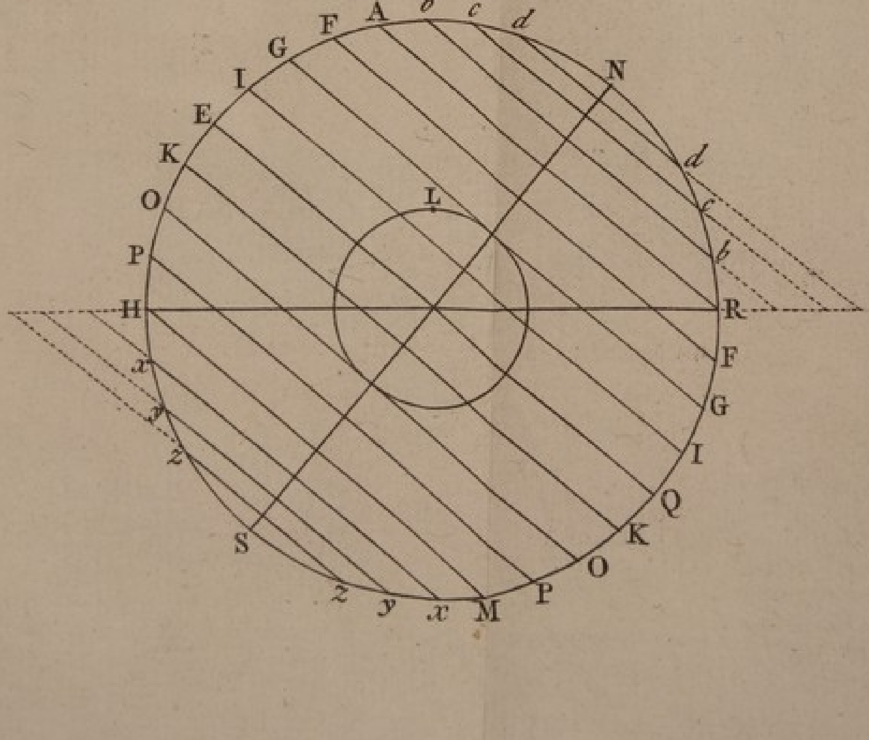

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ally changes its ſituation in the heaven, ſo as to go round, in a celeſtial parallel correſponding to the parallel of the place: thus, fig. 27, A the zenith of London goes round in the celeſtial parallel ABCDEFGH, according to the order of thoſe letters: the cauſe of this change of place in the zenith of London is this; by the rotation of the earth, London is carried round in its parallel *abcd &c*, according to the order of thoſe letters, and by that means comes ſucceſſively to be under different parts of the correſponding parallel ABCD *&c*; that is, London has for its zenith, ſucceſſively different points of that parallel: ſo that, when the place of London is at *a*, the zenith, or point over London will be A; when London is at *b*, the zenith will be B; when London is come in its parallel to *c*, the zenith will be C, *&c*. By this motion of the zenith of London round the parallel ABCD *&c*, from A to B, from C to D, from D to E, and ſo on, every point in that parallel will appear to come to the zenith of London, the contrary way; that is, the ſeveral points A, B, C, D, E, *&c*, will appear to come ſucceſſively, one after another, according to the order of thoſe letters, to the zenith of London: firſt the point A, then B, after that C, then D, *&c*. FIG. 27

343 By the rotation of the earth from weſt to eaſt, every point in the heaven, except the celeſtial poles, which are immoveable, appears to go round from eaſt to weſt, either in the celeſtial equator, or in a circle parallel to the celeſtial equator: thus, fig. 28, a point A, which is in the celeſtial equator, appears to go round in it, according to the order of the letters ABCD *&c*; a point L in the heaven which is not in the celeſtial equator, will appear to be carried round in a parallel drawn through that point, ſuch as is the circle LMNOPQRS, according to the order of thoſe letters. The further any point in the heaven is from the celeſtial equator, the leſs is the parallel deſcribed by it; thus, the point *p* deſcribes the parallel *pqrstu*, leſs than the parallel LMNOPQRS. 28 28

CHAP. 7. THE PARALLEL, RIGHT, AND OBLIQUE SPHERE: THE ARCTIC, AND ANTARCTIC CIRCLE.

344 In each of the ſix following figures, the ſphere of the heaven is repreſented, with the globe of the earth in the middle of it; N and S are the celeſtial poles, N the arctic, and S the antarctic pole; in fig. 29, 31, and 33, the celeſtial equator is repreſented by EQ, the north parallels by *aa*, *bb*, *cc*; and the ſouth parallels by *xx*, *yy*, *zz*: all ſtrait lines, as they would appear, if they were to be viewed with the eye at an infinite diſtance, and in the plane of the celeſtial equator extended[a], in ſuch a view, only one half of the equator and of each parallel, *viz*. the convex ſemicircle[b], can be ſeen; in fig. 30, 32, and 34, 29 31 33 30 32 34

a § 254 and 258. b § 260.

the

FIG. the celeſtial equator and parallels, that they may be ſeen entire, are repreſent-
30 ed by oblong ellipſes, ſuch as they would appear, if they were to be viewed
32 obliquely, with the eye a little elevated above the plane of the equator, and at
34 an infinite diſtance[a]; in theſe, and moſt of my other figures of this kind, in which the pictures of entire circles are given, ſuch as they would appear drawn upon a glaſs ſphere, and viewed obliquely, I have repreſented the concave ſemicircles[b], which are furtheſt from the eye, by pointed ſemiellipſes; and the convex ſemicircles[c], which are neareſt to the eye, by black ſemiellipſes; that they may the more eaſily be diſtinguiſhed from one another.

345 An inhabitant of the earth who lives at either of the poles, has one of the celeſtial poles always in his zenith, the other in his nadir; he has alſo the equator coincident with his horizon: and therefore, all the celeſtial parallels, being
29 parallel to the equator, are parallel to his horizon: ſuch a perſon is ſaid to live
30 in *a parallel ſphere*, or to have *a parallel horizon:* fig. 29, 30.

346 An inhabitant of the earth who lives under the equator, has both the celeſtial poles in his horizon, and is ſaid to live in *a right ſphere*, or to have
31 *a right horizon*; becauſe the celeſtial equator E Q, and all the parallels *aa*, *bb*,
32 *cc*, and *xx*, *yy*, *zz*, cut his horizon H R at right angles, fig. 31, 32.

347 An inhabitant of the earth who lives between either of the poles and the equator, is ſaid to live in *an oblique ſphere*, or to have *an oblique horizon*; becauſe the celeſtial equator cuts his horizon obliquely; and all the parallels in
33 the ſphere of heaven, have their planes oblique to the plane of his horizon,
34 fig. 33, 34. In an oblique ſphere, ſome of the parallels interſect the horizon at oblique angles; ſome are entire above, ſome entire below the horizon; and theſe alſo are all ſo ſituated, that their planes extended would interſect the
37 plane of the horizon extended, at oblique angles: thus, let fig. 37 repreſent the earth ſurrounded with the ſphere of the heaven; let an inhabitant of the earth be placed in north latitude at L; his horizon is H R, which is interſected obliquely by the equator E Q, and by all the parallels between A R and H M, ſuch as F F, G G, I I, *&c:* the parallel A R is entire above the horizon, as are alſo all the parallels between A R and the north pole N; ſuch as *bb*, *cc*, *dd*: the parallel H M is entire below the horizon, as are alſo all the parallels between H M and the ſouth pole S; ſuch as *xx*, *yy*, *zz*: if the planes of theſe were extended, as they are repreſented in the figure before us, by the pointed lines; they would interſect the plane of the horizon extended, at oblique angles.

348 The largeſt parallel which appears entire above the horizon of any place in north latitude, is by the ancient aſtronomers called *the arctic circle* of that place: within this circle, between it and the arctic pole, are compre-

a § 257 and 258. b § 260. c § 260.

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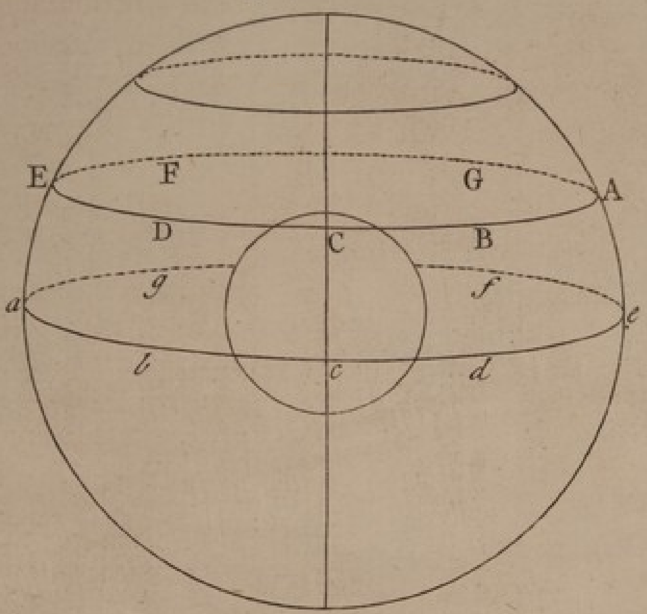

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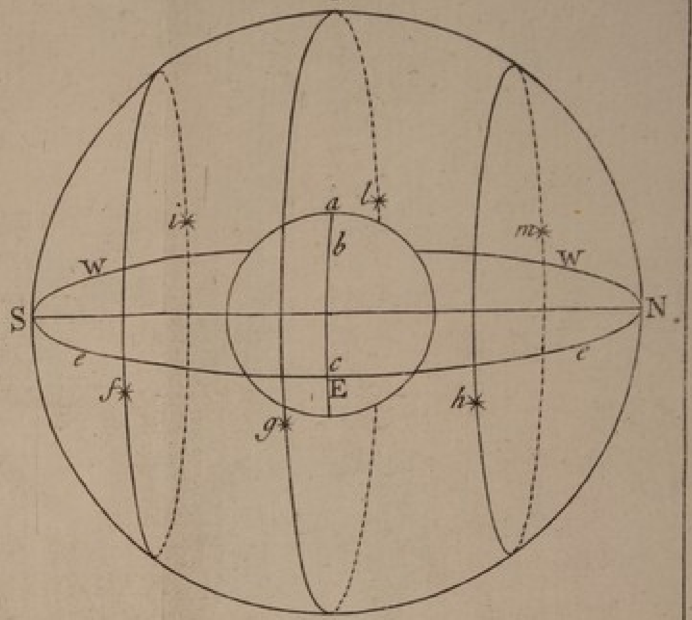

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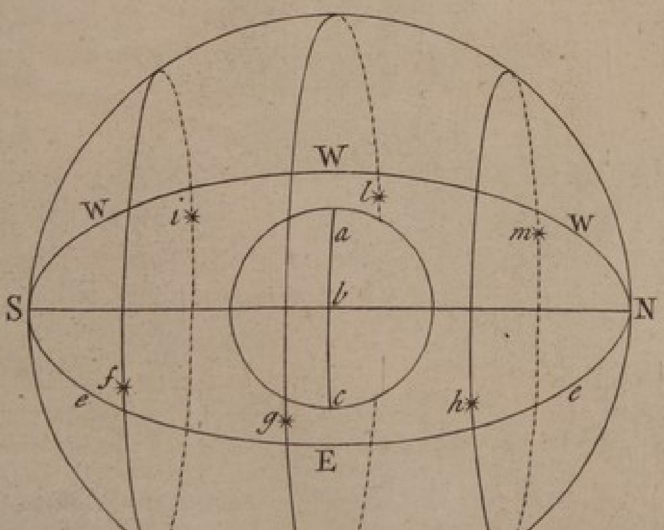

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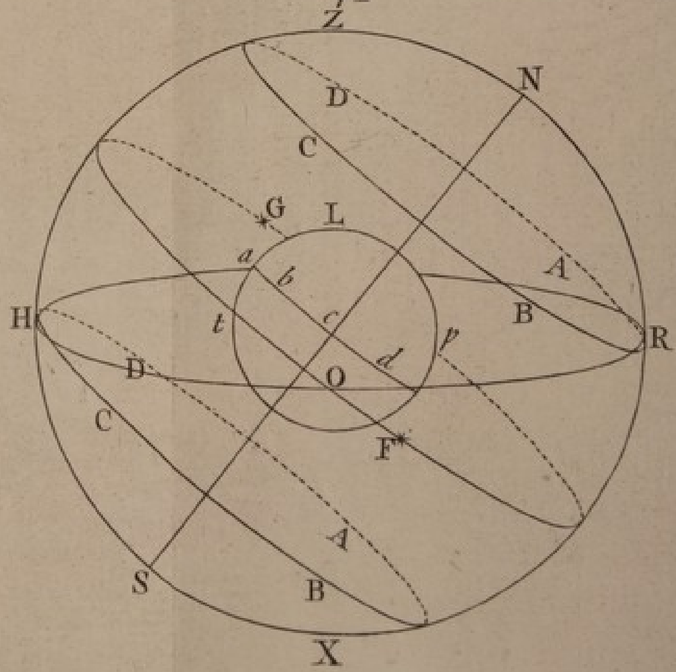

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hended all the ſtars which never ſet in that place, but are carried perpetually round above the horizon, in circles parallel to the equator. The largeſt parallel which is hid entire below the horizon of any place in north latitude, is *the antarctic circle* of that place, according to the ancients: this circle comprehends all the ſtars which never riſe in that place, but are carried perpetually round below the horizon, in circles parallel to the equator.[a] FIG.

349 *In a parallel ſphere, the equator may be conſidered as both arctic and antarctic circle*[b]; for, the equator being coincident with the horizon, all the parallels on one ſide of the equator are entire above the horizon, and all the parallels on the other ſide of the equator are entire below the horizon: thus, ſince an inhabitant under the north pole has the equator EQ coincident with his horizon, fig. 29, all the north parallels *aa*, *bb*, *cc*, are entire above his horizon, and viſi- 29
ble; and all the ſouth parallels *xx*, *yy*, *zz*, are entire below his horizon, and inviſible to him: on the other hand, an inhabitant under the ſouth pole has all the ſouth parallels entire above his horizon, and all the north parallels entire below it; as will appear from a view of the 29th figure inverted.

350 *In an oblique ſphere, the nearer any place is to one of the poles, the larger are the arctic and antarctic circles* in that place, as being nearer to the celeſtial equator, which is a great circle: thus, if a place C is in 30° of north latitude, fig. 35, the horizon of it is HR, the arctic circle is AR, the antarctic HM: if a 35
place D is in 80° of north latitude, fig. 36, the horizon is HR, the arctic circle 36
AR, the antarctic HM; both much greater than in the 35th figure.

351 *In a right ſphere, the arctic and antarctic circles have no place*; becauſe no parallel appears entire above the horizon, or is hid entire below it; but every parallel is divided into equal parts by the plane of the horizon: this appears by fig. 31, where the equator EQ and every parallel is divided into two 31
equal parts by the plane of the horizon. Some modern geographers, in their maps and globes, by the arctic and antarctic circles underſtand two fixt circles, drawn parallel to the equator, at the diſtance of 23° 30′ from each of the poles; but theſe are, properly ſpeaking, *the polar circles*; and will hereafter be deſcribed under that name: § 371.

a The arctic circle is called alſo *maximus ſemper apparentium*, and *circulus perpetuæ apparitionis*; and the antarctic circle, *maximus ſemper occultorum*, and *circulus perpetuæ occultationis*; *vide ſcriptores græcos de ſphæra*, Geminum, Proclum, *&c*: *vide etiam* Scalig. *in* Manil. lib. 1. *qui tamen ibi male eos reprehendit qui circulum arcticum eundem ſemper cum æquatore cœleſti & tropicis polum habere ſtatuunt; mutatur quidem æquatoris cœleſtis locus, per punctorum æquinoctialium regreſſum, ut infra patebit; ſed mutantur itidem tam tropici quam circulus arcticus & antarcticus, ita ut æquatori ſint omnes ſemper paralleli.*

b Gemin. *introd. cap. de circulis ſphæra.*

FIG.

CHAP. 8. THE DIFFERENCE IN THE APPARENT DIURNAL MOTION OF THE SUN AND OTHER HEAVENLY BODIES, IN THE SAME HORIZON; OR IN DIFFFRENT POSITIONS OF THE HORIZON: THE TROPICS: THE EQUINOXES: THE SOLSTICES.

352 By the definition of the horizon §278, it appears, that the plane of the horizon of every place upon the earth is invariable, ſo that it always cuts the ſurface of the earth in the ſame points; and this ſection of the globe of the earth is the circumference of a great circle, from every point of which, the place whoſe horizon it is, is 90° diſtant: ſo that by the rotation of the earth, the plane of every horizon is carried round along with the earth, and therefore there will ariſe, from the different poſition of the horizon in reſpect of the equator and its parallels, the following differences in the apparent motion of the ſphere of the heaven, and of the heavenly bodies.

38 353 To an inhabitant in a parallel ſphere, fig. 38, by the plane of his horizon *abcdefg* going round according to the order of thoſe letters, the viſible hemiſphere of the heaven and all the heavenly bodies which are therein will appear to go round the contrary way, according to the order of the letters ABCDEFG, above the horizon, in circles parallel to it: § 343 and 345.

354 In a right, and oblique ſphere, the horizon of every place is carried round along with the earth in ſuch a manner, that the eaſt ſide of it is always ſucceſſively ſinking below thoſe ſtars and other heavenly bodies which are in the eaſtern part of the heaven; by means whereof the ſtars, &c appear to riſe above it, on the eaſt ſide: and the weſt ſide of the horizon is conſtantly riſing above the ſtars, &c, and covering them; by means whereof, the ſtars, &c in the weſtern part of the heaven appear to ſink down below the weſt ſide of the horizon, or to ſet.

355 And this riſing and ſetting of the ſtars and other heavenly bodies, in a
39 right ſphere, is in circles which cut the horizon at right angles: thus, fig. 39
40 and 40 are pictures of a right ſphere, *a* is the place of the inhabitant, *e* E *e* W W
the plane of his horizon extended to the heaven, and viewed obliquely, *e* E *e*
is the eaſt ſide, and w W w the weſt ſide of the horizon; *f*, *g*, *h*, are ſtars in
the eaſtern hemiſphere of the heaven, and *i*, *l*, *m*, ſtars in the weſtern hemi-
39 ſphere: it is plain, that when the earth is in the ſituation repreſented in fig. 39,
the ſtars *f*, *g*, *h*, are below the horizon, and inviſible; and the ſtars *i*, *l*, *m*, are
above the horizon, and viſible: but when the earth, by the rotation round its
axis N S, according to the order of the letters *a b c*, is come into the ſituation
40 repreſented in fig. 40, then, by the eaſt ſide of the horizon *e* E *e* ſinking below
the

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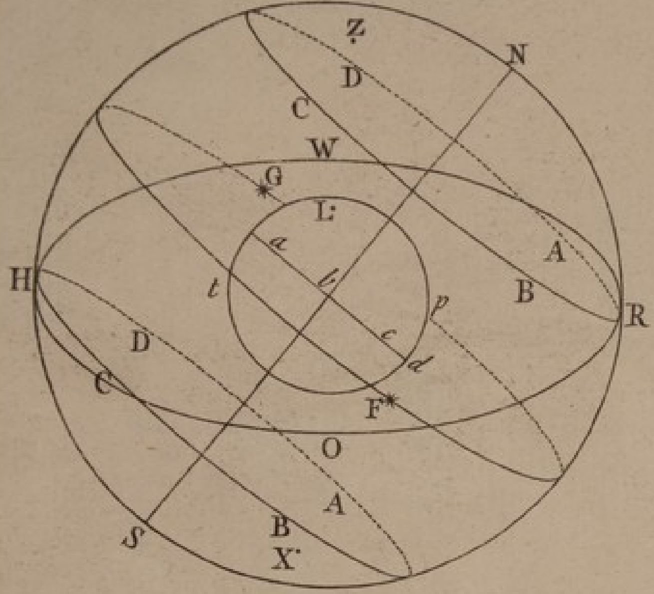

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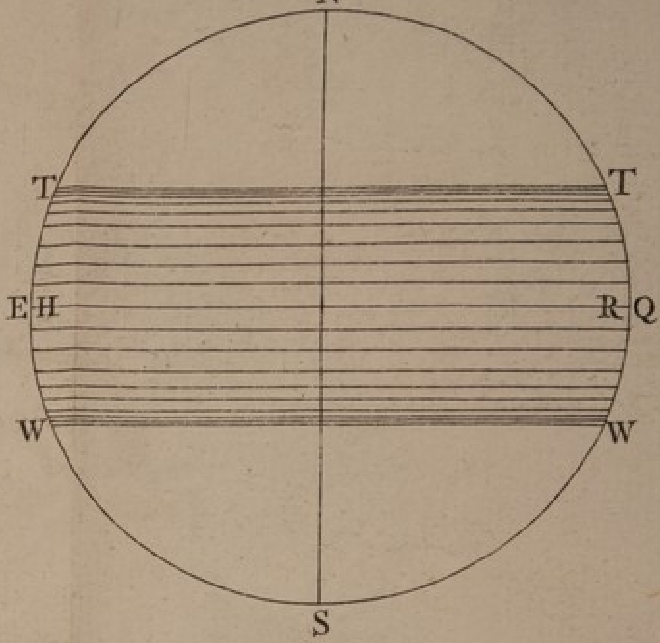

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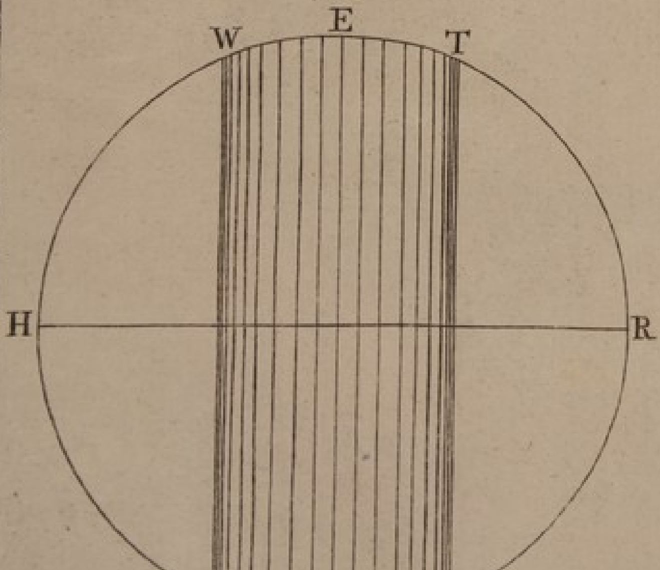

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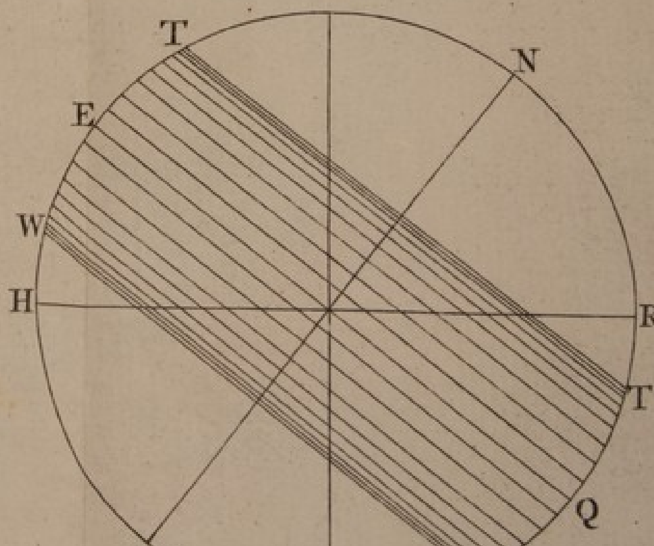

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the ſtars *f*, *g*, *h*, thoſe ſtars will appear to have riſen above the eaſt ſide of the FIG.
horizon; and by the weſt ſide of the horizon wWw riſing above the ſtars *i*, *l*, *m*, 40
and covering them, thoſe ſtars will appear to be ſet below the weſt ſide of the horizon.

356 In an oblique ſphere, the riſing and ſetting of the heavenly bodies is in circles which cut the horizon at oblique angles: the 41 and 42 figures are 41
pictures of an oblique ſphere, in which, let HZRX repreſent the ſphere of the 42
heaven, L*pct* the globe of the earth, let the point L be London, whereof Z is the zenith, and X the nadir; let HOR be the plane of the horizon of London; if the earth be imagined to turn round upon its two poles N and S, according to the order of the letters *abcd*, ſo that the point *a* upon the earth moves into the place of the point *b*, and the point *b* moves into the place of *c*, the appearances produced by this rotation of the earth will be the ſame as they would be, if the ſphere HZRX turned round upon the poles thereof N and S, the contrary way, according to the order of the letters ABCD: to be more particular, if the earths rotation be ſuch, that from the ſituation repreſented fig. 41, it comes into the 41
ſituation in fig. 42; it is evident, that by the ſinking of the eaſt ſide of the ho- 42
rizon HOR obliquely below the ſtar F, the ſtar F will appear to riſe obliquely above the eaſt ſide of the horizon HOR; as alſo that, by the riſing of the weſt ſide of the horizon HWR obliquely above the ſtar G, and covering it, the ſtar G will appear to ſet, or ſink obliquely below the weſt ſide of the horizon: what is here ſaid, to explain the riſing and ſetting of the ſtars, is applicable to the ſun, moon, or any of the heavenly bodies, and explains their riſing and ſetting alſo.

357 The ſun, ſeen from our earth, appears in a different point of the heaven, every day of the year: if the ſun be obſerved only for a few days together at a time, this change of place is hardly diſcoverable, except by nice aſtronomical obſervations; and therefore, when we are conſidering the ſuns place, only in order to explain his diurnal motion round the earth, his riſing and ſetting, and cauſing the viciſſitude of night and day, we may look upon him as continuing in the ſame point of the heaven, during the time of one or two natural days: the change of the ſuns place in the heaven is however, in any conſiderable number of days, very obvious to every body; it is from hence, that he appears to riſe and ſet in different parts of the horizon, at different times of the year; from hence it is, that his height at noon is ſo much greater in ſummer than in winter; in a word, it is to the change of the ſuns place in the heaven, that we owe the difference we find in the length of the days and nights, and in the ſeaſons of the year. The year is the time in which the ſun goes through the ſeveral changes of his place in the ſphere of the heaven, and returns to the ſame place again: the cauſe of the ſuns appearing thus to change his

FIG. his place is really the motion of the earth round the ſun, whereby we change our place, and view him from different ſtations; and conſequently, at different times of the year, ſee him in different parts of the heaven: this annual motion of the earth round the ſun will be more fully explained in the next book; it is ſufficient for our preſent purpoſe to obſerve, that the ſun, by this motion of the earth, appears ſometimes in the equator, ſometimes north, and ſometimes ſouth of the equator, and to conſider the difference of the ſuns apparent diurnal motion ariſing from hence, either in the ſame horizon, or in different poſitions of the horizon.

358 When the ſuns place is in the celeſtial equator, his apparent diurnal motion is in the celeſtial equator it ſelf; when the ſuns place is in any other point of the heaven, his diurnal motion is in a parallel drawn through that
28 point: § 343: fig. 28.

359 Twice a year the ſun appears in the equator; then his apparent diurnal motion is in the celeſtial equator; all the reſt of the year he is either in north declination, and then his apparent diurnal motion is in a north parallel; or in ſouth declination, and then his apparent diurnal motion is in a ſouth parallel. At the beginning of the ſpring, about the 10th of March, the ſun is in the equator; from that time, he appears every day to decline more and more towards the north, and deſcribes a parallel every day more northward than the parallel of the preceding day, till ſummer begins[a], about the 11th of June; then he is in his utmoſt northern declination, and his diurnal motion is in the moſt northern parallel in the ſphere of the heaven which he ever appears in: from this time, his declination grows leſs and leſs, and his diurnal motion is in a parallel nearer every day to the equator than the parallel of the preceding day, till he comes to be in the equator again, about the 12th of September: from that time, he declines more and more ſouth, till he comes to his utmoſt ſouthern declination; there he deſcribes the moſt ſouthern parallel he ever appears in, about the 11th of December: from that time, his declination grows leſs and leſs, and his diurnal motion is in a parallel every day nearer and nearer to the equator, till he arrives at the equator again, the next ſpring.

360 The moſt northern and ſouthern parallels the ſun ever deſcribes are called *the tropics*, from a greek word *tropè* which ſignifies turning; becauſe in thoſe two parallels the ſun is in his utmoſt declination, and from thence begins to turn back towards the equator again. The northern tropic is called *the tropic of Cancer*, and *the ſummer tropic*; becauſe it paſſes through that part of the heaven which is called the ſign Cancer, or the Crab; and when the ſun appears therein, the ſummer begins, to thoſe who live in north latitude. The

a Aſtronomers begin the four ſeaſons in March, June, September, and December; as will appear when we come to treat of the ſeaſons.

ſouthern

ſouthern tropic is called *the tropic of Capricorn*, and *the winter tropic*; becauſe FIG.
it paſſes through a part of the heaven which is called the ſign Capricorn; and when the ſun appears therein, winter begins, to thoſe in north latitude: in 43
fig. 43, 44, 45, EQ is the equator, TT, the ſummer, WW the winter tropic. 44

361 The time the ſun is above the horizon of any place is called *an artificial day*; the time the ſun is below the horizon of any place it is *night* in that place. By the day is ſometimes meant the natural, and ſometimes the artificial day; but this will not occaſion any ambiguity in the expreſſion, if the author be tolerably careful, and the reader any thing attentive. 45

362 In a right and oblique ſphere, by the ſinking of the eaſt ſide of the horizon below the ſun, the ſun appears to riſe above the eaſt ſide of the horizon; and by the riſing of the weſt ſide of the horizon above the ſun, the ſun appears to ſet below the weſt ſide of the horizon: in a right ſphere, this riſing and ſetting of the ſun is in circles that make right angles with the horizon; in an oblique ſphere, the ſun riſes and ſets obliquely: all this is eaſily underſtood from what has been ſaid of the riſing and ſetting of the ſtars, § 355, 356.

363 In a parallel ſphere, an inhabitant under the north pole has the ſun above his horizon, and it is conſequently perpetual day with him, all the time the ſun is in north declination; that is, for ſix months together, from the 10th of March to the 12th of September, § 359; but the ſun is below his horizon, and it is night with him, all the time the ſun is in ſouth declination; that is, for ſix months together, from the 12th of September to the 10th of March, § 359. On the other hand, it is day with an inhabitant under the ſouth pole, for ſix months together, all the time the ſun is in ſouth declination; and night, ſix months together, all the time the ſun is in north declination: fig. 43. 43

364 When one part of the circle in which the ſun appears to go round the earth, in his diurnal motion, is above, and the other part below the horizon of any place, that part of the circle which is above the horizon is called *the ſuns diurnal arc*; becauſe all the time the ſun appears therein, it is day in that place; that part of the circle which is below the horizon, is *the ſuns nocturnal arc*; 44
and whilſt the ſun is moving therein, it is night in that place: fig. 44, 45. 45

365 In a right ſphere, ſince the equator and every parallel is divided into two equal parts by the horizon, § 351, the diurnal arc is equal to the nocturnal, every day in the year: under the line therefore, there is perpetual *equinox*, that is, the days and nights are equal, throughout the year; every day being 12 hours long, and every night of the ſame length. See fig. 44. 44

366 Every place in an oblique ſphere has the day equal to the night, when the ſun is in the equator[a], about the 10th of March, and the 12th of September: for this reaſon, thoſe two ſeaſons are called *the equinoxes*; and the equator, *the equinoctial*

a Becauſe the equator is divided into two equal parts by the horizon. § 177.

FIG. *equinoctial circle*, or *the equinoctial:* the 10th of March is called *the vernal*, the 12th of September *the autumnal equinox*; becauſe one of theſe is the beginning of the ſpring, the other of the autumn: this time of ſpring and autumn is with regard to thoſe who live in north latitude; as for thoſe who live in ſouth latitude, their ſpring begins in September, and their autumn in March: but it may be obſerved here, once for all, that all the aſtronomical books we have were written by authors who lived on the north ſide of the equator, and had the north pole elevated above their horizon; and therefore many terms and expreſſions uſed in aſtronomy, are ſuch as are proper for perſons in that ſituation: thus we call it the vernal equinox when our ſpring begins; we look upon the north as the upper part of the heaven; and call any motion in the heaven, from ſouth to north, aſcending; and from north to ſouth, deſcending.

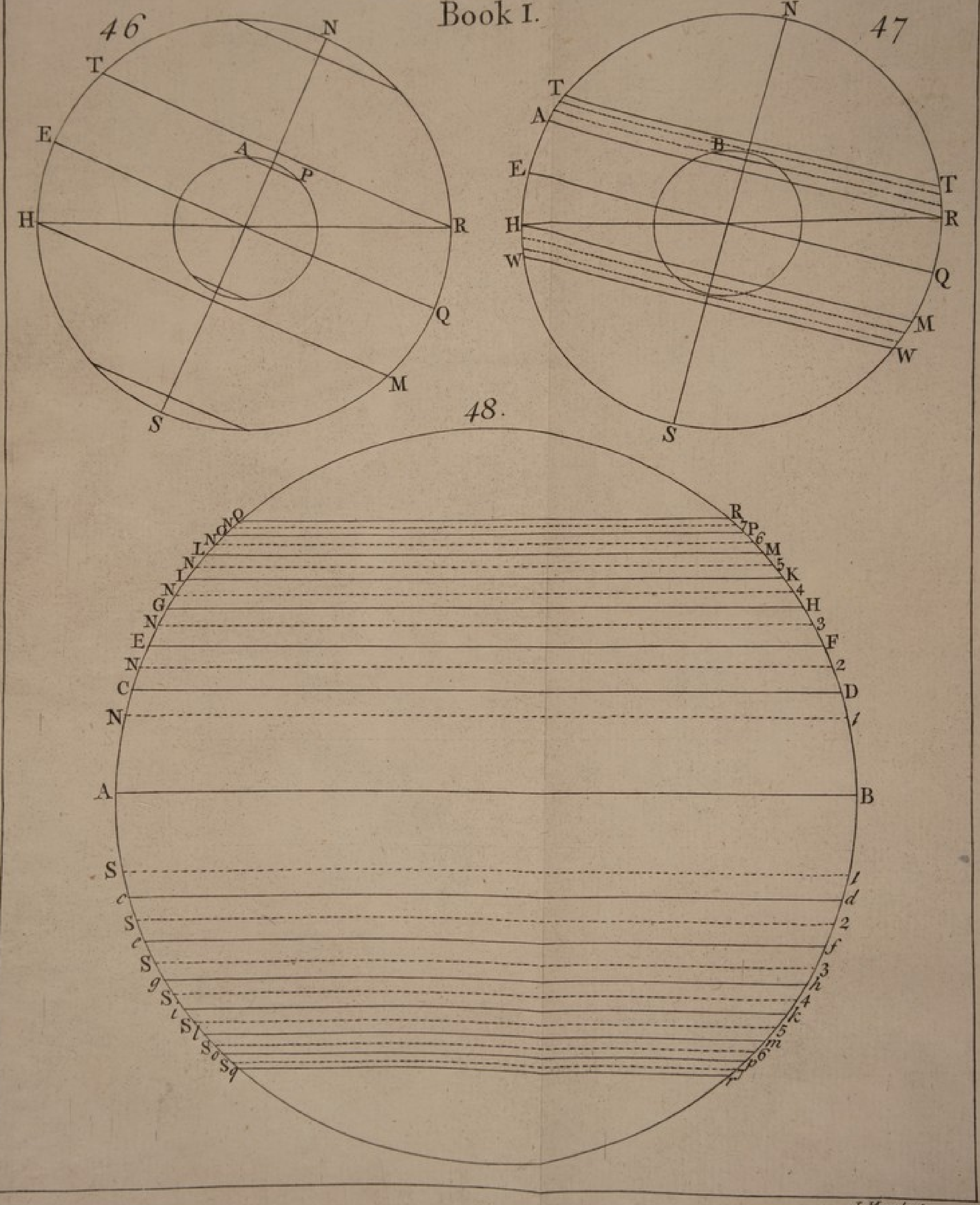
367 At all other times of the year when the ſun is not in the equator, the days are not of the ſame length with the nights, in an oblique ſphere; becauſe every parallel which is interſected by the plane of the horizon is divided by it
45 into two unequal parts. See fig. 45.

368 Every place in north latitude has the day longer than the night, all the time the ſun is in north declination; and the day is longer, the greater that declination is: and the longeſt day is when the ſun is in the tropic of Cancer:
45 the reaſon is evidently this; fig. 45, the north parallels are all divided unequally by the horizon, in ſuch a manner, that the diurnal arc in every parallel exceeds the nocturnal: and the further north any parallel is, the more unequally is it divided; and the more does the diurnal exceed the nocturnal arc; and therefore, the tropic of Cancer being the furtheſt north of any of the parallels which the ſun ever appears to deſcribe, his diurnal arc does then moſt exceed his nocturnal arc when he is in that tropic; and conſequently then is the longeſt day and the ſhorteſt night.

369 Every place in north latitude has the night longer than the day, all the time the ſun is in ſouth declination; and the day is the ſhorter and the night the longer, the greater the ſouth declination of the ſun is; and the ſhorteſt day and longeſt night is when the ſun is in the tropic of Capricorn: the reaſon of
45 this is alſo eaſily ſeen by fig. 45, by which it appears, that all the ſouth parallels are unequally divided by the horizon, in ſuch a manner, that the diurnal arc in every one of them is leſs than the nocturnal; and the further ſouth any parallel is, the more unequally is it divided, and the more does the nocturnal arc exceed the diurnal: the tropic of Capricorn therefore being the furtheſt ſouth of any of the parallels the ſun ever deſcribes, the nocturnal arc does then moſt exceed the diurnal, and then will be the ſhorteſt day and the longeſt night when the ſun is in that tropic,

370 When

Book I.



J. Mynde sc.

370 When the ſun is near the celeſtial equator, his declination alters ſo faſt, that in two or three days time it is eaſy to obſerve a change therein; when he is near either of the tropics, his declination changes ſo ſlowly, that no ſenſible difference in it can be perceived for ſeveral days together: if all the parallels of the ſuns apparent diurnal motion for every day of the year were to be drawn upon the ſphere of the heaven, thoſe parallels would be moſt diſtant from one another which are neareſt to the equator; from the equator towards each of the tropics the parallels would be cloſer and cloſer, till very near the tropics; and there the diſtance between them would be inſenſible; ſo that the ſun, when near either of the tropics, ſeems in his diurnal motion to be carried round the earth in the ſame parallel for ſeveral days together: the cauſe of his changing his declination in ſo different a manner, at different times of the year, will be ſhewn in the ſecond book, when the poſition of the ecliptic comes to be treated of, it is ſufficient at preſent to lay down the fact: in fig. 43, 44, and 45, the parallels of the ſuns diurnal motion are drawn at their proper diſtances, for every ten days of the year: a greater number of parallels would have made the figure a little confuſed, and theſe are enough to ſhew the inequality of their diſtances from one another. FIG. 43 44 45

371 The ſeaſons of the year when the ſun is in the tropics are called *the ſolſtices*; becauſe at thoſe times the ſun ſeems to be at a ſtand, with regard to his declination; neither going further from the equator, nor coming nearer to it, for ſeveral days following: near the 11th of June is *the ſummer*, and near the 12th of December is *the winter ſolſtice*. [a]

372 The faſter the ſuns declination changes, the greater difference will there be between the diurnal parallels of any two days immediately following one another; and conſequently the greater increaſe or decreaſe will there be in the length of the artificial day, in an oblique ſphere, in the ſame compaſs of time, § 368, 369: the ſuns declination changes faſteſt near the equinoxes, and ſloweſt near the ſolſtices, § 370; near the equinoxes therefore the lengthening or ſhortening of the days is moſt ſenſible, near the ſolſtices they ſeem to continue of the ſame length for ſeveral days together.

373 Fig. 43, 44, and 45, are pictures of a parallel, right, and oblique ſphere, in each of which EQ is the equator, TT the tropic of Cancer, WW the tropic of Capricorn, the ſtrait lines between the tropics are the ſuns diurnal parallels, one for every ten days, which he appears to deſcribe going from the equator towards each tropic, and coming from the tropic towards the equator again: thus, about the 10th of March he deſcribes the equator EQ, the next day he goes a little into north declination, and deſcribes a parallel about one degree 43 44 45

a *Solſtitialis dies idem eſt qui brumalis, apud* Gellium, lib. 9. cap. 7.

FIG. north from the equator, the day following he goes a little further into north declination, and his apparent diurnal motion is in a parallel further north; and thus he continues going every day further into north declination, and deſcribes in his diurnal motion a parallel every day further north than that of the preceding day, but though the ſun continues all the time increaſing in north declination, yet is this increaſe every day leſs and leſs, as he goes further from the equator, till he comes to his utmoſt north declination, then he deſcribes the tropic of Cancer TT, about the 12th of December; from that time, his declination decreaſes every day, in ſuch a manner, that he deſcribes the ſame diurnal parallels over again in an inverted order, as he goes backwards towards the equator, at which he arrives about the 12th of September; then he goes into ſouth declination, more and more every day, and deſcribes every day a parallel more ſouth than the parallel of the preceding day, till he comes to his utmoſt ſouth declination, about the 12th of December; then he deſcribes the tropic of Capricorn WW; and from that time his declination decreaſes, and he deſcribes every day a parallel nearer to the equator than the parallel of the preceding day, till he comes to deſcribe the equator again, about the 11th of March following.

374 It has already been obſerved, § 350, that the nearer a place is to either of the poles, the nearer to the celeſtial equator will the arctic and antarctic
46 circles be: if a place A in north latitude, fig. 46, be ſo near the north pole, that the northern tropic TR is the arctic circle; when the ſun is in that tropic, he will be carried round therein above the horizon, and make it continual day in that place for 24 hours, § 348: and when the ſun is in the ſouthern tropic HM, which is alſo the antarctic circle in that place, he will be carried round below the horizon, and make it continual night, for 24 hours: § 348.

46 375 A parallel AP drawn through a place A, whoſe longeſt day is 24 hours, is called *the polar circle:* a parallel drawn in the heaven correſponding to this circle[a] is the polar circle in the ſphere of the heaven: the polar circle is either north or ſouth: the *north polar circle* is drawn upon the earth through thoſe places in north latitude which have their longeſt day 24 hours, and the northern tropic for their arctic circle, and the ſouthern for their antarctic: *the ſouth polar circle* paſſes through thoſe parts of the earth in ſouth latitude which have their longeſt day 24 hours: the polar circles are at the ſame diſtances from the poles as the tropics are from the equator; namely, 23° 30′.

47 376 If a place B, fig. 47, is ſtill further north than A was ſuppoſed to be in the foregoing ſection, ſo as to be within the polar circle, the arctic circle AR and the antarctic HM will be nearer to the equator than the tropics are; and will each of them comprehend more of the parallels of the ſuns diurnal motion, beſides the tropics: in this ſituation, all the time the ſun is ſo far in north declination

a § 341.

declination as to be within the arctic circle, he will be carried round above the horizon of that place, § 348, and it will be continual day there; and all the time the sun is so far in south declination as to be within the antarctic circle, he will be carried round below the horizon, § 348, and it will be continual night.

377 From what has been said of the sun's apparent motion in places situated in north latitude, in the three sections immediately preceding, it is easy to understand, that a place in south latitude, whose antarctic circle is the southern tropic, will have 24 hours continual day, when the sun is in that tropic; a place within the south polar circle will have continual day all the time the sun is within the antarctic circle, and continual night all the time he is within the arctic circle of that place: *&c.*

378 I have hitherto, in considering the appearances of the heavenly bodies, had no regard to refraction, by which all the rays that come from them, as they enter our air and pass through it to our eyes, are refracted or bent, §. 213: the nature of refraction will be shewn more at large, when the atmosphere which surrounds our earth comes to be treated of; it is sufficient for the present to observe, that thereby all the heavenly bodies are made to appear higher than they really are; and that the nearer they are to the horizon, the greater is the refraction: the sun therefore is, by means of refraction, made to appear longer above the horizon than he really is, and, by that means, the artificial day is longer in every part of the earth than it would be without refraction.

CHAP. 9. CLIMATES.

379 The ancients, considering the diversity there is in the rising and setting of the heavenly bodies, especially of the sun, and, in consequence thereof, the difference in the length of the days and nights in different places, according as they are more or less distant from the equator, divided the earth, so much of it as was then known to them, into climates: and, instead of the method now in use of setting down the latitude of places in degrees and minutes, they contented themselves with saying in what climate the place under consideration was situated; and when they had a mind to be more exact, they would tell us that it was in the beginning, the middle, or end of such a climate.

380 *A climate* is a space upon the surface of the earth contained between two parallels, so far distant from each other that the longest day in one differs half an hour from the longest day in the other parallel: the word climate

is derived from a greek word that signifies to bend or incline, the difference of climates arises from the different inclination or obliquity of the sphere[a]: the ancients took the parallel wherein the length of the longest day is twelve hours and three quarters for the beginning of the first climate: as for those parts which are nearer to the equator than that parallel, they were not accounted to be in any climate; either because they may in a loose and general sense be considered as being in a right sphere, though, strictly speaking, only the parts directly under the equator are so; or because they were thought to be uninhabitable, by reason of the heat, and were besides unknown.

381 Climates are either on the north or south side of the equator: *the number of* the northern *climates* most generally received is seven; to which the like number of southern climates correspond: the names of the northern climates were not generally taken from the order in which they follow one another; but each climate was denominated from some remarkable place which was supposed to be situated in the middle of it: the names of the northern climates, according to the ancients were these:

the climate the middle of which passes through

1 Meroe.
2 Syene in Egypt.
3 Alexandria in Egypt.
4 Rhodes.
5 Rome: according to others, through the Hellespont.
6 The Borysthenes; that is, through the mouth of that river.
7 The Riphean mountains.

The southern parts of the earth being then very little known; the southern climates received their names from the northern ones to which they did in such a manner correspond, that they were as far distant from the equator southward as the others were northward: their names were these[b];

the south climate which corresponds to the north climate through -

1 Meroe.
2 Syene.
3 Alexandria.
4 Rhodes.
5 Rome, *or* the Hellespont.
6 The Borysthenes.
7 The Riphean mountains.

[a] *Quæ græci κλίματα dicunt, inclinationes coeli vocat* Vitruvius lib. 1. c. 1: & Gellius lib. 14. c. 1. *coeli divergentias*, Gellius *ibid.*

[b] Gr. ἀντιδιαμερόης &c: *ubi ἀντὶ in compositione similitudinem vel æqualitatem significat.*

382

382 A parallel is ſaid to paſs through *the middle of a climate* when the longeſt day in that parallel differs a quarter of an hour from the longeſt day in either of the extream parallels that bound the climate: this parallel does not divide the climate into 2 equal parts, but the part neareſt to the equator is larger than the other; becauſe the farther we go from the equator the leſs increaſe of latitude will be ſufficient to increaſe the length of the longeſt day a quarter of an hour: in the middle parallel of the firſt climate the longeſt day is 13 hours: in the middle of the ſecond climate 13 hours and an half: in the middle of the third 14 hours, &c. In fig. 48, let AB be the equator, N 1 a north parallel where the longeſt day is 12 hours and $\frac{1}{4}$, CD a parallel where the longeſt day is 13 hours, N 2 a parallel where the longeſt day is 13 hours and $\frac{1}{4}$; the parallel N 1 is the beginning, CD is the middle of the firſt northern climate: N 2 is the end of the firſt and the beginning of the ſecond climate: and all the ſpace between the parallels N 1 and N 2 is ſaid to be in the firſt northern climate: the parallels N 2 and N 3 contain the ſecond northern climate; and the parallel EF is in the middle thereof, &c: if we take parallels at the like diſtances, on the ſouth of the equator, we ſhall have the ſouthern climates; thus, the parallels S 1 and S 2 contain the firſt ſouthern climate; the parallels S 2 and S 3 contain the ſecond, &c. in like manner, *cd* is ſaid to paſs through the middle of the firſt ſouthern climate; *ef* through the middle of the ſecond, &c. FIG. 48

383 We may obſerve that every climate has three parallels which mark the beginning, the middle, and end of it: and that the parallel which marks the end of every preceding climate is the beginning of that which is immediately ſubſequent: ſome of the ancients, divide the earth by theſe parallels, and ſometimes by a parallel do not mean a meer linear circle but a ſpace of ſome breadth; in which ſenſe *a parallel* is the ſame as half a climate: and ſhews the difference of a quarter of an hour in the length of the longeſt day.

384 Some of the moderns reckon the different climates by the increaſe of half an hour, in the length of the longeſt day; as has been deſcribed, § 380, beginning at the equator, and going on till they come to the polar circle, where the longeſt day is 24 hours: from the polar circle towards the pole, they count the climates by the increaſe of a whole natural day in the length of the longeſt day; till they come to a parallel under which the day is of the length of 15 natural days, or half a month: from this parallel, they proceed to reckon the climates by the increaſe of half months or whole months in the artificial day; till they come to the pole it ſelf, under which the length of the day, is ſix months. Thoſe between the equator and polar circles are called *hour-climates*; thoſe between the polar circles and the poles, *month-climates*.

385 Both ancient and modern writers differ very much from one another in the

the number of climates, becauſe of the different views in which they conſider them; the ancient aſtronomers[a] conſidered the climates from the equator to each of the poles, in order to ſhew the difference in the apparent motion of the heavenly bodies, eſpecially the ſun, in all the different ſituations of places upon the earth which can be imagined; the geographers [b] chiefly conſidered the parts of the earth then known; later writers, to take in new diſcoveries, increaſe the number of climates: this ſubject is treated of at large by *Ricciolus, geograph. reformat. l. 7. c. 9, 10, &c.* [c] The uſe of a table of climates is, the climate in which any place is ſituated, or the length of the longeſt day in that place, being given, to find the latitude; or the latitude of a place being given, to find the climate, or the length of the longeſt day in that place.

386 In common ſpeech, we uſe the word climate in a more looſe and general ſenſe; ſo that when two countries are ſaid to be in different climates, it is vulgarly underſtood that the quality and temperature of the air, and the ſeaſons of the year, are remarkably different in one from what they are in the other: this is not true of different climates, in the aſtronomical ſenſe of the word, as defined § 380; for the difference of half an hour in the length of the longeſt days in two places is ſo far from being the occaſion of any conſiderable difference either in the air, or inhabitants, that we may ſometimes find a great likeneſs between the countries and inhabitants of different climates, and a great difference between thoſe which are in the ſame parallel: the difference in the temperature of the air, and the conſtitutions and tempers of the inhabitants, may often be better accounted for, by the different ſituation of countries, as to their being high and mountainous, or low and level; near to the ſea, or diſtant from it; their being woody, fenny, &c; as alſo by the nature of the ſoil and the water. *Hippocrates de aëre, aquis, & locis; fusè.*

387 The following table is taken out of *Ricciolus*, who in calculating it has made an allowance for the effects of refraction, which other writers have neglected to do, in their tables of climates: refraction, by making the ſun appear higher than he is, keeps him longer above the horizon of every place upon the earth; and conſequently makes the artificial day longer than it would be without refraction[d]. In this table, the climates are diſtinguiſhed by the increaſe of half an hour in the longeſt day, till it comes to be 16 hours; from thence, by the increaſe of one hour in the longeſt day, till it comes to be 20 hours; and from thence by the increaſe of 2 hours, till it comes to be 24 hours; there the month-climates begin, which are diſtinguiſhed by the increaſe of 15 days in the length of the longeſt artificial day.

a Hipparchus *apud* Strabon. l. 2. Ptolem. *magn. conſtruct.* l. 2. c. 6. b Strabo *loco citato.*
c *See* alſo Varenius *geograph.* l. 2. cap. 25. prop. 13. d § 378.

Climate	Parallel		Height of the pole. D.	M.	Longest Day. H.	M.	Middle of north Climate passes through	Middle of S. Clim. passes through
	1		2	59	12	15		
I	2	M	7	18	12	30	Mindanao Isl.	Isl. Ascension.
	3		11	29	12	45		
II	4	M	15	56	13	0	Goa.	Isl. St. Helena.
	5		19	33	13	15		
III	6	M	23	8	13	30	S. Lucar in California.	Assumption in S. Amer.
	7		26	50	13	45		
IV	8	M	29	49	14	0	Cairo.	Coquimbo in Chili.
	9		32	48	14	15		
V	10	M	35	35	14	30	C. di Chille in The Morea.	Mouth of R. de la Plata.
	11		38	9	14	45		
VI	12	M	40	32	15	0	Alcala d' Henares.	Baldivia.
	13		42	41	15	15		
VII	14	M	44	42	15	30	Asti in Piedm.	Coronatorum Lacus.
	15		46	33	15	45		
VIII	16	M	48	15	16	0	Brisac in Alsace.	Port Desire.
	17		51	14	16	30		
IX	18	M	53	46	17	0	Hamburg.	Mid. of Str. of Magellan.
	19		55	55	17	30		
X	20	M	57	44	18	0	Jeroslaw.	C. Horn.
	21		59	20	18	30		
XI	22	M	60	39	19	0	Ergimulum.	
	23		61	47	19	30	In Tart.	
XII	24	M	62	4	20	0	N. of Freezeland. *	
	25		64	12	21	0		
XIII	26	M	65	10	22	0	S. of Iceland.	
	27		65	43	23	0		
XIV	28	M	65	54	24	0	Middle of Icel.	

* This Freezeland is no where to be found, *Baudrand* Vol. 2. pag. 442.

					Continual Day in North Lat.	Continual Night in North Latitude.	Continual day in South Latitude.
	29		66	2	Days 15	Days 12	Days 14
XV	30	M	66	53	31	27	30
	31		67	43	45	41	44
XVI	32	M	69	30	62	58	60
	33		71	8	77	71	74
XVII	34	M	73	0	93	87	89
	35		75	56	108	101	104
XVIII	36	M	78	6	124	117	120
	37		81	10	139	132	135
XIX	38	M	84	0	156	148	150
	39		87	40	172	162	164
XX	40	M	90	0	188	180	178

FIG.

CHAP. 10. ASTRONOMICAL TERMS ARISING FROM THE DIFFERENCE OF THE NOON SHADOWS, IN DIFFERENT PARTS OF THE EARTH; ASCII, AMPHISCII, HETEROSCII, PERISCII. ASTRONOMICAL TERMS ARISING FROM THE INHABITANTS OF THE EARTH LIVING IN THE SAME, OR IN DIFFERENT PARALLELS; SYNOECI, PERIOECI, ANTOECI, ANTICHTHONES, ANTIPODES. THE ZONES.

388 When the ſuns apparent diurnal motion is in a circle which paſſes through the zenith of any place upon the earth, *the ſun* is that day ſaid to be *vertical* to that place; becauſe the ſun will that day at noon be in the zenith, directly over the head of an inhabitant of that place.

389 At the equinoxes, about the 10th of March and the 12th of September,
31 the ſun, being in the celeſtial equator, is vertical to all thoſe who live under
32 the line: fig. 31, 32.

390 When the ſun is in any of the celeſtial parallels, he is that day vertical to thoſe who live in a correſponding parallel upon the earth[a]: thus, when the ſun is in 10° north declination, he is that day vertical to thoſe who live in 10° of north latitude: thus again, when the ſun is in either of the tropics, he is that day vertical to all who live in a correſponding parallel upon the earth[a], which is one of the terreſtrial tropics. The utmoſt declination of the ſun, either north or ſouth, is 23° 30′, the celeſtial tropics are therefore parallels drawn 23° 30′ from the celeſtial equator; and the terreſtrial tropics, which are uſually drawn upon the terreſtrial globe, are the ſame number of degrees and minutes from the terreſtrial equator, being correſponding parallels.[a]

391 Since the ſun, in his apparent diurnal motion, is never carried round in a parallel further from the celeſtial equator than the tropics, § 360, he is never vertical to thoſe who live without the terreſtrial tropics; that is, above 23° 30′ from the terreſtrial equator.

392 All who live between the tropics have the ſun vertical twice a year: thus, the ſun is vertical to thoſe who live under the line, twice a year; in March, and September; § 389, thus again, if a place is in 10° north latitude, the ſun will be vertical to it, when he is in 10° north declination, which he is twice a year; once as he goes, increaſing in north declination, from the equator towards the northern tropic; the other time as, his declination decreaſing, he comes back again from the northern tropic towards the equator.

393 All who live between the tropics have the ſun at noon ſometimes north, and ſometimes ſouth: thus, they who live in a place, which is in 20° north la-

a § 341.

titude

titude, have the ſun at noon to the north of their zenith, when the ſun is in more than 20° north declination: at all other times, when the ſun is either in ſouth declination, or not ſo much north as 20°, he will be ſouth from their zenith at noon.

394 Thoſe places that lye without the tropics never have the ſun vertical: but ſuch of them as are in north latitude, have the ſun at noon always to the ſouth; and ſuch of them as are in ſouth latitude, have the ſun at noon always to the north of their zenith.

395 When the ſun at noon is in the zenith of any place, the inhabitants of that place were by the ancients called *aſcii*, that is, without ſhadow; becauſe the ſhadow of a man ſtanding upright, when the ſun is directly over his head, is not extended beyond that part of the earth which is directly under his body: in ſuch a ſituation, the ſhadow of an upright pillar, whilſt the ſun is in the zenith, will fall upon that part of the earth upon which the pillar ſtands; and therefore will not be viſible.

396 Since the ſhadow of every opake body is extended from the ſun; when the ſun at noon is ſouthward from the zenith of any place, the ſhadow of an inhabitant of that place, and indeed of every other opake body, is extended towards the north: when the ſun is northward from the zenith of any place, the ſhadow falls towards the ſouth.

397 All who live between the tropics have the ſun at noon, ſometimes north, and ſometimes ſouth from their zenith, § 393; and conſequently their ſhadows at noon fall at one time of the year towards the ſouth, at another time of the year towards the north; theſe were called *amphiſcii*, that is, having both kinds of meridian ſhadows.

398 They who live without the tropics have their noon ſhadows always the ſame way; and are therefore called *heteroſcii*, that is, having but one kind of ſhadow: if they are in north latitude, their meridian ſun being always ſouth, § 394, their noon ſhadows will be always towards the north: this is the caſe of Europe in general, and of England in particular: they who live in ſouth latitude, without the ſouthern tropic, have the ſun at noon always north, and conſequently their noon ſhadow always falls towards the ſouth.

399 When a place is ſo far diſtant from the equator that, when the days are longeſt in that place, the ſun is carried round 24 hours or longer above the horizon of it[a]; the inhabitants thereof, during that time, are called *periſcii*, that is, having their ſhadows go round them: the nearer a place is to one of the poles, the longer are the inhabitants thereof *periſcii*: if there be any inhabitants, under the poles, they are *periſcii* for ſix months together: and indeed ſeveral days more, upon the account of refraction § 387.

[a] § 374.

400 The inhabitants of different parts of the earth may be confidered with regard to the parallels in which they live; in order to know whether the length of the days, or the times of the feveral feafons of the year, are the fame, or different therein: if two places were fo near together that there was no obfervable difference between their feveral horizons, the inhabitants of thofe places were by the ancients called *fynæci*[a]; that is, near neighbours: thefe, having the fame horizon, have the nights and days, and the feafons of the year alike, and at the fame time. The inhabitants of diftant places in the fame parallel were called *periæci*; that is, living in the fame circle: thefe, being on the fame fide of the equator, have the feafons of the year alike, and at the fame time; having alfo a like elevation of the pole, and a like horizon, the heavenly bodies appear in both to rife, to come to their meridians, and to fet, in the fame manner, *fuprà* chap. 8, but at different times of the day, according as their meridians are more or lefs diftant, § 311; they have therefore the fame kind of days and nights, but at different hours. Some writers reftrain the appellation of *periæci* to thofe, who live in oppofite points of the fame parallel; when it is noon in one of fuch places it is midnight in the other, § 302. When two places are in parallels which are equally diftant from the equator, but one of them in north, the other in fouth latitude; the inhabitants were called *antæci:* thefe have a like elevation of the poles, but in one place the north, in the other the fouth pole is elevated; they have therefore a like increafe of days and nights, and like feafons of the year, but at different times of the year; it being the longeft day and the beginning of fummer in one place, when it is the fhorteft day and the beginning of winter in the other: fome will have the *antæci* to be under the fame geographical meridian, fo as to have the day or night at the fame time, fee § 302. If two places were in parallels equally diftant from the equator, one in north, the other in fouth latitude, and in oppofite meridians[b]; the inhabitants of one place were, in refpect of the inhabitants of the other place, called *antichthones*, that is, living upon oppofite parts of the earth; or *antipodes*, that is, having their feet oppofite: when two perfons are *antipodes*, the zenith of one is the nadir of the other; § 277, and 281. They who are *antipodes* have a like elevation of the pole, but of different poles; they have alfo like days and nights, and like times of the year; but every thing at oppofite hours of the day, and oppofite feafons of the year: thus, when it is noon with us, it is midnight with our *antipodes*; when the days are longeft, and fummer begins with us, the days are fhorteft, and winter begins with them.

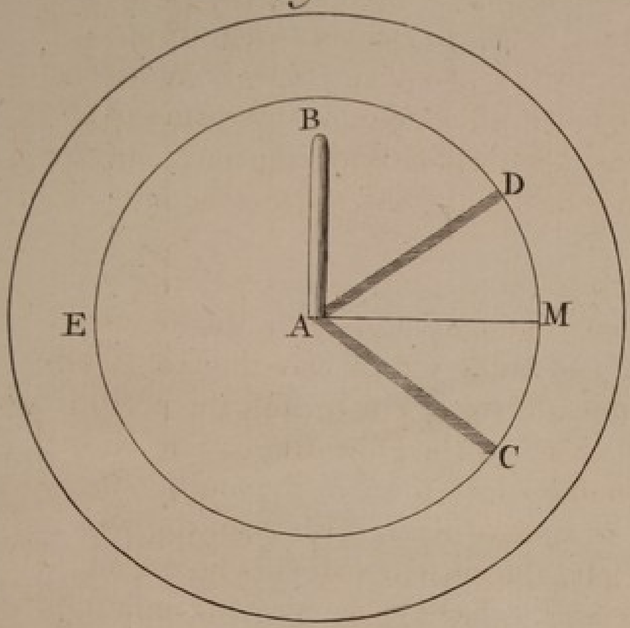
401 *The zones* are parts of the fpherical furface of the earth, into which it is divided by the tropics, and polar circles: all that part of the earth which lyes

a Cleomed. *cap.* περὶ οἰκήσεων. b § 300.

between

Book I.

49



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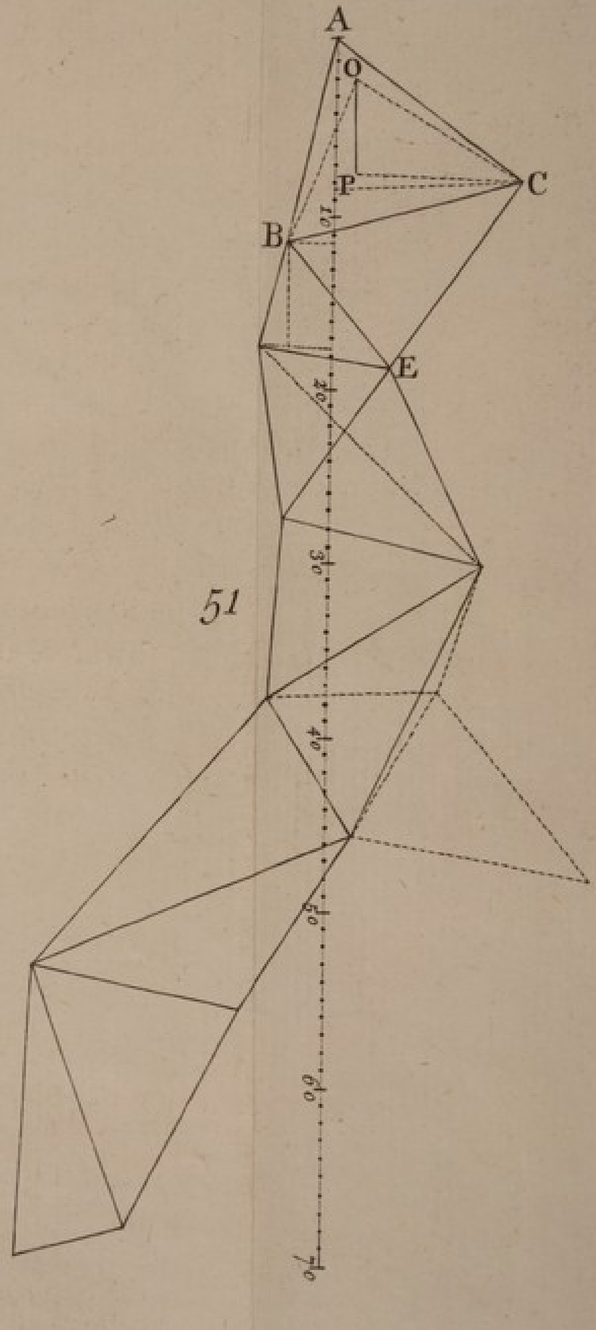

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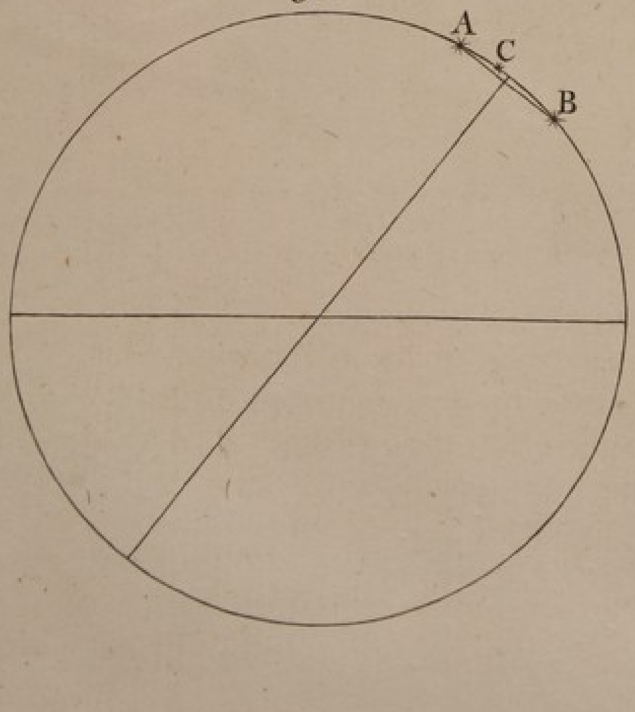

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between the two tropics is called *the torrid zone*; this ſome of the ancients thought uninhabitable, by reaſon of the great heat, which they imagined muſt be there, when the ſun is vertical: but it is now known, that many parts of it are inhabited, and that when the ſun is vertical to them, his heat is uſually qualifyed with cool breezes, and refreſhing ſhowers. Between each tropic and the polar circle next to it, lyes *a temperate zone*; the polar circles comprehend the *frigid zones*; theſe were ſuppoſed to be uninhabitable, by reaſon of the cold: the zones are generally ſaid to be five; one torrid, two temperate, and two frigid: ſome make the number of them ſix, dividing the torrid zone into two by the equator.[a]

402 When any *parts of the earth*, or *of the heaven* are ſaid to be *on the right hand*, or *on the left*, theſe expreſſions have different meanings in different writers; to underſtand which it is neceſſary to know which way the face is ſuppoſed to be turned: geographers look towards the north, becauſe the northern part of the earth is moſt known; with them therefore the eaſt is on the right hand, the weſt on the left: aſtronomers look towards the ſouth, obſerving the heavenly bodies as they come to the meridian; with them the weſt is on the right hand, and the eaſt on the left: the ancient augurs, who pretended to divine by obſerving from what part of the heaven thunder and lightning came, which way birds flew, *&c*, ſet their faces towards the eaſt; ſo that the ſouth was on their right hand: the poets looked towards the fortunate iſlands in the weſt; and had therefore the north on their right hand.[b]

The following verſes may ſerve to help the memory.

To the north pole turns the geographer;
At the meridian looks th' aſtronomer;
The augur, where aurora ſmiles;
The poet tow'rds the happy iſles.

CHAP. II. HOW TO DRAW A MERIDIAN LINE.

403 In a right ſphere, every point in the heaven appears to riſe at right angles above the eaſt ſide of the horizon, and to go gradually higher and higher till it is at the meridian, there it is at the higheſt, and from thence it falls lower and lower, till it ſets at right angles below the weſt ſide of the horizon.

In any place in an oblique ſphere, every point in the heaven not com-

a The word *zone* ſignifyes a girdle or belt.

b Ricciol. *geogr. reform. p.* 4. *ubi hoc diſtichon Brietii profert,*
Ad boream, terra; ſed cœli menſor ad auſtrum;
Augur ad exortum movet; occaſumque poeta.

 prehended

FIG. prehended within the arctic circle of that place appears to come obliquely above the east side of the horizon, and to rise gradually higher and higher, till it comes to the meridian, there it is at its greatest height, and from thence it descends obliquely lower and lower, till it sets below the west side of the horizon. In any place in an oblique sphere, every point in the heaven which is comprehended within the arctic circle of that place rises gradually from the lowest point of the parallel of its apparent motion, and goes higher and higher till it comes to the meridian, and from thence descends gradually, till it returns to the lowest point again: the lowest point of every parallel, being opposite to the highest, is in the opposite meridian.[a]

404 The rotation of the earth, which is the cause of the apparent diurnal motion of the heavenly bodies, being supposed equable and uniform, as there is no reason to imagin it to be otherwise, the apparent altitude of every point in the heaven is the same at equal distances from the meridian, whether ascending towards the meridian, or descending from it; provided the point does not in the mean time change its declination, but continues all the while to move in the same parallel: from hence and from the preceding section is derived the following method of finding a meridian line.

405 *To find a meridian line by the sun*; upon an horizontal plane, at the
49 point A, fig. 49, erect a perpendicular wire AB; an hour or two before noon, for example, about 10 in the morning, make a mark at D, where the shadow of the wire terminates; take away the wire, and from the center A through the point D draw a circle CMDE; replace the wire as before; as the sun rises higher, the shadow will grow shorter, till noon, when it is at the shortest; then as the sun grows lower, the shadow will grow longer; observe in the afternoon when the extremity of the shadow just touches the circle again, and make a mark there, as C; find the middle point M of the arc CD, and from the center A draw through it the line AM, this is the meridian line; or a line made by the common section of the planes of the meridian and horizon[b]. The reason of the operation is this; at equal distances from noon, before and after it, the sun is of the same height, and in verticals equally distant from the meridian: therefore conversely, a circle drawn through the zenith equally distant from any two verticals, in both of which the sun is at the same height, is the meridian. The planes of two such verticals, or rather their common sections with the plane of the horizon, are found, by marking the shadows of the wire before and after noon, when they are of the same length, as AC and AD are, by § 25: for other methods of finding the meridian line, see *Ricciol. Almagest, l.* 10. § 4. *Tacquet astron. l.* 5. *c.* 4. *Suite des memoires de l'Acad. Royale pour l' ann.* 1718. *pag.* 22. *edit. Par.*

a § 300. b § 160.

406 I have

406 I have here ſuppoſed the ſuns declination to continue the ſame, forenoon and afternoon; this operation therefore is to be performed at one of the ſolſtices, when the ſuns declination does not ſenſibly alter for ſome time, § 371; and the ſummer ſolſtice is much the beſt, becauſe the ſun is then higheſt, and changes his altitude faſteſt; whereas at the winter ſolſtice he is ſo low, that the obſervations of him are liable to errors ariſing from refraction, and his motion above the horizon is ſo oblique, that he changes his vertical faſter than he does his altitude; which is inconvenient in an operation that is to determin his vertical by his altitude.

There are moreover ſome other cautions to be obſerved in finding the meridian line by this method; 1. A clear day ſhould be choſen, and the horizontal plane ſhould be white, or of ſome light colour, that the ſhadow upon it may appear the more diſtinct; 2. The wire muſt not be too long, that the extremity of the ſhadow may be well defined; *Ricciolus* propoſes to have it about 6 inches long; 3. The end of the wire muſt not be a ſharp point, but about the thickneſs I have drawn it in the figure, that the end of the ſhadow may be diſtinct; 4. When accuracy is required, from the center A draw ſeveral concentric circles, that you may mark in each of them the points where the ſhadow of the wire terminates, at ſeveral times before and after noon; as at 9 in the morning, and 3 in the afternoon; at 11 in the morning, and 1 in the afternoon, *&c*: if the meridian line paſſes through the middle of all the arcs thus marked out, the agreement of ſo many ſeveral obſervations will be a good proof, that the meridian line, found the ſame by them all, is ſufficiently exact.

407 *One meridian line being given, another may be drawn* upon another horizontal plane, by the following method; hang a thread with a plummet exactly over the ſouth end of the meridian line given, and another thread with a plummet over the ſouth end of the plane upon which the meridian line is to be drawn; let one perſon obſerve at noon, the moment when the ſhadow of the firſt thread falls exactly upon the meridian given, and let another obſerver, at the ſame time, mark two diſtant points in the ſhadow of the ſecond thread: a line drawn through thoſe points is the meridian line required. By the ſame method may a meridian line be found upon a ſouth wall, by marking two points in the ſhadow of a thread hung at a little diſtance from it: if the meridians are near, he that obſerves the ſhadow of the firſt thread, may let the other know the moment it falls upon the meridian line, by ſaying *now:* if they are far diſtant, it ſhould be done by the motion of the hand, becauſe ſound takes ſome time to paſs from one place to another.

408 The meridian line is the very baſis of aſtronomical obſervations: a meridian line being found, there may be placed over it a quadrant or ſextant in

ſuch

FIG. ſuch a manner, that though it be moved up or down to give it different elevations, in order to view through the ſights of it the celeſtial bodies at different altitudes; yet the plane of that ſide of the inſtrument upon which the degrees are marked ſhall continue all the while in the plane of the meridian. *The mural arc in the Royal Obſervatory at Greenwich* is a wall built of black marble, one ſide of which, ſtanding exactly in the plane of the meridian, has a large and accurately divided braſs quadrant fixt to it, moveable round its center, and with teleſcopic ſights. See the deſcription of it in *Smith*'s *Optics*.

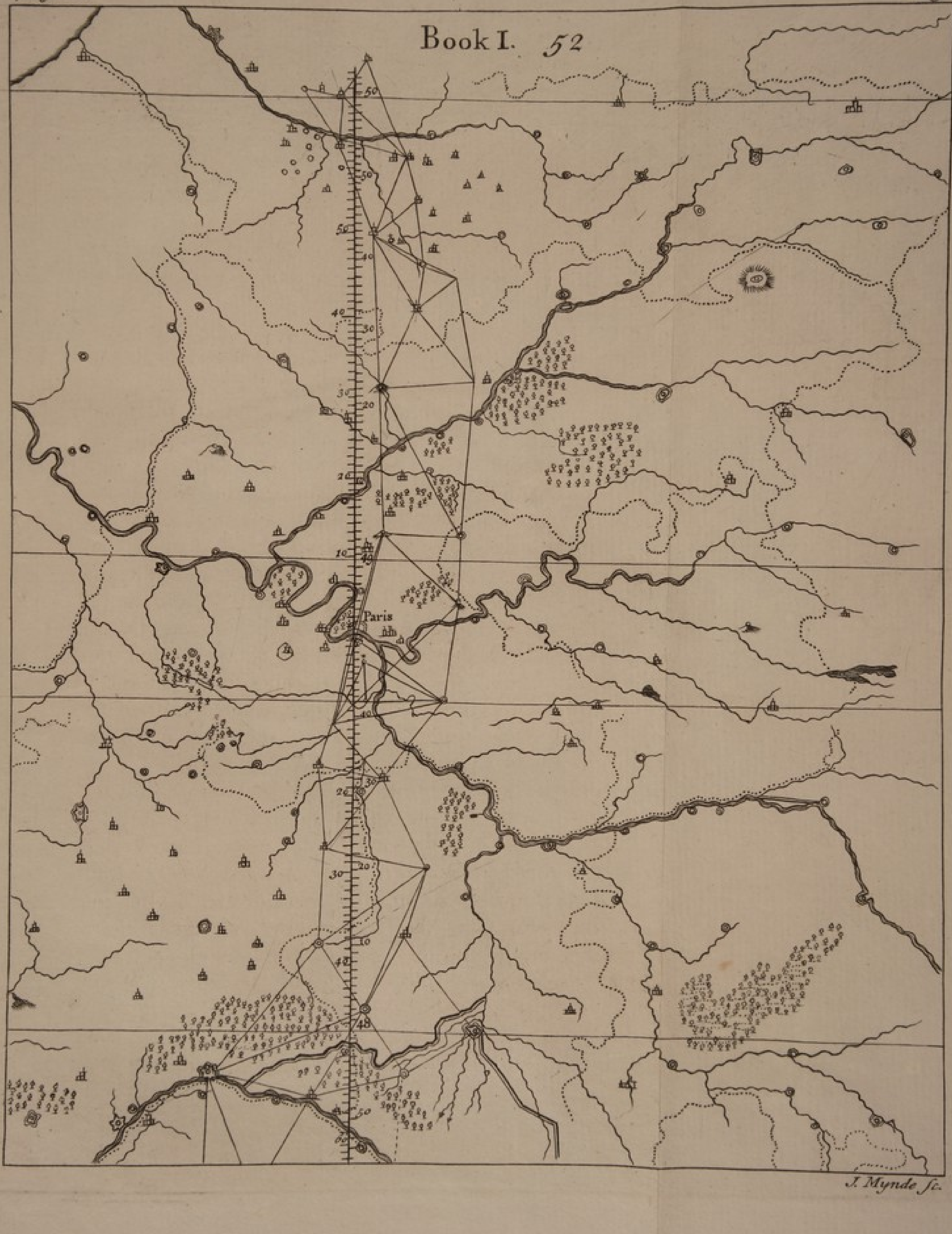
CHAP. 12. TO OBSERVE THE TRANSITS OF THE HEAVENLY BODIES: TO FIND THE HEIGHT OF THE POLE; THE MERIDIAN OF THE R. OBSERVATORY AT PARIS: GNOMONS, AND THEIR USE.

409 *To obſerve the tranſits, or paſſages of the heavenly bodies croſs the plane of the meridian*; a meridian line being found by § 405, hang two threads with plummets exactly over it, at a little diſtance from one another, and they will be in the plane of the meridian; if you place your eye cloſe to one of the threads, in ſuch a manner that you make it cover the other, and both appear as one thread; when a ſtar is behind the threads, it is in the meridian: by the ſame method may the ſun be viewed, through a ſmoked glaſs; when the threads paſs through his center, he is in the meridian: but the beſt way of obſerving either the ſun, moon, ſtars or planets, is through a teleſcope placed in the meridian, with two croſs hairs, one of which is in a vertical, the other in an horizontal poſition: when the vertical hair paſſes through the center of the ſun, he is in the meridian.

410 *To find the elevation of the pole*, in any place; with an inſtrument fixt in the plane of the meridian by § 408, take, by one of the methods ſhewn § 284, 285, 286, the greateſt and leaſt height of ſome ſtar which never ſets in that place, but is comprehended within the arctic circle thereof, the middle
50 height between theſe two extreams, is the elevation of the pole: thus, fig. 50, obſerve the height of the ſtar A, when in the meridian, at its greateſt height at A; ſuppoſe it found 60° 30′: twelve hours after, by the rotation of the earth, the ſame ſtar will be in the oppoſite part of the meridian, at its leaſt height at B; ſuppoſe this found 40° 30′: the difference between the greateſt height and the leaſt is 20°: half this difference, *viz.* 10°, added to the leaſt height, or taken from the greateſt, gives the elevation of the pole, 52° 30′.

411 *The elevation of the pole* may be *found by one obſervation* of the height of a ſtar in the meridian, if the declination of the ſtar be known: thus, in the table of the declination of ſtars for the year 1730[a], I find the declination of the

a *Connoiſſance des temps, ann.* 1730.



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the pole ſtar to be 87° 52′ 18″: its diſtance from the pole, being the complement of its diſtance from the equator, is then 2° 7′ 42″: ſuppoſe I find the greateſt height of this ſtar, in the meridian at c, fig. 50, to be 54° 38′ 12″: take from thence the ſtars diſtance from the pole, 2° 7′ 42″, and the remainder is the height of the pole, 52° 30′ 30″. The elevation of the pole may alſo be found, by taking the leaſt height of a ſtar, and adding thereto the diſtance of the ſtar from the pole; but care muſt be taken, not to chooſe a ſtar which comes near the horizon when it is at the loweſt: once for all, let it be remembred, that thoſe obſervations of the ſtars, *&c* are beſt which are made neareſt to the zenith; as being leaſt liable to the errors ariſing from the uncertainty, and variableneſs of refraction. FIG. 50

412 *To find the height of the equator*; take the meridian height of a ſtar which has no declination, but is in the equator; or take the meridian height of the ſun when he is in the celeſtial equator; the height of the equator is here found at once: the height of the equator may alſo be found by the meridian height of a ſtar which has declination, or by the meridian height of the ſun when he is not in the equator, provided it be firſt known what and how much the declination of the ſtar or the ſun is at the time of making the obſervation; thus, ſuppoſe, in the year 1730, I am in a place where I want to know the height of the equator; I find the ſtar called *Aldebaran* or the *Bulls* eye is that year in 15° 56′ 48″ north declination [a]; I obſerve the meridian height of it, and find it 45° 2′; from 45° 2′, I take the ſtars declination, 15° 56′ 48″; and the remainder 29° 5′ 12″ is the height of the equator. Thus again, ſuppoſe, Octob. 10th 1730, I obſerve the meridian height of the ſun to be 31° 4′; the ſuns declination that day is 6° 38′ 46″ [b], and, this declination being ſouth, the ſun is to an inhabitant in north latitude ſo much lower than the equator; I muſt therefore add the ſuns declination to his height; the ſum of theſe two numbers, *viz* 37° 42′ 46″ is the height of the equator.

413 *Scholium*, the height of the equator being found, the elevation of the pole is known; or the elevation of the pole being found, the height of the equator is known: for one of theſe is the complement to the other § 328, & 330.

414 Aſtronomers give us *tables of declination* for ſome *of the ſtars*, which tables muſt be calculated for ſome particular time, becauſe the declination of the ſtars alters a little every year, as we ſhall ſee hereafter; we have in ſome of the common almanacks, tables of the declination of ſome of the principal ſtars, for the current year; theſe are very uſeful for ſailors, that they may find at any time of the night in what latitude they are, by the ſtars, in the manner juſt now deſcribed, § 412: in ſome almanacks the ſuns declination is ſet down for every day of the year; that, by his meridian height, the latitude may be

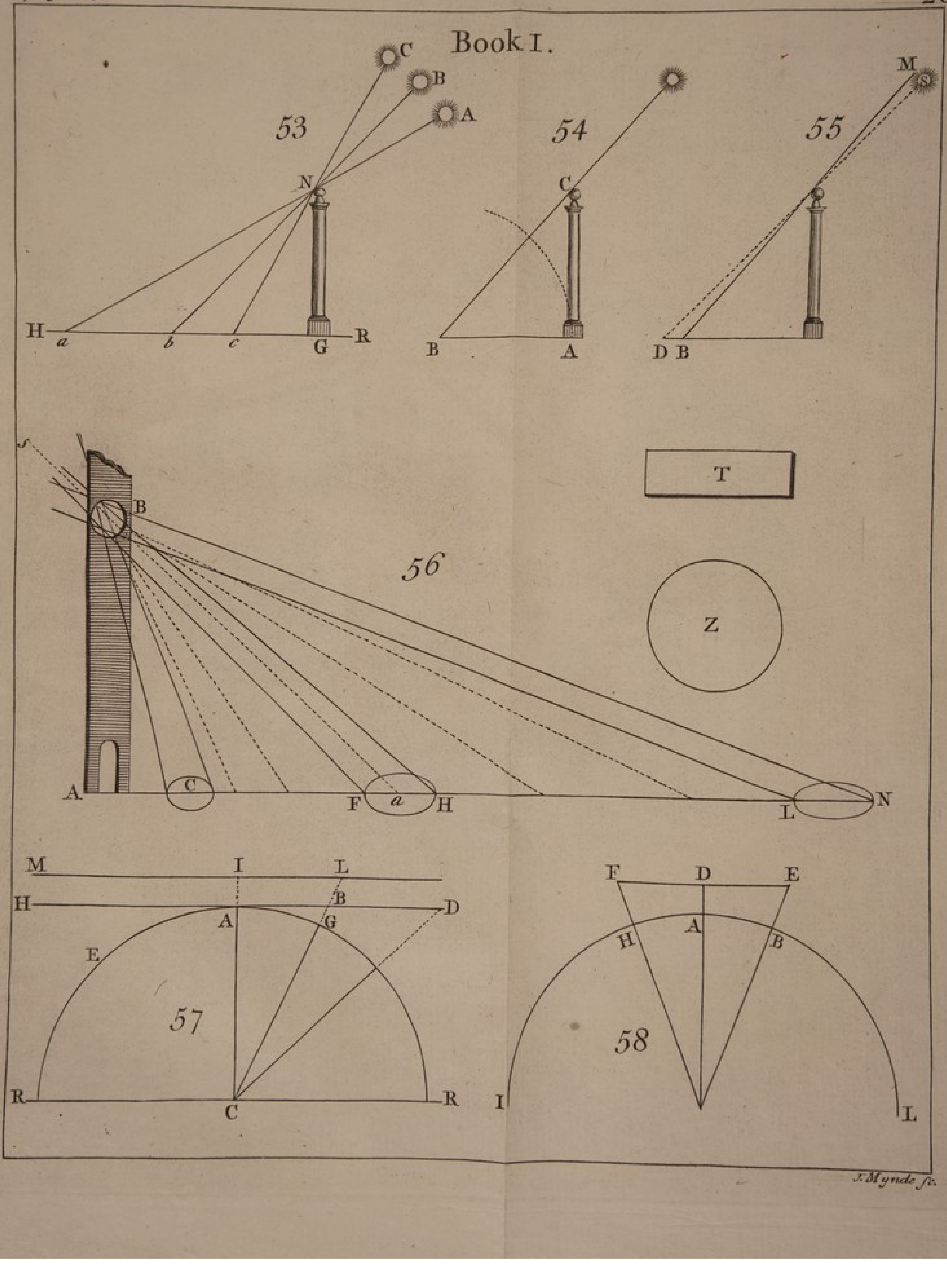
a b *Connoiſſance des temps, ann.* 1730.

FIG. be found in the day time. At sea, where they cannot have a fixt meridian line, they take the greatest height of the sun or a star for the meridian height.

415 *A meridian line* may be *verifyed, prolonged* to what distance we please, and the length of it *measured. The meridian of the Royal Observatory at Paris* being found, and an instrument with telescopic sights placed vertically[a] therein, the north and south points of the visible horizon were observed through the sights, and upon the north point a pillar was erected; then, by another instrument placed horizontally, several distant objects, as steeples, *&c* were viewed, and the angles the visual lines made with the meridian line were observed: then, from the places of those objects, as from so many new stations, other objects were observed; and where proper ones did not occur, large poles or trees were set up to be viewed: by this means several triangles were formed along the meridian: in order to measure these triangles, a paved way near Paris, from *Villejuive* to *Juvisy*, being strait and lying from north to south, was made choice of for *the fundamental base*. For actual measuring the length of this way, two poles were made use of, each of which was four *toises*[b] long, and made of two pike-staves joyned together at the great ends by a screw: the method observed in measuring was as follows; one of the measuring poles was first laid upon the ground, and then the other was joyned to it end to end, along by a rope stretched from north to south; then the first pole was taken up and laid down at the end of the second, and so on successively: and for the greater ease in keeping the account, the measurer who laid down the second pole had ten little stakes given him, one of which he stuck into the ground at the end of his pole every time he laid it down; so that every stake marked 8 *toises*, and when all the 10 stakes were stuck into the ground they marked eighty *toises*: in this manner, the length of the high way between the middle of the mill of *Villejuive* and the pavilion of *Juvisy* was twice measured; and was found to be 5663 *toises* and 4 feet, in going; and 5663 *toises* and one foot, in returning: but, as a nearer approach to exactness could not be hoped for, the round number of 5663 *toises* was pitched upon as the length of this fundamental base. This base is in fig. 51, represented by the line OP, and the calcu-
51 lations of the triangles were built upon it, in the following manner; from O one end of the base, was observed the angle COP; from the other end P, the angle COP was observed; and from the station C, the angle OCP: and thus all the angles of the triangle CPO and the length of one side OP being known, the lengths of the remaining sides OC and PC were found by calculation. The next step was to observe all the angles of the triangle OBC, and from thence, and from the known length of the side OC to calculate the other side OB and

a § 408. b A *toise* is six Paris feet.

BC. Then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J. Mynde sc.

B C. Then, all the angles being obſerved, and the ſide B C being known of the triangle ABC, which may be called the firſt or principal triangle of the meridian of the Obſervatory, the other ſides A B and A C were found. Then, from one of the ſides now known, and the angles obſerved, all the ſides of the next adjoyning triangle C B E were found. Thus they proceeded from one triangle to another, to the place where the meridian ended, in the ſouth part of France; and there the laſt triangle was terminated by a baſe of the length of 7246 *toiſes*, which was actually meaſured, in order to verify the preceding operations. FIG. 51

416 The meridian line of Paris being prolonged, in the manner juſt now deſcribed, the ſituation of ſeveral other places in France was determined by trigonometry; and an accurate map of the country drawn; eſpecially of thoſe parts which lye near the meridian of Paris: we have this map, with the triangles formed along the meridian, in the *Suite des memoires de l'Acad. Royale des ſciences, année* 1718: I have, in fig. 52, given an exact copy of ſo much of it as I thought neceſſary for my purpoſe, taken from the Paris edition: in the book juſt now cited we are told, that the longitudes of Montpelier and ſome other places in France were found to be the ſame, by aſtronomical obſervations, as the trigonometrical operations had determined them to be: this ſhewed at once the truth of thoſe trigonometrical operations, and what exactneſs may be expected in determining the longitude of places by thoſe aſtronomical obſervations: thoſe obſervations were of emerſions of the ſatellits of Jupiter. 52

417 There was one method of making obſervations very much uſed by the ancients, which is proper to be now mentioned; and that was by the length of the meridian ſhadows caſt by an upright pillar of a known height upon a level pavement: a pillar erected for this purpoſe was called *a gnomon* [a], becauſe thereby the height of the pole, and the ſeaſons of the year, may be known: the center of the baſe of the pillar may be called *the center of the gnomon:* the greater the height of the ſun is, the ſhorter is the ſhadow of a gnomon; and converſely, the ſhorter the ſhadow is, the greater is the ſuns height: thus, fig. 53, let the gnomon be GN, the pavement HR; when the ſun is at A, the ſhadow reaches to *a*; when the ſun is at B, the ſhadow reaches to *b*; when he is ſtill higher at C, the ſhadow reaches only to *c*; in obſervations of this kind, it was uſual to ſet down what proportion the length of the ſhadow bore to the height of the pillar; that is, the height of the pillar being divided into a certain number of equal parts, to ſay how many of thoſe parts the length of the ſhadow, beginning to meaſure it from the center of the gnomon, amounted to, at the equinoxes or ſolſtices: the moſt ancient obſervation of this kind, that we meet with, is that made by *Pytheas*, in the time of *Alexander* the Great, at 53

a *Solis umbilicus quem gnomonem vocant.* Plin. N. H. l. 2. c. 72.

FIG. Marseilles, where he found the height of the gnomon was to the meridian shadow, at the summer solstice, as $213\frac{1}{8}$ to 600; just the same as *Gassendus* found it to be, by an observation made in the same place, almost two thousand years after, in the year 1636.[a]

418 *To find the elevation of the pole by the shadow of a gnomon:* it is sufficient for this purpose, to find the meridian height of the sun; for that being given, the height of the equator is found, by § 412; and consequently the elevation of the pole, by § 413: now *the meridian height of the sun* is *found by the*
54 *gnomon* in the following manner; in the fifty fourth figure, let the gnomon be AC, let the shadow be AB; and let CB be part of a ray drawn from the center of the sun, passing by the top of the gnomon and terminating the shadow at B; these three lines form a right-angled triangle BAC; whereof the two legs AC and AB are given; the number of feet, inches &c contained in each of them being found by actually measuring them: from hence either of the acute angles may be found in this manner; let one leg be radius, and the other will be tangent of the opposite angle, § 140: thus, if we make AB radius, AC will be tangent of the opposite angle ABC; this tangent is thus found by the golden rule; as the number of feet, inches, &c in AB is to the number of feet, inches, &c in AC; so is the radius or the whole sine 10000000, to a fourth number, which is the tangent required: this fourth number found in the table of tangents makes known the angle ABC, § 120: and this angle is the measure of the suns meridian height at the time of the observation: which was the thing required to be found.

419 The following *example* will serve to illustrate this proposition; *Pliny*[b] tells us, that at Rome, at the equinoxes, the shadow is to the gnomon as 8 to 9:
54 suppose then, making use of the figure last mentioned, the gnomon AC to be 90 feet, and the shadow AB 80 feet; if we make AB radius, AC will be tangent of the angle ABC: we may say then as AB of 80 feet, is to the whole sine 10000000; so is AC of 90 feet, to a fourth number: *viz.* 11250000, tangent of the angle ABC: the angle answering to this tangent in the table, § 120, is $48° 22'$; this is therefore the height of the equator at Rome, and the elevation of the pole there is $41° 38'$: § 112, 113.

420 *Ricciolus*[c] takes notice of these defects in the observations of the suns height, made with the gnomon, by the ancients, and some of the moderns; 1, they did not reckon the suns parallax, which makes his apparent altitude $10''$ less than it would be, if the gnomon were placed at the center of the earth, as will be better understood when the suns parallax comes to be treated of; 2, they

a Gassendus *de vita* Peireskii *ad ann.* 1636. *v.* Ricciol. *alm.* l. 3. c. 14. & Geogr. *reform.* l. 7. c. 4. & 5.
b *Nat. hist.* lib. 2. cap. 72. c Geogr. *reformat.* l. 7. c. 4.

did

did not conſider refraction, by which the apparent height of the ſun is a little FIG.
increaſed; 3, they made their calculations from the length of the ſhadow, as if it were terminated by a ray coming from S, the center of the ſuns diſk, fig. 55, 55
ſuch as is expreſt by the pointed line SD; whereas the ſhadow is in reality terminated by the ray MB, coming from M, the upper edge of the ſuns diſk: ſo that, inſtead of the height of the center of the ſun, their calculations gave the height of the upper edge of his diſk: the errors ariſing from hence are ſmall, and of no conſequence in ſome caſes, but in order to find the height of the pole, the moment of the ſolſtices or equinoxes, or the obliquity of the eliptic, with accuracy, they muſt be corrected in the following manner: to the altitude of the ſun found by the gnomon, add the ſuns parallax 10″, and take from it the ſemidiameter of the ſun, about 16′, and the refraction, which is different at different altitudes of the ſun, as will be ſeen in the table of refractions, and you have the ſuns true altitude: thus, in order to correct the obſervation mentioned in § 419; to the meridian height of the ſun at Rome, found by the gnomon at the equinox to be 48° 22′, add the ſuns parallax 10″, which makes 48° 22′ 10″; from this ſum take the ſuns apparent ſemidiameter 16′, and the refraction 1′ 57″, and the remainder 48° 4′ 13″ is the true height of the ſuns center, and conſequently the true height of the equator at Rome, the complement whereof 41° 55° 47″ is the elevation of the pole.

421 There are alſo other kinds of gnomons, which ſhew the height of the ſun by letting his rays ſhine through a hole in a plate of metal, ſo as to form his picture upon a level pavement: in an inſtrument of this ſort, *the center of the gnomon* is the point in the pavement which is exactly under the center of the hole: the way of finding the meridian height of the ſun by one of theſe gnomons is the ſame as by the other firſt deſcribed; only, inſtead of the length of the ſhadow caſt by the pillar, we here meaſure the diſtance of the ſuns picture from the center of the gnomon.

422 Of this kind was the gnomon made in the church of *St. Petronia* at Bologna, in the year 1576, by *Egnatio Dante*; the nature of which is eaſily underſtood, by fig. 56, taken out of *Ricciolus*[a]: AB is the ſouth wall of the church, 56
near the top of which is placed a braſs plate of the thickneſs repreſented by the letter T; the bigneſs of the hole in the plate is ſhewn by the circle Z; the plate was ſet inclined in the wall in an angle of about 45° ½, which is the height of the equator in that place; the height of the hole in the plate from the ground is near 66 Bologna feet; the line AN is 169 ſuch feet, drawn upon a marble pavement, not exactly in the meridian, but as near it as the pillars would admit of; the ellipſis C ſhews the place of the ſuns picture upon the

a *Almageſt. nov.* l. 2. cap. 14.

FIG. pavement, at the ſummer, the ellipſis LN, at the winter ſolſtice; and the ellipſis
56 FH at the equinoxes: when the diſtance of the ſuns picture from the center of the gnomon A is to be meaſured, we muſt take the center of the picture, which, for example, at the equinoxes is the point *a*, marked by the ray *s a*, drawn fromthe center of the ſun.

423 Of this kind alſo was the gnomon made in the ſame church of *St. Petronia* at Bologna, in the year 1645, by *Dominico Caſſini*; who placed the braſs plate, through the hole of which the rays of the ſun were to paſs, in the roof of the church, and drew a meridian line 120 feet in length upon the pavement: the thing is ſo well repreſented in the reverſe of a medal ſtruck upon that occaſion, that I thought it would be agreeable to the reader to ſee an exact copy thereof: I have therefore taken one out of the *Giornale de letterati*, and prefixt it as an head-piece before the firſt book of this work: a larger picture of it may be ſeen in *Wright*'s travels.

424 *Bianchini* and *Maraldi* did in the ſame manner, draw a meridian line upon the pavement of the great hall of the baths of *Diocleſian*, now the church of the *Carthuſians*, in Rome: an account of this is given by *Bianchini* in a treatiſe entituled *Blanchinus de nummo & gnomone Clementino.*

425 A gnomon may be made, and a meridian line drawn, after the manner of *Caſſini*, by the following method; place the braſs plate with a hole in it in the ſouth end of the roof of the building; by a thread with a plummet at the end of it let down through the center of the hole, find the point in the pavement which is exactly under it, this point is *the center of the gnomon*; from this center, draw ſeveral concentric circles; an hour or two before and after noon, mark the points where the northern, as alſo where the ſouthern edge of the ſuns picture touches theſe circles, and you will have ſeveral arcs; a line drawn from the center of the gnomon through the middle of theſe arcs is a meridian line: the reaſon of this operation is the ſame as of that deſcribed § 405.

426 Theſe meridian lines now mentioned, are drawn upon long plates of braſs, with which the marble pavement is inlaid; there are alſo drawn thereon lines croſſing the meridians at right angles, to ſhew how far the center of the ſuns picture at noon reaches, at different times of the year: when the ſuns picture at noon is furtheſt from the center of the gnomon, the ſun is then loweſt, § 417, and conſequently he is that day in his greateſt ſouth declination, and it is then our winter ſolſtice; when the ſuns picture at noon is neareſt to the center of the gnomon, the ſun is higheſt, and conſequently he is then in his greateſt north declination, and it is our ſummer ſolſtice.

427 It is obvious that the leſs the ſuns altitude is, the further from the center will the place of his picture be; for the ſame reaſon as the ſhadow of an upright pillar is longer, the higher the ſun is: as was ſhewn § 417.

428 *To*

428 *To find the time of the solstice*; observe the distance of the suns picture at noon from the center of the gnomon, the day before, and the day after the solstitial day; if these distances are exactly equal, the meridian heights of the sun are for those two days exactly equal, and then the time of the suns being in the solstitial point is exactly at noon: if the distance of the suns picture from the center of the gnomon be greater the day before the solstice than it is the day after, the time of the solstice is before noon; if on the contrary, the time of the solstice is after noon.

It is exceedingly difficult by this method, to find the moment of the solstices within some hours; for at those times the suns declination, and consequently his meridian height, alters not above 15″ in a natural day; and therefore an error of more than 15″ in the observation of the suns meridian height, will occasion an error of a whole day in fixing the time of the solstice; an error of more than half 15″, will cause an error of half a day; and so on in this proportion. *V. Ricciol. alm.* l. 3. c. 14. in *Gregory*'s astronomy l. 3. *prop.* 11. we have a more accurate method of finding the solstices communicated by Dr. *Halley* in the Philos. transactions of the year 1695.

429 *To find the time of the equinox*; on the day of the equinox, find by a gnomon the meridian height of the sun, and the height of the equator, by § 419; if these be equal, the equinox is exactly at noon; if the height of the sun be different from that of the equator, then, as many minutes as the sun is higher than the equator, so many hours is the moment of the equinox before noon; as many minutes as the sun is lower than the equator, so many hours is the equinox after noon: the reason of this computation is this; at the equinoxes the declination of the sun alters at the rate of 24′ in a natural day, which is 1′ in an hour. From these two last sections it appears, that the equinoxes are much more easily observed than the solstices.

430 It is not improbable that some of those many obelisks[a] erected in Egypt, and dedicated to the sun, were made use of as gnomons; as we are informed by *Pliny*[b] one of them was, at Rome, which *Augustus* brought thither and set up in the *Campus Martius:* the height of this obelisk was 116 feet, it had a round ball placed on the top of it, that the end of the shadow might be seen more distinctly, and the stone pavement upon which the shadow fell was inlaid with brass rulers, which, by marking the different lengths of the meridian shadow, shewed the lengthning and shortning of the days. It is hardly worth mentioning in this place, that the Spaniards, at their conquest of Peru, found pillars of curious and costly workmanship set up in several places,

a *Vid.* Bargaei *commentar. de obelisco, ap.* Graev. *Thes. R. ant. Tom.* 4.
b *Nat. hist.* l. 36. c. 10.

by

by the meridian ſhadows whereof their *Amautas* or philoſophers had, by long experience and repeated obſervations, learned to determine the time of the equinoxes: thoſe ſeaſons of the year were celebrated by them with great feſtivity and rejoycing, in honour of the ſun, whom they fancied at thoſe times to ſit, in all his glory, upon his throne which they erected for him: and therefore on thoſe days they preſented him with rich offerings of gold, ſilver, jewels and other valuable things, adorning his throne, as they did alſo the pillars, with fragrant herbs and flowers. [a]

CHAP. 13. OF THE MEASURES OF LENGTH OF DIVERS NATIONS.

431 Before the dimenſion of the earth be attempted, it will be proper to aſcertain the length of thoſe meaſures, by which the magnitude thereof is to be expreſt: and firſt we will conſider the leſſer meaſures of length, by which the greater are uſually eſtimated; the leſſer meaſures of length have been ſometimes taken from the dimenſions of the parts of an human body, as the foot, the cubit, the palm, &c; here, if we take a man well proportioned and of a middle ſtature, *a foot* is the diſtance between the heel and the tip of the great toe; *a cubit* is the diſtance between the elbow and the end of the middle finger; *a palm* is the breadth of the hand, or four fingers; and *an inch* is the breadth of the thumb; twelve of which are equal to the length of the foot: ſometimes theſe meaſures are taken from other things, as the thickneſs of a middle ſized corn of barley or wheat, and for a meaſure ſtill ſmaller the thickneſs of a hair taken out of an horſes or a camels tail: [b] but in all theſe meaſures there is an uncertainty, ariſing from the difference in the proportions and ſtatures of men, and in the bigneſs of the grains of corn, &c; and therefore, in moſt civilized nations, it is uſual to keep in ſome publick place authorized ſtandards of thoſe meaſures which are moſt in uſe, that recourſe may be had thereto.

432 *Ricciolus* [c] propoſes the following method to find the length of the ancient Roman foot; there was kept in the Capitol, for a ſtandard, a meaſure of a cubic form, called from its ſhape *quadrantal*, or *amphora*; the dimenſion of the inſide of this veſſel was a foot every way; and it contained 80 pounds of wine or water [d]: the ancient pound contained 12 ounces, and the ounce 8 drachms [e]: the weight of the ancient Roman ſilver coin called *denarius* was a drachm [f]: ſeveral of theſe pieces ſtill entire and not ſenſibly diminiſhed by

a *Garcilaſſo de la Vega* Royal hiſtory of Peru, l. 2. c. 22.

b *Sic Arabes. v.* Ricciol. c Geogr. *reform.* l. 2. c. 1. & 2. d Feſtus *in voce quadrantal*, Rhemnius Fannius *de menſ. & pond. ap.* Graev. *Tom.* 2. e *Uncia fit drachmis bis quatuor* ---- Rhemnius Fannius, *unciaque in libra pars eſt quæ menſis in anno.* Rhemnius Fannius. f *Drachma Attica denarii argentei habet pondus, inquit* Plinius, *nat. hiſt.* l. 21. c. 34.

time,

time, were very carefully weighed, and found to weigh at the rate of 8 to a modern Roman ounce[a]; from whence it may be concluded that the Roman ounce and pound are the ſame now as they were anciently: and conſequently if a cubic veſſel be made containing 80 modern Roman pounds of clean rain water, a ſide thereof will give us the length of the ancient Roman foot.

433 The *Congius* was the eighth part of the *amphora*, and contained 10 pounds of wine or water[b]; a ſide of a veſſel of this capacity of a cubic form would ſhew the length of half the Roman foot. *Villalpandus*[c] has given us a print of a braſs *congius* in the *Farneſe* collection, whoſe ſhape was ſuch, that the dimenſions of the ſeveral parts of it ſhewed the length of the Roman inch, half foot, and foot; it being ſo contrived, as he thinks, on purpoſe that it might ſerve for a ſtandard of thoſe ſeveral meaſures in length, as well as for a meaſure of capacity: particularly the thickneſs of the upper rim or lip of this veſſel was an inch, and depth of it exactly a foot: the inſcription upon it ſhews it to have been made in the time of *Veſpaſian*, according to the ſtandard in the Capitol, and that it contained 10 pounds weight: the Roman foot taken from this is therefore called *the foot* of *Veſpaſian*, to diſtinguiſh it from other Roman feet which are next to be deſcribed.

434 There is at Rome an ancient ſepulchral monument of *Coſſutius*, upon which a foot-rule, pair of compaſſes, ſquare, and mallet are cut *in relievo:* of this ſtone, which was formerly in the garden of *Angelo Coloti* a learned antiquary, from whence ſome writers call the foot taken from thence *the Colotian foot*, we have a print in *Lucas Pætus*[d], it is the opinion of this author, that the rule, as well as the reſt of the tools, was placed there to ſhew of what trade *Coſſutius* was, but that the length of it may be drawn at random, there being no reaſon for the workman to be exact about it; and that the Roman foot might better be taken from ancient braſs rules, of which he had three exactly of the ſame length, marked with ſuch diviſions as agreed with the number of equal parts into which the Roman foot is by ancient writers ſaid to be divided: though he meaſured ſome other ancient braſs rules which were of a different length. There is in the Vatican gardens another like monument of *Statilius*, having a foot with its diviſions cut upon it, which are not upon the foot of *Coſſutius:*

a Bp *Hooper* in his enquiry into the ancient meaſures obſerves, that under the Conſuls the weight of the *denarius* was at the rate of 7 to an ounce; that under the firſt Emperours it was diminiſht ſo as to weigh but the eighth part of an ounce; and that afterwards under the *Gordians* and the following Emperours it roſe to its firſt weight.

b *Uti quadrantal vini octoginta pondo ſiet. Congius vini decem pondo is ſiet. Fragment. veteris plebiſciti apud* Feſtum, *voc. pondera publica.*

c Tom. 3. *apparat. urbis & templi Hieroſolym.* l. 3. c. 25.

d *De menſur. & ponder. Rom. & Græc. ap.* Graev. *Theſ. Rom. ant. Tom.* 2.

a *qua-*

a *quadrantal* made by this foot of *Statilius* was found to hold 80 Roman pounds of water; *Greaves*[a] denies this experiment to have been made with accuracy, this author who ſeems to have ſurpaſſed all that went before him in exactneſs, ſhews there is a difference between the foot of *Coſſutius* and that of *Statilius*, whereas other writers had careleſly affirmed them to be both exactly of a length: and he gives the following reaſons why he takes that of *Coſſutius* to be the ancient Roman foot; 1, the length of it is the ſame as that of ſeveral ancient braſs rules, which he carefully meaſured; 2, he found almoſt all the ſtones of white marble in the pavement of the Pantheon to be exactly three Coſſutian feet ſquare, and the leſſer ones of Porphyry one and a half ſquare of the ſame foot: 3, the dimenſions of many of the ſtones in the foundation of the Capitol, and the arcs of *Titus* and *Severus* were ſuch, as made it probable they were cut out by this meaſure; 4, from the neatneſs of the ſculpture, he thinks it not likely the carver would cut the rule too ſhort or too long, when he might as eaſily give it the true length of a foot: 5, having made a *quadrantal* by this foot he meaſured the capacity of it, and found it contained exactly 7 and a half of the *Farneſe congius:* and whereas it ought to have held juſt 8 *congii*, according to what is ſaid of the *amphora* by *Feſtus* and *Rhemnius Fannius*, his opinion is, that when thoſe authors affirm that the length of every one of the ſides of the *amphora* was equal to the Roman foot, they write what was vulgarly believed upon tradition; not that they were preciſely equal, but that they came the neareſt to it of any known meaſure: in like manner he obſerves, both Greek and Roman writers ſpeak of the Roman *denarius* and Grecian *drachma* as of the ſame value; whereas they were not exactly ſo, but only by common eſtimation, ſo that one paſſed for the other, not being much different in weight and value.

235 The learned Bp *Hooper* in his enquiry into the ſtate of the ancient meaſures, p. 153, and 166, ſhews that the cubical relation of the *amphora* to a foot, and of the *congius* to the half foot, was very probably accidental only, and not primarily deſigned; and that it could not be deſigned by the *decemviri*, ſince the doubling the cube was afterward in *Plato*'s time a problem not well underſtood by the Greeks themſelves: and indeed by the *plebiſcitum* it appears, that the capacity of the *amphora* was to be regulated by the weight of the water it was to contain, rather than by the dimenſion of its ſides.

436 The length of the Roman foot being once found, their other meaſures are eaſily known, by variety of paſſages in ancient writers, which tell us what proportion there was between thoſe meaſures and the foot: as when one

a In his diſcourſe of the Roman foot and *denarius*.

tells

tells us that the palm was the fourth part of a foot; another, that the pace was five feet; a third, that the *ſtadium* was 625 feet; *&c.*

437 The *mile* was a Roman meaſure containing a thouſand paces, from whence it had its name[a]: the pace being five feet, the Roman mile was 5000 Roman feet. There was a gilded pillar erected in the *forum* by *Auguſtus*, which from its uſe was called *millarium aureum*[b]; it had inſcriptions upon it ſhewing the diſtances from thence of the principal cities and towns in Italy; and in the great roads there was a ſtone ſet up at the end of every mile, upon which was marked the number of miles it was diſtant from the *milliarium:* from hence come thoſe expreſſions, ſo common amongſt Latin writers, *ad primum, ſecundum, &c lapidem*, to ſignify the diſtance of ſo many miles; as when *Livy*, l. 5, ſays the Romans met the Gauls *ad undecimum lapidem*, eleven miles from Rome. The mile, though originally a Roman meaſure, is often made uſe of by ſuch Greek writers as were acquainted with the Roman affairs: it is ſtill in uſe amongſt ſeveral nations of Europe, but in different places is of a different length.

438 *Caſſini*[c] attempted to find the length of the ancient Roman mile, and of the foot which meaſured it, by the following method; the diſtance between Narbonne and Nîmes is ſaid by *Strabo*, l. 10, to be 88 miles; this diſtance, when the meridian of Paris was prolonged, in the manner deſcribed § 415, was meaſured trigonometrically, and found to be 67500 *toiſes*; if this number be divided by 88, the quotient will be 767, the number of *toiſes* in a mile; and if this laſt number be multiplyed by 6, the product will be 4602, we may caſt away the odd 2 feet as of little conſequence in ſo large a number, and take the round number 4600 for the number of Paris feet in a Roman mile, of 5000 Roman feet: the Paris foot then is to the Roman, as 46 to 50, or as 23 to 25; this is the ſame proportion as there is between the Paris and the modern Roman foot, and conſequently the Roman foot is the ſame now as it was anciently.

439 That this is the true proportion between theſe ancient and modern meaſures, is thus confirmed by the ſame author, by another inſtance: the diſtance between Bologna and Modena is ſet down in the itinerary of *Antoninus*[d], and in the tables publiſhed by *Peutinger*, 25 miles; this diſtance alſo has been meaſured trigonometrically, and found to be 19143 *toiſes*; this number divided

a It is called by *Cicero milliare* and *milliarium*, but more frequently *mille paſſus.*

b Dio. l. 54. Plutarch. *in Galba*, *v.* Panciroll. & Donat. *deſcript. urb. Romæ*, *ap.* Graev. *Theſ. Rom. ant. Tom.* 3. Setting up of mile-ſtones in the Roman roads was long before begun by *C. Gracchus*. Plutarch. *in Gracchis.*

c *Suite des memoires de l'Academie Royale des ſciences ann.* 1718, pag. 150 *ed. Par.*

d *De itinerariis antiquis & recentibus v.* Ricciol. *Geogr. reform.* l. 3. c. 3.

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by 25 makes the mile of 766 *toiſes*, but one *toiſe* leſs than it was found to be in the preceding ſection, thus the Roman mile and the foot which meaſured it ſeem to be pretty well aſcertained.

440 The *ſtadium* is a meaſure of greek original, being the length of the race-ground at Piſa in Elis, where the Olympic games were celebrated; it was marked out by *Hercules*, 600 feet long, meaſuring it by the length of his own foot; and his ſtature being above the common ſize, his foot was proportionally longer than that in common uſe: *Columella*[a] and *Pliny*[b] expreſly ſay, that a *ſtadium* was 625 Roman feet; this number is the eighth part of 5000; and accordingly 8 *ſtadia* are reckoned to a mile: the Olympic *ſtadium* of 600 Herculean feet is commonly to be underſtood when nothing is ſaid to the contrary: in ſome parts of Greece the *ſtadium* was ſhorter, conſiſting of 600 common feet, of a leſs dimenſion than thoſe of *Hercules*[c]: this may occaſion ſome uncertainty in ſome paſſages of ancient authors, where they meaſure diſtances by the *ſtadium*, becauſe it does not always appear which *ſtadium* is meant.

441 There is great diverſity in the modern mile, in different places: the preſent Roman mile contains, according to *Ricciolus*[d], 984 paces; which is but 16 paces leſs than the ancient Roman mile, of 1000 paces: in other parts of Italy, the miles are of different lengths: the mile of Ancona, according to the ſame author, contains 1375 Roman paces; the mile of Bologna, $1266\frac{2}{3}$; the mile of Florence, 1270; that of Ferrara but 898; &c.

442 The Engliſh mile is very uncertain, if we meaſure the diſtances of places by vulgar eſtimation of the number of miles; for then the mile is uſually longer, the further from London: the Engliſh meaſured or ſtatute mile is 5280 Engliſh feet, or 1056 Engliſh paces, each pace being five feet.[e]

443 The French reckon diſtances by leagues, which are very different in different parts of France; *Caſſini*[f] reduces them to three ſorts; 1, the league near Paris, of 2000 *toiſes*; 2, the common league, of 2282 *toiſes*; 3, the league near the coaſt of 2853 *toiſes*.

444 The ancient Grecian foot is generally ſuppoſed to be in proportion to the ancient Roman as 25 to 24, that is to exceed it half a Roman inch: thus we are told by *Greaves* in his diſſertation of the Roman foot p. 40, and *Arbuthnot* in his tables of ancient coins, weights and meaſures; but this I think is true of the Olympic or Herculean foot: for from what *Gellius* ſays l. 2. c. 1. it appears that the common Grecian foot was leſs than this. *Philander* in his comment on *Vitruvius* mentions a porphyry pillar in Rome, upon which there

a Lib. 5. c. 1. b Lib. 2. c. 28. c Gellius lib. 2. cap. 1. Cenſorinus *de die natali* c. 11 *tit. ult.* *Ricciolus*, obſerves upon this occaſion, that if the foot of Hercules was exactly a ſixth part of his height, he was ſix Roman feet and 3 inches high. *Geogr. reform.* l. 2. c. 4. d *Geogr. reformat.* l. 2. c. 8. e Coke 4 *inſtit.* chap. 61. f *Suite des memoires de l'Acad. Royale annee* 1718. p. 247.

was

was an inſcription in greek letters, ſignifying the length of it to be 9 feet, he ſays that he meaſured it, and that the foot there made uſe of exceeded the Roman but the 9th part of an inch: this pillar is alſo mentioned by other authors, but was not to be found when *Greaves* was at Rome, nor ſeveral years before. *Ricciolus* takes the common greek foot to be the ſame with the Roman one deduced by *Villalpandus* from the *congius* of *Veſpaſian.*

445 *Caſſini* gives us the following proportions between the modern foot of different parts of Europe, in the *Suite des memoires de l'Acad. Royale, année* 1718, p. 250. If the Paris foot be divided into 12 inches, every inch into 12 lines, and every line into 10 equal parts, the whole foot will be divided into 1440 equal parts, of which parts the Bologna foot contains 1682; the Rhinland or Leyden foot, 1390; the Engliſh foot, 1350; the Roman foot, 1306.

The *toiſe* is a meaſure which contains ſix Paris feet: as our fathom is ſix Engliſh feet, and the Grecian ὀργυιὰ was ſix Grecian feet.

446 *Greaves* compared the Engliſh foot, taken from the iron ſtandard at Guild-Hall in London, with the ſtandards of divers nations: he gives us a table of them in his diſſertation of the Roman foot, out of which I ſelected the following particulars.

Of ſuch parts as the Engliſh foot contains	1000
The Roman foot, or that on the monument of *Coſſutius* in Rome, which *Greaves*[a] found to be of the ſame length with the ſtandard of the preſent Roman foot cut upon a ſtone in the Capitol, under the direction of *Lucas Pætus*, contains	967
The foot on the monument of *Statilius*	972
The foot of *Villalpandus* deduced from the *Congius* of *Veſpaſian*	986
The Greek foot	1007
The Paris foot	1068
The Rhinland or Leyden foot uſed by *Snellius*	1033
Add to theſe out of *Arbuthnot*'s tables the Bologna foot	1250

Larger tables of the ancient and modern meaſures of divers nations may be ſeen in *Ricciolus Geogr. reformat.* lib. 3. c. 4: *Greaves & Caſſini, loc. citat:* *Arbuthnot*'s tables: and in the authors quoted by thoſe writers.

447 The proportion between theſe ſeveral feet being thus known, if any diſtance be expreſt in one of theſe meaſures, it is eaſy to know what it is in any other of theſe meaſures, by the golden rule: thus, Engliſh feet may be reduced to French, or French to Engliſh, *&c.*

448 It is a common experiment, known to every body, that if *a pendulum* be put into motion, it will ſwing faſter or ſlower according as the thread or

a Diſſert. of the Roman foot. v. *etiam* Fabrettum *de aquis & aquæduct. diſſert.* 2. *ap.* Græv. *T.* 4.

wire of it is ſhorter or longer: a pendulum which meaſures three Paris feet 8 lines and a half from *the center of oſcillation*, or upper end of the wire where its ſwing begins, to the center of the ball, will perform one ſwing in a ſecond of time: this then is *an univerſal meaſure*, whoſe length we ſhall have, if we make a pendulum that will perform 60 ſwings in a minute, or 3600 in an hour: it has indeed been diſcovered, by the ſame clock going ſlower the nearer it was to the equator, that a pendulum kept of the ſame length will ſwing ſlower, the nearer it is to the equator, and faſter the nearer it is to either of the poles: and conſequently, that if we would have a pendulum ſwing ſeconds, it muſt be made ſhorter, the nearer we are to the equator; this difference of length, ariſing from the difference of latitude, is however ſo inconſiderable, that a pendulum which ſwings ſeconds may ſerve very well for an univerſal meaſure, for the greateſt part of Europe.[a]

449 Such an univerſal meaſure as has now been deſcribed, would ſerve to ſhew what proportion there is between the different meaſures of different nations, as well as if the original ſtandards were compared with one another: it would likewiſe ſo aſcertain thoſe ſtandards, that it would eaſily be diſcovered if in time to come any change ſhould be made in them.

450 It would indeed be very well if all meaſures of length were taken from the univerſal meaſure: thus the length of a pendulum which ſwings ſeconds might be called the univerſal yard: a third part of this might be the univerſal foot: five ſuch feet the univerſal pace: 6 ſuch feet the univerſal *toiſe* or fathom: 1000 univerſal paces might be the univerſal mile.

CHAP. 14. THE DIMENSIONS OF THE EARTH.

451 It has already been proved that the earth is round[b]; we are now to ſhew how the magnitude of this globe of the earth, its circumference, diameter, ſuperficial, and ſolid content, may be found in miles, yards, feet, or any other known meaſure.

452 *To find the meaſure of a great circle upon the earth:* draw a meridian line at any place which you make choice of for your firſt ſtation[c]; and take the height of the pole there[d]; prolong the meridian line[e], either northwards, till you come to a place where the pole is elevated one degree more, or ſouthwards, till the height of the pole is one degree leſs than at the firſt ſtation; find the diſtance between theſe two places in miles, yards, feet, or any other known meaſure[f]; and you have then the number of miles, yards, &c, contain-

a *Picard meſure de la terre.* b § 273. c By § 405. d By § 410, 411, 412. e & f By § 415.

ed

ed in one degree, or the 360th part of a great circle upon the earth; this number multiplyed by 360 gives the whole circumference of a great circle upon the earth, in the ſame meaſure, and ſhews the number of miles, yards, feet, *&c*, contained therein.

Scholium, If the meridian be further prolonged, ſo that there is a difference of ſeveral degrees between the heights of the pole in the two places, which are made choice of for the firſt and laſt ſtations, the errors to which the obſervations of thoſe heights of the pole may be liable, will then be divided amongſt all thoſe degrees; and will therefore be of leſs conſequence, than when they are placed to the account of one degree only: with this view, the meridian of Paris was ſo far prolonged, that there was the difference of about $8^\circ\frac{1}{2}$ between the elevations of the pole, at the two extremities thereof; for at the north end of it, in the parallel of Dunkirk, and near that place, the height of the pole was $50^\circ\ 51'$; and at the ſouth end, at Collioure, near Rouſillon, it was but $42^\circ\ 20'$: the difference meaſured upon the meridian is $8^\circ\ 31'\ 11''\ \frac{5}{6}$; the diſtance between the parallels of Collioure and Dunkirk meaſured by trigonometry, in the manner above deſcribed[a], was found, all proper allowances being made, to be 486156 *toiſes*; this number divided by $8^\circ\ 31'\ 11''\ \frac{5}{6}$ will give 57061 *toiſes* to a degree; inſtead of this, *Caſſini* thought proper to take *Picard*'s meaſure of 57060 to a degree, being a round number, and very little different from his own: the earth is here ſuppoſed to be exactly ſpherical, ſo that all the degrees meaſured in a great circle thereof are equal.[b]

453 Since there are 57060 *toiſes* in a degree, if this number be multiplyed by 360, the product 20541600 will be the number of *toiſes* contained in a great circle upon the earth.

454 The circumference of a circle being given, its diameter may be found, by § 68; thus, from the circumference of a great circle upon the earth in the preceding ſection, the diameter of the earth is found to be 6538594 *toiſes*; the ſemidiameter then is 3269297 *toiſes:* theſe meaſures are given us by *Caſſini*, in the *Suite des memoires de l'Acad. R. ann.* 1718. pag. 247 *edit. Par.* and are the ſame as were before given by *Picard*, in his *meſure de la terre*; *art.* 11.

455 There being ſix Paris feet in a *toiſe*, if the foregoing numbers be multiplyed by 6, we ſhall have the following dimenſions of the earth in Paris feet:

	Paris feet.
One degree of a great circle upon the earth is	342360
The circumference of a great circle upon the earth is	123249600
The diameter of the earth is	39231564
The ſemidiameter of the earth is	19615782

a By § 415. b *Suite des mem. de l'Acad. R. ann.* 1718. p. 247.

456 Since

456 Since, according to *Greaves*'s table,[a] the Paris foot is to the English foot, as 1068 to 1000; we may by the golden rule find the following dimensions of the earth in English feet:

	English feet
A degree of a great circle upon the earth is	365640
A minute of a degree is	6094
A second is	$101\frac{1}{2}$
The circumference of a great circle upon the earth is	131630573
The diameter of the earth is	41899310
The semidiameter of the earth is	20949655

457 If these English feet be reduced to English miles, each mile containing 5280 feet, we shall have the following dimensions of the earth in English statute miles:

	English miles
A degree of a great circle upon the earth is	$69\frac{1}{5}$
A minute of a degree is	$1\frac{9}{60}$
The circumference of the earth is	24930
The diameter of the earth is	$7935\frac{2}{5}$
The semidiameter of the earth is	$3967\frac{1}{2}$

458 The circumference of the earth being given, by § 457, the surface of the earth will by § 204 be found to be 200,000,000 square English miles.

459 The surface of the earth being given by § 458, the solid content of the earth will by § 205 be found to be 266,000,000,000 cubic, English miles.

460 To find the measure of the earth is a problem which, in all likelyhood, has been studied by astronomers, ever since the earth was believed to be spherical: *Laërtius* [b] mentions *Anaximander*, the disciple of *Thales*, as the first amongst the Greeks who wrote upon this subject: *Archytas* [c] of Tarentum an eminent Pythagorean famous for his skill in mathematics and mechanics, seems to have made some attempts this way: perhaps these were the authors of the most ancient opinion we have of the magnitude of the earth, recorded by *Aristotle*, in his book *de cælo*[d], *viz.* that the circumference of the earth is four hundred thousand *stadia:* this is almost twice as much as it has since been determined to be; but such a mistake, made when astronomy was in its infancy, is very pardonable: it is probable *Aristarchus* of Samos considered the magnitude of the earth as well as of the sun, and moon: *Archimedes*[e] mentions the ancients who held the circumference of the earth to be 300000 *stadia:* what methods were used by these Geometers does not at present appear, but that

a § 446. b γῆς καὶ θαλάσσης περίμετρον πρῶτος ἔγραψεν Laertius *in* Anaximandro.

c Hor. Od. 28. lib. 1. *Te maris & terræ numeroque carentis arenæ*
Mensorem cohibent Archyta. d Lib. 2. cap. *ult.* e *In arenario.*

they

they were obſervations of ſtars in the zenith, or in the horizon, and actual meaſuring ſome part of the circumference of the earth, is very probable, from what the writer *de cælo* remarks in the place juſt now quoted; that we have different ſtars paſs through our zenith, according as our ſituation is more north or ſouth; and that in the ſouthern parts of the earth we have ſtars come above our horizon, which if we go northward will no longer be viſible to us.

Theſe different appearances of the ſtars point out two ways of meaſuring the earth; one of which is by obſerving ſtars which paſs through the zenith of one place, and do not paſs through the zenith of another; the other by obſerving ſome ſtars which come above the horizon in one place, and are obſerved at the ſame time to be in the horizon of another place.

461 *Eratoſthenes*, at Alexandria in Egypt, made uſe of the firſt of theſe methods; he knew, that at the ſummer ſolſtice the ſun was vertical to the inhabitants of Syene, a town ſituated in the confines of Ethiopia, under the tropic of cancer, where they had a well built for that purpoſe, on the bottom of which the rays of the ſun fell perpendicularly on the day of the ſummer ſolſtice; he obſerved, by the ſhadow of a wire ſet perpendicular in an hemiſpherical baſin, how much the ſun was on the ſame day at noon diſtant from the zenith of Alexandria, and found that diſtance to be a 50th part of the circumference of a great circle in the heaven; ſuppoſing then Alexandria and Syene to be under the ſame meridian, he concluded the diſtance between them to be a 50th part of a great circle upon the earth; and this diſtance being by meaſure 5000 *ſtadia*, that the circumference of the earth is 250000 *ſtadia*: but becauſe this number divided by 360 would give $694\frac{4}{9}$ *ſtadia* to a degree, either *Eratoſthenes* himſelf, or ſome of his followers, aſſigned the round number 700 *ſtadia* to a degree; which multiplyed by 360 makes the circumference of the earth 252000 *ſtadia*: and this is the reaſon why different authors give us theſe two different numbers for the meaſure of *Eratoſthenes*.

462 *Poſidonius*, who lived in the time of *Pompey* the great, attempted to meaſure the circumference of the earth, by the other method of horizontal obſervations: he knew that the ſtar called Canopus was but juſt viſible in the horizon of Rhodes, and that at Alexandria its meridian height was a 48th part of a great circle in the heaven, or $7^{\circ}\frac{1}{2}$; this ſhews what part of a great circle upon the earth the diſtance between thoſe places amounts to; ſuppoſing them both to be under the ſame meridian, and the diſtance between them to be 5000 *ſtadia*, the circumference of the earth will be 240000 *ſtadia*: this is the firſt meaſure of *Poſidonius* related by *Cleomedes*[a], a writer of the ſame age, who remarks that a leſs meaſure is to be taken, if the diſtance between Rhodes and Alexandria

a Lib. I. cap. *ult.*

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is found to be leſs than it was juſt now ſaid to be. *Strabo*[a] makes the circumference of the earth, according to *Poſidonius*, to be 180000 *ſtadia*, at the rate of 500 *ſtadia* to a degree; the occaſion of this diverſity is thought to be this; the ſame author in another place[b] relates, that *Eratoſthenes* meaſured the diſtance between Rhodes and Alexandria, and found it to be but 3750 *ſtadia*; taking this for a 48th part of the earths circumference, according to *Poſidonius*, the whole circumference will be 180000 *ſtadia*: this meaſure, in which the number of degrees aſſigned by *Poſidonius* and the number of *ſtadia* meaſured by *Eratoſthenes* are made uſe of, was received by *Marinus*[c] of Tyre and others, and is generally aſcribed to *Ptolemy*, becauſe he makes uſe of it in his geography, where he often follows *Marinus*.[d]

463 The method of *Poſidonius* is juſtly rejected, becauſe of the uncertainty of refraction, in ſtars that are near the horizon: the method of *Eratoſthenes* is explained at large, and corrected by *Ricciolus*, *geograph. reformat.* lib. 5. c. 3. ſee alſo *Varenius*'s *geography*, l. 1. c. 4.

464 *Caſſini* remarks, that, taking exactly the mean between the laſt dimenſions of *Eratoſthenes* and *Poſidonius*, a degree of a great circle upon the earth will be 600 *ſtadia*, and a minute of a degree 10 *ſtadia*, that is a mile and a quarter of the ancient Roman meaſure; which is juſt a mile of the modern Italian meaſure; for the modern Italian mile is equal to a mile and a quarter of the ancient meaſure, as appears by the diſtance between Bologna and Modena, which is 20 modern Italian miles, and was 25 ancient Roman miles: ſo that, according to this way of reckoning, a degree of the circumference of the earth is 60 modern Italian miles, and 75 ancient Roman miles: the circumference of the earth is 21600 modern, and 27000 ancient miles: and allowing 3 ancient miles to a mean league, a degree will be 25 leagues; and the whole circumference 900 leagues[e].

465 After *Eratoſthenes* and *Poſidonius*, ſeveral others have made uſe of the different heights of the pole in diſtant places under the ſame meridian, to find the dimenſions of the earth: that great encourager of learning among the Arabians *Almamoon* Calif of Babylon, about the year of Chriſt 800, had the diſtance meaſured between two places ſituated two degrees aſunder, and under the ſame meridian, in the plains of Sinjar near the red ſea: the reſult was, that the mathematicians employed in this affair, whether they meaſured each degree

a Lib. 2. pag. 95. *ed.* Caſaub.

b Lib. 2. pag. 126. *ed.* Caſaub.

c Ptolem. *geogr.* l. 1. cap. 7.

d *V.* Ricciol. *geogr. ref.* l. 5. c. 8. & Caſſini *Suite des memoires de l'Acad. R. annee* 1718, p. 16.

e *Suite des memoires de l'Acad. R, annee* 1718. pag. 16. *ed. Par.*

ſeparately,

ſeparately, or went over the whole way more than once, found at one meaſuring 56 miles; at another 56 miles $\frac{1}{3}$; or as ſome have it $56\frac{2}{3}$ in a degree [a].

466 *Fernelius* [b] a learned French Phyſician, in the year 1525, made the next attempt to find out the circumference of the earth: for this purpoſe, he firſt took the height of the pole at Paris, then, going from thence directly northwards, till he came to the place where the height of the pole was one degree more than at Paris, he meaſured the length of the way, by the number of the revolutions of the wheel of his coach in which he travelled; and, after proper allowances for the riſings, declivities, and turnings, which he met with in the road, he concluded 68 Italian miles to be contained in a degree.

467 After this *Snellius* [c], an eminent Dutch mathematician, took the heights of the pole at Alcmaer and Bergen-op-zoom, and found the difference between them 1°. 11′. 30″. he meaſured the diſtances between the parallels of thoſe two places, by taking ſeveral ſtations, and forming ſeveral triangles; by means whereof he found one degree to contain 341676 Leyden feet: he meaſured alſo the diſtance between the parallel of Leyden and Alcmaer, which differ in the elevation of the pole half a degree, and by this meaſuring he found 342120 Leyden feet were contained in a degree: he took the mean number between theſe two, and aſſigned 342000 Leyden feet to a degree; which, according to *Picard*, reduced to French meaſure, make 55021 *toiſes*.

468 Our countryman *Norwood*, in the year 1635, having taken the height of the pole at London and York, and meaſured the diſtance between the parallels of thoſe two places, aſſigns 367200 Engliſh feet, which is 69 miles $\frac{1}{2}$ and 14 poles, to a degree; each pole being 16 feet $\frac{1}{2}$: the method uſed by *Norwood* is deſcribed by him, in a ſmall treatiſe called the ſea-mans practice.

469 *Ricciolus* [d], after the year 1654, having made uſe of ſeveral methods to determine the circumference of the earth, aſſigns to one degree 64363 Bologna paces; which make 61650 French *toiſes*.

470 About the year 1669, the Royal Academy of Sciences at Paris, thought it worth the while to make a new trial for the ſolution of this famous problem; and the rather, becauſe in the former attempts no body had made uſe of teleſcopic ſights, which are much the beſt for this purpoſe; for by them the view may be directed to an object at a greater diſtance, and to a point of an object with more certainty; and conſequently the triangles for meaſuring diſtances may be formed with greater accuracy, than otherwiſe can be done.

a Alfragani *element. aſtron.* c. 10. *& ibi* Chriſtmannus. Ricciol. *geogr. reformat.* lib. 5. c. 11. Picard. *meſure de la terre. Suite des memoires ann.* 1718. chap. 1.

b Fernelius *Coſmotheoriæ* c. 1. Ricciol. *geogr. reform.* l. 5. c. 10. *Suite des memoires ann.* 1718. ch 1.

c Snellius *in* Eratoſthene *Batavo* lib. 2. Ricciol *Geogr. reformat.* lib. 5. cap. 11. *Suite des memoires de l' Acad. R. ann* 1718. p. 17. *ed. Par.*

d Ricciol. *Geogr. reform.* lib. 5.

The fundamental base of the trigonometrical operations was much longer than either *Snellius* or *Ricciolus* had made use of, it has already been described § 415; the distance measured was between the parallels of Sourdon and Malvoisine; the difference between the heights of the pole in these two places was a little more than one degree; the result of the whole was, that one degree was concluded to contain 57060 *toises*. *Picard* in a treatise intituled *mesure de la terre*, gives an account of the whole process in this essay to find the dimensions of the earth, together with a description of the instruments made use of therein, and the manner of adjusting them: this piece was afterwards translated into English by *R. Waller* F. R. S. there is also a large extract out of it published by *Cassini*, *Suite des memoires de l'Acad. R. ann.* 1718, *part.* 2. *chap.* 6.

471 The members of the Royal Academy at Paris, knowing that the longer portion of the meridian was measured, the more accurately would the circumference of the earth be found [a], prolonged the meridian of the R. Observatory quite cross the kingdom of France, and measured it trigonometrically, in the manner already described, § 415, and in the beginning of this chapter: this work was begun in the year 1683, but no progress was made therein till the year 1700, and it was not finished till the year 1718: they made use of the fundamental base of *Picard*, as being measured with sufficient accuracy; an account of the whole process was published by *Cassini* F. in the year 1720; under this title, *Suite des memoires de l'Academie Royale des sciences, année* 1718; in this work it is shewn, that there are mistakes in *Snellius*, in the calculations of some of his triangles, so that his dimensions of the earth are not to be depended upon [b]: it is likewise shewn what defects there are in the methods used by *Ricciolus* [c], the chief occasions of which were his taking too short a fundamental base, and not sufficiently considering refraction.

472 Though *Snellius* had made some mistakes in his calculations, there is no room to question the accuracy of his observations; Holland is, by reason of its flatness, the fittest country in Europe to measure an arc of the meridian therein, and *Snellius* had this uncommon opportunity of finding the exact length of his fundamental base, *viz.* the distance between one tower at Leyden and another at Souterwode; a frost happened, just after the country round Leyden had been overflowed, this enabled him to take two stations upon the ice, the distance between which he carefully measured three times over, and then from those stations observed the angles the visual rays pointing at those towers made with the strait line thus taken upon the ice: these considerations induced *Peter Van Muschenbroek* professor of philosophy and mathematics at Utrecht to make new observations, and form triangles upon the fundamental base

a See the *Scholium* to § 452. b *Suite des memoires partie* 2. c. 8. c *Suite des memoires partie* 2. c. 9.

baſe of *Snellius*, which he did in the year 1700 [a]: the reſult of his operations is FIG.
this, he aſſigns 5703 *toiſes* to a degree, which is but 27 *toiſes* leſs than the French aſtronomers had done. I have here given an account of all the attempts to meaſure the earth which are worth relating: that of the French aſtronomers was made with ſuch care and exactneſs, that I think we may very well acquieſce therein.*

CHAP. 15. THE DIFFERENCE BETWEEN THE APPARENT LEVEL AND THE TRUE: THE EXTENT OF THE VISIBLE HORIZON.

·473 *A truly level ſurface* is a ſegment of any ſpherical ſurface which is concentric to the globe of the earth: the ſurface of the ſea or of any large piece of water, when ſtill, forms it ſelf into a truly level ſurface. *A true line of level* is an arc of a great circle which we imagine to be deſcribed upon a truly level ſurface: *The apparent level* is a ſtrait line drawn tangent to an arc or line of true level. Every point of the apparent level, except the
point of contact, is higher than the true level: thus, fig. 57, let E A G be an 57
arc of a great circle drawn upon the earth, to a perſon who ſtands upon the earth at A the line H D is the apparent level, parallel to his rational horizon R R; but this line, the further it is extended from his ſtation A, the further it recedes from the center; for B C is longer than A C, and D C is longer than B C, &c.

·474 Since the ſemidiameter of the earth is known [b], it is eaſy *to compute how much the apparent level is above the true*, if it be known what the diſtance of the object looked at horizontally is from the ſtation of the obſerver: thus, fig. 57, let the obſerver ſtanding at A look through a teleſcope placed horizontally, at the object B; here B A C is a right-angled triangle [c], in 58
which if A C be made radius, A B will be tangent, and C B ſecant of the angle A C B [d]; now to find this tangent, ſay, as the number of feet in A C the ſemidiameter of the earth is to the number of feet in A B the diſtance of the object; ſo is A C as radius to A B as tangent; that is, ſo is 10000000 to a fourth number; which is the tangent required: the tangent A B being found in the table, we have the ſecant C B, from which if the radius C G be taken, the remainder G B is the exceſs of the ſecant above the radius; or the height of the apparent level above the true. See the following table.

a Muſchenbroek *Diſſertat. de magnitudine terræ.* b § 456. c § 123. d §. 140.

* Other geometrical methods of findi g out the diameter of the earth, without any celeſtial obſervations, may be ſeen in *Kepler, Varenius, Ricciolus*, and others: but, from the variableneſs of refraction, they are leſs certain than the method deſcribed §. 452, for which reaſon I have omitted them. See *Caſſini obſerv. faites en div. endr.* p. 16. & ſeq.

A TABLE

A TABLE SHEWING THE HEIGHT OF THE APPARENT LEVEL ABOVE THE TRUE.

If the distance of the object from the place of the spectator be — which measured in a great circle upon the earth amounts to — the height of the apparent level above the true will be

Seconds	Feet	Inch.	Inch.	Sec.	Feet	Inch.	Inch.
1	101	6. 8		31	3148	6. 8	
2	203	1. 6		32	3250	1. 6	
3	304	8. 4		33	3351	8. 4	
4	406	3. 2		34	3453	3. 2	
5	507	10. 0	0. 074	35	3554	10. 0	
6	609	4. 8		36	3656	4. 8	
7	710	11. 6		37	3757	11. 6	
8	812	6. 4		38	3859	6. 4	
9	914	1. 2		39	3961	1. 2	
10	1015	8. 0	0. 296	40	4062	8. 0	4.746
11	1117	2. 8		41	4164	2. 8	
12	1218	9. 6		42	4265	9. 6	
13	1320	4. 4		43	4367	4. 4	
14	1421	11. 2		44	4468	11. 2	
15	1523	6. 0		45	4570	6. 0	
16	1625	0. 8		46	4672	0. 8	
17	1726	7. 6		47	4773	7. 6	
18	1828	2. 4		48	4875	2. 4	
19	1929	9. 2		49	4976	9. 2	
20	2031	4. 0	1. 186	50	5078	4. 0	7.409
21	2132	10. 8		51	5179	10. 8	
22	2234	5. 6		52	5281	5. 6	
23	2336	0. 4		53	5383	0. 4	
24	2437	7. 2		54	5484	7. 2	
25	2539	2. 0		55	5586	2. 0	
26	2640	8. 8		56	5687	8. 8	
27	2742	3. 6		57	5789	3. 6	
28	2843	10. 4		58	5890	10. 4	
29	2945	5. 2		59	5992	5. 2	
30	3047	0. 0	2. 670	60	6094	0. 0	10. 680

THE CONTINUATION OF THE FOREGOING TABLE.

Min. (If the distance of the object from the place of the spectator be)	Feet. (which measured in a great circle upon the earth amounts to)	Feet. Inch. (the height of the apparent level above the true will be)	Min. (If the distance of the object from the place of the spectator be)	Feet. (which measured in a great circle upon the earth amounts to)	Feet. Inch. (the height of the apparent level above the true will be)
1	6094	0 10. 680	31	188914	851 9. 828
2	12188	3 6. 580	32	195008	907 8. 532
3	18282	7 11. 853	33	201102	965 3. 528
4	24376	14 1. 812	34	207196	1024 7. 884
5	30470	22 1. 932	35	213290	1085 9. 600
6	36564	31 11. 412	36	219384	1148 8. 676
7	42658	42 5. 436	37	225478	1213 5. 112
8	48752	56 9. 384	38	231572	1277 10. 908
9	54846	71 9. 876	39	237666	1348 2. 064
10	60940	88 7. 728	40	243760	1417 1. 764
11	67034	107 2. 940	41	249854	1496 11. 388
12	73128	127 7. 512	42	255948	1569 10. 452
13	79222	149 9. 444	43	262042	1638 9. 084
14	85316	173 8. 736	44	268136	1716 0. 108
15	91410	199 4. 320	45	274230	1794 11. 424
16	97504	226 9. 264	46	280324	1875 7. 032
17	103598	255 11. 568	47	286418	1958 0. 000
18	109692	286 11. 232	48	292512	2042 2. 328
19	115786	319 7. 188	49	298606	2128 2. 016
20	121880	354 0. 504	50	304700	2215 6. 792
21	127974	390 4. 248	51	310794	2305 5. 472
22	134068	428 5. 352	52	316888	2396 9. 240
23	140162	468 10. 224	53	322982	2489 10. 368
24	146256	510 6. 084	54	329076	2584 8. 856
25	152350	553 11. 232	55	335170	2681 4. 704
26	158444	599 1. 776	56	341264	2779 9. 912
27	164538	646 1. 680	57	347358	2880 0. 480
28	170632	694 10. 944	58	353452	2982 0. 408
29	176726	745 5. 568	59	359546	3085 8. 628
30	182820	797 8. 484	60	365640	3191 2. 208

475 The

475 The foregoing table is taken from *Caſſini* [a], only his French toiſes, feet, inches, and lines are here turned into Engliſh feet, inches, and decimal parts of an inch [b]: one *uſe of the table* is, an arc of a great circle upon the earth being given in ſeconds or minutes, to find the length thereof in Engliſh meaſure; thus, an arc of 8″ is 812 feet 6 inches and 4 tenths of an inch; thus again, an arc of 20′ is 121880 Engliſh feet. *Another uſe of the table* is, an arc of a great circle upon the earth being given, in ſeconds or minutes, or in feet and inches, to find what is the exceſs of the ſecant above the radius, or the height of the apparent level above the true: this is ſo little in very ſmall arcs, that it is here given only for theſe numbers of ſeconds, 5″, 10″, and from thence for every 10″: in the table of minutes, it is given for every minute, from 1′ to 60′, and then for every 10′, from 1°, to 2°: thus, if an arc be 20″, or 2031 feet 4 inches, the height of the apparent level above the true is 1 inch 186: thus again, if the diſtance of the place of an object from the place of the obſerver be 30′, or 182820 feet, the height of the apparent level above the true is 797 feet 8 inches: *Another uſe of the table* is, that the diſtance of any object which is viewed through ſights placed horizontally being given, the height of it may be found; or, converſely, the height of the object being given, its diſtance may be found. Thus, if the diſtance of a mountain whoſe top is in the ſenſible horizon be 15′, or 91410 feet, the height of the mountain is 199 feet 4 inches; thus, converſely, if the height of a tower whoſe top appears in the ſenſible horizon be 199 feet 4 inches, the diſtance of the tower from the place of the ſpectator is 15′, or 91410 feet.

476 If the diſtance of an object given be a number of feet which is not in the table, take the number of feet in the table which is neareſt to the number given, and ſay, as the ſquare of the number thus taken, is to the ſquare of the number given; ſo is the height of the apparent level above the true, correſponding to the number taken, to the height of the apparent level which correſponds to the number given: thus, if it be enquired what is the height of the apparent level above the true, when the diſtance of the object is 200000 feet, the neareſt number to this in the table is 201102, the height of the level correſponding thereto is 965 feet, ſay then, as the ſquare of 201102 is to the ſquare of 200000, ſo is 965 to a fourth number of feet, by which the apparent level exceeds the true at the diſtance of 200000 feet. I have hitherto ſuppoſed the line of level to be a tangent to an arc of a great circle drawn upon the ſurface of the earth, whereas, in levelling, the eye is uſually ſome height, ſuppoſe

a *Suite des mem.* part. 2. chap. 5.

b The decimal parts ariſe from turning French meaſure into Engliſh, but may be neglected in any meaſure which exceeds 2 or 3 feet.

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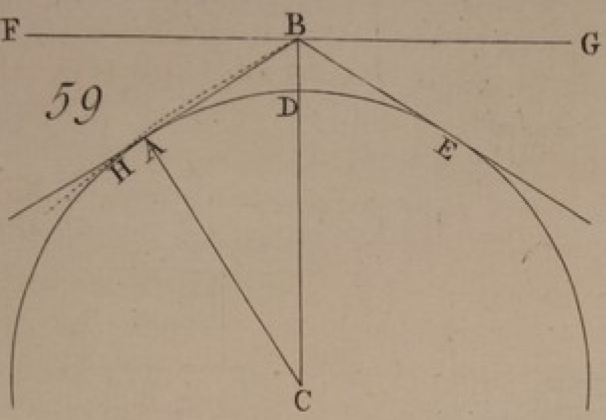

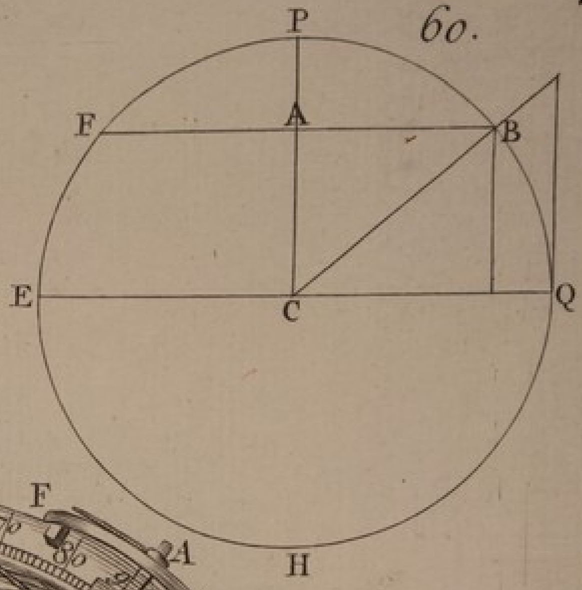

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four feet, above the surface of the earth; but this makes no difference in levelling: FIG.
for as the height of the eye must be added to the radius AC, it must be added 57
also to the secant CB, because ML is supposed in levelling to be parallel to HD: there is indeed a difference between the length of AI and BL, but it is quite insensible. *Ricciol.* l. 6. c. 24.

477 *Another use of the table* is for levelling, in order to convey water from one place to another. *Levelling* is the art of finding out whether two given points above the surface of the earth are of equal height, that is equally distant from the center of the earth or not; and, if they are of different heights, what that difference is: the common methods of levelling are sufficient for laying pavements or walks, for conveying water to small distances, for placing horizontal dials, or astronomical instruments: but in levelling the bottoms of canals which are to convey water to the distance of many miles, the difference between the apparent and true level must be taken into the account: thus, fig. 58 let IAL be an arc of a great circle upon the earth, let it be required to cut a canal whose bottom shall be a true level from A to B, of the 58
length of 5078 feet or 50″, the common method is to place the levelling instrument in the bottom of the canal at A, and looking through the sights placed horizontally at a stick set up perpendicular at B, to make a mark where the visual ray or line of the apparent level points, as E; and then to sink the bottom of the canal at B as much below E as A is below D: but this will not give us a true level, for, by the table, at the distance of 50″ or 5078 feet, the apparent level is 7 inches above the true; and therefore, to make a true level, B must be sunk 7 inches lower than the apparent level directs: so that if A be 4 feet below D, B must be 4 feet 7 inches below the mark E. I have here mentioned the error which will arise from placing the level at one end of the line to be levelled, and shewn how to correct it; but in most cases, it is better to take a station in the middle of the line to be levelled; thus, if the points H and B are to be levelled, place the instrument in the middle at A, and setting up sticks perpendicular at H and B, make marks upon each stick where 58
the apparent level points, as E and F; those points are level: and if you sink H as much below F as B is below E, HAB will be a true level. When the bottom of a canal is thus truly level, if water be let in at one end, it will rise to the same height at the other. If water be required to run with any velocity, that is of another consideration: a river will run, though very slowly, which hath not above six inches descent below the true level for a mile in length: if a river whose water is foul be required to run, with such a velocity as to carry its foulness into the sea, sixteen inches, or at the least one foot fall below the true level, in a mile running, has been thought sufficient, by persons skilful

in

FIG. in that affair. *Vide Ricciol. geogr. reformat.* l. 6. c. 24. The visible horizon hath
been already described, and hath been shewn to have a different extent at a
different height of the eye[a]; I now proceed to a further consideration of it.

·478 The semidiameter of the earth and the height of the eye being given,
the extent of the visible horizon is thus *found*; let ADE be a piece of a great cir-
59 cle upon the earth, C the center of the earth, B the eye of the observer, BD
the height of the eye, BA and BE lines drawn from the eye touching the sur-
face of the earth at A and E, and terminating the visible horizon, the length
of BA is required; in order to find it, proceed in this manner; add DB the
height of the eye, which I will here suppose to be 5 feet, to DC the semidia-
meter of the earth, which is 20949655 feet[b], and you have the length of CB,
20949660 feet; draw CA, and you have a triangle BAC, whose angle at A is
a right one, by § 28, make the hypotenuse CB radius, and CA will be the sine
of the opposite angle ABC, § 140 case I; say then, as CB is to CA, so is the
whole sine or radius to the sine of the angle ABC: this angle being found, its
complement ACB is known[c], and consequently the arc AD is also known, and
may be found in feet or miles by the table[d], or by § 456; thus, in the example
before us, as 20949660 is to 2094655, so is the radius 10000000 to a 4th
number, *viz.* 9999993; which number, is the sine of an angle of 89° 56′:
the angle ABC then is 89° 56′, and therefore its complement ACD is 4′, and
the arc DA is 4′ [e], that is, by the table[f] 24376 feet.

·479 *The depression of the horizon of the sea* at a given height of the eye may
59 be thus *found by calculation:* in fig. 59 if the eye be at B, the sensible horizon
is FG, the depression of the horizon of the sea is the angle FBA, which, being
the complement of ABC, is equal to ACD, that is 4′, by §. 478.

·480 Since the depression of the horizon of the sea, or the angle FBA, fig.
59 59, may be found by observation, §. 294; *the extent of the visible horizon*, at
any height of the eye, may also be *found by observation:* for its semidiameter
59 DA differs not sensibly from an arc of a great circle upon the earth of the same
number of minutes and seconds as the angle of depression is observed to be[g];
and the number of feet contained in that arc may be found in the table[h], thus,
if the depression of the horizon is 30′, the semidiameter of the visible horizon
is also 30′, that is, by the table, 182820 feet. Different authors give us diffe-
rent extents of the visible horizon: either because they differ in the measure
of the earth's semidiameter from whence it is computed, or in their ac-
count of the measures which they make use of: thus, when they differ in the
number of *stadia*, it may be because they differ in the measure of the *stadium*:
Vide Ricciol. geogr. reformat. l. 6. c. 22. *Varen.* l. 3. c. 34.

a § 293 & 294 b §. 456. c §. 55. cor. 5. d §. 474. e §. 30. f § 474. g §. 479. h §. 474.

Book I.

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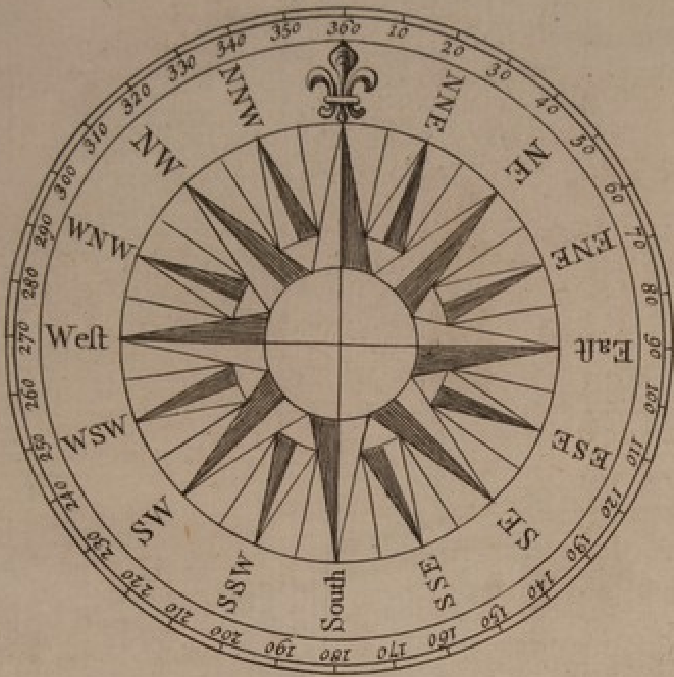

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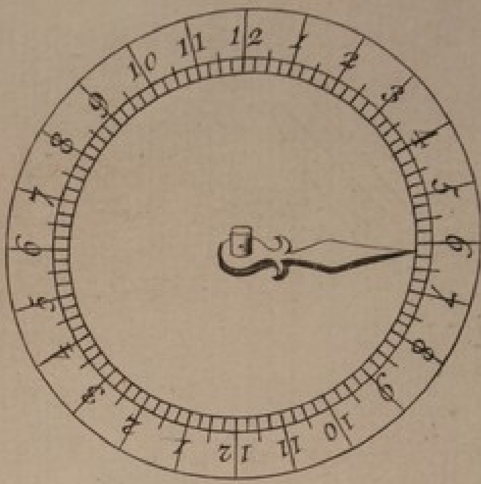

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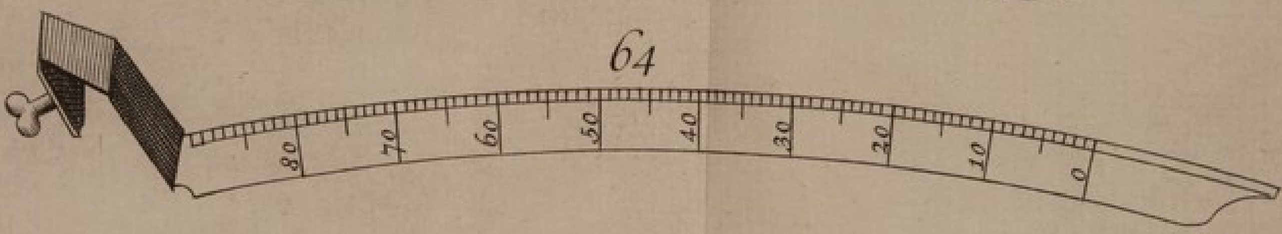

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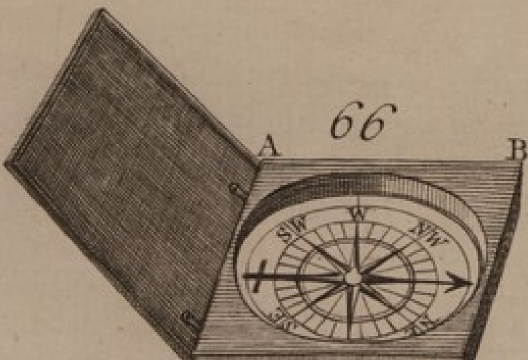

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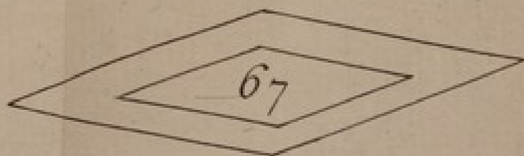

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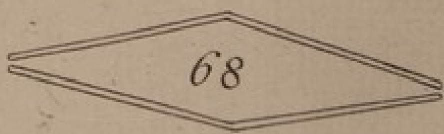

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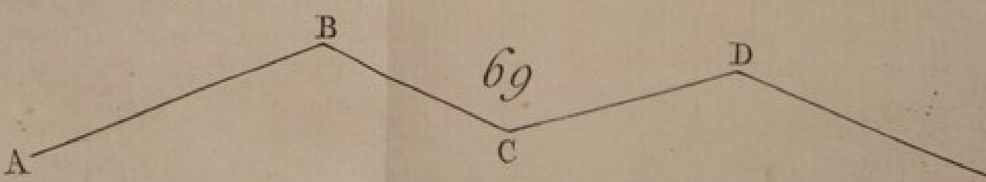

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481 The following table shews the different depression of the horizon of the sea at different heights of the eye, as it comes out, calculated from the dimension of the earth, by the method taught § 294; and as it was found by observation, with the difference between these two, which is owing to refraction: it is taken from *Cassini* [a], only I have turned his French into English feet.

The height of the eye above the surface of the sea. Feet	Inches	The depression of the horizon of the sea. ′ ″	
1157	6, 9	32 30	by observation
		36 18	by calculation
Difference by refraction		3 48	
775	2, 3	27 0	by observation
		29 36	by calculation
Difference by refraction		2 36	
571	11, 0	24 0	by observation
		25 25	by calculation
Difference by refraction		1 25	
387	3, 4	19 45	by observation
		20 54	by calculation
Difference by refraction		1 9	
288	4, 3	15 0	by observation
		17 1	by calculation
Difference by refraction		2 1	
187	0, 9	13 0	by observation
		14 41	by calculation
Difference by refraction		1 41	
9	7, 3	3 20	by observation
		3 18	by calculation

a *Observations astronomiques faites en divers endr.* p. 18. Ed. Par.

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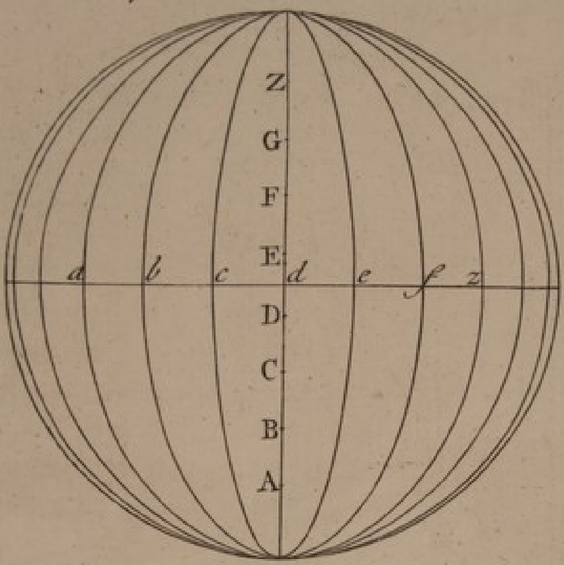

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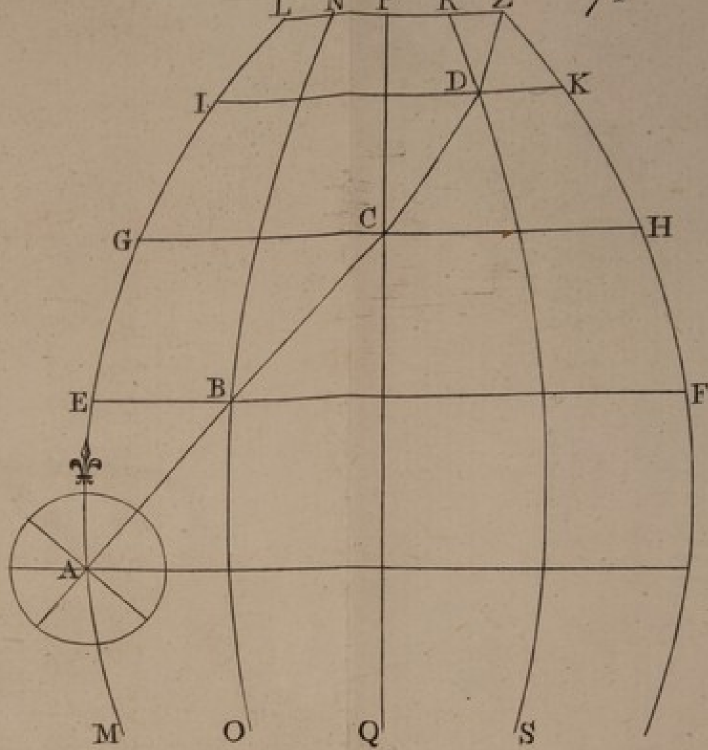

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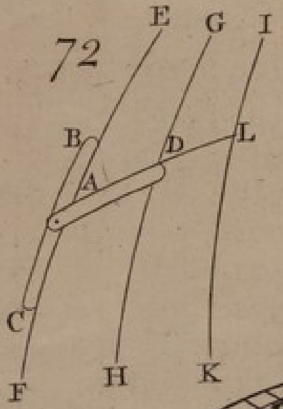

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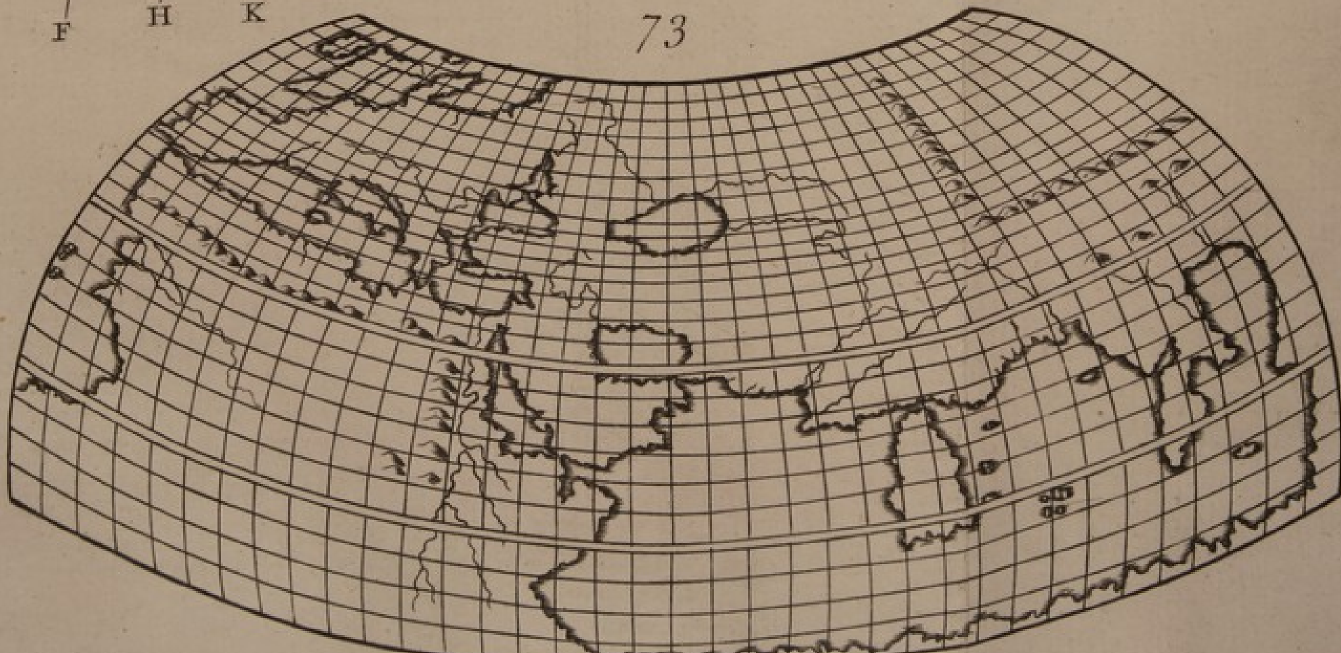

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A TABLE SHEWING THE MEASURE OF A DEGREE OF LONGITUDE IN DIFFERENT LATITUDES.

Deg. of lat.	Engl. feet.	Geogr. miles.	Deg. of lat.	Engl. feet.	Geogr. miles.
0	365640	60.	36	295809	48. 54
1	365584	59. 99	37	292013	47. 92
2	365417	59. 96	38	288128	47. 28
3	365139	59. 92	39	284156	46. 63
4	364749	59. 85	40	280096	45. 96
5	364249	59. 77	41	275952	45. 28
6	363637	59. 67	42	271723	44. 59
7	362914	59. 55	43	267412	43. 88
8	362082	59. 42	44	263019	43. 16
9	361138	59. 26	45	258547	42. 43
10	360085	59. 09	46	253995	41. 68
11	358922	58. 90	47	249366	40. 92
12	357650	58. 69	48	244661	40. 15
13	356269	58. 46	49	239881	39. 36
14	354779	58. 22	50	235029	38. 57
15	353181	57. 96	51	230105	37. 76
16	351476	57. 68	52	225110	36. 94
17	349663	57. 38	53	220048	36. 11
18	347744	57. 06	54	214918	35. 27
19	345719	56. 73	55	209722	34. 41
20	343589	56. 38	56	204463	33. 55
21	341354	56. 01	57	199142	32. 68
22	339016	55. 63	58	193760	31. 80
23	336573	55. 23	59	188319	30. 90
24	334029	54. 81	60	182820	30. 00
25	331382	54. 38	61	177266	29. 09
26	328635	53. 93	62	171658	28. 17
27	325788	53. 46	63	165997	27. 24
28	322841	52. 98	64	160286	26. 30
29	319796	52. 48	65	154526	25. 36
30	316654	51. 96	66	148719	24. 40
31	313415	51. 43	67	142867	23. 44
32	310080	50. 88	68	136971	22. 48
33	306652	50. 32	69	131034	21. 50
34	303129	49. 74	70	125056	20. 52
35	299515	49. 15			

FIG. The meaſure of a degree in any parallel is found by the following proportion: as the radius is to the coſine of the latitude of any parallel, ſo is the number of feet, yards, miles &c. in a degree of a great circle, to the number of
60 feet, yards, miles &c. in a degree of that parallel. *Demonſtration*, let EPQH be a meridian drawn upon the earth, EQ the equator, FB a parallel, ſuppoſe of 40°: I ſay the circumference of the equator is to the circumference of the parallel FB, and conſequently a degree in the equator or in any great circle is to a degree in that parallel, as CB the ſemidiameter of the equator is to AB the ſemidiameter of the parallel: but AB is coſine of the arc BQ which is the latitude of the parallel FB; therefore a degree in the equator is to a degree in the parallel, as the radius is to the coſine of the latitude. Q. E. D. By this propoſition the foregoing table is calculated, which ſhews the meaſure of a degree of longitude in the ſeveral parallels drawn through every degree of latitude, from the equator to the latitude of 70°. In the firſt column of the table is the degree of latitude, the ſecond column ſhews the meaſure of a degree in engliſh feet, the third column ſhews it in geographical miles and decimal parts: *a geographical mile* is the ſixtieth part of a degree of a great circle upon the earth.

CHAP. 17. THE USE OF THE TERRESTRIAL GLOBE.

485 *The terreſtrial globe* is an image of the earth in little, which exhibits to our view the ſurface of the earth and the parts thereof, as ſeas, continents, iſlands, lakes, rivers, countries, kingdoms and ſtates, &c. in their proper di-
61 menſion, ſhape and ſituation. See fig. 61.

486 It hath already been obſerved, that we may imagine what circles we pleaſe to be drawn upon the ſurface of the earth: ſome of theſe imaginary circles, as the equator with ſome of its parallels and ſecondaries, are actually drawn upon the globe; others, as circles of diſtance, or poſition, the horizons and meridians of different places, may be repreſented by the apparatus or furniture of the globe.

487 *The equator*, deſcribed § 298, is drawn with double and ſometimes with treble lines, and is divided into 360 degrees of longitude, beginning at the firſt meridian: in large globes, each degree is ſubdivided into halves and quarters of a degree: the equator ſhews at once whether any given place upon the globe is in north or ſouth latitude. § 326.

488 *Secondaries of the equator* or *meridians* deſcribed § 299, are, upon ſmall globes, uſually twelve in number, ſo that there are twenty four geo-
graphical

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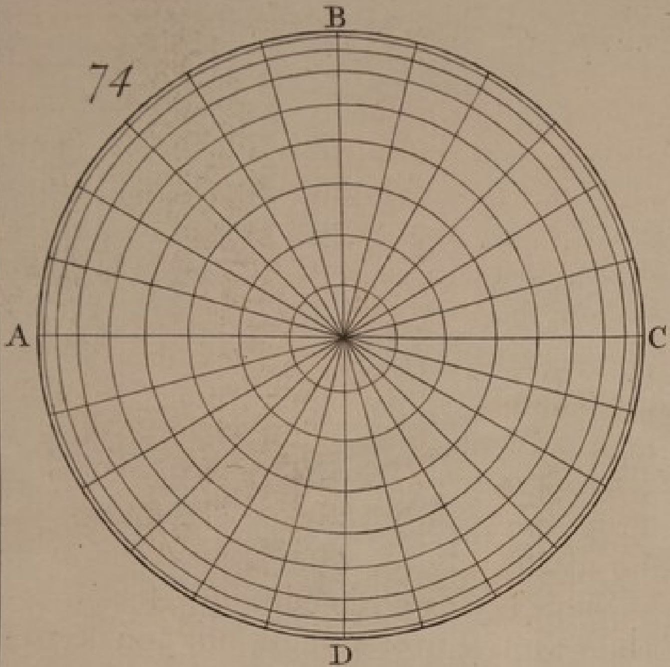

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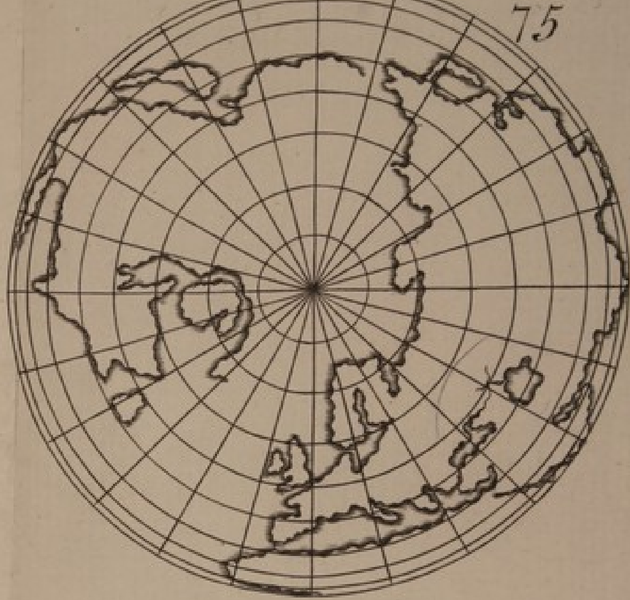

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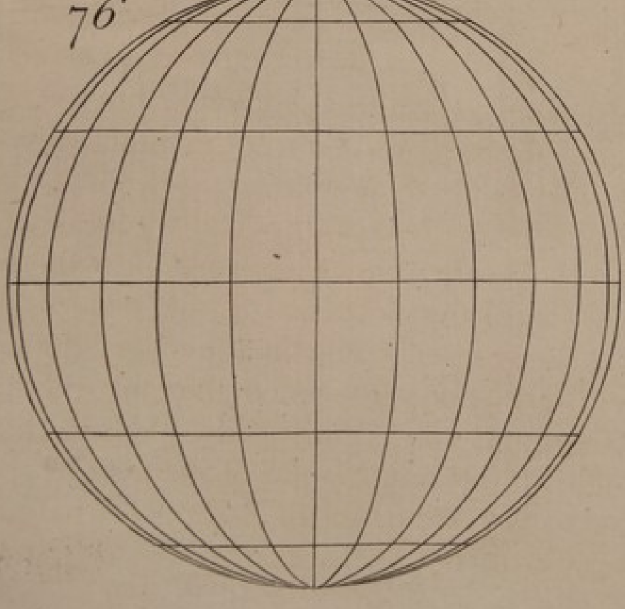

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graphical meridians, deſcribed § 300, drawn at equal diſtances, one through every fifteenth degree of the equator; *the firſt meridian*, deſcribed § 309, is diſtinguiſhed from the reſt by double lines. Theſe meridians give a general view of the longitude of places, but ſhew it accurately in thoſe places only through which they are drawn. FIG.

489 *Terreſtrial parallels*, deſcribed § 335, are uſually drawn on each ſide of the equator, through every tenth degree of the firſt meridian: they give a general view of the latitude of places, but ſhew it accurately in thoſe places only through which they are drawn. In large globes, both meridians and parallels may be more numerous. The circle which cuts the equator obliquely will be conſidered hereafter.

490 *The tropics*, deſcribed § 390, and the *polar circles*, deſcribed § 375, are drawn with double lines, to diſtinguiſh them from the other parallels. *The zones*, deſcribed § 401, are eaſily ſeen upon the globe. *The furniture of the globe* is now to be conſidered.

491 *The axis of the globe* is a ſtrait wire paſſing through the globe at the poles, and repreſents the axis of the earth, deſcribed §. 298.

492 *The meridian of the globe* is the braſs circle in which the globe is ſuſpended by the axis: It hath one ſide graduated, or divided into 360 degrees, the innermoſt edge of this graduated ſide is properly the meridian, deſcribed § 299, and divides the globe into the eaſt and weſt hemiſpheres.

493 The meridian conſiſts of two ſemicircles; one of them ABC, which is 61
commonly made uſe of to expreſs *the geographical meridian*, deſcribed § 300, is divided into two quadrants, the degrees whereof are numbered 10, 20, 30, &c. to 90; beginning at the equator, and proceeding towards each of the poles, in order to ſhew the latitude of places: the other ſemicircle ADC which repreſents *the oppoſite meridian*, deſcribed § 300, is alſo divided into two quadrants, the numbers thereon 10, 20, 30, &c. proceed from each pole towards the equator, in order to ſhew the elevation of the pole.

494 The geographical meridian is generally meant, when we ſpeak of the meridian in the uſe of the globes. *The zenith point of the meridian* is the point
directly over the center of the horizon of the globe, as L is, fig. 61. 61

495 *The horizon of the globe* is the wooden circle on the top of the frame which ſupports the meridian, with the globe ſuſpended therein: the upper ſide of this circle is properly the horizon, and repreſents the plane of the horizon of any place which is brought to the zenith point of the meridian; and when this is done, the globe is ſaid to be rectified to the horizon of that place:
thus, fig. 61, London ſtands exactly over the center of the horizon, and the 61
globe

FIG. globe is rectified to the horizon of London. How to rectify the globe to the horizon of any place will be shewn §. 509.

The horizon hath two notches for the meridian to slide in, when different elevations of the pole are to be exhibited: there is also, on the bottom of
61 the frame, a little piece of wood marked H, with a notch in it cut in such a manner, that the meridian, sliding therein, may always intersect the horizon at right angles, and be supported at a proper height, so that exactly half the globe and half the meridian may be always above the horizon. In using the globe, the graduated side of the meridian is to be turned towards the east side of the horizon, as in fig. 61.

496 The horizon of the globe hath several circles upon it, among which I shall at present only take notice of the circle of the winds, leaving the rest to a more proper place. *The circle of the winds* hath the 4 cardinal points, described §. 299 and 304, as also the intermediate points, in all 32, with their names, or the initial letters of their names, these are called *the points of the compass*: it is also divided into 360 degrees, in order to shew lesser deviations from the cardinal points. The circle of the winds may be drawn upon paper, a card,
62 or any horizontal plane, and is then usually called *the compass*: fig. 62.

497 *To set* or *rectify the compass*: if *the meridian line of a compass*, that is the line S N which is drawn through the north and south points, be placed exactly over, or parallel to a meridian line of the place where we are, its points will then shew us the respective points in the horizon of that place; its north point will stand towards the north, its east point towards the east, and so of the rest.

61 498 *The hour circle* is a small circle of brass, F G, so placed upon the meridian as to have one of the poles in its center, and that usually the north pole, because the northern parts of the earth fall most frequently under our consideration. It is divided into twice 12 or 24 equal parts, to answer the several hours of the natural day, the two figures of 12 are to be placed exactly
61 over the meridian, the 12 on the south side at F expresses 12 at noon, the other 12 at G stands for 12 at night. The numbers on the west side shew the hours from noon to midnight, the numbers on the east side shew the hours
63 from midnight to noon. See fig. 63.

499 *The hour index* is a small brass pointer, to be put upon that end of the axis which passes through the center of the hour circle: if the globe be turned round in the meridian, the axis will carry the hour index round, so as to make it point successively to all the divisions of the hour circle: however, the index is moveable upon the axis, so that we may hold the globe still and turn the index till it points at what hour we please.

500 *The*

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500 *The quadrant of altitude* is a thin narrow ſlip of braſs bent into a quarter of a circle, fig. 64, with one edge divided into 90 degrees, it hath at one end, which may be called *the center of the quadrant*, a ſcrew, to faſten it to the zenith point of the meridian, the other end is at liberty, and may be carried round the horizon. FIG. 64

501 *To find the diſtance between two places* upon the globe: lay the quadrant of altitude upon the globe, ſo that the graduated edge may paſs through both the places, and obſerve how many degrees and minutes are between them: or thus, with a pair of compaſſes, ſet one foot upon one place, and open the compaſſes till the other foot ſtands upon the other place, then, carry this diſtance to the equator, and, ſetting one foot of the compaſſes upon the firſt meridian, obſerve how many degrees and minutes it is, which you may turn into engliſh miles, by §. 457.

502 *To find all places that are at a given diſtance from a place given:* for example, to find all places that are ten degrees from London: open a pair of compaſſes till they meaſure ten degrees upon the equator, then, ſetting one foot upon London, turn the other round, and it will paſs through all the places that are ten degrees from London. By the ſame method, we may find all places that are at an equal diſtance from any given place: thus, ſetting one foot of a pair of compaſſes upon London, and turning the other round through Rome, we may ſee all places that are at the ſame diſtance from London that Rome is; as alſo what places are nearer to, or further from London than Rome is.

503 *To find the latitude of any place* upon the globe: bring the place to the meridian, and the degree and minute under which it lies ſhews its latitude: thus, bring London to the meridian, as in fig. 61, and it appears to be in 51° 31′ north latitude. If a place lying under the equator be brought to the meridian, the mark over it will be 00, becauſe it has no latitude, § 326.

504 *To find all places which have the ſame latitude with a given place:* ſuppoſe the given place be London, turn the globe round, and all places that paſs under the ſame point of the meridian that London doth, have the ſame latitude with London. *To find the difference of latitude* of two given places upon the globe, as London and Paris: find the latitude of each place, by § 503, and the difference is eaſily known.

505 *To find the longitude of any place upon the globe:* bring the place to the meridian, and the degree and minute of the equator the meridian then paſſes through is the longitude: thus, if Rome be brought to the meridian, its longitude will appear to be 12° 45′, upon our engliſh globes, which have the firſt meridian drawn through London.

506 *To*

FIG. 506 *To find all places which have the same longitude with a given place:* as Naples, it is sufficient to bring Naples to the meridian; for all places then under the meridian have the same longitude as Naples: § 307. *To find the difference of longitude* of two places: find the longitude of each place by § 505 and the difference is easily known.

507 *To find a place upon the globe, its longitude and latitude being given:* let the place be Aracta, the longitude of which I find, in the table §. 331, to be 44°. 55′ east from London, and latitude 36°. 0′ north: bring 44°. 55′ of the equator to the meridian, and under the 36° of N. latitude is Aracta, or the place where it ought to be: for this method will serve *to insert a place upon the globe, its longitude and latitude being given.*

508 *To rectify the globe to the latitude of any place:* let the place be London, which, by the table §. 331, is in 51°. 31′ N. latitude: move the brass meridian in the notches till the north pole of the globe is elevated 51°. 31′ above the north side of the horizon, that is, till the elevation of the pole is equal
61 to the latitude: as in fig. 61.

509 *To rectify the globe to the horizon of any place,* as London: rectify the globe to the latitude of London, by §. 508, and bring London to the meridian; the horizon of the globe will then represent the horizon of London.

510 *To find towards what point of the compass any place lyes from a given place:* if it be enquired towards what point of the compass Lisbon lyes from London, rectify the globe to the horizon of London, by §, 509, screw the center of the quadrant of altitude to the zenith point of the meridian, and turn the other end round till the graduated edge passes through Lisbon; then observe what point of the horizon in the circle of the winds the graduated edge passes through, which in the present case will be S. W. by S, we say then Lisbon lyes South West by South from London.

511 *To find the angle of position between any place and a given place:* if it be enquired what is the angle of position of Lisbon and London, that is, what angle a great circle drawn through these two places makes with the meridian of London, do every thing directed by § 510, and observe how many degrees of the horizon are contained between the graduated edge of the quadrant of altitude and the meridian; which in the present case will be 33 degrees 45′: the angle of position of Lisbon with regard to London is then 33° 45′.

512 *To rectify the globe to the meridian of the place where we are,* which is the same thing as *to rectify the globe to the situation the earth is in every day when it is noon in that place:* suppose the place is London, rectify the globe to the horizon of London, by § 509, then turn the frame of the globe about till the north and south points of the horizon of the globe are towards the north


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north and ſouth: the ſouth may be known by the ſun at noon, the north, by FIG.
the pole ſtar any time of the night: the globe may alſo be rectified to the meridian of any place, by a meridian line, or by a magnetic needle in a compaſs-box, which I ſhall therefore now deſcribe.

513 *The loadſtone* hath, beſides its power of attracting iron and ſteel, a certain *polarity*, or power of turning it ſelf, in ſuch a manner, that one point in its ſurface ſhall ſtand towards the north, and the oppoſite point towards the ſouth pole of the earth; for which reaſon, theſe points are called the north and ſouth *poles of the loadſtone:* this may be ſeen, by incloſing a loadſtone in cork till it will ſwim, and putting it into water, where, if rightly balanced, it will turn its poles towards the reſpective poles of the earth, nearly though not exactly; a loadſtone properly ſuſpended by a thread will alſo turn in the ſame manner. This polarity or *verticity* is communicated to iron or ſteel, by rubbing them upon the loadſtone, ſo that if a needle or ſtrait piece of wire properly touched with a loadſtone be thruſt through a round piece of cork, and thrown into water, it will, as it ſwims, turn its ends north and ſouth: a ſmall long piece of ſteel thus touched, with a little braſs ſocket in the middle of it, by means whereof it may be ſuſpended in an horizontal poſition, ſo as to turn freely about, upon a ſharp pointed pin ſet perpendicular, is *the magnetic needle*, fig. 65: if a compaſs be drawn at the bottom of a box, and the 65
magnetic needle ſuſpended over its center, it makes *the* common *compaſs-box*, fig. 66; which ſhould be made of braſs, wood, glaſs, marble, &c. with this 66
caution, that, except the needle, there be no iron or ſteel about it, leſt it ſhould affect the verticity: ſome have thought that a braſs box is not proper for accurate obſervations, leſt filings of iron ſhould chance to be mixed with the braſs, in caſting.

514 *To ſet the compaſs-box*, ſo that the points of the compaſs ſhall ſtand towards the reſpective points of the horizon of the place where we are: ſet the box upon a table, or any level plane, with this caution, that no iron or ſteel be near it, then turn the box gently about, till the needle, after vibrating to equal diſtances on each ſide the meridian line of the compaſs, reſts exactly over it; that line then points north and ſouth. This is true only in a few places, for in almoſt every part of the earth, there is a *variation of the needle*; that is, it does not point exactly north, but declines from the meridian, towards the eaſt or weſt: thus, this preſent year 1736, the variation was obſerved at London, by Mr. *Graham*, as he informs me, to be 15°. 15′, weſt. The preſent variation of the needle in the place where we are muſt be known, in order to ſet the compaſs-box exactly.

FIG. 515 The variation of the needle is not only different in different parts of the earth, ſo as to be eaſt in ſome, and weſt in others, at the ſame time, and more eaſt or weſt in one place than another; but there is alſo a *variation of the variation*, that is, the variation in the ſame place changes in a tract of time: thus, in the year 1576, when the variation was firſt diſcovered by *Norman* at London, it was 11°. 15′, eaſtward; in the year 1665, it was 1°. 22′. 30″, weſtward; in the year 1666, 1°. 35′. 36″, weſt: in the year 1722, 14°. 17′, weſt: in the year 1736, 15°. 15′, weſt. See *Whiſton*'s Hiſtorical Preface to his treatiſe of the dipping needle, p. 7. See alſo *Phil. Tranſact.* N. 40.

516 There is alſo *a very ſmall variation of the variation* amounting only to a few minutes of a degree, in the ſame place, at different hours of the ſame day, but this is diſcoverable only by very accurate obſervations, no notice can be taken of it at ſea, and the ſetting the globe doth not require ſuch exactneſs; I only mention it here, becauſe I am ſpeaking of the variation. By Mr. *Graham*'s obſervations made in London from Feb. the 6th, 1722, to May the 10, 1723, the greateſt variation was 14°.45′, weſt; the leaſt 13°. 50′, weſt: See *Phil. Tranſact.* N. 383. It has alſo been obſerved, that different needles, eſpecially if touched with different loadſtones, will differ a few minutes in their variation. V. *Poleni epiſt. Phil. Tranſact.* N. 421.

517 *To find the variation:* ſet the meridian line of the compaſs-box over a meridian line, or, if the compaſs-box be ſquare, lay one of the ſides to which
66 the meridian line of the compaſs is parallel, as AB or CD, upon a meridian line, and the needle will ſhew the variation.

518 Some large globes have a compaſs-box upon the pedeſtal, as IK, fig.
61 61, if the compaſs-box be ſet by § 514, the points of the horizon of the globe will be directed towards their reſpective points in the horizon of the place where the globe is, and the globe is then rectified to the meridian of the place.

519 *To rectify the globe to the preſent ſituation of the earth, at any hour of the day:* if you be in London, and would bring the globe into the ſituation the earth is in at four in the afternoon: rectify the globe to the meridian of London, by §. 512: ſince the rotation of the earth carries the meridian and hour-circles of London upon the globe coinciding with the like circles upon the earth, the ſituation of the globe will then correſpond to that of the earth, and if it ſtands in the ſun, it will be illuminated as the earth is.

520 *The hour of the day being given at one place*, as London, *to find what hour it is at any other place* upon the globe, as Naples: rectify the globe to the horizon of London, by § 509, ſet the hour index at 12 at noon, turn the globe round till Naples is at the meridian, the index will then ſhew what hour it is at London, when it is noon at Naples: thus, if it points at 11 in the

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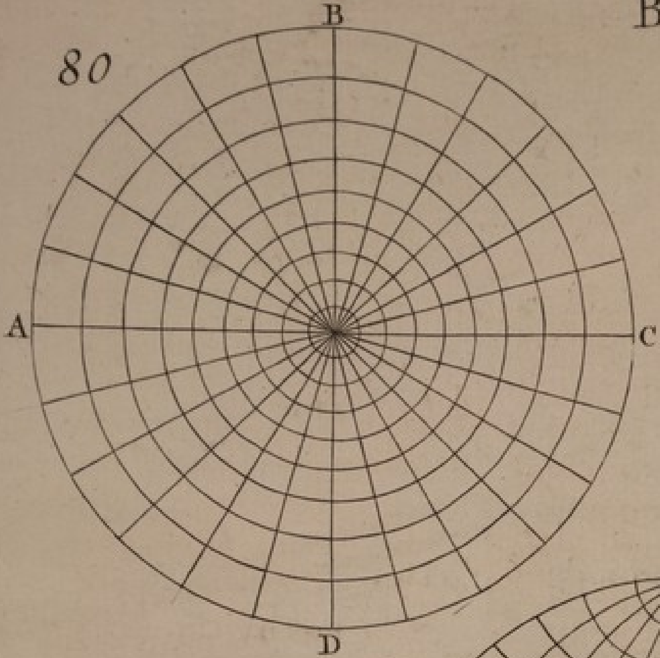

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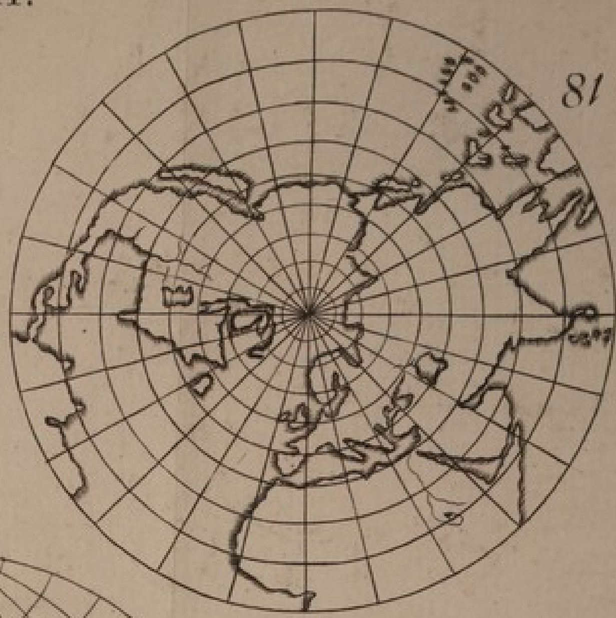

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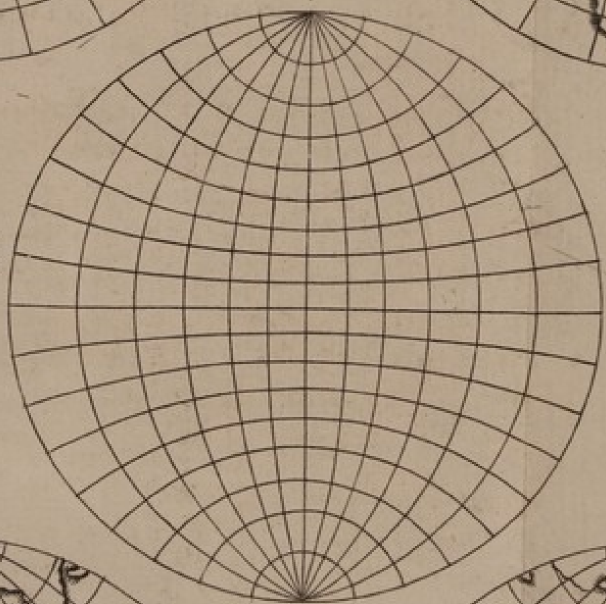

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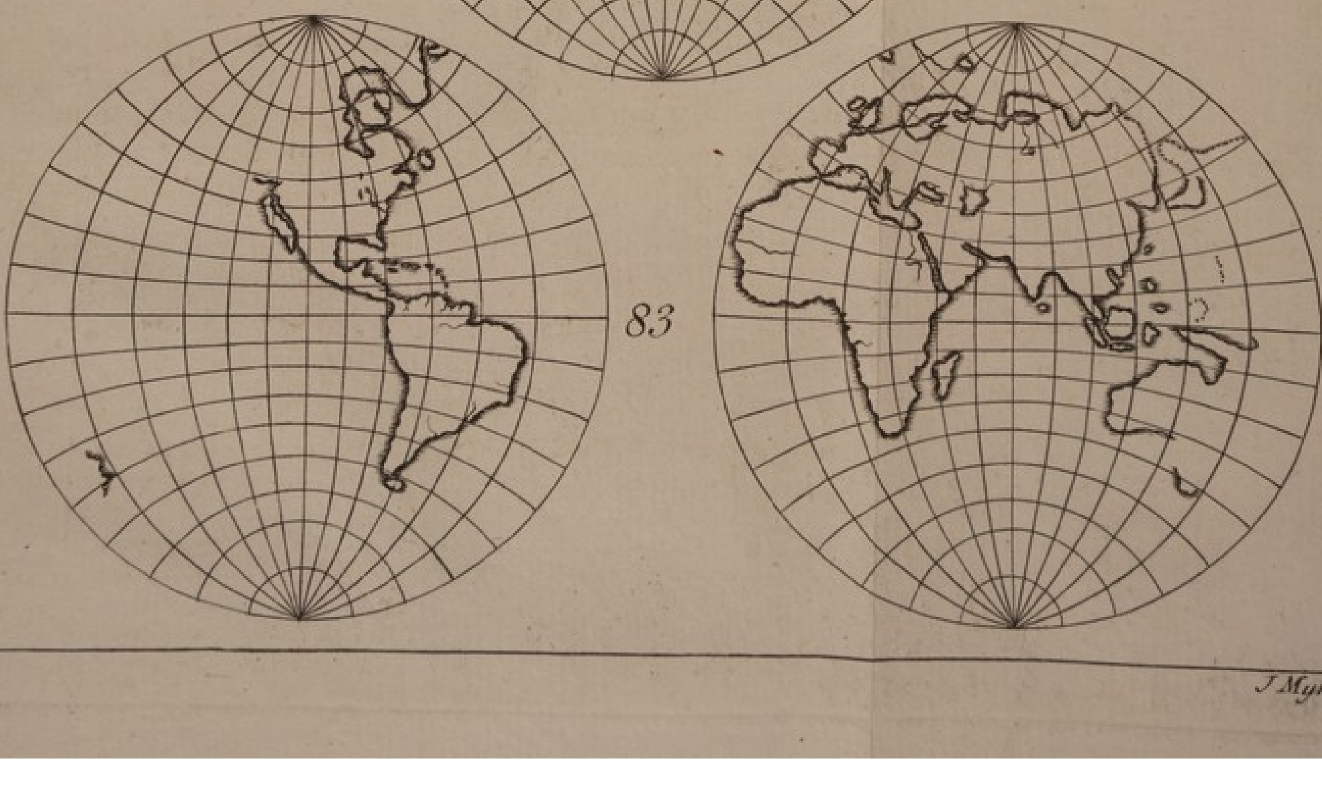

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the morning, it ſhews that it is 11 in the morning at London, when it is noon at Naples; and conſequently, whatever is the time given at London, the time of the day at Naples is an hour forwarder in the day; as if it be 2 in the afternoon at London, it is 3 in the afternoon at Naples &c: this problem may be reſolved more accurately without the globe, by § 333, and the table § 331; theſe would ſhew us that the time of the day at Naples is fifty nine minutes and one ſecond forwarder than at London: it may be proper to obſerve once for all, that though globes ſerve very well to help the imagination, in conceiving the nature of problems to be ſolved, yet they cannot come up to the accuracy of calculation, in the ſolutions they help us to. FIG.

521 In *the ſeaman's compaſs*, the circle of the winds is drawn upon a card, on the under ſide of which, under the meridian line of the compaſs, the magnetic needle is fixt, which is then a thin plate of ſteel of the ſhape repreſented fig. 67, or only two wires, fig. 68, with a ſmall braſs ſocket, by means where- 67
of the card is ſuſpended horizontally upon a ſharp pin ſet upright in a box, 68
and directed by the verticity of the needle, ſo that, by looking thereon, the points of the compaſs in the horizon of the place where the ſhip is may be known, allowance being made for the variation: the ſeaman's compaſs-box hath a weight at the bottom of it, and is hung in two braſs circles, to keep it in an horizontal poſition, notwithſtanding the motion of the ſhip; it is placed in the forepart of the ſhip, where the pilot ſits, and by looking upon his compaſs is able to know, every moment, the points of the compaſs in the horizon of the place where the ſhip is; and conſequently can ſteer her towards what point he pleaſes. How to find the variation at ſea ſhall be ſhewn hereafter.

CHAP. 18. NAVIGATION EXPLAINED BY THE GLOBE: THE RHUMBS.

522 *Navigation* is the art of guiding a ſhip at ſea from one place to another, in the ſafeſt and moſt convenient manner: in order to attain this end, four things are eſpecially neceſſary; 1 to know the ſituation and diſtance of the places: 2 to know, at all times, the points of the compaſs: 3 to know the line in which the ſhip is to be directed from one place to the other: 4 to know, in any part of the voyage, what point of the globe the ſhip is upon.

523 For the firſt, the knowledge of the diſtance and ſituation of the places between which a voyage is to be made implies, beſides a general notion of geography, our being acquainted in particular with the iſlands, rocks, ſands, ſtraits, rivers, &c. near which we are to ſail; the bending in, or running

FIG. ning out of the ſhores, the ſigns of being near land, which are, in ſome places, the appearance of ſome ſorts of birds, the floating of weeds upon the ſurface of the ſea, and very near land, the depth and colour of the water: moreover, the knowledge of the time of the winds ſetting in, particularly of the trade-winds or monſoons: the ſeaſons when ſtorms and hurricanes are to be expected, and the ſigns of their approach: the motion of currents, but eſpecially of the tides: all which is to be learned, by the uſe of good ſea-charts and journals of voyages, but chiefly by obſervation and experience.

524 The ſecond thing required in navigation is, to know at all times the points of the compaſs in the horizon of the place where the ſhip is: the ancients, to whom the polarity of the loadſtone was unknown, as well as its power to communicate that property to iron and ſteel, uſed in the night to find the north, by the pole ſtar; in the day time they found the eaſt or weſt, by the riſing or ſetting of the ſun; the method of doing this ſhall be ſhewn hereafter. Another way they had of knowing the points of the compaſs was, by a view of the land: for their maps ſhewed the bearings of one head-land or cape from another: for this reaſon, the ancients could not venture far from ſhore, where they could have nothing to direct them in bad weather, when neither ſun nor ſtars were to be ſeen. The moderns, beſides the methods uſed by the ancients, have the advantage of the ſeaman's compaſs, deſcribed in the foregoing chapter; by means whereof, they can, at any time, in the wide ocean, and in the darkeſt night, know where the north is, and conſequently, the reſt of the points of the compaſs.

525 The third thing required to be known in navigation is, the line which a ſhip deſcribes upon the globe of the earth, in going from one place to another: this will be treated of in the remaining part of this chapter.

526 *The ſhorteſt way* from one place upon the earth to another is an arc of a great circle drawn through the two places: *The moſt convenient way for a ſhip* is that by which we may ſail from one place to another, directing the ſhip all the while towards the ſame point of the compaſs: a ſhip is guided by *ſteering her*, or directing her progreſs towards ſome point of the compaſs: the line wherein a ſhip is directed is called *the ſhips courſe*, which is named from the point towards which ſhe ſails: thus, if ſhe ſails towards the N. E. point, her courſe is ſaid to be north eaſt: in long voyages, a ſhips way may
69 conſiſt of ſeveral different courſes; as from A to B, from B to C, from C to D, fig. 69: when we ſpeak of a ſhips courſe, we conſider one of theſe at a time: navigation would be exceedingly perplexing, if the courſe were every moment to be changed; the ſeldomer it is changed, the more eaſily is a ſhip guided: and therefore that courſe is the moſt convenient for ſailing, wherein the

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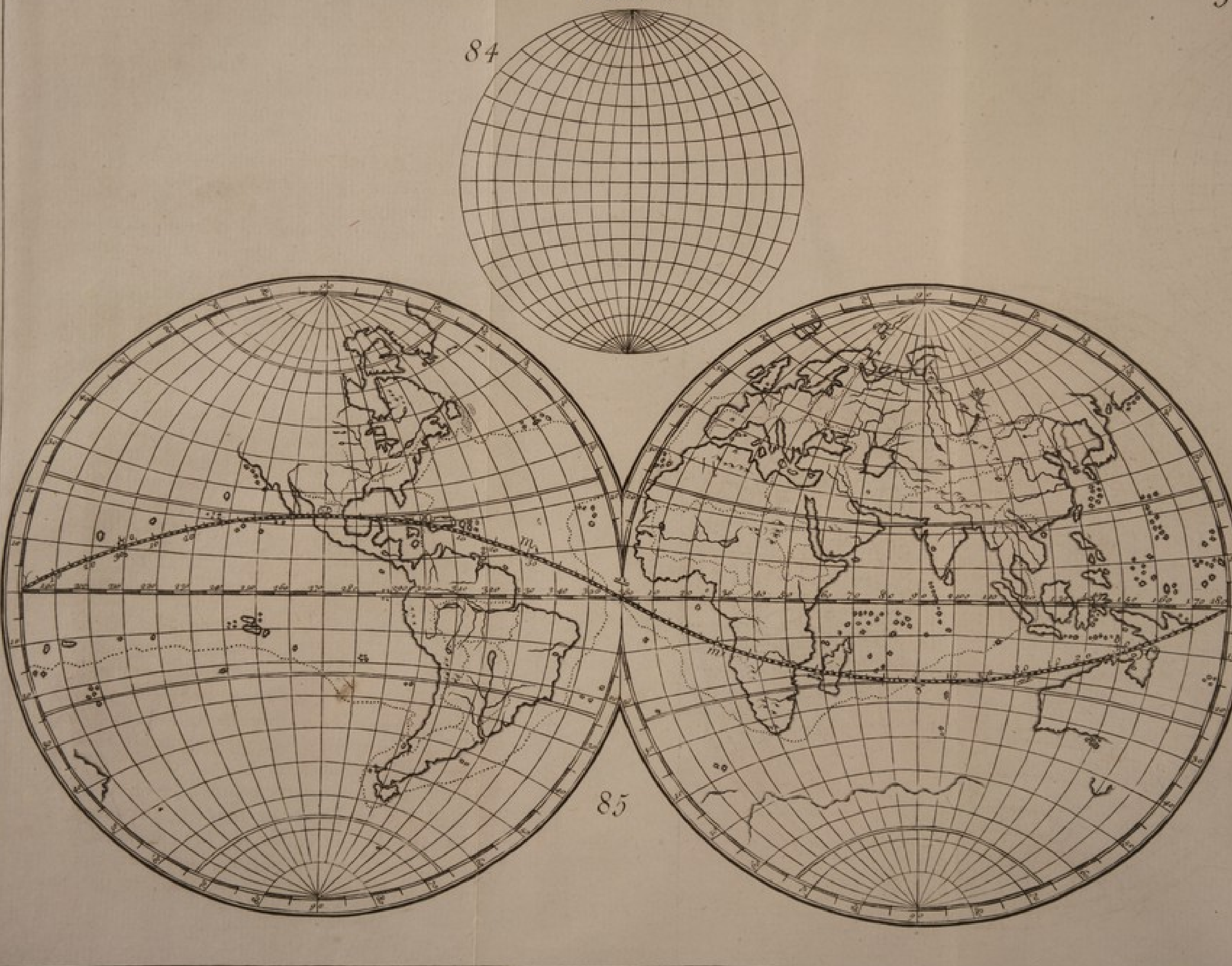

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the ſhip is directed, all the while, towards the ſame point of the compaſs. FIG.

527 *If two places* A *and* Z *lye under the ſame meridian*, the courſe from one to the other is due north or ſouth: thus, fig. 70, let A Z be part of a meri- 70
dian, if A lyes ſouth from Z, the courſe from A to Z is north; and the courſe from Z to A is ſouth: the truth of this is evident from the nature of the meridian, that it marks upon the horizon the north and ſouth points, and that every point of any meridian is north or ſouth from every other point of it: thus, fig. 70, if A be ſouth from Z, it is ſouth from all the intermediate points, as B, C, D, E, &c. as may be ſeen upon the globe, by bringing any of thoſe points to the zenith 70
point of the meridian; and conſequently, if we are to go from Z to A, when we are come to any of thoſe points, we muſt continue the courſe ſouth, to arrive at A: again, if Z be north from A, it is north from all the intermediate points, and therefore, if we are to go from A to Z, when we are come to any of thoſe points, we muſt continue our courſe north, in order to arrive at Z. From this propoſition, we may, by way of converſe, deduce the following corollary; *if a ſhip ſails due north or ſouth*, ſhe will continue in the ſame meridian.

528 *If two places lye under the equator*, the courſe from one to the other is an arc of the equator, and is due eaſt or weſt: thus, fig. 70, let *a z* be part of the equator, if *a* be weſt from *z*, the courſe from *a* to *z* is eaſt; and the courſe from *z* to *a* is weſt: for, ſince the equator marks the eaſt and weſt 70
points upon the horizon, every point of the equator lyes eaſt or weſt from every other point of it: thus, fig. 70, if *a* be weſt from *z*, it is alſo weſt from every intermediate point, *b*, *c*, *d*, *e*, &c; as may be ſeen upon the globe, by placing it as for a right ſphere, by § 346, and bringing *a* or *z* or any of the intermediate points to the zenith of the meridian, and conſequently, if we are to go from *z* to *a*, when we are arrived at any of thoſe points, we muſt continue our courſe due weſt, in order to arrive at *a*: again, if *z* be eaſt from *a*, it is eaſt likewiſe from every intermediate point; and therefore, if we are to go from *a* to *z*, when we are come to any of thoſe points, we muſt continue our courſe due eaſt, in order to arrive at *z*. From hence, by way of converſe, we have the following corollary; *if a ſhip under the equator ſails eaſt or weſt*, ſhe will continue under the equator. In this caſe, and the foregoing, § 527, the courſe, being an arc of a great circle, viz. the meridian or equator, is the ſhorteſt way, as well as the moſt convenient.

529 *If two places lye under the ſame parallel*, the courſe from one to the other is due eaſt or weſt: this may be ſeen upon the globe, by the following method, bring any point of a parallel to the zenith, and ſtretch a thread over it perpendicular to the meridian; the thread will then be a tangent to the parallel, and ſtand eaſt and weſt from the point of contact: therefore, the con-

verſe

FIG. verſe is true, that if a ſhip in any point of a parallel be directed eaſt or weſt, ſhe will go in a tangent to that parallel; and, ſince ſhe muſt go upon the ſurface of the globe of the earth, ſhe will be always in that point of the tangent which touches the parallel: that is ſhe will always be in the parallel. Hence this corollary, *If a ſhip in any parallel ſails due eaſt or weſt*, ſhe will continue in the ſame parallel. In this caſe, the moſt convenient courſe, though not the ſhorteſt, from one to the other is to ſail due eaſt or weſt.

530 *If two places* A and Z *lye neither under the equator, nor in the ſame meridian, nor in the ſame parallel*, the moſt convenient, though not the ſhorteſt,
71 courſe from one to the other is in a rhumb, fig. 71: If we ſhould in this caſe attempt to go the ſhorteſt way, in a great circle drawn through the two places, we muſt be perpetually changing our courſe: for, whatever the bearing of Z is from A, the bearings from all the intermediate points, as B, C, D, E, &c. will be different from it, as well as different from each other; as may eaſily be ſeen upon the globe, by bringing firſt the point A, and then the points B, C, D, E, &c. ſucceſſively to the zenith of the meridian, and obſerving the bearing of Z from each of them: thus, ſuppoſe, when the globe is rectified to the horizon of A, the bearing of Z from A be north eaſt, and the angle of poſition of Z with regard to A 45°; if we bring B to the zenith of the meridian, we ſhall have a different horizon, and the bearing and angle of poſition of Z from B will be different from the former: and if we go on, to bring the other points, C, D, E, &c. to the zenith of the meridian, we ſhall for each of them have a different horizon, and Z will have a different bearing and angle of poſition: from hence we may draw this *corollary*, when two places lye one from the other towards a point not cardinal, if we ſail from one place towards the point of the others bearing, we ſhall never ar-
71 rive at the other place: thus, if Z lyes north eaſt from A, if we ſail from A towards the north eaſt, we ſhall never arrive at Z.

71 531 *A rhumb* upon the globe is a line drawn from a given place A, fig. 71 ſo as to cut all the meridians it paſſes through at equal angles: the rhumbs are denominated from the points of the compaſs, in a different manner from the winds: thus, at ſea, the north eaſt wind is that which blows from the north eaſt point of the horizon, towards the ſhip in which we are; but we are ſaid to ſail upon the N. E. rhumb when we go towards the north eaſt: ſometimes the lines drawn towards the 4 cardinal points are called whole rhumbs, and the middle points between them half rhumbs, and theſe are again divided into quarter rhumbs: ſometimes they divide the 32 points into 4 quarters, and call the rhumb next the eaſt the firſt rhumb, the next to that the ſecond rhumb, &c. Every rhumb bears a certain relation to the meridians through

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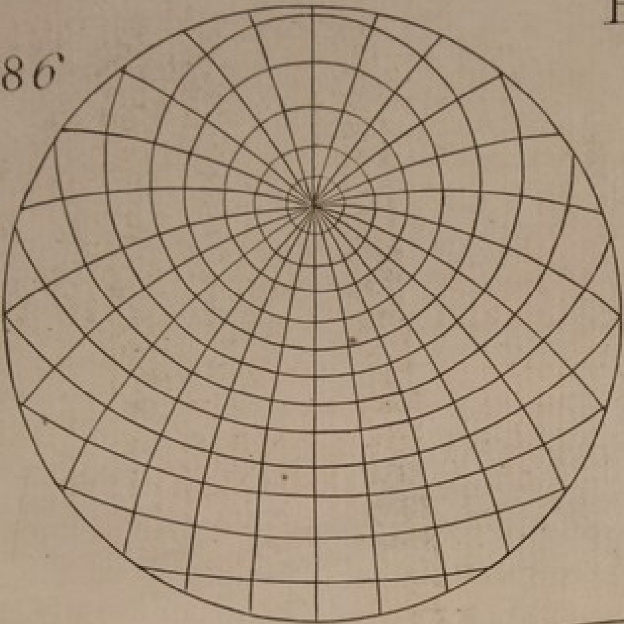

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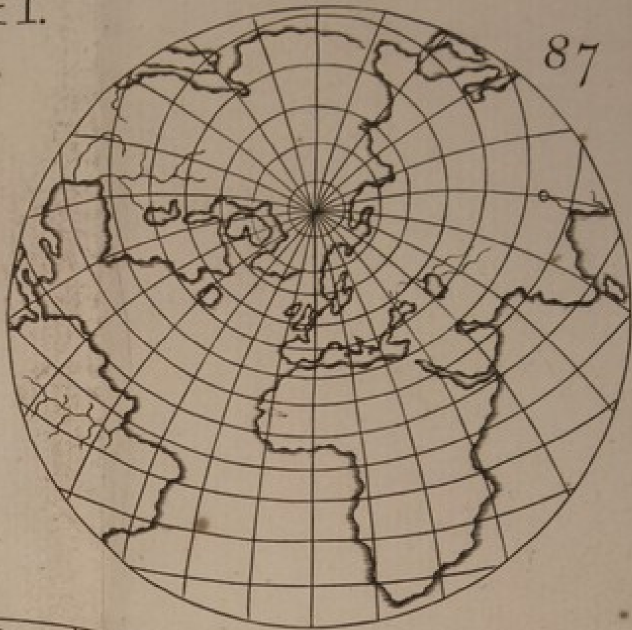

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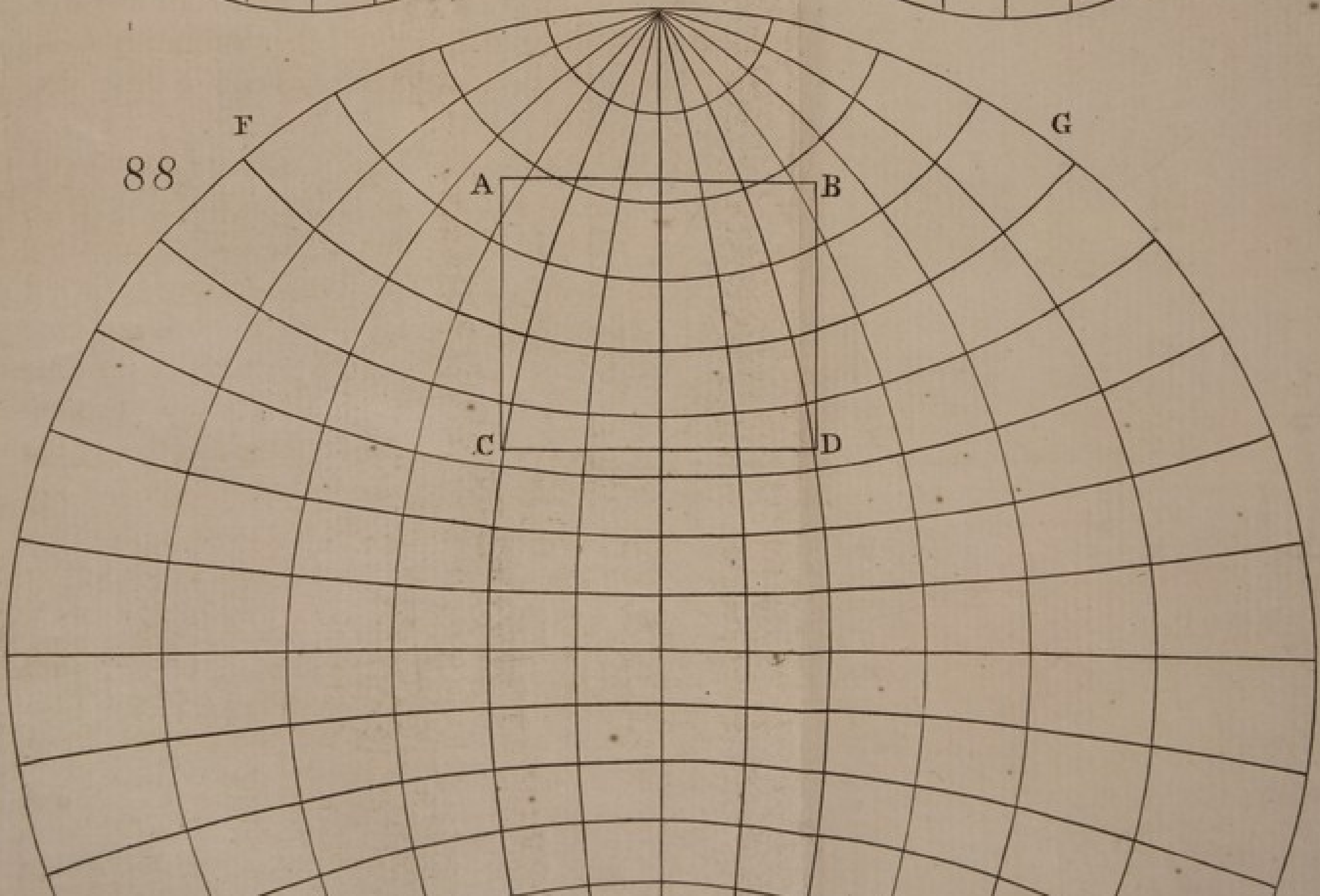

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through which it is drawn, thus, the north rhumb is ſaid to make an angle infinitely ſmall with the meridian, that is, it is coincident with it· the eaſt rhumb makes a right angle, the half rhumbs make half right angles with all the meridians they paſs through &c. it is from this relation that the definition of a rhumb is taken, and from hence it is ſaid to be one eſſential property of a rhumb that it makes equal angles with all the meridians it paſſes through, thus, fig. 71, the rhumb ABCDZ paſſing through the meridians LM, NO, PQ, makes the angles LAB, NBC, PCD, equal, from whence it follows, that the direction of a rhumb is, in every part of it, towards the ſame point of the compaſs: thus, from every point of a north eaſt rhumb upon the globe the direction is towards the north eaſt, and that rhumb makes an angle of 45° with every meridian it is drawn through: we have, on large globes, the compaſs, with rhumb lines proceeding from the center of it, drawn here and there upon the ſea: if the center of a compaſs be in the equator, the four whole rhumbs are arcs of great circles, namely the meridian and equator: if the center of a compaſs be out of the equator, the north and ſouth rhumbs only, are arcs of a great circle, namely the meridian: every other rhumb is a ſort of *helix* or ſpiral line, which continually approaches nearer to one of the poles, but never can come to it. FIG. 71

532 Another property of the rhumbs is, that equal parts of the ſame rhumb are contained between parallels of equal difference of latitude; ſo that a ſhip, continuing in the ſame rhumb, will run the ſame number of miles, in ſailing from the parallel of 10° to the parallel of 30°, as ſhe does in ſailing from the parallel of 30° to that of 50°, or from the parallel of 50° to that of 70°, &c: thus, fig. 71, let LM, NO, PQ, RS be meridians, EF the parallel of the latitude of 10°, GH the parallel of 30°, IK the parallel of 50°, if we draw through them the rhumb ABCD, the lines AB, BC, and CD will be equal, upon the globe: this rule is true, as far as the rhumbs need be conſidered in navigation, but not of any uſe near the poles, becauſe the rhumbs never reach the poles[a]. 71

533 A rhumb may be drawn upon a globe by two rulers bent according to the curvature of the globe, if one of them AD be joyned at one end A to the middle of the other fixt ruler CB, ſo as to be moveable to any angle; the following example ſhews the method of doing it: if it be required to draw from the point A the north eaſt rhumb, move the ruler AD till the angle BAD is 45°, the angle that rhumb makes with the meridian, then apply the edge of the ruler BC to the meridian EF, with the vertex of the angle at A, which is to be the center of the compaſs, the line AD drawn by the edge of the move- 72

a Metius *in doctrina ſpherica* l. 5. c. 4. Vide etiam *de rhumbis*, Varen. *geogr.* l. 3. c. 39. Ricciol. *geogr. reformat.* lib. 10. c. 21.

able

FIG. able ruler is the rhumb required from A to D; which, by applying the edge of the fixt ruler to the next meridian G H, with the vertex of the same angle A at D, may be continued from D to L in the next meridian I K, &c: a curve drawn through these points A, D, L, &c. will be the rhumb required. The more numerous the meridians are, the more exact will the rhumb-lines be: if a compass with rhumbs be thus drawn upon a globe, with the center of the compass
71 upon a given point A, every rhumb will shew towards what point of the compass we must sail, to go from A to any other place, as B, C, D, &c. through which that rhumb passes: thus, fig. 71, if the rhumb A B C D be north east, we
71 must sail north east, to go from A to B, or to C, or D.

The fourth thing mentioned to be required in navigation was, to know at any time, what point of the globe a ship is upon: but before we proceed to this we shall consider the nature and use of maps, because maps are used in the practice of navigation, though the theory be learned by the globe.

CHAP. 19. OF MAPS AND THEIR USE.

534 *A map* is a representation of some part of the surface of the earth, delineated upon a plane: the earth being round, no part of the spherical surface of it can be accurately exhibited upon a plane, and therefore some have proposed the making of *globular maps*[a]; for this purpose, a plate of brass might be hammered, or, at a less expence, a piece of pastboard might be formed into a segment of a sphere, and covered on its convex side with a map projected in the same way as the papers of the common globes are: a map made in this method would shew every thing in the same manner, as it would be seen upon a globe of the same diameter with the sphere upon the segment of which it was delineated: and indeed maps of this sort would be in effect segments of such a globe, but they are not in common use.

535 Maps are either general or particular; the ancients sometimes described all the parts of the then known earth in *one general map*[b], as fig. 73: in
73 this view, one of them compares the shape of the earth to the leather of a sling[c], whose length exceeds its breadth: the length of the then known parts of the earth from east to west was considerably greater than from north to south; for which reason, the former of these was called the longitude, and the other the latitude[d].

536 The modern *general maps* are such as give us a view of an entire hemisphere, or half of the globe; and are projected upon the plane of some great

a Ricciol. *geogr. reform.* l. 10. c. 28. b Magini *geogr. vet. & nov. part.* 2. c Dionys. *perieges.* v. 7. d Ptolem. *geogr.* l. 1. c. 6.

circle,

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circle, which terminates the projected hemisphere, and divides it from the other half of the globe, as the equator, or the meridian, or horizon of some place: from this circle the *projection* is denominated, and said to be *equatoreal*, *meridional*, or *horizontal*.

537 *Particular maps* are such as exhibit to us less than an hemisphere; of this sort are maps of the great parts into which the earth is divided, as Europe, Asia, Africa, North America, South America; or maps of particular kingdoms, provinces, countries, or of lesser districts.

538 *In maps three things are chiefly required: the first* is, to shew the longitude and latitude of places, or the situation they are in with regard to the circles of the globe: this all maps in general, which are laid down from tables of longitude and latitude, perform, by means of the meridians and parallels delineated upon them, in what manner soever they be projected: and they do this the more accurately, the greater number they have of meridians and parallels.

539 *The second* requisite is, to exhibit the shape of countries the same, and the extent of them in the same proportion, as upon the globe: this cannot be done accurately in any general maps, except globular ones; but in particular maps, which take in but a small part of the earth, as a province, or county, the defect will not be sensible.

540 *The third* is, that the bearings and distances of places from one another be truly shewn: this in globular maps would be done in the same manner as upon the globe: it is also done in the true chart described § 553, so as to serve the purposes of navigation: but that chart is very deficient in the second requisite, which was the shewing countries in their true shape and proportion.

541 In *general maps*, the circles of the globe are projected, according to the rules of perspective, the most useful of which to our present purpose have been already laid down in the introduction, from § 250 to the end. The *projections* of the circles in general maps are of two sorts, one *convex*, the other *concave*: to understand which, we may imagine the globe upon which the circles are delineated to be of thin glass, and that half of it is viewed at a time; now we may be conceived to view this hemisphere, either on the convex or concave side, and we may suppose it to be placed at different distances from the eye; from which diversity of our view, there will arise different projections, or pictures of it in a map: if the eye be supposed to view the hemisphere at an infinite distance, the *projection* of its circles, whether it be viewed on the convex or concave side will be the same, namely the *orthographic*, described § 254: in this projection, the parts about the middle are very well exhibited, but the extream parts are very much contracted: the reason

FIG. of which appears, if we confider fig. 147 and 148 of the introduction, which fhew us, that the orthographic projections of convex and concave femicircles divided into equal parts are fimilar, and if the planes of them continued pafs through the eye, they are ftrait lines, unequally divided, fo as to have their divifions much lefs near their extreams than about the middle. If we imagine two femicircles cutting each other at right angles to be drawn upon a glafs hemifphere, with divifions marked at every tenth degree, and viewed at an infinite diftance, with the eye in fuch a fituation that the planes of both femicircles continued pafs through it, the orthographic projection of them, whether
74 concave or convex, will be the lines AC and BD, fig. 74, with the unequal divifions, through which I have drawn circles. To fhew *the orthographic equatoreal projection*, fig. 74 is the orthographic projection of the circles upon the plane
75 of the equator; and fig. 75 is a general map of the northern hemifphere, formed upon that projection: here, the meridians are all ftrait lines, and the parallels compleat circles. For an example of *the orthographic meridional projection*,
76 fig. 76 is an orthographic projection of the circles upon the plane of a meri-
77 dian; and fig. 77 is a general map of an hemifphere, formed upon that projection: here, all the meridians are projected into femiellipfes, by § 258, except that the plane of which produced paffes through the eye, and that is a ftrait line, by § 258: this projection has one advantage not to be found in any other general map, namely, that the decreafe of the parallels from the equator to the poles appears therein in true proportion.

542 *The orthographic horizontal projection* has great variety, according to
78 the different latitude of places, and is pretty difficult to execute; fig. 78, though not perfectly exact, will ferve to give any perfon an idea of it; the center of this map is in Chaldea, about the place where I fuppofe Ur of the Chaldees to have been fituated, it is therefore projected upon the horizon of that place, or near the matter: it was delineated by me in the *camera obfcura*,
79 from *Senex's* great globe, as was alfo the map fig. 79: in a map drawn this way, the extream parts are a little more contracted than in the orthographic projection, from which, notwithftanding it differs very little in the main, though in the orthographic projection the globe is fuppofed to be at an infinite diftance, but in this is placed at a moderate diftance from the eye.

543 The great contraction of the extream parts in the orthographic projection makes it fo deficient in the fecond quality required in maps, that it is feldom ufed, except when the difk of the earth, in a folar eclipfe, is to be exhibited; of which in its proper place: the method commonly made ufe of in the conftruction of maps is *the ftereographic projection*, wherein the eye is fuppofed, from fome point in the furface of a fphere, to view the concave of the

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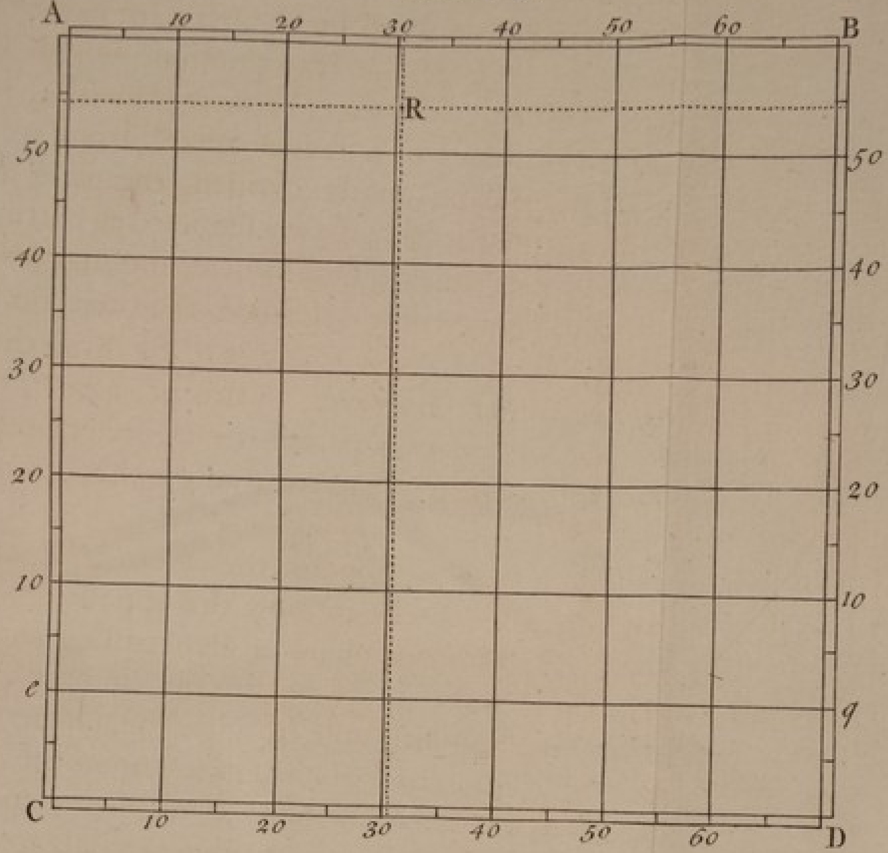

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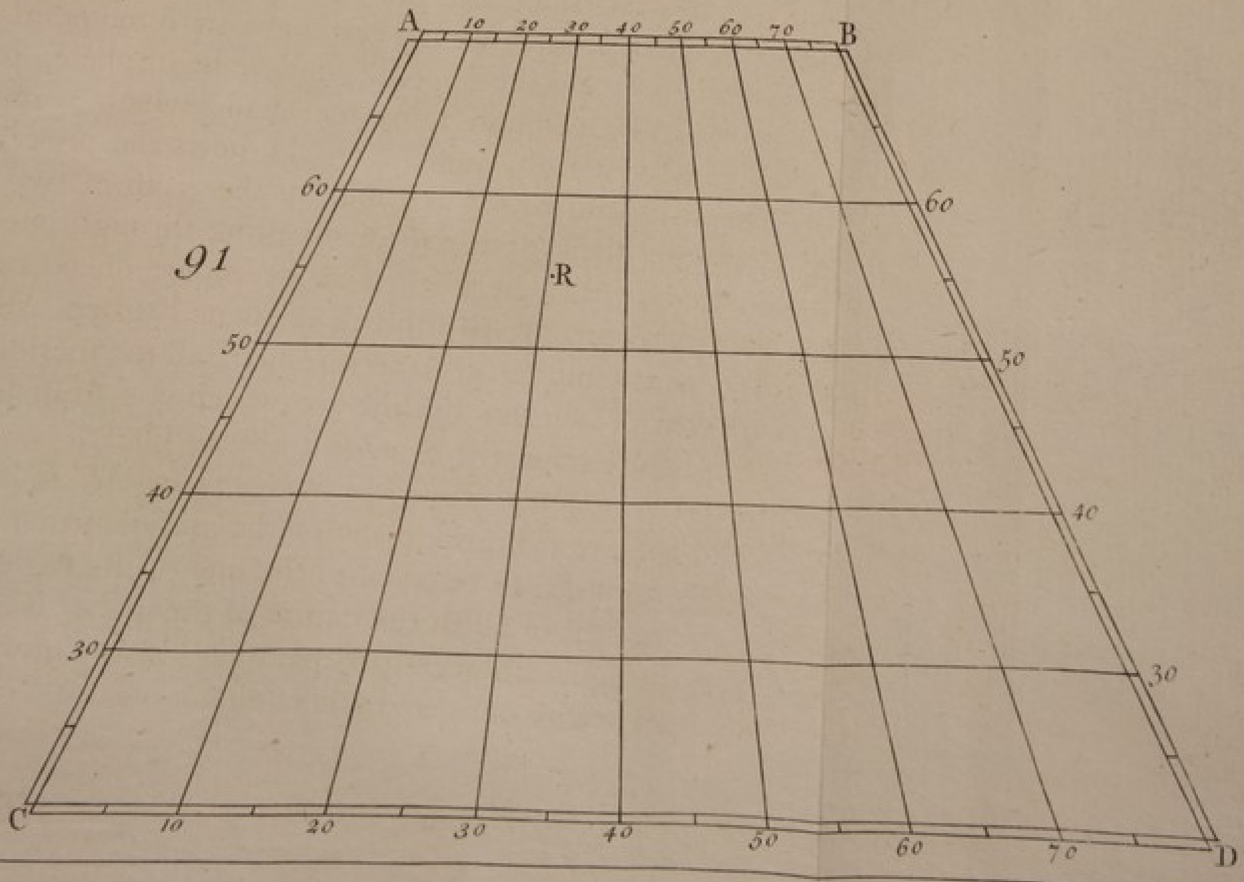

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the oppoſite hemiſphere: in this projection, the parts about the middle are a little contracted, ſo as to be too ſmall for the extream parts, the reaſon whereof, will appear from fig. 156 of the introduction, which ſhews us, that if a concave ſemicircle with equal diviſions be viewed, with the eye in the plane of it continued, at the diſtance of a ſemidiameter from its center, the projection will be a ſtrait line unequally divided, the parts appearing leſs the nearer to the center; conſequently, if two ſemicircles cutting one another at right angles, drawn upon a concave hemiſphere, and marked with equal diviſions be viewed in the manner now deſcribed, the projection of them will be ſtrait lines unequally divided, as A C and B D, fig. 80; the parts appearing leſs, the nearer to the center: however, in this projection, the proportion between the middle and the extream parts is much better preſerved than in the orthographic. *The ſtereographic projection* is alſo either *equatoreal, meridional,* or *horizontal.* FIG. 80

544 *The equatoreal projection* ſuppoſes the eye to be ſituated in one of the poles of the earth, and from thence to view the oppoſite concave hemiſphere, with its circles, projected upon a plane of glaſs paſſing through the equator: thus, the eye is ſuppoſed to be in the north pole, in order to view the ſouthern hemiſphere; and in the ſouth pole, to view the northern hemiſphere: fig. 80 is the ſtereographic projection of the circles upon the plane of the equator, and fig. 81 is a map of the northern hemiſphere, upon that projection: here, the meridians are all ſtrait lines, and the parallels are compleat circles. 80 81

545 *The meridional projection* ſuppoſes the eye to be in ſome point of the equator, and from thence to view the oppoſite concave hemiſphere, projected upon a glaſs plane paſſing through ſome meridian, which a meridian drawn through the eye cuts at right angles: fig. 82 ſhews the projection of the circles upon a meridian, and fig. 83 is a map of the earth in two hemiſpheres, projected upon the plane of a meridian paſſing through one of the Canary iſlands called Ferro: this meridian is made choice of, becauſe, by making the projection thereon, one hemiſphere contains Europe, Aſia, and Africa; and the other, north and ſouth America: here, all the meridians are arcs of circles, except that drawn through the eye which is a ſtrait line; all the parallels alſo are arcs of circles, the equator is a ſtrait line. 82 83

546 There is *another meridional projection* invented by *M. de la Hire*, wherein the diſtance of the eye from the plane of the meridian upon which the projection is made is ſuppoſed to be equal to the ſine of the angle of 45°: this projection comes the neareſt of all to the nature of the globe, becauſe the meridians are ſet therein at equal diſtances, the parallels alſo are nearly equidiſtant; I ſee no good reaſon why our geographers do not make uſe of it: fig.

 84

FIG. fig. 84 is the projection of an hemiſphere with its circles, according to *M. de la*
84 *Hire's* method; and fig. 85 exhibits a map of the two hemiſpheres of the earth,
85 according to that projection. *Bion, uſage des globes, l.* 3. *c.* 1. § 2.

547 In *the horizontal projection*, the eye is ſuppoſed to be in that point of the ſurface of the globe which is diametrically oppoſite to the place upon the horizon of which the projection is made, and from thence to view the oppoſite concave hemiſphere with its circles, projected upon a glaſs plane paſſing through that horizon: thus if we project a map of this ſort upon the horizon of London, the eye is ſuppoſed to be at the place of the Antipodes to London, and from thence to view the concave hemiſphere: there is great variety in this ſort of projection, for if the place the horizon of which it is upon be under the pole, the horizontal projection is the ſame as the equatoreal, § 544: if the place be under the equator, it is the ſame as the meridional, § 545: if the place be in an oblique ſphere, the projection will be different according to the different latitude of the place: for it will approach nearer to the equatoreal or meridional projection; according as the place is nearer to
86 one of the poles, or to the equator: fig. 86 is an horizontal projection for the
87 latitude of 51° 31′, and fig. 87 is a map projected upon the horizon of London, whoſe latitude is 51° 31′: the chief advantage of this kind of maps is this, that the place upon the horizon of which the map is projected is always in the center of it, and we may ſee the bearings of places from it.

548 *A particular map* is a part of a general one, and may be made upon the ſame principles, as, by projecting a large hemiſphere, and taking ſo much
88 of it as the map is deſigned to contain: thus, fig. 88, from the hemiſphere EFGH we may take ABCD; when a large part of the earth is to be repreſented, the meridional projection deſcribed § 545 is commonly made uſe of.

549 When we are to delineate *a map of a ſmaller part of the earth*, if it be near the equator, the meridians and parallels may be repreſented by equi-
90 diſtant ſtrait lines: as fig. 90, if at ſome diſtance from the equator, the parallels may be equidiſtant ſtrait lines, and the meridians ſtrait lines a little
91 converging towards the neareſt pole; as fig. 91: or the meridians may be ſtrait lines converging towards the neareſt pole, and the parallels circular: of
89 this kind is the map of Europe, fig. 89, taken from *Senex*.

550 When we are to make *a map of a very ſmall diſtrict*, as of a county, or hundred, whatever part of the earth it be in, the meridians and parallels may be equidiſtant ſtrait lines, drawn through every minute, or every 4′, 10′, or 15′, &c. of longitude, according as the largeneſs of the map will allow: for as a ſmall part of a great circle upon the earth does not differ ſenſibly from

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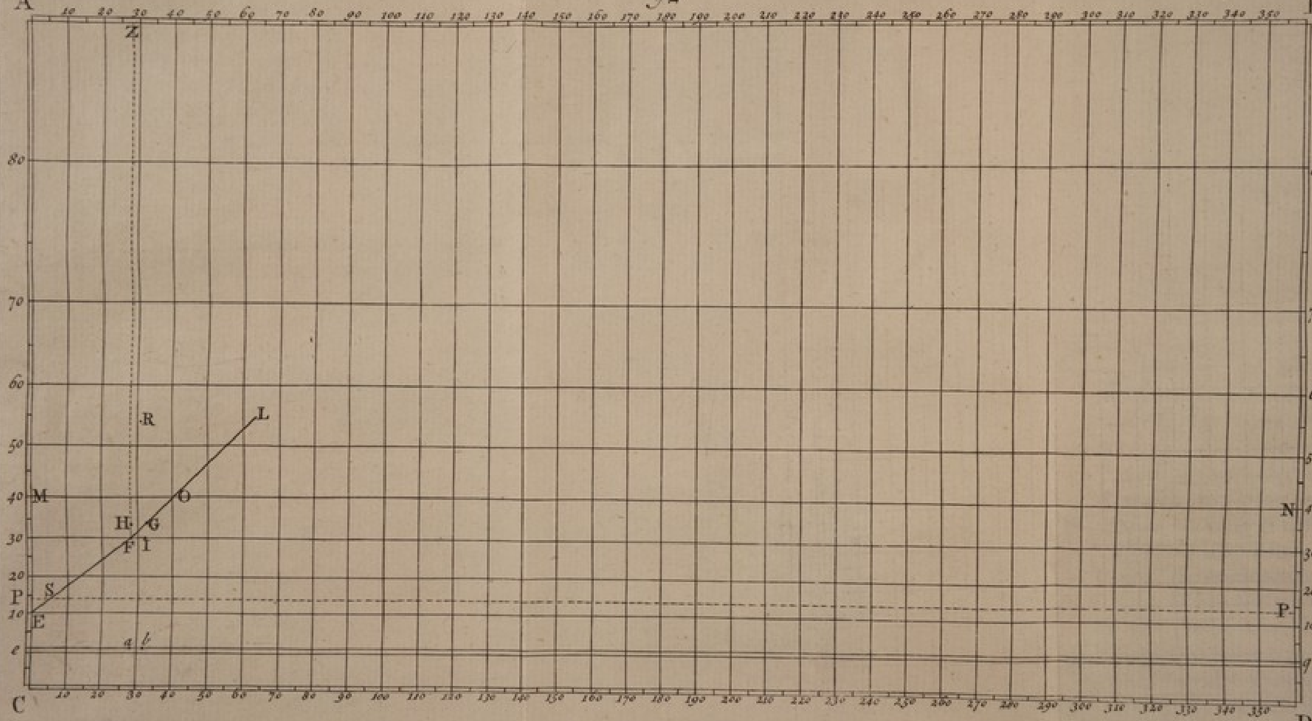
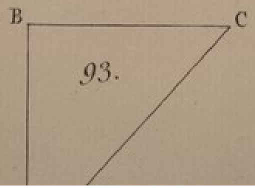




93.

from a ſtrait line, ſo a ſmall part of the ſpherical ſurface of the earth differs FIG.
not ſenſibly from a plane.

551 *Sea charts* are particular maps, for the uſe of navigation, wherein is exhibited ſome part of the ſea, with the ſhores that bound it: the inland parts are often omitted as of no uſe to the ſailor, except where there are large rivers for him to go up, or ſea-marks for him to ſee at a diſtance; but the parts of the ſea near the ſhore are carefully laid down, with marks ſignifying rocks, ſands, or flats, and figures expreſſing the *ſoundings*, or depth of the water: ſea-charts are of two ſorts, as in the two following ſections.

552 *The plain chart* is, where meridians and parallels are expreſſed by equidiſtant ſtrait lines, as fig. 90: this ſhews the longitude and latitude of places 90
very well, but is erroneous in ſhewing the rhumb which muſt be ſailed upon, to go from one place to another, except when the places are very near the equator; becauſe no allowance is made therein for the decreaſe of the parallels abovementioned, chap. 17.

553 In *Wright's chart*, commonly called *Mercator's*, the meridians and parallels are both expreſt by ſtrait lines, but from the equator towards the poles the length of a degree upon the meridians is increaſed, in the ſame proportion as the length of a degree decreaſes in the parallels, upon the globe. To underſtand the nature of this chart, we may ſuppoſe the globe, with its uſual delineations upon it, to be put into an hollow cylinder of the ſame diameter with the equator, with its axis coincident with the axis of the cylinder, and then to ſwell, as if it were blown like a bladder, all the parts ſtretching uniformly, ſo that the meridians lengthen in the ſame proportion as the parallels do, till every part of its ſurface touches the concave ſurface of the cylinder: then would each parallel have the ſame diameter with the equator, the meridians would be ſtrait lines, parallel to each other, and conſequently in all latitudes would have the ſame diſtance, as on the equator, they would alſo be lengthened in the proportion before mentioned, from the equator towards each pole: and the rhumbs would unbend, and be projected into ſtrait lines upon the ſurface of the cylinder: if we imagine the ſurface of this cylinder to be cut open, along one of the meridians; and unbent into a parallelogram, the projection of the meridians and parallels would appear as in fig. 92: if places are laid down therein, from a table of longitude and lati- 92
tude, the map will indeed be very deficient in the third particular required in maps, but is nevertheleſs vaſtly more convenient for navigation than any other ſort of maps whatſoever, becauſe the rhumbs are here reduced to ſtrait lines, ſo that we need only draw a ſtrait line between any two places, in order to find what rhumb we muſt ſail upon, to go from one place to another.

554 Maps

FIG. 554 Maps have uſually a compaſs drawn upon them, by which the north
ſide may be known: when we uſe a map upon a table, we generally lay it
with the north ſide fartheſt from us; and when a map is hung upon a wall,
the north is placed uppermoſt: in both theſe caſes, the eaſt ſide of the map
is on the right hand, the weſt on the left, I need not ſay the ſouth is oppo-
ſite to the north: the lines drawn from eaſt to weſt are parallels, the two ex-
89 tream parallels as A B and C D, fig. 89, 90, 91, 92, are divided into degrees,
90 and each degree into halves and quarters of a degree, or into 5′, 10′, or ſingle
91 minutes, according to the largeneſs of the map: the lines from north to ſouth
92 are meridians, the two extream meridians A C and B D are divided into de-
grees of latitude, and each degree into halves, quarters, &c.

555 *To find the latitude of a place in a map:* ſtretch a thread over the place,
ſo that it may cut the ſame degree and minute of latitude, in the two outſide
90 meridians A C and B D; the degree and minute marked by the thread in thoſe
91 meridians is the latitude of the place: thus, fig. 90, 91, 92, the latitude of
92 the place R is 54°. 30′.

556 *To find the longitude of a place in a map:* ſtretch a thread over the
place, ſo that it may cut the ſame degree and minute in the two extream pa-
90 rallels A B and C D, fig. 90, 91, 92; the degree and minute cut by the thread
91 is the longitude; thus, the longitude of R is 30°. 15: we may uſe the edge
92 of a ruler inſtead of a thread.

557 *To find a place in a map, its longitude and latitude being given:* ſtretch
one thread over the degree and minute of latitude in the two extream me-
90 ridians A C and B D, fig. 90, 91, 92, and another thread over the degree and
91 minute of longitude in the two extream parallels A B and C D; the point where
92 the threads croſs one another will ſhew the place. This method will alſo
ſerve *to inſert a place in a map, its longitude and latitude being given.*

558 What has been ſaid in the three ſections immediately preceding, is
applicable only to ſuch maps as have either the meridians, or parallels, or
both, repreſented by ſtrait lines; as fig. 89, 90, 91, and 92: in a map where
89 the parallels are expreſt by curves, as fig. 89, *to find the latitude of any place;*
draw with a pencil, or imagine to be drawn, a parallel through it, and the
degree which is cut in the extream meridians A C and B D is the latitude of
88 that place: in a map where the meridians are expreſſed by curves, as fig. 88,
to find the longitude of any place; draw with a pencil, or imagine to be drawn,
a meridian through it, and the degree where it cuts the equator, or one of
the extream parallels A B or C D, ſhews the longitude of that place.

559 The fourth thing neceſſary to be known in navigation was, *to find at any time what part of the globe a ſhip is upon:* the chief problem in naviga-
tion

tion is, to find in what courſe a ſhip muſt ſail, in order to arrive at the place FIG.
to which ſhe is bound: for this purpoſe it is previouſly neceſſary to know, in what place the ſhip is. The port from whence a ſhip begins her voyage is ſuppoſed to be known, as to longitude and latitude, and to be ſet down in the chart: when the ſhip has ſailed ſome time, as 24 hours, it is uſual to find the point upon the chart where the ſhip is then ſuppoſed to be: this point is marked by ſome with the prick of a pin: this point being found, a line drawn from it to the place we are bound to ſhews the courſe to be ſailed upon; and we may find what rhumb it is, if we obſerve what angle that line makes with the meridians in the chart: thus, fig. 92 if a ſhip ſets out 92
from E, and is found to be arrived at F, if we are to go to G, the line FG is the courſe to be ſailed, and the angle which this line makes with the meridian is eaſily found by the protractor, introd. § 33; or if a compaſs drawn upon a thin tranſparent piece of horn be laid with its center upon F, and its meridian upon the meridian of F, the edge of a ruler layed from F to G will ſhew the rhumb to be taken: the angle HFG in the example before us is 45°, therefore the rhumb is north-eaſt. See the table § 570.

560 *The finding the place where the ſhip is*, which is uſually done every day at 12 a clock, *depends upon four things*; viz. 1 the *longitude*, and 2 the *latitude* of that place, 3 the *courſe* the ſhip has run, 4 the *diſtance*, that is the way ſhe has made, or the number of leagues or miles ſhe has run in that courſe, from the place of the laſt obſervation: now any two of theſe being known, the reſt may eaſily be found.

561 *If the longitude and latitude be known*, nothing more is requiſite; for the place may be marked upon a globe, by § 507, or upon the chart, by § 557: but how to find the longitude at ſea, with certainty, is not yet diſcovered; what attempts have been made towards it, ſhall be ſhewn in its proper place: in the mean time, we will leave it out of the preſent conſideration, except ſo far as it may be found by the courſe or diſtance, as in § 562, caſe 1 and 2: we proceed now with the courſe, diſtance, and latitude.

562 *From the courſe and diſtance* to find the ſhip's place: here are four caſes, 1, if *the courſe has been under the ſame meridian*, as § 527, then the diſtance in geographical leagues or miles turned into degrees and minutes will give us the latitude, and conſequently the ſhip's place; the longitude being the ſame as at the laſt obſervation: thus, fig. 92, if a ſhip in ſailing from F 92
towards Z, has run 40 leagues, or 120 geographical miles, which are thoſe in uſe at ſea, whatever the latitude of F was, the latitude of the place ſhe is now come to will be 2° different from it; that is, it will be 2° leſs if ſhe has ſailed towards the equator, and 2° more if from the equator: thus, if the latitude

FIG. titude of F was 30° north, and the ſhip has ſailed 40 leagues north, ſhe will
92 be in 32° north latitude; and ſince ſhe continues in the ſame meridian F Z, her place is that point of this meridian which is cut by the parallel of 32° north latitude: to find this point, ſet one foot of a pair of compaſſes upon the 30° in one of the extream meridians in the chart, and the other upon the 32° of the ſame, then, with this opening, ſet one foot upon F, and turn the other north, and where it falls upon the ſame meridian, as at H, there is the ſhip's place.

Caſe 2, *If the courſe has been in the equator*, as § 528, the diſtance in leagues or miles turned into degrees and minutes gives us the difference of longitude:
92 thus, fig. 92, if a ſhip ſailing from *a* towards *q* has run 40 leagues or 120 miles eaſt, her place is then 2° eaſt from *a*, that is, at *b*.

Caſe 3, *If the courſe has been in a parallel*, as § 529; turn the diſtance in leagues or miles into degrees and minutes, and take the meaſure of thoſe degrees and minutes upon one of the graduated meridians, with a pair of compaſſes, ſetting one foot as much above the parallel as the other below it; then carry this diſtance to the parallel, and ſet it off from the place ſailed from, towards the eaſt or weſt, according as the courſe has been: thus, fig.
92 92, if a ſhip ſailing from F in the latitude of 30° has run 180 miles, that is, 2°, eaſt, take the diſtance of 2° with a pair of compaſſes, ſetting one foot upon the meridian A C in the 29°, and opening the other to 31°; carry this diſtance to the courſe, ſet one foot upon F, and turn the other eaſt, and where it falls, as at the point I, there is the ſhip's place.

Caſe 4, *If the courſe has been oblique*, that is, towards a point not cardinal, turn the diſtance in leagues or miles into degrees and minutes, then ſet one foot of a pair of compaſſes upon one of the graduated meridians, in the latitude ſailed from, and extend the other north or ſouth, according as the courſe has been, till it takes in the number of degrees and minutes the ſhip has run; carry this diſtance and ſet it off upon the line of the courſe, from the place of the laſt obſervation, and you will have the ſhip's place, without any conſi-
92 derable error: thus, if F the place ſailed from, be in the latitude of 30°, and the ſhip has run 60 leagues or 180 miles, which is equal to 3°, in a north-eaſt courſe F L, ſet one foot of a pair of compaſſes on the graduated meridian A C in 30°, and extend the other northward to 33°, then, with this opening ſet one foot of the compaſſes upon F, and at G, where the other foot falls upon the line F L, there is the ſhip's place.

563 *From the courſe and latitude* given, to find the ſhip's place: draw the line of the courſe, and lay the edge of a ruler over the degree of latitude in the two graduated meridians; the point where the edge of the ruler cuts the line

line of the courſe is the ſhip's place; thus, fig. 92, ſuppoſe a ſhip ſailing from 92
F north-eaſt is come into 40° of north latitude, for the line of the courſe draw FL, making an angle of 45° with the meridian, where this line is cut by the line MN, the parallel of 40°, namely at O, is the place of the ſhip.

564 *From the diſtance and latitude* given, to find the ſhip's place: lay the edge of a ruler over the degree of latitude in the two graduated meridians, take the diſtance turned into degrees and minutes, with a pair of compaſſes, by § 562, caſe 4, ſet one foot upon the place the ſhip failed from, and where, with this opening of the compaſſes, the other foot touches the edge of the ruler, there is the place of the ſhip: thus, fig. 92, if a ſhip ſailing from E is 92
come into the latitude of 14° north, and the diſtance in leagues amounts to $5^{\circ}\frac{1}{4}$, meaſure $5^{\circ}\frac{1}{4}$ from E northwards upon the meridian AC, with the compaſſes, then ſet one foot upon E, where the other touches the line PP, namely at S, is the place of the ſhip: in finding the place of the ſhip, by the foregoing propoſitions, we have ſuppoſed two of theſe three things to be exactly known, 1 the courſe, 2 the diſtance, 3 the latitude of the place the ſhip is arrived at; if there is uncertainty in any of theſe *data*, it will occaſion a like uncertainty in the place of the ſhip: the method of finding each of them, and how far it may be depended upon, will be ſhewn in the following ſections.

565 *To find the courſe:* this is known by the ſea-compaſs, § 521 and 524, but with theſe uncertainties, 1 the variation cannot be always exactly known, for want of obſervations, 2 a current, or 3 the ebbing and flowing, or 4 the rolling of the ſea, may carry the ſhip out of the line in which ſhe is directed, 5 the wind, when the ſhip does not ſail exactly before it, which is ſeldom the caſe, drives the ſhip out of the courſe in which ſhe is directed; this alteration of her courſe is called her *lee-way*, and allowance for it muſt be made, in order to find the true courſe: but this lee-way is different, according to the different angles the wind makes with the intended courſe, the different ſtrength of the wind, and the number of ſails made uſe of.

566 *To find the diſtance*, or number of miles the ſhip has run: this is ſometimes gueſſed at, by knowing how far the ſhip will ſail in ſuch a time, with ſuch a wind, which is found by experience, by obſerving how far ſhe has ſailed in ſuch a time, under the ſame meridian, or near it, when the diſtance may be pretty exactly meaſured, by the difference of latitude: but the moſt certain way of reckoning the diſtance is by *the log-line*: *the log* is a triangular piece of board, poized with lead at one corner, to make it ſwim upright: it is faſtened to the end of a line which is divided into equal parts, the diviſions are called *knots*, becauſe every one of them is marked with a knot, that they may be counted in the dark, by feeling them with the fingers: a knot

ſhould be an aliquot part, it is uſually the 120th part, of a geographical mile, that it may bear the ſame proportion to a mile, as half a minute does to an hour: the line is wound upon a reel which turns round eaſily, and is placed in the hinder part of the ſhip: when they *heave the log*, as they commonly do once every hour, they let it down into the water, and when ten fathoms are gone from off the reel, the log is ſuppoſed to be out of the eddy of *the ſhip's wake*, then the half minute glaſs is turned up, and when it is run out, they ſtop the reel, and obſerve how much line is wound off, to find how far the log is run from the ſhip, or rather the ſhip from the log, in that time; and conclude, that as many knots as run off from the reel in half a minute, ſo many miles the ſhip ſails in an hour: thus, if 6 knots run off in half a minute, the ſhip ſails at the rate of 6 miles an hour: but here likewiſe muſt be ſome uncertainty, from the rolling of the ſea when it runs high, from the drift of currents, and from the difference of the wind, which ſeldom continues exactly in the ſame tenor for an hour together.

567 *Vitruvius l.* 10. *c.* 14. mentions a method uſed by the ancients of meaſuring a ſhips way by wheels on the outſide, which being turned round by the water, turned other wheels with their indexes within the ſhip, in the ſame manner as the wheel of a coach is made to turn the wheels of *a way-wiſer*, and ſhew the diſtance travelled by land[a]: *De Chales, Navigat. l.* 5. *prop.* 6. deſcribes a machine by which the ſtrength of the wind may be eſtimated, this alſo would be of uſe to meaſure a ſhips way[b].

568 *To find the latitude*: this is done by taking with inſtruments the meridian height of the ſun, or ſtars; but cannot be done ſo accurately at ſea as at land, by reaſon of the motion of the ſhip: however, the latitude is found with much greater certainty than either the courſe or diſtance, and ſhould therefore be often taken when opportunity ſerves, to correct them thereby:

569 Since *ſailing in a parallel* requires only the keeping the courſe due eaſt or weſt, § 529, and the latitude is found with greater certainty than either the courſe or diſtance, § 568; it is uſual, in ſailing between the tropics to get into the latitude of the place to which the ſhip is bound, and ſteer directly eaſt or weſt, according as the place lyes from the ſhip: for this purpoſe, the *trade-winds* or *monſoons* are to be obſerved. See monſoon in the index.

570 Since, in the conſtruction of the compaſs, the 360° of the circle are divided into 32 equidiſtant points, the diſtance of any two adjoyning points muſt be 11° 15′; for 32 times 11° 15′ is 360: from hence, the angle which the line of any courſe makes with the meridian being given, the rhumb ſailed upon may be known; or converſely, the rhumb being given, the angle of the courſe may be found, by the following table.

a. v. & *Phil. tranſact.* N. 391 & 408. b. v. & Ricciol. *geograph. reformat. l.* 1. *c.* 3. & *l.* 10. *c.* 23.

A TABLE OF THE ANGLES WHICH EVERY RHUMB MAKES WITH THE MERIDIAN.

North.	South.	Rhumbs	D.	M.	North.	South.
		¼	02	49		
		½	05	37		
		¾	08	26		
North by Eaſt	South by Eaſt	1	11	15	N. by W.	S. by W.
		1 ¼	14	04		
		1 ½	16	52		
		1 ¾	19	41		
N. N. E.	S. S. E.	2	22	30	N. N. W.	S. S. W.
		2 ¼	25	19		
		2 ½	28	07		
		2 ¾	30	56		
N. E. by N.	S. E. by S.	3	33	45	N. W. by N.	S. W. by S.
		3 ¼	36	34		
		3 ½	39	22		
		3 ¾	42	11		
North Eaſt.	South Eaſt.	4	45	00	North Weſt.	South Weſt.
		4 ¼	47	49		
		4 ½	50	37		
		4 ¾	53	26		
N. E. by E.	S. E. by E.	5	56	15	N. W. by W.	S. W. by W.
		5 ¼	59	04		
		5 ½	61	52		
		5 ¾	64	42		
E. N. E.	E. S. E.	6	67	30	W. N. W.	W. S. W.
		6 ¼	70	19		
		6 ½	73	07		
		6 ¾	75	56		
Eaſt by North	Eaſt by South	7	78	45	W. by N.	W. by S.
		7 ¼	81	34		
		7 ½	84	22		
		7 ¾	87	11		
Eaſt	Eaſt.	8	90	00	Weſt.	Weſt.

571 Thus I have entered upon the uſe of the terreſtrial globe, and ſhewn the nature and uſe of maps and charts: the mechanical methods of delineating them I omit, as foreign to my purpoſe; they may be ſeen in *Varenius*'s Geography, and in a treatiſe of maps and globes printed A. D. 1717. I have likewiſe explained the nature of the rhumbs, and ſhewn how to find the place of a ſhip upon the chart, mechanically, which is ſufficient to give the reader a general notion of navigation: in the writers upon that ſubject, we have rules to find the place of a ſhip, by trigonometrical calculation: the foundation of which calculation is this; in oblique ſailing, the line of the ſhips way together with the meridian of the place from whence ſhe ſailed and the parallel of the place where ſhe is arrived form a *rhumb-triangle*; which, though curvilinear upon the globe, may, when the diſtance ſailed is ſmall, be conſidered as rectilinear, without ſenſible error, and is accordingly drawn ſo upon both the plain chart and *Mercators*: thus, fig. 93, ſuppoſe 93
a ſhip ſails from A to C, draw AB to repreſent the meridian of A, for the parallel of C draw CB perpendicular to AB, and there will be formed the rhumb-triangle ABC, whoſe angle at B is a right one by conſtruction, the angle at A is the angle of the courſe, the hypotenuſe AC is the diſtance, AB is the difference of latitude, and BC is in plain ſailing called the departure, and in *Mercators* ſailing the longitude: now this triangle being right angled, if one acute angle and one ſide thereof be known, the other two ſides and the remaining acute angle may be found, by § 143: or if two ſides be given, the remaining ſide and the two acute angles may be found by § 98, here it is to be remarked, that though the calculation of any problem is more exact than conſtruction, or drawing it in lines geometrically; yet navigation by trigonometry muſt be attended with all the uncertainty which ariſes from the errors to which the *data*, upon which it is founded, viz. the courſe, diſtance, and latitude, are liable: ſince there are no methods of finding theſe beſides thoſe laid down in this chapter.

CHAP. 20. THE HEIGHT OF MOUNTAINS, THE DEPTH OF THE SEA.

572 Mountains are ſo conſiderable parts of the earth as to demand ſome notice ſhould here be taken of them: many of them furniſh the ſpring-heads of large rivers, ſome are famous for the mines of rich metals contained in their bowels, others are remarkable for the dreadful eruptions of fire, ſmoke, ſtones and aſhes to which they are ſubject; theſe and many other particulars relating to mountains I leave to thoſe writers who deſcribe the countries wherein

wherein they are found, or write the natural hiſtory of them, ſee *Varen. geog. l.* 1. *c.* 10. my preſent deſign leads me only to enquire into the height of mountains, in order to find what proportion it bears to the diameter of the earth, and how far it may be objected to what has been ſaid of its roundneſs.

573 The height of mountains has often engaged the attention of the inquiſitive, though we have little of certainty upon that ſubject delivered to us by the ancients: ſometimes authors content themſelves with only telling us how many days it takes to go from the bottom of a mountain to the top: thus, *Strabo*[a], ſpeaking of ſome of the higheſt mountains in Greece, writes that an able traveller might walk from the bottom of any of them to the top in a days time, whereas it would take him above five days to go up one of the Alps: ſometimes they ſay how long the ſun may be ſeen to enlighten the top of a mountain, before his riſing in the morning, and after his ſetting in the evening; to this purpoſe, we have accounts of the mountains Caucaſus and Caſius, in *Ariſtotle*[b] and other writers: ſometimes they relate how far off the top of a mountain may be ſeen, or to what diſtance the proſpect from thence reaches, or in general, that the top of a mountain is above the middle region of winds and rain: in proof whereof, it is ſaid of ſome mountains which had anciently ſacrifices offered upon the tops of them, that the aſhes have been obſerved to lye there undiſturbed from one years end to another, ſo that characters drawn therein were not effaced[c]: mount Athos is particularly taken notice of for caſting a ſhadow to the diſtance of above 80 miles, as far as Myrine a town in the Iſland of Lemnos[d], in the market-place of which, there was erected the ſtatue of an heifer that uſed to be covered by the ſhadow, according to a celebrated verſe upon that occaſion,

Αθως καλύπτει πλεῦρα Λημνίας βοός.

The Lemnian heifer is by Athos cover'd.

Atlas is ſaid to hide his head in the clouds, and by the poets is therefore feigned to ſupport the heaven: but I find only three mountains recorded to have had their height taken with accuracy, probably by trigonometry, by any of the ancients: Olympus and Pelion in Theſſaly, and Cyllene in Arcadia have not only ſerved to embelliſh the writings of the poets, but have alſo employed the ſkill of geometers. Olympus was found by *Xenocrates* to riſe above ten *ſtadia* higher than the temple of *Apollo* built at the foot of it, he ſeems to have uſed a good deal of care in this affair, becauſe, in an epigram of his extant in *Plutarch*[e], he ſays the height of it is ten *ſtadia* and a ſixth part of a *ſtadium* wanting two feet, and pleads the merit of the performance to recommend him-

a Strabo *geogr. l.* 4. b Ariſt. *Meteor. l.* 1. *c.* 63. *Solin. c.* 37. c *de* Atho *refert* Solinus c. 16. de Cyllene Gemin. c. *de ſignif. aſtrorum.* Plin. *nat. hiſt. l.* 4. *c.* 10. e Plut. *in vita P. Æmilii.*

ſelf

ſelf to the favour of *Apollo*. The other two were, by order of ſome princes, meaſured by *Dicearchus*[a], the height of Pelion was found by him to be 10 *ſtadia*, of Cyllene 15 *ſtadia*. For the meaſure of the *ſtadium* ſee § 440.

574 Amongſt modern travellers, the Pic of Teneriff[b] is famous for its height: we are told it may be ſeen at ſea to the diſtance of 4°, which is about 270 Engliſh miles; it is by many thought to be the higheſt mountain upon the whole earth: others think the mountains which run through ſouth America exceed all others in height; for whereas the air on the tops of ſeveral very high mountains has been ſaid, by reaſon of its thinneſs, to occaſion reachings, difficulty of breathing, and ſometimes vomiting[c], the air here is ſo unfit for reſpiration, that upon a party of Spaniards croſſing over them at the only paſs which is practicable, many of their men and horſes died ſuddenly. *Varen. Geogr. l.* 1. *c.* 10.

575 The height of a mountain may be conſidered either abſolutely, that is how much its elevation is above the ſurface of the ſea, or relatively, i. e. how much higher it is than the ground upon which the ſtations are taken to meaſure it. *Ricciolus* in his *geographia reformata l.* 6. has a large account of mountains, and the ſeveral attempts which have been made to meaſure the height of them, both by the ancients and moderns; he ſhews ſeveral trigonometrical methods of doing it, as does alſo *Varenius l.* 1. *c.* 9. one of the principal of theſe I have explained § 475, but they are all liable to uncertainty, by reaſon of refraction: it is probable the ancients did not take refraction into the account, for that reaſon the heights of mountains which they give us are greater than they ought to be; the moderns have conſidered refraction, but it is ſo variable, that it is hardly poſſible to aſcertain at any time what allowance ought to be made for it.

576 *The mercurial barometer* ſeems to promiſe better ſucceſs in this affair than can be expected by any other means: it is now univerſally agreed on, that the quickſilver is ſuſtained in the tube of the barometer by the preſſure of the air upon that quickſilver wherein the lower end of the tube is immerſed, that the farther from the center of the earth the barometer is placed, the ſhorter is the column of air, and the leſs its weight by the preſſure whereof the quickſilver is ſupported in the tube, and conſequently, the lower will it ſubſide: thus, whatever is the height of the quickſilver in the tube at the bottom of a well, it will ſtand lower when the barometer is brought up to the ſurface of the earth, and will ſubſide ſtill lower if it be carried up to the top of an high tower; and this ſubſiding of the quickſilver is in a certain propor-

a Plin. *nat. hiſt. l. c.* b Ricciol. *geogr. reformat.* lib. 6. c. 13.
c Mr Edens found nothing of this on the top of Teneriff, v. *Phil. tranſ.* N. 345.

tion

tion to the height of the place where the experiment is made. When the gentlemen of the academy of ſciences at Paris drew the meridian line mentioned § 415, they made uſe of barometrical obſervations to determine the height of ſome of the higheſt mountains in France, and of ſome of the Pyrenees, which ſeparate that kingdom from Spain: by the ſame method, *Dr. Scheuchzer* took the heights of ſeveral of the Alps; from the detail of his obſervations, which may be ſeen in the *philoſophical tranſactions* for the year 1728, n. 405 and 406, it appears that the higheſt of the Alps, the tops whereof are covered with everlaſting ſnow, do not riſe above 10000 Paris feet, which is 10680 Engliſh feet, or 2 Engliſh miles 120 feet, above the level of the ſea, and theſe mountains, which are undoubtedly the higheſt in Europe, that gentleman is of opinion may equal the height of any upon the globe.

577 *The depth of the ſea* has been thought by ſome to anſwer to the height of mountains, as if the earth had been once a perfect globe, and the mountains conſiſted of what was taken out of the cavities made for the reception of the waters, but this is mere conjecture without any ſolid foundation: the depth of the ſea is in many places unknown, being unfathomable by the line, though great lengths have been made uſe of for that purpoſe. *Mr. Boyle in his treatiſe of ſubterranean and ſubmarine regions* § 2, mentions a curious traveller who, upon enquiring whether he had taken notice of any extraordinary deep ſoundings in the vaſter ſeas, anſwered that on the other ſide of the line about the latitude of 35° they let down 400 fathoms of line, and that the lead which weighed about 30 or 35 pounds by going ſo deep appeared when drawn up again intenſely cold like ice: there are in the ſame treatiſe ſeveral proofs that the ſea-water is colder the deeper we go. *Varenius*[a] tells us the depth of the ſea has in ſome places been found a German mile which is equal to four Engliſh miles. *Ricciolus*[b] writes of ſome engliſhmen having ſounded with lines to the depth of 3000 ells, but he ſpeaks of it by hearſay. *Olaus magnus*[c] ſpeaks of ſome parts of the northern ſeas being ſo deep that a ſhip load of line would not ſuffice to ſound them to the bottom, but this I ſuppoſe is ſaid at random. *Ceſar*[d] is ſaid to have found the depths of ſome parts of the Mediterranean and Adriatic not to exceed 15 *ſtadia*, which is almoſt two Engliſh miles: it is probable that it was from this relation that *Pliny*[e] ſays the depth of the ſea is in ſome places 15 *ſtadia*. In the *philoſophical tranſactions* for the year 1728 N. 405 we have a deſcription of a machine to meaſure the greateſt depths of the ſea, but if any experiments have been made therewith they are not yet communicated to the public.

a *Geogr. l.* 1. *c.* 12. b *Geograph. reformat. l.* 6. *c.* 21. & *l.* 10. *c.* 1. c *l.* 2. *c.* 10.
d Priſcianus *apud* Majol. *dier canicular. colloq.* 10. e *N. Hiſt. l.* 2. *c.* 102.

578

578 Mr. *Boyle*, in the place before cited, ſays he was very inquiſitive about *the inequality of the bottom of the ſea*, by the information he received of profeſt *divers*, and other curious Perſons who had opportunities of ſeeing *divers* at their work and converſing with them, or who had ſounded the ſea in ſeveral places, it appears that the floor of the ſea is in many places exceedingly unequal, being here flat and there craggy, rocks riſing to a conſiderable height in ſome parts, and valleys ſinking as deep in others: that generally the depth of the ſea is found to increaſe or decreaſe gradually, but in ſome places is ſo very unequal that in caſting the lead on one ſide of the ſhip they find it 20, 30, or perhaps 40 fathoms deeper than they had found it juſt before when they ſounded from the other ſide: particularly he was told by an ancient and experienced pilot that not far from the mouth of our channel he has ſometimes found the bottom of the ſea ſo abrupt, that in ſailing twice the length of his ſhip the water has deepened from thirty to an hundred fathoms, if not much more; and this ſudden alteration of depth is chiefly obſervable near the ſhore, though there are inſtances of the like far out at ſea: but as in ſailing far from land there is not ſo much occaſion for ſounding, it is only known in general that the depths in the wide ocean are very great, the particular depths are known but in very few parts of it.

579 In ſailing near the ſhore, the ſounding line with the lead is often caſt out, to find the depth of the water: the lead has often tallow or greaſe upon the lower end of it, that it may bring up with it ſand, gravel, ſhells, &c. in order to ſhew what kind of ſoil is at the bottom, the knowledge of the depth of the water and the kind of ſoil is very uſeful to find exactly where the ſhip is, to prevent her running aground, and carry her ſafe into port

580 *The proportion of the ſurface of the earth to that of the ſea*, ſo far as diſcoveries have been made, may be found, by taking the paper of a terreſtrial globe and ſeparating the land from the ſea with a pair of ſciſſars, and comparing the reſpective weights of each: this experiment ſuppoſes the delineation of the globe to be correct, the paper whereon it is printed ſhould alſo be of an equable thickneſs as near as poſſible; weighing thus the papers of *Mr. Senex*'s globe of 16 inches diameter, the weight of the paper whereon the ſea was repreſented was 349 grains, that of the land 124 grains: ſo the ſurface of the ſea is almoſt three times as great as that of the land hitherto diſcovered. I omitted weighing the parts contained within the polar circles, becauſe it is not known to any degree of exactneſs how much of them is land and how much is ſea.

ASTRONOMY. BOOK II.

CHAP. I. THE SYSTEM OF THE WORLD, THE FIXT STARS, THE PLANETS, THE TWINKLING OF THE STARS, THEIR DIFFERENT MAGNITUDES,

581 *The syſtem of the world* is the whole collection of thoſe great bodies which compoſe the univerſe of material beings, and comprehends the ſtars, the ſun, the planets, and comets, together with the indefinitely extended ſpace wherein they are contained[a]: from the author whoſe opinion is followed, in the deſcription of the number, magnitude, ſituation, motion, and other affections of thoſe bodies, it is called the *Ptolemaic* ſyſtem, the *Tychonic*, the *Copernican* &c. I ſhall, before I have done, endeavour to give the reader a general view of the ſeveral ſyſtems which have been advanced by the moſt celebrated philoſophers and aſtronomers, in order to account for the appearances of the heavenly bodies; but I ſhall in the firſt place treat of that ſyſtem which was anciently taught by the diſciples of *Pythagoras*[b], after long diſuſe revived about 200 years ago by *Copernicus*, cultivated afterwards by *Galileo*, *Kepler*, and others, and greatly improved by the diſcoveries of Sir *Iſaac Newton*. The method I propoſe to make uſe of is this, taking it at preſent for granted that this ſyſtem is the true one, I ſhall lay down the ſeveral parts of it, and ſhew under each head how the appearances of the heavenly bodies hitherto obſerved naturally reſult from ſuch an order and diſpoſition of them as is here ſuppoſed: this exact correſpondence of the *phænomena* with the *hypotheſis* is alone ſo ſtrong an argument in favour of the truth of it, that we might very well acquieſce therein; but we ſhall meet with other proofs in the progreſs of this work.

582 The ſtars, as well thoſe ſeen by the naked eye as thoſe which are diſcoverable by the teleſcope, keep always the ſame ſituation in reſpect of one another, and are therefore called *fixt ſtars:* thus, if we conſider any number of ſtars which appear near to one another and to our view form a triangle, ſquare, or any other figure, regular or irregular, we have reaſon to believe,

a Κόσμος ἐστὶ σύστημα ἐξ οὐρανοῦ καὶ γῆς καὶ τῶν μεταξὺ φύσεων. Diodorus *ap.* Achill. Tat. p. 129. *edit.* Petavii: iiſdem fere verbis, Cleomedes l. 1. κόσμον, ἐκ τῆς διακοσμήσεως, *primus appellavit* Pythagoras, Achill. Tatius *ibid.* ἰτὸ ὅλον λέγουσι [Stoici] τὸν κόσμον, πᾶν δὲ μετὰ τοῦ κενοῦ. *id. ibid. univerſum, univerſitatem, & rerum univerſitatem vocat* Cicero. b See the hiſtory of aſtronomy at the end of this work.

that

that ever ſince the creation of our earth, they have always appeared to its inhabitants to form the ſame figure, as to ſhape and dimenſions, as they do at preſent, and will probably continue to do ſo as long as our earth ſhall laſt: this is true of the fixt ſtars in general, as far as we are able to judge, by comparing the lateſt obſervations of the ſtars with the moſt ancient ones whereof we have any account remaining; as for particular changes which have been obſerved in ſome ſtars, and may be looked upon as exceptions to the general rule, they ſhall be treated of in a chapter upon that ſubject.

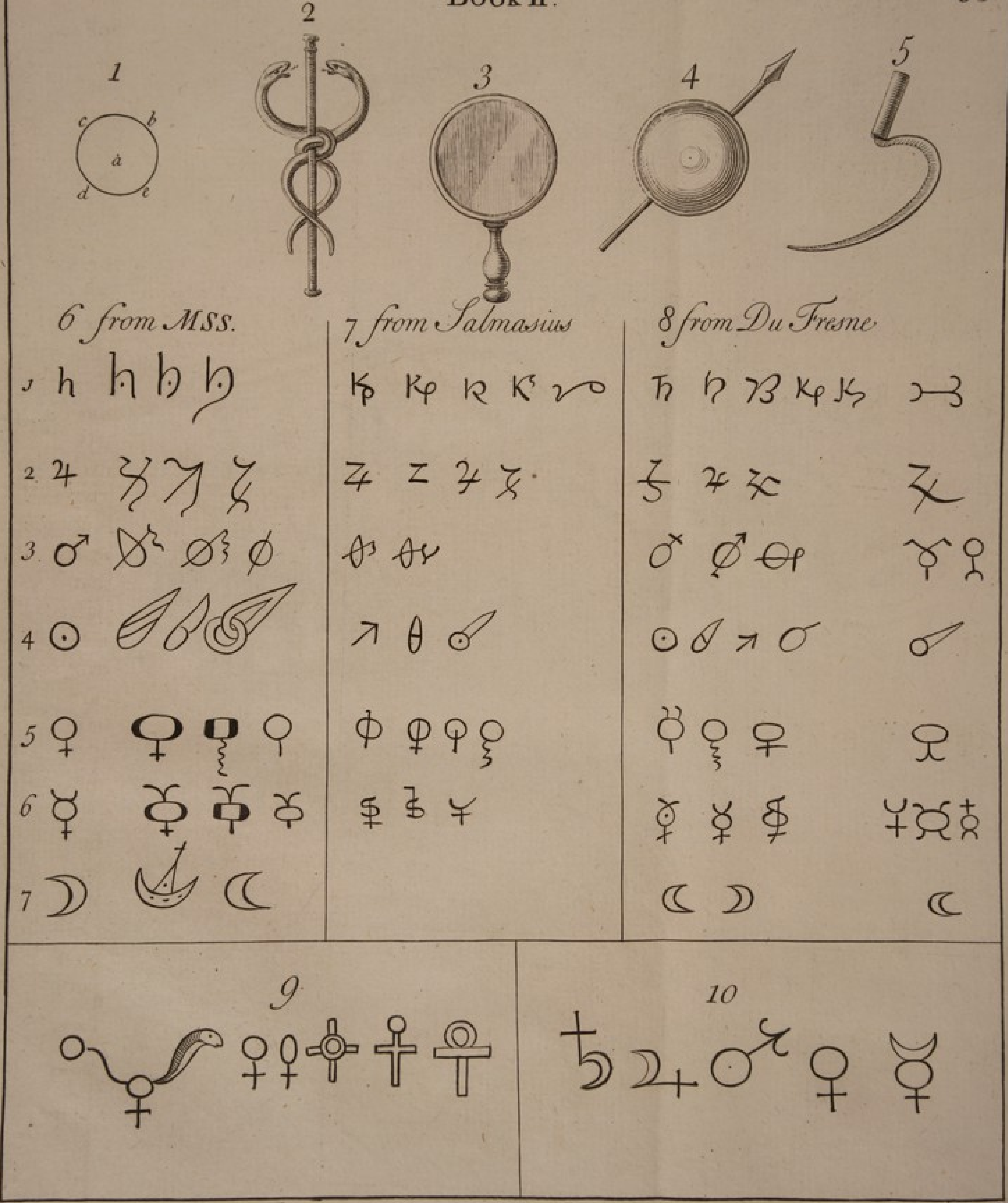
583 Beſides the fixt ſtars, there are to be ſeen in the heaven five *planets*, which by common ſpectators are not diſtinguiſht from the ſtars, though they be of a very different nature; I ſhall treat of them more particularly by and by, it is ſufficient at preſent to take notice that they do not keep their places, as the fixt ſtars are obſerved to do, but are ſeen ſometimes in one part of the heaven and ſometimes in another: from this change of place they are called planets or wanderers[a]; from hence alſo they came firſt to be diſtinguiſhed from the fixt ſtars, and to have the natures and motions of them enquired into.

584 There is another difference between the fixt ſtars and the planets, which may very properly be taken notice of in this place, *the fixt ſtars twinkle*[b], whereas the planets ſhine with a ſteady light: the cauſe of this difference ſeems to be this, the fixt ſtars are at ſuch an immenſe diſtance from us, that their apparent diameters are exceedingly ſmall, ſo that every little particle of duſt that floats in the air and comes between our eye and any fixt ſtar is big enough to cover it, and hide it for a moment from our ſight: now our air near the earth is ſo full of various kinds of particles which are in continual motion, that ſome one or other of them is perpetually paſſing between us and any ſtar that we look at, which makes us every moment alternately ſee it and loſe the view of it; and this twinkling of the ſtars is greateſt in thoſe ſtars which are neareſt the horizon, becauſe they are viewed through a good deal of thick air, where the intercepting particles are moſt numerous, whereas ſtars that are near the zenith do not twinkle ſo much, becauſe we do not look at them through ſo much thick air, and therefore the intercepting particles, being fewer, come leſs frequently before them: as for the planets, they, by reaſon of their being much nearer to us than the ſtars, have a ſenſible apparent magnitude, and that ſo great as not to be covered by the ſmall particles before mentioned, and therefore they do not twinkle, but ſhine with a ſteady light. That this is a true account of this matter, any one may be eaſily ſatisfied by the following experiment; lay a ſmall flat piece of glaſs of about the bigneſs of a ſilver peny upon the ground between your ſelf and the

a *By* Milton *wandring fires. Errones vocat* Nigidius, *ap.* Gellium. b Ricciol. l. 6 c. 2. Tacquet *aſtron.*

ſun,

page 171.


1
c
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6 from MSS.
7 from Salmasius
8 from Du Fresne
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ſun, with the plane of it a little declining from the ſun, ſo that retiring from it three or four hundred yards you may ſee the light of the ſun ſhining upon it to that diſtance or farther: if you come ſo near the glaſs that the image of the ſun reflected from it appears bigger than one of the largeſt ſtars in the heaven, you will ſee it ſhine with a ſteady light, and look like a planet; but if you keep your eye upon it and go from it to the diſtance of three or four hundred yards, till its apparent diameter is no bigger than that of a ſmall ſtar, you will perceive it twinkle in the ſame manner as the ſtars do: in like manner, if you turn your face towards the ſun, and look upon a plowed field where there are many ſmall ſtones, you may obſerve ſome of them that are at a diſtance to twinkle, whilſt others that are nearer ſhine with a ſteady light. FIG.

585 It muſt be confeſt, that ſome of the ſtars appear ſo large to the naked eye, that one would be apt to think they were too big to be covered by the ſmall duſty particles juſt now mentioned; but it is to be conſidered, that all luminous bodies appear larger than other bodies of the ſame dimenſions, becauſe the force wherewith the particles of light emitted from them fall upon the retina, is ſuch as to cauſe a trembling or vibration, not only in thoſe parts upon which the picture is painted, but alſo in the parts round about: thus, fig. 1, ſuppoſe the light emitted from a ſtar ſhould really fall upon only the 1
point *a* of the retina [a], yet if it comes with ſuch force as to cauſe a trembling round about that point as far as the circle *bcde* reaches, the ſtar will appear of the ſame magnitude as if its picture on the *retina* took up the area of that circle: if the force of the emitted rays be abated, as they are by paſſing through glaſſes, whereby many of them are reflected, the luminous object loſes ſome of that adventitious apparent magnitude, and paints its picture nearer to its true dimenſions [b]. And thus it is that the fixt ſtars looked at through a teleſcope are ſtripped of that glare of rays which to the naked eye ſeem to ſtream every way, and then though the glaſſes magnify them perhaps an hundred times, yet ſo immenſely great is their diſtance from us as to make their apparent diameters even thus magnified ſtill inſenſible, ſo that they appear like points: the caſe is very different if we view any of the planets through a teleſcope, their diſtances are moderate in compariſon of that of the ſtars, and therefore a teleſcope that magnifies an hundred times will very ſenſibly increaſe their apparent magnitudes.

586 *The fixt ſtars* appear to us *of different magnitudes:* this may ariſe from one of theſe two cauſes, either they differ in their bigneſs, and thoſe ſtars are

a I mean here a phyſical point, v. §. 223.

b Luminous bodies appear larger even through a teleſcope than might be expected from their dimenſions and diſtances: in an experiment made by the R. Academy of Sciences at Paris, a fire of three feet diameter, at the diſtance of 31897 toiſes, appeared under an angle of 8 ſeconds; whereas by calculation it ſhould appear under an angle of 3 ſeconds.

in reality the largeſt which appear ſo to us and ſhine with the ſtrongeſt luſtre, or their diſtances from us may be unequal, and thoſe ſtars may be fartheſt off which ſeem ſmalleſt to the eye and give the fainteſt light; or in ſome inſtances theſe two cauſes may both combine to make that difference which we perceive among the ſtars, and ſome of them may excel in brightneſs as well as appear larger than others, becauſe they are both bigger in themſelves and nearer to us: however this be, aſtronomers have from their apparent magnitudes diſtinguiſhed the ſtars into ſix orders or claſſes: the firſt contains thoſe of the largeſt ſize, the ſecond thoſe which appear next in bigneſs, and ſo on, till we come to ſtars of the ſixth magnitude, among which are counted the ſmalleſt that can be ſeen with the bare eye unaſſiſted with glaſſes: as for thoſe which cannot be diſcerned without the teleſcope, and are therefore called *teleſcopic ſtars* they are not reckoned into the ſix orders. Now although this diſtribution of the ſtars be generally received, we are not to imagine that all the ſtars of any one of theſe claſſes are exactly of the ſame bigneſs, we may rather ſay there are almoſt as many orders of ſtars as there are ſtars, there is ſuch a difference in the bigneſs, colour, and brightneſs of them: thus, ſome of thoſe which are reckoned of the firſt magnitude are much larger than others which are placed in the ſame claſs, ſo that there is for that reaſon a diſagreement among the aſtronomers in this reſpect, and the ſame ſtars are counted by ſome of the firſt magnitude, which others have aſſigned to the ſecond: there is alſo the like uncertainty with reſpect to the other claſſes.

CHAP. 2. THE CONSTELLATIONS, UNFORMED STARS, CATALOGUES OF THE STARS, THE NUMBER OF THE STARS, THE MILKY WAY.

587 The ſphere of the fixt ſtars was by the ancients divided into ſeveral *conſtellations* or *aſteriſms*: a conſtellation is a collection of ſtars which in the heaven appear near to one another, and may be imagined to repreſent the figure of ſome real or imaginary animal, or of ſome other known viſible thing: as a ram, a lion, a centaur, an harp, a crown &c. the number of the ancient conſtellations is 48, the number upon our preſent globes is about 70: I call thoſe the ancient conſtellations which we have received from the Greeks, and particularly from *Ptolemy* [a]: we find ſome of theſe occaſionally mentioned by *Homer* and *Heſiod*, but *Aratus* [b] profeſſedly treats of them all, except two or three which were invented after his time, and that in the following method: 1 he ſhews how each conſtellation is ſituated in reſpect of thoſe that are near it, 2 what poſition it is in with regard to the principal cir-

a In his *Almageſt* or μεγάλη σύνταξις *in fine lib.* 7, *&* *initio lib.* 8.

b *v.* Arati *phænomena*

cles

cles of the ſphere, 3. what other conſtellations riſe or ſet with it: this falls far ſhort of the accuracy of *Hipparchus* the Rhodian and of *Ptolemy*, as to ſetting down the places of the ſtars; but was ſufficient for the uſe of ſailors, and the purpoſes of husbandry, which were the ends chiefly propoſed by this author, who lived about 270 Years before the birth of our Saviour, and is the poet cited by St. *Paul*, Acts 17. 28. *Aratus* has been in ſuch eſteem, as to be tranſlated by *Cicero*, *Ceſar Germanicus*, and *Ovid*, paraphraſed by *Avienus*, and illuſtrated by about 50 commentators [a]. *Hipparchus* the Bythynian [b] has ſhewn, by ſeveral paſſages quoted from the writings of them both, that he followed the deſcriptions of *Eudoxus*, who flouriſhed about 100 years before him, and it is very probable that the Greek aſtronomers who ſucceeded him continued to uſe the ſame figures of the conſtellations, all along down to *Ptolemy*, though with ſome variations and additions.

588 *Ptolemy*'s work has been always in ſuch eſteem among the aſtronomers, that almoſt all who have written ſince his time have agreed in drawing the figures of the conſtellations, or ſuppoſing them to be drawn, ſo as to anſwer his deſcription of them, as far as poſſible: and indeed this is neceſſary, to avoid confuſion in comparing ancient and modern obſervations together: thus for example, the great Bear ſhould be ſo delineated that every ſtar in that conſtellation which is taken notice of by *Ptolemy* may be in the ſame part of the figure, *viz.* the ſnout, the eye, the forehead, *&c.* as he deſcribes it. It does not appear that *Ptolemy* publiſhed any *pictures of the conſtellations*, if he did they are not come to our hands; the moſt ancient pictures we have of them are thoſe publiſhed out of an ancient manuſcript by *Grotius* [c]; but theſe he juſtly obſerves, though venerable for their antiquity, are by no means agreeable to the originals in the heaven: as for the figures printed in ſome editions of *Hyginus* [d], the deſigners of them ſeem to have followed their own fancies in delineating them, without any regard to the deſcriptions of the author.

589 One *uſe of the conſtellations* was to diſtinguiſh the ſtars from one another: thus, if we mention the ſtar in the bull's northern eye, an aſtronomer knows what ſtar is meant, as well as if we pointed it out to him in the heaven. In the infancy of aſtronomy, only the principal ſtars were taken notice of: thus, at firſt only ſeven ſtars were reckoned in the little bear, and the ſame number in the great bear, and they were then called the two wains or waggons, each of theſe having four ſtars in the form of a parallelogram, which repreſent the wheels, as the three ſtars lying almoſt in a ſtrait line do the beaſts of draught: agreeably to this the 7 principal ſtars in the great bear are at this day commonly called Charles's wain.

a Scaliger *Not. in* Manilium p. 25. & Grotii *Syntagma Arateorum in epiſt. dedicat.* b *a* Petavio *editus in Uranologio.* c *in Syntagm. Arateorum.* d *Poeticon Aſtronomicon.*

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590 *The names of the conſtellations* and the *number of ſtars* obſerved in each of them by different aſtronomers are as follows.

The ancient conſtellations.		Ptolemy	Tycho	Hevel.	Flamſt.
Urſa Minor	the little Bear	8	7	12	24
Urſa Major	the great Bear	35	29	73	87
Draco	the Dragon	31	32	40	80
Cepheus	Cepheus	13	4	51	35
Bootes	Bootes	23	18	52	54
Corona Bor.	the N. Crown	8	8	8	21
Hercules, *Engonaſin*	Hercules kneeling	29	28	45	113
Lyra	the Harp	10	11	17	21
Cygnus, *Gallina*	the Swan	19	18	47	81
Caſſiepea	Caſſiepea	13	26	37	55
Perſeus	Perſeus	29	29	46	59
Auriga	the Waggoner	14	9	40	66
Serpentarius	Serpentarius	29	15	40	74
Serpens	the Serpent	18	13	22	64
Sagitta	the Arrow	5	5	5	18
Aquila, Vultur	the Eagle		12	23	71
Antinous	*Antinous*	15	3	19	
Delphin	the Dolphin	10	10	14	18
Equulus, *Equi ſectio*	the Horſes head	4	4	6	10
Pegaſus, *Equus*	the Horſe	20	19	38	89
Andromeda	Andromeda	23	23	47	66
Triangulum	the Triangle	4	4	12	16
Aries	the Ram	18	21	27	66
Taurus	the Bull	44	43	51	141
Gemini	the Twins	25	25	38	85
Cancer	the Crab	23	15	29	83
Leo	the Lion		30	49	95
Coma Berenices	*Berenices Hair*	35	14	21	43
Virgo	the Virgin	32	33	50	110
Libra, *Chelæ*	the Scales	17	10	20	51
Scorpius	the Scorpion	24	10	20	44
Sagittarius	the Archer	31	14	22	69
Capricornus	Capricorn	28	28	29	51
Aquarius	the Water Bearer	45	41	47	108
Piſces	the Fiſhes	38	36	39	113
Cetus	the Whale	22	21	45	97
Orion	Orion	38	42	62	78

Eridanus

The ancient constellations.		Ptolemy	Tycho	Hevel.	Flamst.
Eridanus, *Fluvius*	Eridanus	34	10	27	84
Lepus	the Hare	12	13	16	19
Canis major	the great Dog	29	13	21	31
Canis minor	the little Dog	2	2	13	14
Argo, Navis	the Ship	45	3	4	64
Hydra	the Hydra	27	19	31	60
Crater	the Cup	7	3	10	31
Corvus	the Crow	7	4		9
Centaurus	the Centaur	37			35
Lupus, *fera*	the Wolf	19			24
Ara	the Altar	7			9
CoronaAuſtralis	the S. Crown	13			12
Piſcis Auſtralis	the S. Fiſh	18			24

The new ſouthern conſtellations.

Columba Noachi	Noah's Dove	10
Robur Carolinum	the Royal Oak	12
Grus	the Crane	13
Phœnix	the Phenix	13
Indus	the Indian	12
Pavo	the Peacock	14
Apus, Avis Indica	the Bird of Paradiſe	11
Apis, Muſca	the Bee, or Fly	4
Chamæleon	the Chameleon	10
Triangulum Auſt.	the S. Triangle	5
Piſcis volans, Paſſer	the flying Fiſh	8
Dorado, Xiphias	the Sword Fiſh	6
Toucan	the American Gooſe	9
Hydrus	the Water Serpent	10

Hevelius's conſtellations made out of unformed ſtars.

		Hevel.	Flamſt.
Lynx	the Lynx	19	44
Leo minor	the little Lyon		53
Aſterion & Chara	the Greyhounds	23	25
Cerberus	Cerberus	4	
Vulpecula & Anſer	the Fox and Gooſe	27	35
Scutum Sobieſki	Sobieſki's Shield	7	
Lacerta	the Lizard	10	16
Camelopardalus	the Camelopard	32	58
Monoceros	the Unicorn	19	31
Sextans	the Sextant	11	41

591 The conſtellations are ſo delineated as to take in the ſtars, eſpecially the moſt remarkable ones, into ſuch parts of the figures as are moſt eaſily diſtinguiſht: thus, *the bull* is drawn ſo as to have one ſtar in his ſouthern, another in his northern eye; one in the tip of his northern, another in the tip of his ſouthern horn &c: beſides the ſtars which form the conſtellations, there are others which could not be comprehended in the figures, but are contained in the interſtices between them; theſe, becauſe not reduced into any certain figure, are called *unformed ſtars* [a]: ſome of theſe which were reckoned amongſt the unformed by the ancients have been from time to time made into new conſtellations by later aſtronomers: thus, to conſole the Queen of *Ptolemy Euergetes*, for the loſs of a lock of her hair which was ſtollen out of the temple of *Venus*, where ſhe had dedicated it on account of a victory obtained by the King her huſband, *Conon* an aſtronomer out of ſome unformed ſtars near the tail of the lyon made the conſtellation of *Berenice's hair* [b]: thus *Antinous* [c] the favourite of *Adrian*, beſides being deified by that Emperor, was placed amongſt the ſtars, and a conſtellation made out of ſome unformed ſtars near the eagle received its name from him: in later times, the celebrated *Hevelius* made ſeveral new conſtellations out of the unformed ſtars, which are now drawn upon our globes, but in fainter lines, in order to diſtinguiſh them from the ancient ones: I ſhall mention but one inſtance more, that Sir *Charles Scarborough* phyſician to *Charles* 2, gave the name of *Cor Caroli* to a ſingle ſtar of the 2d magnitude near the great bear, in memory of that excellent but unfortunate Prince *Charles* 1.

592 Since the diſcovery of South-America, the Portugueſe and Dutch navigators, croſſing the line, and having a view of the ſtars near the ſourh pole, have furniſhed our globes with new ſouthern conſtellations which were unknown to the ancients: as *el Dorado* the golden fiſh, *el Cruzero* the croſs, which we call the Croſiers &c.

593 In the numbers ſet down in the foregoing table, the unformed ſtars are reckoned to the ſeveral conſtellations to which they belong: *Coma Berenices* and *Antinous* are printed in a different character, becauſe, though both of them be mentioned by *Ptolemy*, the firſt of theſe is counted by him among the unformed of the lyon, the latter among the unformed of the eagle. The numbers of *Tycho* are taken from his *progymnaſmata*, thoſe of *Hevelius*, not having his *prodromus* at hand, I tranſcribed from *Flamſtead*'s *Hiſtoria Cæleſtis* vol. 3, as I did alſo the numbers of the new ſouthern conſtellations. *Flamſtead*'s numbers of ſome of the old ſouthern conſtellations I have encreaſed by the addition of thoſe ſtars of them which cannot be ſeen in *England*, but

a *Stellæ informes*, ἀμόρφωτοι Ptolomeo. b Ricciol. *almageſt*. l. 6 c. 4. c Xiphilinus in Adriano.

but have been obſerved at Sta. *Helena* by Dr. *Halley*. The names in the firſt column are thoſe in common uſe, ſeven of *Ptolemy's* names are different from them, theſe are added in italic: thus *Hercules* is by him called *Engonaſin, i. e.* a man kneeling: inſtead of *the ſwan* he has a word which ſignifies a fowl in general, or particularly one of the hen-kind: *Pegaſus* in *Ptolemy* is *the horſe:* in the room of *Libra*, he has *Chelæ*, *the claws*; for among the ancients the *Scorpion* was drawn larger than at preſent, ſo that the claws of it took up that part of the heaven which is now aſſigned to *Libra: Eridanus*, is by him called *the river:* and in lieu of *the wolf* he has *the wild beaſt*. Several of the conſtellations have more names than one: thus, *Bootes* is alſo called *Arctophylax:* and *Ophiuchus* is another name for *Serpentarius:* not to mention other names which ſometimes occur, eſpecially among the poets.

594 Beſides the additions mentioned, § 591 and 592, there have alſo at different times been ſome alterations made in the forms of the conſtellations: thus, *Ptolemy*, who chiefly followed *Hipparchus*, ſays, *l.* 7. *c.* 5. of his *Almageſt*, that he does not always make uſe of the ſame figures with thoſe before him, but had, for the ſake of giving his figures a truer proportion and adapting them better to the ſituation of the ſtars, made many alterations therein, as the aſtronomers before his time had done, in the conſtellations of thoſe that were more ancient: and he inſtances particularly in ſome ſtars, which, by reaſon of their great diſtance from her head, he placed in the ribs of *Virgo*, whereas *Hipparchus* had placed them in her ſhoulders. This obſervation will explain to us how it comes to paſs that we find a difference amongſt ancient authors, in their deſcriptions of the conſtellations: thus, the bull is drawn according to *Hipparchus* and *Ptolemy* with only head and neck and fore-part, as we have him upon our preſent globes; whereas *Vitruvius*, *Pliny*, and others deſcribe him entire, and place the *Plèiades* in his tail.

595 Beſides the names of the conſtellations, the ancient Greeks, who were imitated herein by the Romans and Arabians, gave names to ſome ſmall collections of ſtars, as alſo to ſome of the moſt remarkable ſingle ſtars, on account of their being ſuppoſed to have ſome particular ſignificancy and influence: thus, the cluſter of ſmall ſtars in the neck of the bull was called the *pleiades:* five ſtars in the bull's face the *hyades:* a cloudy ſtar in the breaſt of the crab was called *præſepe*, *the manger*; and two ſtars near it *aſelli*, *the aſſes:* four ſtars at the extremity of the right hand of Aquarius were called *the urn:* fourteen ſtars between the tails of the fiſhes were called *the lines:* whereof five ſtars were reckoned in the *northern*, and nine in the *ſouthern line*, and the bright ſtar between them was called *the knot:* the *ſouthern crown* was called by ſome *uraniſcus*, by *Hipparchus*, *the herald's rod*, ſuch as *Mercury* is uſually drawn

 with;

with: the preceding ſtar at the feet of *Gemini* was called *propus:* a bright ſtar in the breaſt of *Leo, the lyon's heart*, and *baſiliſcus*, or the royal ſtar: a large ſtar between the knees of *Bootes* was called *Arcturus:* one in the ear of corn which *Virgo* holds in her left hand, *ſpica Virginis:* one in her right wing, προτρυγητής, *vindemiator:* the *Pleiades* were by the Romans called *Vergiliæ*, and the *Hyades*, *Suculæ:* the biggeſt ſtar in the *harp* often takes the name of the conſtellation, being called *Lyra* by the Greeks, and by the Romans *Fidicula*.

596 As the Europeans firſt learned aſtronomy from the Arabians, many *arabick names of* ſome *of the principal ſtars* are ſtill retained by them, though ſome of them are ſo wretchedly mangled by ignorant tranſcribers that it has coſt learned men a good deal of pains to ſet them right, others they have not been able to make any thing of at all, but this very thing, their being uncouth or unintelligible, may perhaps have recommended thoſe names to our aſtrologers; otherwiſe, it ſeems to be as agreeable to good ſenſe for an engliſh writer to call a ſtar *the fiſhes mouth*, as to call it *fomahaut*, an arabick word of the ſame ſignification: the like may be ſaid of the reſt, however, ſince cuſtom has ſo prevailed that we cannot help meeting with thoſe names in books, and upon our globes, I ſhall give thoſe which occur moſt frequently, as correctly as I can, in the index.

597 It is very probable the ſtars, eſpecially ſome of the moſt remarkable collections of them, ſuch as *Charles's wain*, the *Pleiades*, *Orion*, &c. were formed into conſtellations and had names given them, in the early ages of the world: ſome of them, by their different appearances, ſerve to mark out the ſeaſons of the year, and upon that account were not only taken notice of as directors when to begin plowing, ſowing, and other works of husbandry[a], but were alſo thought to have a great influence over the temperature of the air, and the fruitfulneſs of the earth; ſo that, from their being ſigns, pointing out the times of the year when heat or cold, dryneſs or moiſture are uſually predominant, they began to be looked upon as the cauſes of thoſe qualities in natural bodies, and were imagined to have dominion over minerals, vegetables, and animals, over the complections, and conſtitutions, and even the tempers and diſpoſitions of mankind: this opinion found credit the more eaſily, becauſe the ſun, moon, ſtars, and planets were believed to be of a divine nature[b], ſome held they were inhabited by an inferior kind of deities[c],

a Heſiod. *Oper. & dier. l.* 2. *v.* 1 & 2. b Voſſius *de origine & progreſſu Idololatriæ. l.* 2. *c.* 30.
c Εικονας Θεων *vocat* Alcinous, *de doctrina* Platonis. *Singulis aſtris ſingulas animas tribuit* Plato, *in* Timæo *p.* 41. *ed.* Serrani *tam cœlum quam ſtellas animalia eſſe, ex eorum motu, credebant philoſophi vett.* Achilles Tatius *in* Arat. *p.* 128. *ed.* Petav. *Pythagorei exiſtimabant planetas eſſe corpora divina*, Gemin εισαγωγ. *c.* 1.

which

which governed their motions and directed their influences: others that they were animals, and had each of them a living ſoul, which was guided by an intelligence: others, that they were animated by a part of the ſubſtance of the ſupream being: each of theſe notions led mankind to pay them religious worſhip. The moſt ancient idolaters are with great probability thought by ſome learned men to have received the name of *Zabii*, from worſhiping the hoſt of heaven[a]: this they could hardly do, without dividing the ſtars into parcels, as we find their apteſt ſcholars in idolatry the Egyptians did, who divided the heaven into ſeveral regions, which they called the ſtations or manſions of their gods[b].

598 *The Egyptians worſhipped the heavenly Bodies*, but eſpecially the ſun and moon, which they called their great gods: they thought the ſun, whom they called *Oſiris*, a proper repreſentative of the ſpirit of nature, the ſoul of the world, or the ſupream being, who is every where preſent, exerciſing his power over every part of the univerſe[c]. The moon as ſhe receives her light from the ſun was looked upon as female, and called *Iſis*[d], which goddeſs is ſometimes made to ſignify univerſal material nature, conſidered as paſſive, and ſuſceptible of various impreſſions, forms and qualities; but the moon conſidered in another view, as active, diſtributing light and warmth over the face of the earth, was ſaid to be male: thus *Iſis* and the moon were counted of both ſexes[e]. They found, or imagined themſelves to find, in various

a צבא השמים *zeba' haſhamaim* Hyde *de relig. vet.* Perſar. *c.* 3. Pocock. *ſpecim. Hiſt. Arab. alias adfert etymologias* Spencerus, *de leg. Hebr. l.* 2. *c.* 1. *ipſe*, Scaligerum *ſecutus, ex* צבין, *voce Arabica, quæ orientales denotat, nomen derivari contendit.* When we are told, what *Spencer* has ſufficiently made out, that many of the obſervances of the Moſaick law which ſeem to be trifling, or to ſerve only to exerciſe the obedience of the Jews, were inſtituted by God, in order to preſerve that people from the idolatry and ſuperſtition of the *Zabii*; I think we may underſtand by that name, not only the *Chaldeans*, but all other nations alſo, who were guilty of the like practiſes, by whom the Iſraelites were in danger of being infected: eſpecially the *Egyptians*, among whom they lived ſo long, and the inhabitants of thoſe countries whoſe land they were to poſſeſs, or in whoſe neighbourhood they were to be ſettled. *Statuerunt* (Zabii) *nullum eſſe Deum præter ſtellas —— ſtellas eſſe divinas (vel Deos minorum gentium) & Solem eſſe Deum magnum —— reliquos quinque planetas eſſe Deos, ſed duo luminaria eſſe majores: —— Solem regere mundum ſuperiorem & inferiorem, philoſophi apud eos exiſtimarunt —— Deum eſſe ſpiritum ſphæræ, vel orbis cæleſtis, orbes cæleſtes & planetas eſſe corpora, & Deum Opt. Max. eſſe ſpiritum illorum —— crediderunt antiquitatem* (i. e. *æternitatem*) *mundi, quia cœli juxta eos ſunt Dei.* Maimonid. *More Nevoch. l.* 3 *c.* 29 *De Zabiis*, D' Herbelot, *Bibliotheque Orientale, in voce* Sabi. b Kircherus *Oedip. Ægyptiac. T.* 2. *part.* 2. *pagg.* 153, 195, 241. c Ειναι δυο θεους αιδιους ϰ̀ πρωτους τον τε ηλιον ϰ̀ την σεληνην, Diodor. Sic. *l.* 1. Voſſius *de Idololat. l.* 1. *c.* 37. *hinc* ο Θεος *pro ſole*, η Θεα *pro luna, apud* Hor. Apoll. *l.* 1. *hierogl.* 5. & 10, & *alios, hinc Sol vocatur* αθανατος ζευς & δεσποτης κοσμου, Onomacrito (*vulgo* Orpheo) *in hymn.* & εικων παγγενετου Θεου Proclo *hymn. in Solem. Deos omnes ad ſolem, ad lunam Deas omnes referri, oſtendit* Kircher. *Obeliſc. Pamph. l.* 3. *c.* 13. *Solem Oſiridis, lunam Iſidis nomine intelligi, idem ibid.* & *l.* 3. *c.* 7. & *Oed. Ægypt. T.* 1. *p.* 172. & *T.* 3. *p.* 139. Voſſius *de Idololatr.* d *Iſis ab* ישה *derivatur a* Voſſio *Idol. l.* 1. *c.* 38. *de Iſide* Apuleius *Metamorph. l.* 11. e *Hinc* Θηλυς ϰ̀ αρσην Onomacrito *hymn. in lunam, hinc Deus Lunus. v.* & Voſſ. *de Idololatr. l.* 2. *c.* 24.

animals, ſome properties or qualities correſponding to the motions, appearances or influences of the ſun, moon, and ſome of the ſtars: this induced them not only to uſe thoſe animals in their hieroglyphic repreſentations of their deities, but alſo to pay them divine honours: thus, they called *the beetle*[a] a living image of the ſun, they pretended that thoſe animals roll up their eggs in little round pellets of dirt, which they turn towards the weſt, while they themſelves continue creeping on towards the eaſt; by the firſt of theſe motions exhibiting the diurnal, by the ſecond, the annual motion of the ſun and planets. They made *the hawk*[b], upon account of his piercing eye, ſtrength, ſwiftneſs, and ſome other qualities, an hieroglyphic of the ſun, and ſometimes of the ſupream being. By *the ram*[c], a prolific animal, they repreſented the genial fertilizing warmth of the ſun in the ſpring; as they did his violent ſcorching heat in the ſummer, by the hot and furious beaſt *the lyon*[d]. *The bull*[e] was looked upon by them as another emblem of the various powers of the ſun, in forwarding the buſineſs of agriculture, wherein this creature is very ſerviceable, the worſhip of a living bull with ſome peculiar marks, to which they gave the name *Apis*, in one part of Egypt, and *Mnevis* in another, is mentioned by a great number of authors[f]; the Jews golden calf is thought to be an imitation of this piece of Egyptian idolatry. *The goat*[g] had divine honours paid him in ſome parts of Egypt, as a repreſentative of the tendency of univerſal nature to propagate the ſeveral ſpecies of beings; from hence the Greeks took their image of *Pan*[h]. They deified *the Nile*[i] whoſe overflowing is ſo beneficial to the land of Egypt, and as that river was obſerved to begin to ſwell at the riſing of *the dog-ſtar*; this made them have a particular veneration for that ſtar, as if its benign influence contributed to that fruitfulneſs which the Nile occaſioned: they called the ſtar *Iſis*[k], the name of their great goddeſs, and *Thoth*[l], the name of their god *Mercury*, whom for his ſagacity in the invention of letters, arts and ſciences, they ſometimes painted in the form of a dog, or of a man with a dogs head, and worſhipped him under the name of *Anubis*[m]. They called the ſame ſtar *Sothis*, or *Siothi*, which in the Egyptian language, according to *Kircher*, ſignifies holy[n]. *Sihor*[o] and *Siris* are other names for the Nile, from whence *Voſ-*

a Hor. Apoll. *l.* 1. *hierogl.* 10. Kirch. *Obel. Pamph. p.* 122, 308, 335. b Hor. Apoll. *l.* 1. *hieroglyph.* 6. Kircher. *Obeliſc. Pamphil. p.* 309. c Kircher. *ibid. p.* 269. d *Id. ibid. p.* 282. e *Id. ibid. p.* 256. f Kircher. *Oedip. Ægypt. T.* 1. *p.* 194. Voſſ. *de Idololatr. l.* 1. *c.* 29. Selden. *de Diis Syris Syntagm.* 1. *c.* 4. g Kircher. *Obeliſc. Pamph. p.* 274. h Kircher. *ibid.* Voſſius *de Idol. l.* 3. *c.* 74. i Kircher. *Oed. Ægypt. T.* 1. *p.* 48. Salmaſ. *Plinian. exercit. p.* 427. *de Nilo etiam v.* Selden. *de Diis Syr. Syntagm.* 1. *c.* 4. & Voſſ. *de Idol.* k Hor. Apoll. *l.* 1. *hier.* 3. l *Iſi Ægyptiis matrem denotat,* Salmaſ. *de annis climacter. p.* 567; *Thoth patrem,* Chamberlain, *oration. Dominic. p.* 30, *hinc forte* Θεὸς, *nam frigida ſunt etyma vulgo allata.* m *v.* Kircher. & Voſſium *de Idol.* n *Prodrom. Copt. p.* 147. *a* Σηθ Adami *filio trahit* Selden. *de* Diis Syr. *Prolegom. c.* 3. o *Sichor Hebr. niger, a limo ſc. hinc olim* αιγυπτος, *poſtea Melo vocatus.*

ſius

fius[a] derives *Sirius*, the greek name of this ſtar, which was imagined to have ſuch dominion over that river; as alſo *Oſiris*, the name of one of their principal deities. *The wolf*[b], a rapacious devouring animal, was looked upon by them as an emblem of the conſuming power of the ſun. *Virgo* was a repreſentation of their goddeſs *Iſis*. *The Scorpion*[c] was an emblem of the deſtructive power of the malignant genius *Typhon*. *The triangle* was a picture of the land of Egypt, which is of a triangular ſhape; and therefore *Kircher*[d] derives *deltoton*, another name for that conſtellation, from *deltoti*, which in the Egyptian language ſignifies a good country, rejecting the common etymology taken from its reſembling the greek letter Δ. *The balance* was the hieroglyphic of juſtice, and therefore *libra* was thought a proper conſtellation for that part of the heaven wherein the ſun appears at one of the equinoxes, when he diſtributes equal day and night to the whole earth: or, if it be conſidered with regard to the land of Egypt, it may intimate the equal diſtribution of the Nile to the ſeveral parts of the country, by the *genius* of the waters; for the figure of this conſtellation was among the Egyptians a man holding a pair of ſcales[e]. To mention no more, the Egyptians worſhipped *ſerpents* and *fiſhes*[f]. *The altar*[g] is alſo ſaid to have been an hieroglyphic of the land of Egypt. I have here confined myſelf chiefly to ſuch animals and other figures as we meet with among our preſent conſtellations, which I think were moſt of them originally Egyptian.

599 That the Egyptians worſhipped all the animals, and uſed the figures abovementioned as hieroglyphics of their deities, *Kircher*[h] proves at large by the teſtimony of ſeveral ancient authors; to which we may add a remarkable paſſage in *Herodotus*[i], who ſays, that in Egypt all ſorts of beaſts, as well wild as tame, were accounted ſacred: and indeed I am inclined to think they worſhipped the hoſt of heaven and all ſorts of animals, while the children of *Iſrael* lived among them, from the caution *Moſes* gives that people, *Deut.* 4. 15. 'Take heed leſt you corrupt *your ſelves*, and make you a graven image, the ſi-'militude of any figure, the likeneſs of male or female, the likeneſs of any beaſt 'that is on the earth, the likeneſs of any fowl that flieth in the air, the like-

a *De Idol. l.* 2. *c.* 74. *v.* Selden. *de Diis Syr. Proleg. c.* 3. & *Syntag.* 1. *c.* 3. *Siri Ægyptiis filius*, Salmaſ. *de annis Climacter. p.* 566. b Kirch. *Obel. Pamph. p.* 296. *Id. Oed. Æg. T.* 1. *p.* 242. c *Scorpionem pingebant tauri teſticulos rodentem, quod Sol in hoc ſigno, terrom adurens, fertilitati, quam in tauro promovebat, inimicas vires exerat: ejus rei imagines vide ap.* Hyde *de rel. vet. Perſar. c.* 4. d Kirch. *Ob Pamph. p.* 325. *prodr. Copt. p.* 233. e Kircher. *Oed. Æg. T.* 2. *part* 2. *p.* 156 Manil. *l.* 2. *Humana eſt facies libræ* ——— *in quem locum ita* Scaliger: *libripens enim in aſtrotheſia figurabatur, alii a virgine geſtari volunt, ut Kalendaria ambo ruſtica Romana: adulatores poetæ* Auguſto *in manus tradunt. v. locum.* f *De Serpentibus*, Kircher. *Obel. Pamph. p.* 347. Voſſius *de Idololat. l.* 4. *c.* 63. *de piſcibus*, Voſſius *ib. l.* 4. *c.* 51. *ubi tamen piſces a ſapientioribus pro deorum ſymbolis potius quam pro diis cultos fuiſſe innuit, quod etiam de cæteris animalibus exiſtimandum eſt.* g Hor. Apoll. *l.* 1. *hierogl.* 22. h *locis ſupra citatis.* i *In* Euterpe.

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'neſs of any thing that creepeth upon the ground, the likeneſs of any fiſh that 'is in the waters beneath the earth, and leſt thou lift up thine eyes unto hea-'ven, and when thou ſeeſt the ſun and the moon and the ſtars, even all the hoſt 'of heaven, ſhouldeſt be driven to worſhip them, and ſerve them, which the 'Lord thy God hath divided unto all nations under the whole heaven. But the 'Lord thy God hath taken you and brought you forth out of the iron furnace, 'even out of Egypt. The mention here made of their being brought out of the land of Egypt ſeems to be intended, to put the Jews in mind of their deliverance from the idolatrous practiſes of that country, as well as from the ſlavery they had endured therein.

600 The Greeks, who learned aſtronomy of the Egyptians[a], retained ſeveral of their figures, as *the ram*, *the bull*, *the lyon*, *the dog*, *the triangle*, &c. but accommodated almoſt all of them to the fabulous hiſtory of their gods and heroes, whom in this manner they placed among the ſtars[b]; but there is a great diſagreement in their fabulous relations: thus, the Twins are by ſome ſuppoſed to repreſent *Caſtor* and *Pollux*, by others *Apollo* and *Hercules*, or *Triptolemus* and *Jaſion:* I do not think it worth the while to enter into the detail of the hiſtory, whether true or fabulous, to which the conſtellations are ſaid to relate; enough of it may be ſeen in *Hyginus*[c], if any one is not ſatisfied with what he finds there, let him read *Ricciolus Almageſt. l.* 6. *c.* 3, 4, 5, and the authors there quoted, as alſo *Sherburne*'s notes upon *Manilius*. Sir *Iſaac Newton*[d] obſerves that *Muſæus*, who is ſaid to have made the firſt globe among the Greeks, was father to *Orpheus*, one of the *Argonauts*; and that the greateſt part of the figures upon the celeſtial globe are made to relate to things or perſons concerned in the Argonautic expedition, and none of them are ſuppoſed by any authors to bear relation to any tranſaction of later date: this is very true, but the great diſagreement there is among the mythologiſts in their accounts of thoſe figures ſhews them to be of greater antiquity, and that the conſtellations were received ſome time among the Greeks, before their poets, according to their ſeveral fancies, applyed them to different fables[d].

601 It muſt be owned the ſtars are capable of being reduced to figures very different from thoſe now in uſe among us, thoſe ſtars which are formed into the lyon might have made an horſe or any other animal, in fact the conſtel-

a Lucian. *de aſtrologia*. b *Ut Græci omnia ſuis heroibus tribuunt, ita & ſuis Ægyptii: inquit* Voſſius, *de Idol. l.* 1. *c.* 28. *Græci hieroglyphicas Ægyptiorum imagines Diis eorum fabuloſis accommodabant,* Kircher. *Oed. Æg. T.* 2. *part* 2. *p.* 196. c *Poeticon Aſtronomic.* d *Chronology. p.* 84. d Nigidius *duo volumina ſcripſit,* 1 *de ſphæra Græcanica,* 2 *de ſphæra Barbarica; in hoc hiſtoriam Syderum ex mente Ægyptiorum contexuit, in illo juxta ſententiam Græcorum. v.* Scalig. *in* Manil. *p.* 368. & Salmaſ. *de annis Climacter. p.* 592.

lations

lations of the Chineſe and Japoneſe are very different from ours[a]: ſome ſuperſtitious Arabians, though they received their aſtronomy from the Greeks, have given ſome of their conſtellations different figures; this they are ſaid to have done becauſe they thought it unlawful to draw any human figure, and therefore they changed all ſuch on the celeſtial globe into ſome other form, and very often abſurdly enough: thus, inſtead of *Aquarius* they give us the figure of a mule ſaddled carrying two barrels, for *Gemini* two peacocks, *Virgo* with them is a wheat-ſheaf, the *centaur* is an horſe and a bear fighting, *Auriga* is a mule ſaddled, with a bridle drawn ſo as to have ſome ſtars upon it, whereas there are none upon the bridle of *Auriga* as drawn by the Greeks: for *Ophiuchus* they draw a ſtork or crane, for *Hercules* they make a camel with his furniture kneeling, for *Sagittarius* they draw only a quiver, for *Caſſiepea* they place a bitch in a chair, for *Andromeda* a ſea-calf, and for *Cepheus* a dog, inſtead of *Bootes* they put a monſtrous figure that *Scaliger* ſays he could not tell what to make of. *not. in ſphæram Barbaric.* Manil. p. 484.

602 Some chriſtian aſtronomers[b], diſpleaſed to ſee the heaven of the fixt ſtars poſſeſt by the fabulous heathen deities and heroes, have been for making a reformation in that point, and have propoſed to retain the ancient figures, referring them to ſome ſcripture hiſtory: in this view they would have the ram to be a memorial of that which was offered inſtead of *Iſaac*, *Virgo* to repreſent the *B. Virgin*, &c. Others would new model all the conſtellations, and put them into different forms: thus, for the twelve conſtellations of the *Zodiac*, they give us the twelve Apoſtles, &c. but this laſt project would bring intolerable confuſion into aſtronomy, in comparing the ancient and modern obſervations; to prevent which, the beſt way is to draw the figures as near as poſſible to the deſcriptions of *Ptolemy*.

603 There are *two ways of delineating* the figures of *the conſtellations*, either ſuch as they appear in the ſphere of the heaven, or, which are the reverſes of the former, ſuch as are drawn upon the common celeſtial globe: if a large room were built with its inſide of a ſpherical form, the conſtellations might be drawn thereon as they appear in the ſphere of the heaven it ſelf: in this manner they may be ſeen on the concave ſurface of my glaſs ſphere, if one looks into it: in the ſame manner they may alſo be drawn upon two concave hemiſpheres, which would contain them all, or, which would be better, ſegments of ſpheres might be made of braſs or paſtboard[c], of ſuch dimenſions

a Martinii *Atlas Sinic. præfat. p.* 18. Kempfer *hiſt. of Japan.* The Perſian and Indian conſtellations are alſo different from ours: Albumaſar, *introduct. l.* 6. *c.* 1. Souciet, *obſervat. mathemat. aſtronomiques & geograph. faites en Chinie p.* 247. b Schillerus *in cœlo Chriſtiano*, Skikkardus *in aſtroſcopio*, Bartſchius *in globo cœleſti. v.* Ricciol. *Almageſt. l.* 6. *c.* 6. & Sherburne's *Appendix to* Manilius *p.* 140. c *v.* § 534.

menſions that each ſegment ſhould contain a ſingle conſtellation upon its concave ſurface. The convex ſurface of my glaſs ſphere ſhews the conſtellations the ſame as the common celeſtial globe does, that is, ſuch as they would appear if we imagine the ſtars all to be fixt in the ſurface of a ſphere, and to be viewed by a ſpectator on the outſide of it looking upon its convex ſurface.

604 Sometimes the *conſtellations* are *drawn* upon two *planiſpheres* projected upon a great circle, this way gives us the pictures of the two concave hemiſpheres *in plano:* the nature of theſe projections may be underſtood from § 541, but as we have obſerved thoſe maps of the earth to repreſent it in the trueſt proportion which ſhew us a ſmall part of it, § 539, ſo thoſe maps of the heaven will ſhew us the ſtars in the trueſt ſituation which take in only one conſtellation entire, with ſome parts of the adjoyning ones.

605 The firſt *uſe of* all theſe concave *ſpheres*, *planiſpheres*, *globes* and pictures of the conſtellations is, by comparing them with the originals, to know the ſtars in the heaven: it has been already obſerved book 1. chap. 2. that, by the rotation of the earth round her axis one way, the heaven with all the ſtars, &c. appears to revolve the contrary way; ſo that, though the fixt ſtars keep their ſituation with reſpect to one another, the ſphere of the fixt ſtars is changing its poſition with reſpect to us, every moment of the natural day: therefore, to compare the ſtars upon a concave hemiſphere, globe, planiſphere, or picture, with the ſtars in the heaven; we muſt place the globe, hemiſphere, &c. in ſuch a poſition as to correſpond with the preſent ſituation of the heaven: I ſhall hereafter ſhew how *to rectify the celeſtial globe to any time of the night*, that is, to place it ſo that every ſtar upon the globe may point at its correſponding ſtar in the heaven; and then the conſtellations may be known, by comparing the heaven and the globe with one another: thus, if I would find a ſtar called *Arcturus* in the heaven; the globe being rectified to the time of night, I find *Arcturus* thereon, then if I imagine a line to be drawn from the center of the globe through that ſtar, that line continued will point at *Arcturus* in the heaven. Suppoſe, on the other hand, I ſee ſome bright ſtar in the heaven which I want to know upon the globe, I firſt rectify the globe to the time of night, and then if I imagine a line to be drawn from the ſtar to the center of the globe, it will point at the correſponding ſtar on the ſurface of the globe. Maps of the concave ſurface of the heaven, eſpecially ſuch as take in only one conſtellation with ſome parts of thoſe which ſurround it, are very uſeful for the purpoſe of being acquainted with the ſtars: of this ſort are the figures given us by *Bayer* in his *Uranometria*, and thoſe of *Flamſteed* publiſhed after his death by *Hodgſon*; the manner of uſing them will be ſeen by the following example: if I would know the ſtars in the

the great bear, I turn the figure about, till the principal ſtars thereof are in the ſame ſituation with regard to upper or under, right or left, as they appear in the heaven, at the time of making my obſervation; when this is done, it is eaſy, by looking firſt on the heaven and then upon the map, to ſee to what parts of the figure, whether to the eye, ſnout, &c. the reſt of the ſtars are to be referred.

606. *A catalogue of the ſtars* contains both the conſtellations and the unformed ſtars, with the number of ſtars in both, and the place of each ſtar: the firſt of this kind amongſt the Greeks was made by *Hipparchus* of Rhodes, who flouriſhed about 120 years before Chriſt: he, as *Pliny* informs us, *Nat. Hiſt. l.* 2. c. 26, upon the appearance of a new ſtar, began to doubt whether there might not be changes amongſt the fixt ſtars, and therefore made a catalogue of them, ſetting down the place and magnitude of each ſtar, that, if in time to come any new ſtars ſhould come into view, or any of thoſe obſerved by him ſhould increaſe or be diminiſhed in magnitude, or ſhould totally diſappear, ſuch changes might be known to after ages: here we have one *uſe of a catalogue of the ſtars* pointed out to us; another uſe is to determine thereby the true places and motions of the heavenly bodies.

607 The moſt ancient catalogue now remaining is that of *Ptolemy*[a], copied chiefly from *Hipparchus*, but with ſome few alterations, as was ſaid § 594, he ſettles the places of the ſtars as he himſelf obſerved them, in the beginning of the reign of *Antoninus Pius*, about A. D. 140; the number of ſtars in this catalogue is 1026. In imitation of *Ptolemy*, ſeveral aſtronomers have ſince his time made catalogues of the ſtars, computing their places for ſome year in or near their own time: this perhaps may want ſome explanation, for which purpoſe it is to be obſerved, that the place of a ſtar is denoted by ſetting down its longitude and latitude[b], and that, though the fixt ſtars keep the ſame ſituation in reſpect of one another, the ſphere of the heaven appears to have a ſlow motion, by which the longitude of all the ſtars is altered, at the rate of about $50''$ in a year, their latitude continuing the ſame; this makes it neceſſary for any one who makes a catalogue of the ſtars and ſets down their longitudes and latitudes, to tell us for what point of time the catalogue is calculated.

608 The Arabians are the firſt who after *Ptolemy* obſerved the ſtars, and noted down their places: the learned *Hyde*[c] mentions ſeveral of their catalogues, and publiſhed the moſt conſiderable one of them in arabic with a latin tranſlation, it was made by *Ulug Beigh* grandſon to *Tamerlane*, from his

a *Almageſt. l.* 7 & 8. b What the longitude and latitude of ſtars is, will be ſhewn hereafter.
c *Præfat. ad tabb.* Ulug Beighi.

own obſervations, at *Samarcand:* the number of the ſtars contained therein is 1022, the places of the ſtars are reduced to A. D. 1437.

609 The noble *Tycho Brahe*[a] tells us, that he had, by his own obſervations, rectified the places of 1000 ſtars, and that he put that number upon his globe of ten feet diameter; notwithſtanding this, his catalogue publiſhed in his *progymnaſmata*, A. D. 1602, a year after his death, and afterwards by *Longomontanus* in his *Aſtronomia Danica*, contains but 777 ſtars, with their places for the year 1600: we have therein ſome ſtars omitted by *Ptolemy*, though the whole number falls ſhort of his, becauſe ſeveral ſouthern ſtars, which could be ſeen by *Ptolemy* at Alexandria in Egypt, are not viſible in *Tycho*'s more northern ſituation at Uraniburg.

610 About the ſame time with *Tycho*, *William* Landgrave of Heſſe, aſſiſted by *Rothmannus* and *Byrgius*, obſerved the ſtars, and inſerted 400 of them in a catalogue, rectifying their places to the year 1593.

611 *Bayer* in his *Uranometria* publiſhed a catalogue of 1160 ſtars, compiled chiefly from *Ptolemy* and *Tycho*, together with very beautiful figures of the conſtellations[b]: one thing which makes this work valuable is this, that, beſides deſcribing the ſtars in the manner uſed by *Ptolemy*, every ſtar is marked with ſome letter, in ſuch a method that the biggeſt ſtar of every conſtellation is denoted by the firſt letter of the greek alphabet, the next biggeſt ſtar by the ſecond &c: and when any conſtellation contains a greater number of ſtars than that alphabet will reach, thoſe that remain are marked in like manner by letters of the Roman alphabet: by this means every ſtar is as eaſily diſtinguiſht, as if it had a proper name given to it: thus, if mention is made of the ſtar in the conſtellation of the ram marked by *Bayer* with the letter γ, every aſtronomer knows as well what ſtar is meant, as if it were pointed out to him in the heaven: this invention is ſo uſeful, that *Flamſteed* has in his own catalogue taken in *Bayer*'s letters, as far as they go; as *Senex* alſo has done upon his globes of the largeſt ſize, as alſo upon his planiſpheres.

612 *Kepler*, who had the uſe of *Tycho*'s obſervations, publiſhed a catalogue of 1000 ſtars obſerved by *Tycho*, at the end of his *Tabulæ Rudolphinæ*; he adds thereto thoſe ſtars of *Ptolemy*'s catalogue which *Tycho* had omitted, together with thoſe of the new ſouthern conſtellations, from other authors: ſo that his whole catalogue amounts to above 1160: their places are computed for the year 1600.

a *In aſtron. inſtaurat. mechanica.* b *Flamſteed*, after others, juſtly finds fault with *Bayer*'s figures, for being inverted; it ſeems the author himſelf made the ſame complaint, laying the fault upon the deſigner or engraver. Ricciol. *l.* 6. *pag.* 411.

613 The celebrated *Hevelius* is next to be mentioned; he compoſed a catalogue of 1888 ſtars, whereof 1553 were obſerved by himſelf: the places of them were computed by him for the year 1660.

614 The largeſt and moſt complete of all is the Britiſh catalogue of the ſtars, owing to the labours of Mr. *Flamſteed*, Royal profeſſor of aſtronomy at Greenwich; it contains no leſs than 3000 ſtars, many of which are ſo ſmall that they cannot be ſeen without the help of a teleſcope, the places of them are rectified to the year 1689: we have it in the 3d volume of his *Hiſtoria Cæleſtis*, wherein, beſides that of *Ptolemy* which is to be met with in a great many other books of aſtronomy, we have alſo the above mentioned catalogues of *Ulug Beigh*, *Tycho*, *the Prince of Heſſe*, and *Hevelius*, reprinted; together with an account of each of them in the *Prolegomena*.

615 *The* greateſt *number of ſtars* is to be ſeen in a winter's night, when the air is clear, and no moon appears: but aſtronomers[a] tell us that a good eye can hardly reckon above 1000 ſtars at a time in the viſible hemiſphere: for though in a clear night without moon-ſhine they ſeem to be innumerable, this is a deception of the ſight, ariſing from their ſtrong ſparkling, and our looking at them in a general and confuſed manner without reducing them into any order: whereas, if we come to view them diſtinctly, and conſider a ſmall part of the ſphere of the heaven at a time, we ſhall not eaſily diſcover a ſingle ſtar but the ſame has been obſerved by ſome aſtronomer, and is inſerted in his catalogue, and has found a place upon the celeſtial globes of the largeſt ſize. Some perſons are able at the ſame time to ſee a greater number of ſtars than others, by reaſon of the difference there is in mens eyes: I have my ſelf more than once ſeen ſeven, and a learned aſtronomical friend aſſures me he has ſeen eight ſtars among the *Pleiades*, where common eyes can diſcover but ſix, according to that often quoted verſe of *Ovid*,

Quæ ſeptem dici, ſex tamen eſſe ſolent.

Which ſev'n are call'd, though only ſix appear:

but this is nothing to what *Kepler*[b] ſays of his tutor *Mæſtlinus*, that he could reckon 14 ſtars in the *Pleiades* without any glaſſes, and of an eccleſiaſtic, who could in a clear night count to the number of 40 in the buckler of *Orion*. We muſt therefore, notwithſtanding what was ſaid in the beginning of this ſection, be forced to acknowledge the number of the ſtars to be vaſtly great, though there be no reaſon to think it infinite, as *Jordano Bruno*[c] would have us believe.

a Keil's *Aſtron. lect.* 6. *v.* Ricciol. *Almageſt. l.* 6. *p.* 411. b *ap.* Ricciol. *l.* 6. *p.* 411
c *ap.* Ricciol. *Alm. l.* 6. *pag.* 412.

616 An ordinary teleſcope will, in ſeveral parts of the heavens, diſcover ten times as many ſtars as are viſible to the naked eye: *Hook* in his *Micrographia* page 241, ſays, that with a teleſcope of 12 feet he counted 78 ſtars among the *Pleiades*, and with a more perfect teleſcope was able to ſee a great many more: *Galileo* found 21 in a cloudy ſtar in *Orion*, and reckoned at leaſt 80 in the ſpace between his belt and his ſword, and above 500 in another part of him within the compaſs of one or two degrees ſquare; ſo that he was diſcouraged from proceeding in his intention of obſerving all the ſtars of that conſtellation: this makes the account of *Antonius Maria de Rheita*[a] not improbable, who affirms that he counted therein about 2000.

617 That part of the heaven which is called *the milky-way* is found by the teleſcope to owe its whiteneſs to a great number of ſtars ſcattered therein, too ſmall to appear diſtinct to the naked eye: the like is true of ſeveral bright ſpots in the heaven, which appear like ſmall white clouds: the greater perfection teleſcopes are brought to, the greater number of ſtars will they diſcover; and yet there is no queſtion to be made, but that, whatever perfection they can be brought to, there will ſtill remain out of their reach a great number of ſtars ſcattered through the vaſt abyſs of immeaſurable ſpace, ſo that we have reaſon to believe, that only that infinitely wiſe and powerful Being who created them is able to tell the number of the ſtars, and to call them all by their names.

CHAP. 3. THE SOLAR SYSTEM: A PLURALITY OF WORLDS.

618 *The ſolar ſyſtem* conſiſts of the ſun with the planets and comets which perform their revolutions round him: and may be thus deſcribed, in the midſt of a vaſt cavity ſurrounded every way with ſtars, which are all at an immenſe diſtance from the ſun and from one another, is placed *the ſun*, a vaſt globe of fire, fixt as to his ſituation, whilſt our earth with the five planets and ſeveral comets perform their revolutions round him, at different diſtances from him, and in different periods of time. The planets may be conſidered as ſo many earths, which are in different degrees enlightned and warmed by the ſun; perhaps they may be inhabited by creatures both rational and irrational, though very different from thoſe upon our earth. To an inhabitant of any of the planets our earth would appear like one of the reſt of the planets: in this view, we may reckon the earth among the planets. *The names of the planets* are theſe, the neareſt to the ſun mercury, the

a *In radio Sydereomyſt. p.* 197 Ricciol. *l.* 6. *p.* 413. *See* Sherburne's *Notes upon* Manilius *p.* 157.

next

next to him in order venus, then the earth, mars, jupiter, ſaturn. For a further account of the names of the planets ſee the remarks at the end of this chapter.

619 *The diſtances of the planets from the* ſun are, in round numbers, in the following ratio: if we imagine the diſtance of the earth from the ſun to be divided into 10 equal parts, the diſtance of mercury from the ſun is 4, the diſtance of venus 7 of thoſe parts, the diſtance of mars 15, of jupiter 52, of ſaturn 95. How theſe proportional or comparative diſtances are found out, will be the ſubject of enquiry in another place; as will alſo what the real abſolute diſtances of the planets from the ſun are, in ſome known meaſure, and by what means we diſcover them. When we compare the diſtances of the ſeveral planets from the ſun, in a looſer and more general way, we call thoſe ſuperior which are further from the ſun, thoſe inferior which are nearer to him: thus, in reſpect of our earth, venus and mercury are *the inferior*, mars, jupiter and ſaturn *the ſuperior planets:* in order to explain the appearances of the inferior planets, it will be ſometimes ſufficient to conſider only one of them, the caſe of the other being ſo much the ſame, as not to want a particular explanation: in like manner, there is ſo great a ſimilitude between the ſeveral caſes of the ſuperior planets, that an illuſtration of one will make it eaſy to underſtand the reſt.

620 *The periodical times of the planets*, in which they go round the ſun, are in round numbers, as follows: mercury goes round the ſun in 3 months, venus in 7 months, the earth in 12 months, mars in 2 years, jupiter in 12 years, ſaturn in 30 years.

621 The abovementioned are called *primary planets*, to diſtinguiſh them from others of an inferior order; for ſome of the primary planets, in their revolutions round the ſun, are attended with other globular bodies ſmaller than themſelves, which are called *ſecondary planets*, *moons*, or *ſatellits:* thus, our earth is attended by the moon, jupiter has four moons or ſatellits, which are not viſible without the teleſcope, and ſaturn has five, which cannot all be ſeen without the help of very long teleſcopes in a very clear air.

622 Though *the moon* be leſs than any of the primary planets, yet ſhe is ſo much nearer to us, that ſhe appears much larger than any of them do, and gives a great deal more light than all the ſtars and planets together: on account of this, and of her appearing nearly of the ſame dimenſions with the ſun, the ſun and moon are called *two great lights*, and the moon is called *the leſſer light*[a], as being vaſtly inferior to the ſun in brightneſs as well as magnitude. The moon, by enlightning the darkneſs of the night, which ſhe is therefore ſaid to rule, as the ſun is to rule the day, and by her various

a *Gen.* 1. 16.

appearances

appearances dividing the year into parts, which from the moon are called *months*, is of great confideration to the inhabitants of the earth: not to mention at prefent the certain influence fhe has upon the tides, and that lefs certain upon the weather.

623 *The characters of the fun, moon, and planets*, which are often put to fignify them, are thefe that follow: the fun ☉, the moon ☽, mercury ☿, venus ♀, the earth ⊕, or ⊖, mars ♂, jupiter ♃, faturn ♄. For an account of thefe characters fee the remarks.

624 *The number of comets* which go round the fun is not yet afcertained: fo many different ones have been obferved, as to affure us there are at the leaft 20 of them, but of thefe there are only 3 or 4 whofe periodical times and diftances from the fun are certainly known: it is probable the number of comets belonging to the folar fyftem is greater than was juft now mentioned, for fome of them may be too fmall to be feen without glaffes, and the difcovery of fuch muft be owing to their accidentally falling within the telefcope of fome aftronomer, who is looking at the heaven upon fome other account; others, that in fome part of their courfe approach near enough to the earth to be vifible to us, may at the fame time happen to be fo near the fun, as for that reafon to efcape obfervation; for the fplendor of his rays is fuch, that the brighteft ftar or planet difappears when it is immerfed therein, and requires to be at fome diftance from him, in order to be difcernable to us.

625 *Every fixt ftar* may be *a fun* furrounded with its proper planets and comets: the fixt ftars feem to be of the fame nature with the fun, fhining with their own light as he does, many of them may equal and even furpafs him in magnitude; the reafon of their appearing fo fmall is their exceeding great diftance from us. When we fpeak of a *plurality of worlds*, the word world does not fignify the univerfe, as in the definition § 581, but is taken in a more reftrained fenfe: for we may either mean that the feveral planets are habitable in like manner as our earth is, which in common fpeech we fometimes call the world; or we may by the world underftand the whole folar fyftem, and confider the *ftarry fyftems*, that is, the feveral fixt ftars with the planets and comets belonging to each of them, as fo many different worlds: in one or other of thefe fenfes fome of the ancient philofophers, as well as the moderns, have held a plurality of worlds: but this fpeculation will be better refumed hereafter, when we have confidered the planets of the folar fyftem more diftinctly, and feen how well they appear fitted for the habitation of animals.

Remarks

Remarks upon *the names of the planets* in the foregoing chapter.

626 The abovementioned names of the planets are the roman names of heathen gods: as idolatry was propagated at firſt from the eaſt, we muſt ſearch for the origin of both the greek and the roman names of their deities among the eaſtern languages, as learned men have done with good ſucceſs [a]. I make no queſtion, but the planets had originally other names given them, which were expreſſive of the nature of their motions, or appearances, or of the influences they were thought to have: ſome ancient greek names, which we meet with in ſeveral authors [b], ſeem to be of this ſort: there we find ſaturn, whoſe common greek name χρονος *cronos*, time, was given him upon account of the ſlowneſs of his motion [c], was alſo called φαινων *phænon*, i. e. appearing or ſhining [d]: he is thought to have received this appellation, becauſe of all the planets he is the ſeldomeſt hid by the rays of the ſun, or elſe, his light being the dimmeſt of them all, he was called ſo out of a ſuperſtitious cuſtom the ancients had of giving good names to bad things for the ſake of good luck: his ancient hebrew name is thought to be *khiun* [e]. He was counted unfortunate, and of a malign influence, for no better reaſon, I believe, than for his being thought cold and dry by reaſon of his great diſtance from the heat of the ſun and the vapours of the earth, and his appearing of a pale leaden hue: for the aſtrologers judged of the nature of the planets by their colour [f].

Φαεθων *phaethon* is an ancient greek name of the planet jupiter, it is taken from his brightneſs, *Homer* applies the ſame word to the ſun as an epithet [g]. His ancient hebrew name is thought to be *gad*, he has other names *khokhab zedec*, the ſtar of juſtice, and *mazal tob* [h], good fortune: but theſe are of later date. The aſtrologers pretend he is of a benevolent nature, as being of a middle temperament, between the heat of mars and the coldneſs of ſaturn.

Mars was by the ancient greeks called πυροεις *pyrois*, fiery, his perſian and arabic names, *azur* and *azer*, ſignify fire [i], all from his red fiery appearance; which I believe is the beſt reaſon the aſtrologers have for imagining this planet unfortunate, and particularly to be a promoter of war and bloodſhed [k].

a Voſſius, Selden, Hyde. b *Autor de mundo inter* Ariſtot. *opera*, Cicero *de nat. deor. l.* 2. Hyginus, Martianus Capella & *alii.* c Κρονος *dicitur qui eſt idem* χρονος, *id eſt temporis ſpatium*, Cicer. *de nat. deor. l.* 2. d Φαινει λαμπει. Heſych. e כיון Amos 5. 25. f *Stellarum naturas Chaldæi ſiccas, frigidas, humidas, juxta colorum diverſitatem deprehendiſſe ſibi videntur*, *inquit* Albumaſar, *introduct. l.* 4. *c.* 4. *ubi plura huc ſpectantia.* g Ηλιος φαεθων *Il.* λ. *v.* 734. h Selden. *de Diis Syr. Syntag.* 1. *c.* 1. i Hyde *de relig. vet. Perſar. pag.* 63. *ab azer fortaſſe* αηρ, *per metathesin, vel ab* אריץ ariz, *fortis*, *v.* Selden. *de Diis Syr. Syntag.* 1. *c.* 6. k *Aſtrologis ſtella jovis aut veneris conjuncta cum luna ad ortus puerorum ſalutaris, ſaturni martiſve contraria.* Cicero *divinat. l.* 1. *proſperus & ſalutaris fulgur jovis, rutilus horribiliſque martis.* Cic. *ſomn.* Scipion.

Venus

Venus was called εωσφορος *eosphoros*, the morning ſtar, and φωσφορος *phoſphoros*, the harbinger of light, when ſhe appears in the morning, riſing before the ſun; and εσπερος *heſperos*, or the evening ſtar, when ſhe ſets after him: under the firſt and laſt of theſe names ſhe is mentioned by *Homer*, who juſtly ſtiles her, as *Milton* does alſo, Faireſt of ſtars[a] —— It may be obſerved upon this occaſion, that both greek and roman writers frequently comprehend under the name of ſtars all the heavenly bodies in general, which appear as ſuch to common obſervers: we do the ſame in engliſh, complying herein with the vulgar, who are unacquainted with the difference between the ſtars and planets. Venus is thought, upon the account of her beautiful light, to have been the firſt of the planets to which religious worſhip was paid; ſhe was adored in the eaſt under various names[b]. The aſtrologers count her fortunate, the ancients thought her to be moderately hot, by reaſon of her nearneſs to the ſun, and moiſt, becauſe they were ſuch philoſophers as to fancy ſhe was near enough to the earth to be within reach of the vapours aſcending from thence; upon account of theſe two qualities, they imagined this to be a prolific planet.

Mercury is generally ſo near the ſun that he is ſeldom ſeen, this occaſioned him to be unknown to the Greeks, and conſequently unnamed by them, for ſome time; they called him στιλβων *ſtilbon*, from his bright ſhining, his light being exceedingly vivid and ſparkling beyond the reſt of the planets: the aſtrologers think him to be of an indifferent nature, of good or bad influence according to the quality of the ſtars and planets with which he is in conjunction.

The ſun was called by the Phenicians *beel ſamen*[c], the lord of heaven, being the moſt glorious of the heavenly bodies; his common greek name ηλιος *elios* is derived from אל *el*, one of the names of God: his moſt ancient Hebrew name is *ſhemeſh*, a miniſter or ſervant, from his being conſtantly employed in the ſervice of the world, ſay the lexicographers, but I rather think from his being the miniſter or ſervant of the creator, by whom he was made and appointed to rule the day, to divide the light from the darkneſs, and to diſtribute heat and light over the earth: he had other names from his heat, as חמה *khamma*, *pire*[d], or from his light, as *orus*, *phœbus*, *phanes*[e]; the name *mithra*, by which he was known among the Perſians, is by *Voſſius*[f] derived from *mither*, which in their language ſignifies great, but *Hyde*[g], whoſe

a *Iliad*. X. *v*. 318. Εσπερος ος καλλιστος εν ουρανω ισταται αστηρ. b Voſſius *Idololatr*. Selden. *de Diis Syris*. Hyde *de rel. vet. Perſar. c*. 3. c *v*. Selden. *de Diis Syr. Syntag*. 2. *c*. 1. *Sol dux, princeps & moderator reliquorum luminum*. Cic. *ſomn*. Scipion. d *Dicunt Ægyptii ſolem πιρη, ab ignea virtute*. Kircher. *Prodrom. Copt. p*. 146. e *Orus ab* אור *lux*. φανης Sol, Voſſ *de Idol. l*. 2. *c*. 7. φοιβος, καθαρος, λαμπρος. Heſych. f *De Idololatr. l*. 2. *c*. 9. g *De rel. v. Perſ. c*. 4.

consummate

conſummate ſkill in the perſian learning makes his opinion of great weight, derives it from *mihr*, love or mercy, becauſe, ſays he, the whole world is cheriſhed by the ſun, and feels the effects, as it were, of his love: that learned writer, from their own books, has ſhewn at large that the Perſians did not worſhip the ſun, as they are by a great number of authors ſaid to have done, but only conſidered him as a glorious and beautiful light, and the fitteſt ſymbol of the divinity which is to be met with among the viſible parts of the creation; and therefore they paid him, not divine adoration, but only a civil reſpect, as they did alſo to the fire and other elements: and that their turning themſelves towards the riſing ſun, or their ſacred fire, in their devotions was the occaſion of their being thought to worſhip them. And yet I am apt to believe that, whatever the wiſer ſort among them might practice themſelves or teach others, many of the common people even among the Perſians worſhipped both the ſun and the fire: the experience of all times and places ſhews how apt men are, eſpecially the vulgar, to paſs from the uſe of ſymbolical repreſentations of the divinity to the worſhip of the ſymbols themſelves. But whatever the Perſians did, it is certain that other nations worſhipped the ſun by the name of Mithra: the Greeks are ſaid to have had a temple at Alexandria where they offered human ſacrifices to him, and there are ſeveral roman inſcriptions remaining wherein Mithra is ſtiled the invincible, almighty and moſt holy god. *v. Hyde de relig. vet. Perſar. p.* 112.[a]

The names of the moon σεληνη *ſelene* in greek, and *luna* in latin, are both derived from words which ſignify light; one of her names in hebrew לבנה *lebanah* is from her whiteneſs, another ירח *yareakh* is, as ſome tell us, from a word which ſignifies to refreſh; becauſe ſhe was thought to refreſh the earth with her influences.

The greek names of the planets abovementioned are egyptian names expreſſed in greek words of like import; it is common when names have a known ſignification in their original language, for an author who writes in another language to expreſs the meaning of them in words of a like ſignification, though of a very different ſound: there are many examples of this in the tranſlation of the old teſtament by the ſeventy. The words φαινων, Φαεθων &c. are manifeſtly greek, and yet theſe are expreſſly ſaid to be egyptian names by the authors quoted in the margin[b].

627 We have in *Hyde* the chineſe names from a learned native of China[c]: ſome of them are taken from ſuch things as they believe to be under the par-

a *vide etiam inſcriptiones a* Grutero *et* Reineſio *editas.*

b Achilles Tatius *p.* 136. *ed.* Petav. Manetho *apud authorem chronici Alexandrini, p.* 108. *ed.* Raderi, τον γαρ λεγομενον Κρονου αστερα εκαλουν τον λαμποντα· τον δε Διος τον Φαεθοντα· τον δε Αρεως τον πυρωδη· τον δε Αφροδιτης τον καλλιστον· τον δε Ερμου τον στιλβοντα. c *de relig. vet. Perſar. p.* 221.

ticular dominion of each planet; thus, they call mercury *shiu* water: why that planet is thought to preside over that element we are not told, it may be perhaps from his being visible only when near the horizon, in the morning or evening, when the air is commonly moist: he is also called *tchin* the morning star: one name for venus is *kin* gold, another *tai pe* very white: they call mars *ho* fire, and *yungh* flame: jupiter is called *mo* wood, and *çui* a year; for what reason it is not very easy to guess: saturns name is *tu* or *tien* i. e. earth, perhaps from the dullness of his aspect.

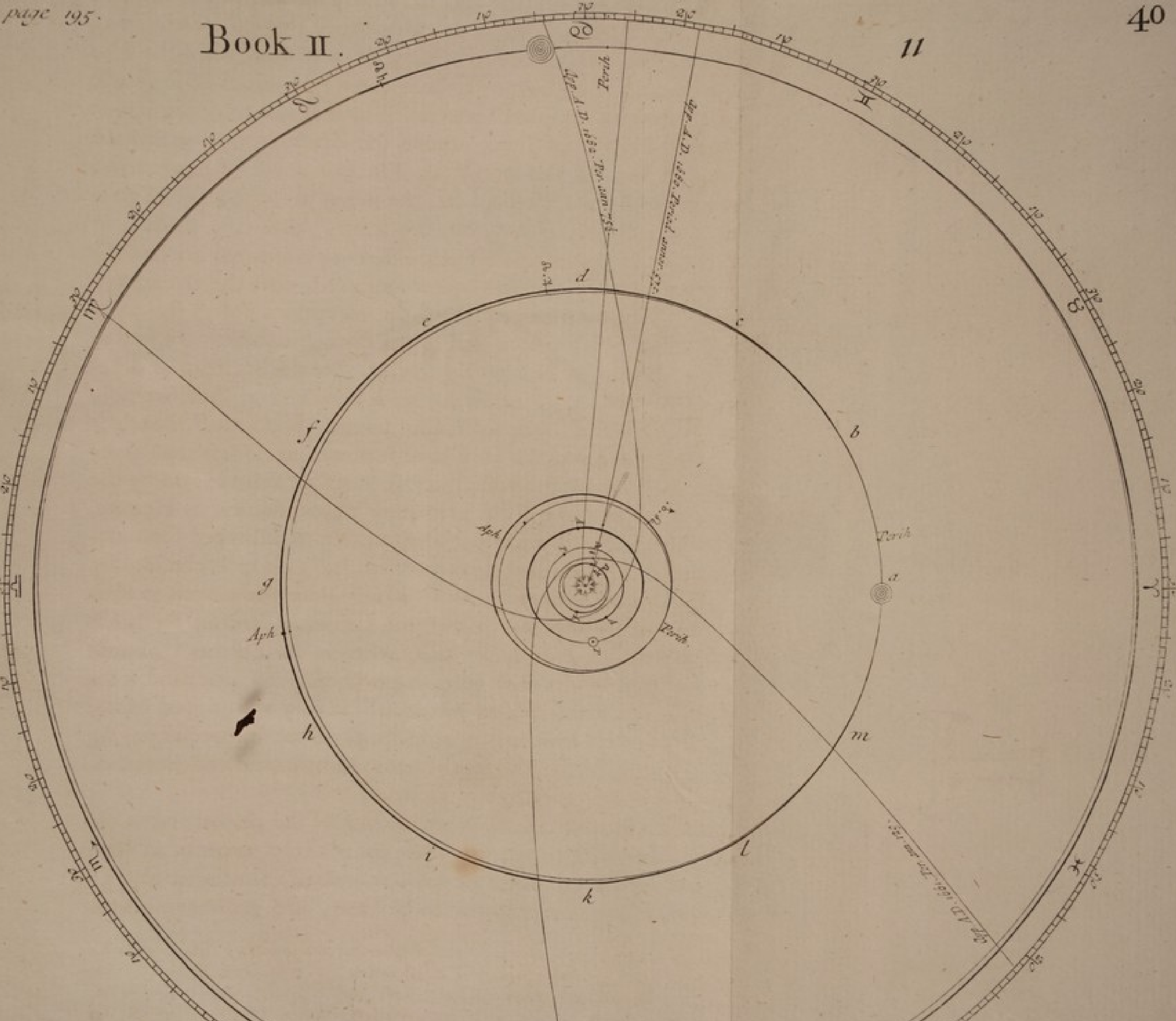
628 The dominion of the heavenly bodies was fancied by superstitious antiquity to be so extensive, that the sun, moon and planets had each of them a particular constellation or portion of the heaven assigned to it, wherein when they were posited they were supposed to be most powerful in their influence; and were therefore said to be in their exaltation: as when in the opposite point of heaven they were said to be in their fall or detriment, and thought to be weak. Besides this, every one of them had its peculiar colour, metal, stone, tree, plant, fruit, flower, animal, number, day, hour, &c. assigned to it; from whence are derived the supposed virtues of amulets and talismans: for the dealers in these fooleries pretend that there is a sympathy between the heavenly bodies and those things which are under their dominions, so that, for instance, that plant, metal, colour &c. over which any planet presides has reciprocally a power of attracting the influences of that planet. Hyde *de relig. vet. Persar. p.* 63 & 129.

629 I have before observed, § 597, that zabiism or the worship of the host of heaven was the most ancient kind of idolatry [a], the custom of deifying dead men was later, though that also is very ancient [b]: when this practice began, it was usual to make the people believe the departed hero was gone to take up his residence in the heaven, or in one of the heavenly bodies, which upon this occasion was consecrated to him [c]: from hence came the *personal names of the planets*, as we may call those in common use, because they were taken from persons deified; though after the planets had received those personal names from deified heroes, the reverse of this became customary, and princes and great men frequently took their names from the planets [d]. The most ancient author [e] now remaining who mentions any names of the

a *v.* & Maimonid. *de Idololatria, cap.* 1. b Some think Misraim was the first who deified his father Ham, whose name חם has the same signification with Ζευς the greek name of Jupiter. *Cumberland's Sanchoniatho p.* 57, 156, 199. c We may see something like this practised in later times, in the deifying *Julius Cæsar* and *Antinous*, *v.* Sueton. *in* Julio. c. 88. & Xiphilin. *in* Adriano. d *v. chronicon Alexandrin. p.* 84. 86. 89. 90. & Hyde *de relig. vet. Persar. p.* 65. e Timæus *Locrus de anima mundi*, *inter opera* Platonis, *p.* 99 *ed.* Serrani, & *ex eo* Plato *in* Timæo, *p.* 38. *autor de mundo*, *apud quem hæc occurrunt prope initium*, ο του Φαινοντος, αμα τω κρονου καλουμενος κυκλος, εξης δε ο Φαεθοντος, Διος λεγομενος. ειθ' ο πυροεις, ο Ηρακλεους τε και Αρεος προσαγορευομενος. εξης δε ο στιλβων, ον ιερον Ερμου καλουσιν ενιοι, τινες δε Απολλωνος. μεθ' ον ο του

planets,

Book II.



planets, calls that neareſt the ſun the ſtar ſacred to Hermes, others called it the ſtar of Apollo. Mars was by the Egyptians called the ſtar of Hercules, by the Babylonians Thurras[f], *Homer* uſes a word very like this laſt for an epithet of Mars as a deity[g], his name in the ancient Etruſcan language was *Turan*[h], but it is not certain the planet was called by that name. Venus, which was by ſome named the ſtar of Juno, among the Egyptians was called the ſtar of Iſis, as jupiter was the ſtar of Oſiris. The ſun as one of the heathen deities had the name of Apollo, Phœbus &c. the moon as a goddeſs had great variety of names, *Iſis*, *Diana*, *Hecate*, &c. See p. 179, note c.

630 This diverſity of names ariſes from different perſons having had the ſame ſtar conſecrated to them: it was before obſerved, that the Greeks applied thoſe ſtories to their own heroes which the Egyptians did to theirs; it may be obſerved further, that a great deal of the confuſion which we find in the hiſtories of the heathen gods is owing to this, that the ancients, at different times, deified various perſons under the ſame name: thus, there were ſeveral Mercuries, ſeveral Marses, ſeveral Venuses, ſeveral Apolloes &c[i], and ſuch a number of Jupiters, that *Varro* is ſaid to have reckoned up no leſs than three hundred[k]. Again, when any of the eaſtern or northern nations are ſaid by the ancients to have worſhipped any of the grecian or roman deities, as Hermes, Jupiter, Apollo, Saturnus; we muſt not imagine they worſhipped them under the greek or roman names, but the writer in that caſe calls the idol by the name of ſome deity of his own country, which came the neareſt to it in the fabulous account of its actions, power and influence, and in the kinds of worſhip which uſed to be paid to it: thus, whereas the northern nations anciently adored the god whom they imagined to preſide in battle, and to be the diſpoſer of victory, a roman writer would tell us they worſhipped Mars; in like manner, if a grecian hiſtorian were to ſpeak of the Egyptians paying divine honours to Thoth, as the inventor of letters, arithmetic and ſeveral other arts, he would ſay they worſhipped Hermes.

I ſhall conclude theſe remarks about the names of the planets, with obſerving that the conſecrating *Cronus* into the planet ſaturn appears to have been mentioned in very ancient hiſtory[l], ſee *Cumberland's Sanchoniatho p.* 37. that learned prelate, *p.* 113, takes *Cronus* to be Ham, and derives this name

φωσφόρον, οἱ Ἀφροδίτης, οἱ δὲ Ἥρας ἐπονομάζουσιν. f *Chronicon Alexandrin. p.* 88. *v. etiam* Salmaſ. Plinian. *exercit. p.* 1235. g Θοῦρος Ἄρης *iliad.* E. & *paſſim.* h *v.* Gorii *Muſeum Etruſcum vol.* 2. *p.* 113. taran. *Cambro-Britannis tonare ſignificat.* Voſſ. *Idol. l.* 2. *c.* 33. *præter Jovem alios etiam Deos & in his Martem tonare, & ſibi propria habere fulmina, credebant Etruſci.* Plinius *N. Hiſt. l.* 2. *c.* 20 & 52. Voſſ. *Idol. l.* 3. *c.* 8. Gorius *Muſei Etruſci vol.* 2. *p.* 79. i Cicero *de nat. Deor. l.* 3. k *Jovis nomine fabuloſa antiquitas dignata eſt reges & principes, qui ſui ordinis cæteros potentia antiſtarent: itaque videas nullo prope ſeculo defuiſſe ſuum Jovem, uſque ad tempora belli Trojani.* Voſſ. *de Idol. l.* 1. *c.* 14. l Philo. *ap.* Euſeb. *Præp. Evang. p.* 40 & 156. *ed.* Vigeri.

FIG. of him from קרן a word which imports such an illustrious person as a king. *Rephas* is the name of saturn in the coptic language, *Kircher. Prodr. Copt. p.* 147, the seventy render *Chiun* in *Amos* 5. 25, by *Rephas*; some copies seem to have had *Remphan*, *Acts* 7. 43; the Bp. *p.* 221, derives it from רפא a word which imports that healthful constitution that produces long life, growth to great stature, and strength: this is more probable than what some learned men think, that the seventy read רין instead of כין, the bottom of the letter כ being effaced in their copy. Ham was especially deified and adored of all the giants before and after the flood, the mightiest men of his race gloried in their likeness to him, and therefore affected to be called *Rephaim*. The Bp. *p.* 199, thinks *Sem* the best son of *Noah* to be the same as *Melchizedec*, that he was called *the just* (*Melchizedec* signifies a righteous king) and that some of his idolatrous posterity consecrated him into the planet jupiter, which was called צדק *zedec* by the eastern people in ancient times, as is shewn by *Bochart* in his *Canaan l.* 2. *c.* 2. if the reader desires to see more about the names of the planets, he may consult the authors referred to in the margin[a].

Remarks upon the characters of the sun, moon and planets.

631 The use of characters in astronomy is probably of great antiquity, especially among the prognosticators, who, besides the conveniency of its being compendious, would like it for giving a mysterious air to their writings: the character of the sun ☉ is thought to be the picture of a buckler, whereof the middle point represents the *umbo* or boss, the bucklers of the ancients used to be bright, in order to dazzle the eyes of their enemies[b]; *Hyde* tells us the Persians call the sun by a word which signifies a buckler[c]: the character in manuscripts is often a buckler seen in a side view, often a cone; see
6 fig. 6, 7, 8, n. 4: a cone was sacred to the sun, *Porphyrius ap. Euseb. præpa-*
7 *rat. evangel. p.* 98, a circle is mentioned as an egyptian character of the sun,
8 by *Clemens* of Alexandria[d], as is also the crescent or common character of the moon ☽, which is the picture of the moon when she is about 4 days old.

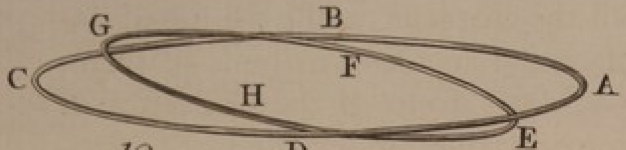
632 As to the characters of the planets, the common opinion[e] is that they were taken from the symbols of those deities whose names they bear, in this

a Ricciol. *Almagest. l.* 7. *c.* 1. Kircher. *Prodrom. Copt. p.* 147. *id. Oedip. Ægypt. tom.* 2. *part.* 2. *p.* 168, 179. Selden. *de Diis Syris.* Vossius *de Idololatr.* Hyde *de relig. vet. Persar.* b *Hinc* ἀσπὶς φαεινὴ *ab* Homero *passim vocatur, huc spectant illa militis gloriosi ap.* Plautum *act.* 1. *sc.* 1.

Curate ut splendor meo sit Clypeo clarior
Quam solis radii esse olim, quom sudum'st, solent:
Ut, ubi usus veniat, contra conserta manu
Præstringat oculorum aciem in acie hostibus.

view

Book II.



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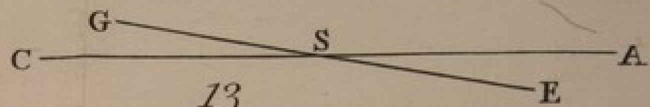

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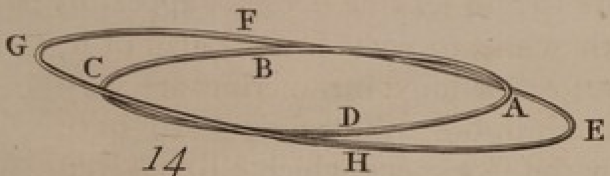

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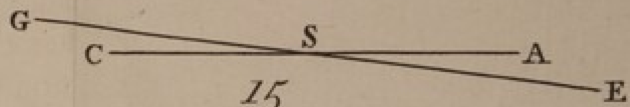

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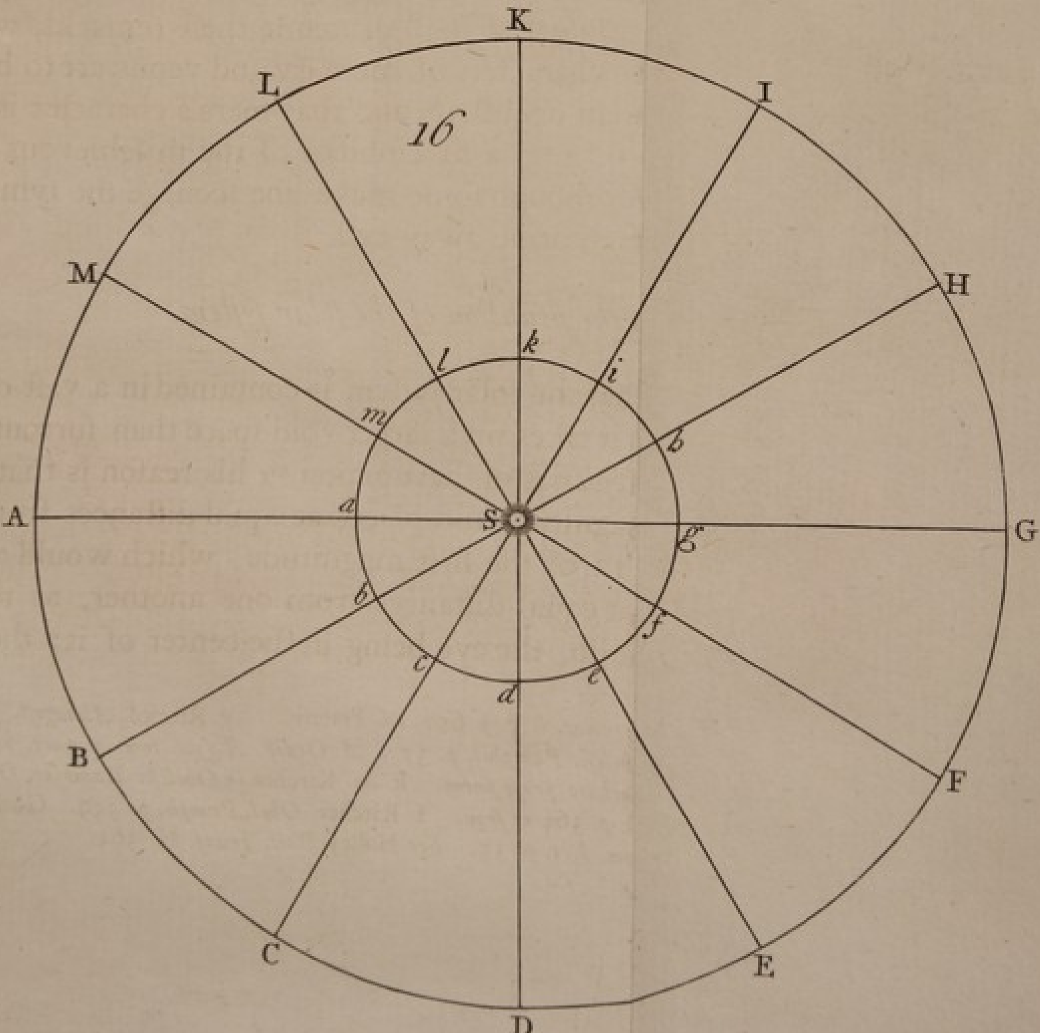

16

view, the character of mercury ☿ is his *caduceus* or rod with ſerpents twiſt- FIG.
ed about it, of venus ♀ a looking-glaſs with a handle, for ſuch we are told 2
the looking-glaſſes of the ancients were, the character of mars ♂ is a dart 3
and buckler, of ſaturn ♄ a ſickle, that of jupiter ♃ is generally agreed to be a 4
Z the firſt letter of his name in greek, with a ſtroke through it as a mark 5
of abbreviation. *Salmaſius*[f] will have all the characters to be the initial let-
ters of the greek names of the planets, I cannot acquieſce in ſome of them,
eſpecially in his deriving the character of mars from Θ the firſt letter of
Θȣρας, becauſe that never was his common name among the greek aſtro-
nomers. *Kircher*[g] compounds the characters of the planets out of ⊙ and ☽, a
croſs + the mark uſed for the four elements, and ♈, the character of *aries*, which
he ſays denotes fruitfulneſs; the manner of combining theſe marks into the
characters of the planets may be ſeen figure 10: his ſcheme does not appear to 10
me ſatisfactory enough to make it worth while to enter into a detail of it.
One objection againſt it is that the characters in ſome manuſcripts are very
different from thoſe in common uſe, though in other manuſcripts they have
a good deal of likeneſs, as may appear by the ſpecimens which I have given
of them partly out of a greek manuſcript in the library of Trinity College 6
in Cambridge of an aſtrological piece tranſlated out of latin into greek, part- 7
ly out of *Salmaſius*[h] and *Du Freſne*[i]. I ſhall conclude theſe remarks, when I 8
have firſt taken notice that the characters of mercury and venus are to be met
with upon ſome of the Egyptian obeliſks[k], and that mars's character is often
drawn with a ſcourge, as fig. 6. n. 3, a fit emblem of the miſchievous influ- 6
ence he was ſuppoſed to have, though ſome make the ſcourge the ſymbol of
the *dii averrunci*[l], deities which drive away evil.

Remarks upon the ſituation of the ſolar ſyſtem.

633 When I ſaid, § 618, that the ſolar ſyſtem is contained in a vaſt cavity, I did not intend to aſſert that it takes up a larger void ſpace than ſurrounds any of the fixt ſtars, though *Kepler* is of that opinion[m]; his reaſon is that if all the fixt ſtars were equal in magnitude and placed at equal diſtances from one another, we ſhould ſee juſt 12 of the firſt magnitude, which would appear to us in a regular form and at equal diſtances from one another, as the angles of an icoſahedron would do, the eye being in the center of it: the next

c *De rel. vet. Perſar. p.* 106. d *Stromat. l.* 5 *p.* 657. *ed.* Potteri. e Ricciol. *Almageſt. l.* 7. *c* 1. f Plinian. *exercitat. p.* 1237. g *Obeliſc. Pamphil. p.* 37, & *Oedip. Ægypt. tom.* 2. *part.* 2. *p.* 402. h *Ubi ſupra.* i *In gloſſario græco-barbaro prope finem.* k *ap.* Kircher. *in Obeliſco Rameſæo, Oed. Æg. tom.* 3 *p.* 161. *v. etiam Obeliſc. Pamph. p.* 364 *et ſequ.* l Kircher. *Obel. Pamph. p.* 359. Gorius *Muſæi Etruſc. V.* 2. *p.* 103. m *Epit. Aſtronom. l.* 1. *p.* 35. *See* Halley *Phil. Tranſ.* N. 364.

order

FIG. order of ſtars would be about 52, which would alſo appear regularly diſperſed, at a diſtance double to the former: the diſtance of the third order of ſtars would be treble that of the firſt, and their apparent magnitudes would be proportionably diminiſhed, and theſe alſo would be uniformly diſperſed, and ſo of the reſt: in ſhort all ſtars of the ſame magnitude would appear uniformly diſperſed upon the ſurface of the heaven; whereas this is ſo far from being the caſe, that in ſome parts of the heaven we ſee 3 or 4 large ſtars near to one another, but in other parts of equal dimenſions, we find none but little ones. If we may offer our conjectures about things ſo far out of our reach, it is probable the ſeveral ſtarry ſyſtems, as well as the ſtars in the centers of them, are very different from one another in dimenſions, though they may be ſimilar in their diſpoſition, and in the uſes they are deſigned for: we may obſerve a diverſity as well as an uniformity in thoſe parts of the creation which lye more open to our view: ſuch a mixture of uniformity and diverſity gives a beauty to the creation, diſplays to us the wiſdom and power of the creator, and is a proof that this univerſal frame was neither the product of a fortuitous concourſe of atoms, nor the work of different deities taking their ſeveral parts: there is uniformity enough to ſhew that all was brought into being and contrived by one mind, and there is variety enough to manifeſt the wiſdom and power of that mind to be infinite.

CHAP. 4. THE ORBITS OF THE PLANETS AND COMETS.

634 The way that a planet or comet deſcribes round the ſun is called its orbit: *the orbits of the planets* may at preſent be conſidered as concentric circles, having the ſun in their common center: in this view they are well

11 enough repreſented in their ſeveral proportions by the 11th figure, where the ſun is in the center, the leaſt circle round him is the orbit of mercury, the next in bigneſs that of venus, the next to that the orbit of the earth, the orbits of mars, jupiter and ſaturn follow in order, and are eaſily diſtinguiſhed, as well by their ſeveral dimenſions as by being marked with the characters of their reſpective planets.

635 *The orbits of comets* are oblong ellipſes, in which they go round the ſun ſo as to paſs quite through the planetary ſyſtem: the three pieces of el-

11 lipſes in the 11 figure repreſent a part of each of the orbits of thoſe three comets whoſe periods and diſtances from the ſun are known, the remaining parts of the ellipſes are to be conceived extended a good way beyond the limits of the paper. Comets in their revolutions round the ſun paſs quite through

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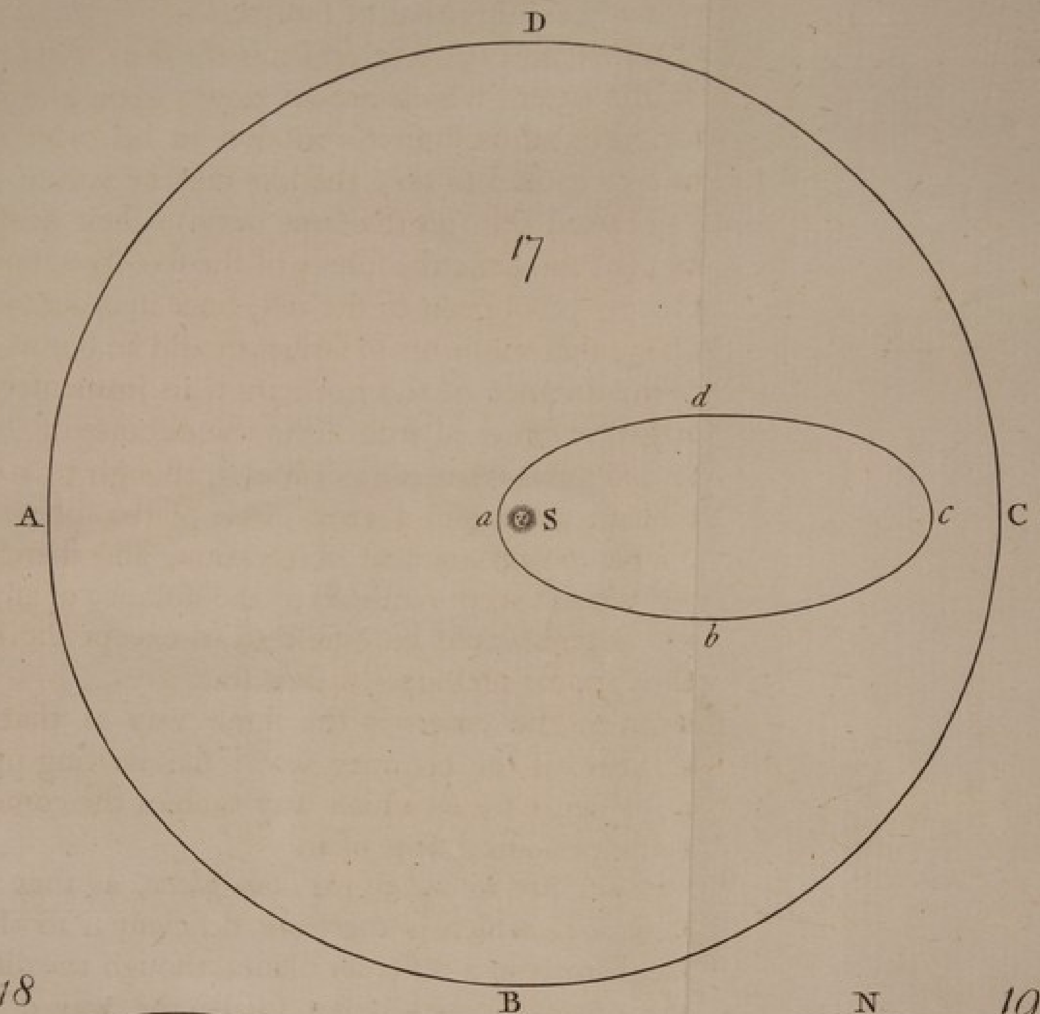

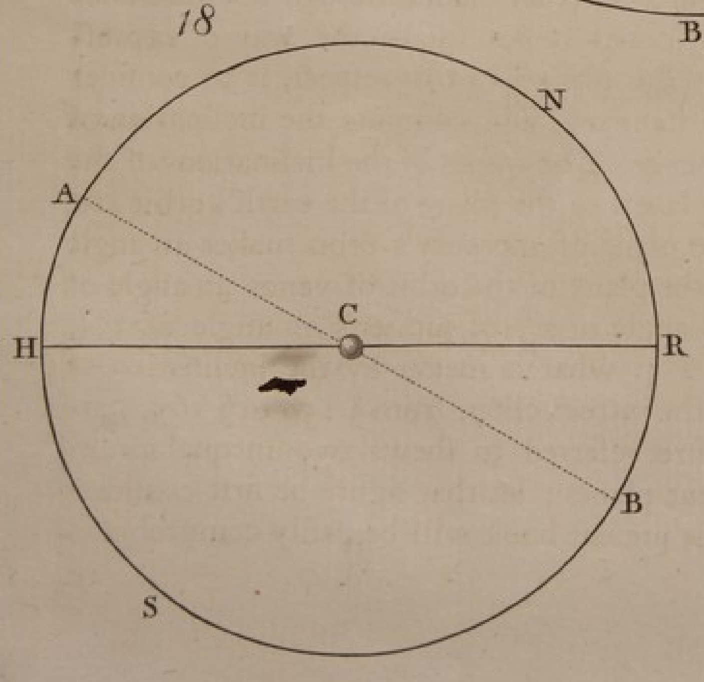

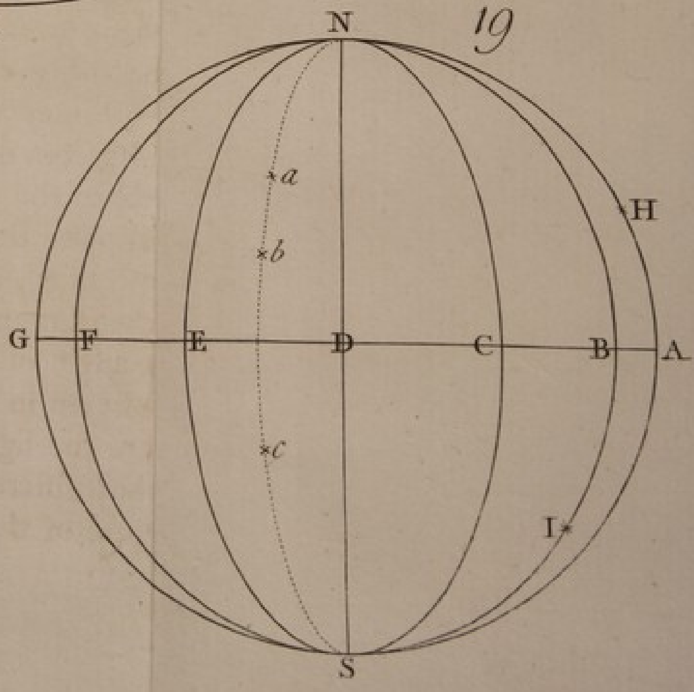

through the planetary ſyſtem: and as in ſome parts of their orbits they come Fig.
very near the ſun, much nearer than mercury, ſo in other parts they go to a great diſtance from him, far exceeding that of ſaturn.

636 *The motion of all the planets in their orbits is the ſame way:* namely according to the order of the letters which are ſet down upon the orbit of jupiter, in the eleventh figure: thus jupiter's motion in his orbit is from 11
a to *b*, from *b* to *c*, from *c* to *d*, and ſo on; the like may be ſaid of the reſt of the planets, they all go round the ſun the ſame way in their orbits: the outermoſt circle of the figure repreſents the ſphere of the fixt ſtars, but it was not poſſible to have this in any proportion to the reſt, ſince in order to do that it ought to be drawn ſo large that the orbit of ſaturn ſhould be but as a point in compariſon of it; for the diſtance of the fixt ſtars is ſo immenſely great, that if the orbit of ſaturn were removed from us to the diſtance of the neareſt ſtar, it would become inſenſible, that is its diameter, though prodigiouſly large in itſelf, would ſubtend an arc in a great circle of the ſphere of the heaven too ſmall to be liable to aſtronomical obſervation, and therefore we may eaſily conceive that if the ſun were removed to the diſtance of any of the ſtars, no part of the ſolar ſyſtem would be viſible to us except the body of the ſun, which would then appear no bigger than a ſtar.

637 *The motion of* ſome of the *comets* is the ſame way as that of the planets; the motion of others is the contrary way: the writing upon the three orbits of comets in the figure ſhews which way each of the comets goes round the ſun, and tells the periodical time of it.

638 *The orbits of the planets are not all in the ſame plane*, as they are repreſented in the eleventh figure, which is therefore deficient as to that particular, but every one of them is in a different plane, though the difference of the inclinations of their ſeveral orbits is but ſmall: the way of expreſſing the ſituation of the orbits of the planets in this reſpect, is to conſider the plane of the earth's orbit as a ſtandard, and compute the inclination of the ſeveral planetary orbits from thence. The angles of the inclinations of the planes of the ſeveral orbits of the planets to the plane of the earth's orbit are, in round numbers, as follows: the plane of mercury's orbit makes an angle with the orbit of the earth of 7°, the plane of the orbit of venus an angle of $3^\circ \frac{1}{3}$, the plane of mars's orbit an angle of 2°, of jupiter's an angle of $1^\circ \frac{1}{3}$, the plane of ſaturn's an angle of $2^\circ \frac{1}{2}$: what is meant by the inclination of planes to one another is ſhewn in the introduction, from § 158 to § 165, particularly in § 164, where the figure referred to ſhews two unequal circles having the ſame center but different planes: let that figure be firſt conſidered, and then the 12 figure of this preſent book will be eaſily comprehend- 12
ed,

FIG. ed, wherein the orbit of the earth ABCD and the orbit of venus EFGH are repreſented in ſuch a perſpective view as makes them appear ellipſes, by § 257, but ſo as to ſhew the different inclination of their planes. The 13
13 figure is another view of them, where the eye being ſuppoſed in the line of their common ſection continued, is conſequently in the planes of both the orbits continued, upon which account they appear as ſtrait lines, by § 258: here the line AC repreſents the orbit of the earth, EG the orbit of venus, and the angle of inclination is ASE. The two following figures are in like man-
14 ner perſpective views of the orbits of the earth and of mars; in fig. 14 ABCD is the orbit of the earth, and EFGH the orbit of mars, in ſuch a perſpective
15 view as makes them appear ellipſes, § 257: in fig. 15, AC is the orbit of the earth, and EG the orbit of Mars, viewed with the eye in the common ſection of their planes continued; by which means they appear ſtrait lines § 258, and ſhew more perfectly the angle of their inclination, which is ASE.

639 We may imagine the planes of the orbits of the ſeveral planets to be extended to the ſphere of the fixt ſtars, and to mark thereon ſo many great circles: theſe may be called *the heliocentric circles of the planets.* The manner in which we imagine theſe circles to be generated demonſtrates that the plane of the heliocentric circle of each planet coincides with the plane of the planet's orbit; and therefore if one of theſe planes be found, the other is known alſo: thus, if I find the earth's heliocentric circle in the ſphere of the heaven, the ſituation of the plane of the earth's orbit is thereby diſcovered.

640 *The heliocentric circle of any planet* is the circle which the planet would appear to deſcribe in the ſphere of the heaven, to a ſpectator placed in the ſun: it has already been obſerved, that all very diſtant objects always appear to us in ſome part of the ſphere of the heaven, § 248; if therefore a ſpectator placed in the ſun were to look at any planet, it would always appear to him as if it were ſituated among the fixt ſtars; and if he continued to view it during one of its entire periods, though it were all the while in reality going round him at a diſtance incomparably leſs than that of the ſtars, it would ſeem to him to be continually changing its place in the concave ſurface of the ſphere of the heaven, ſo as to deſcribe, by its apparent motion, a great circle thereon: this great circle would be the heliocentric circle of that planet, becauſe it is deſcribed by a line drawn from the eye in the place of the ſun's center to the ſphere of the fixt ſtars, always paſſing through the planet, and conſequently always in the plane of its orbit. This may be illuſtrated
16 by the 16 figure, where let *abcdef* be the orbit of a planet, ABCDEF the heliocentric circle of the ſame, to a ſpectator placed at S the center of the ſun, the planet, in the time that it is going round in the circle *abcdef*, would appear

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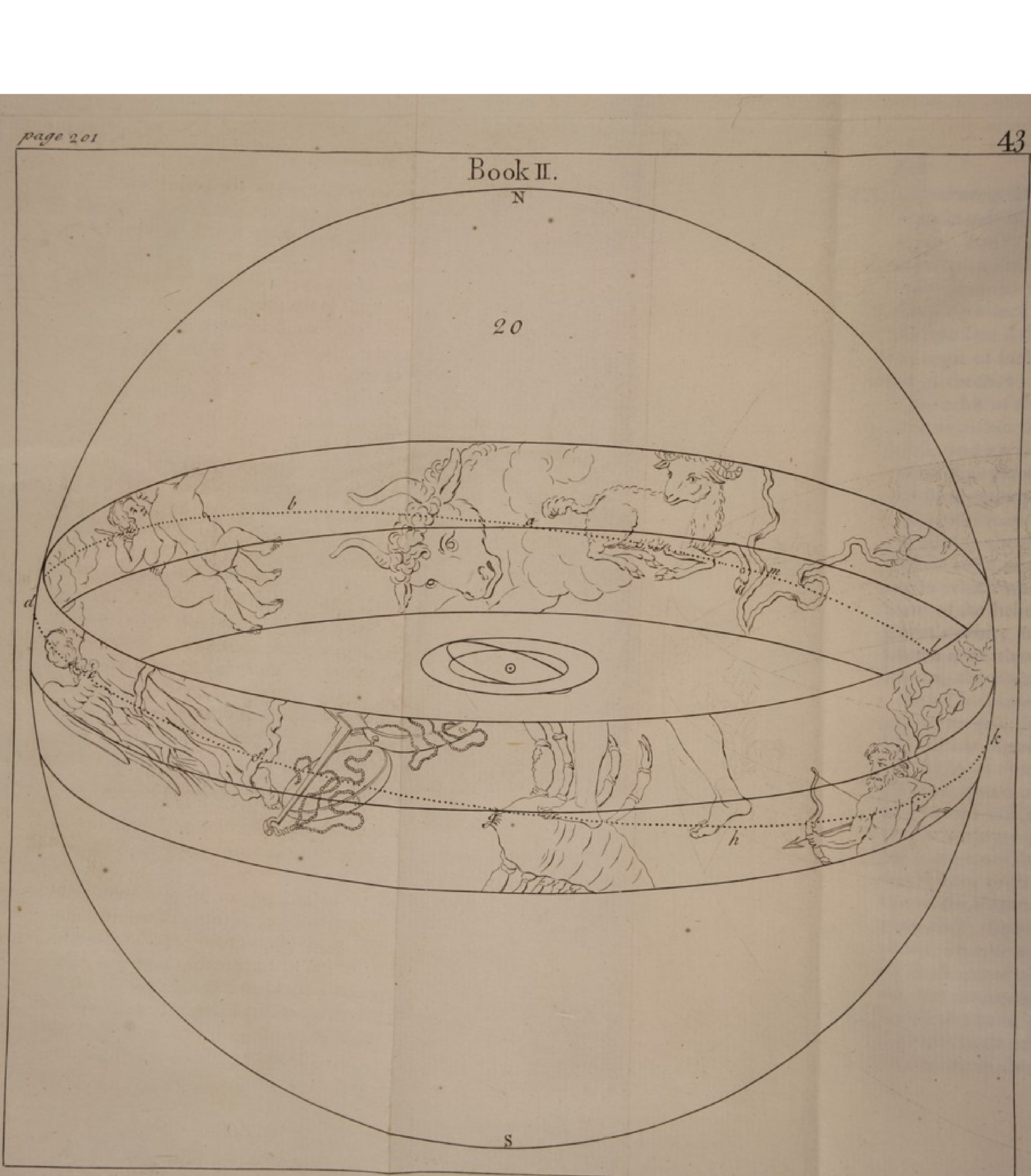

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appear to go round in the circle ABCDEF: for when the planet is at *a*, it would appear to him to be at A, where a line drawn from his eye at S through *a* the place of the planet terminates: when the planet is at *b*, it would appear at B: when at *c*, at C: &c. We may ſay then in general, that to a ſpectator in the ſun the ſeveral planets would appear to deſcribe different heliocentric circles, in different periods of time. If the orbits of the planets were all in the ſame plane, their heliocentric circles would all coincide, that is, one circle would expreſs them all; but as the planes of their orbits are all different, their heliocentric circles muſt be different alſo: and ſince their periods in which they appear to go round their heliocentric circles are the ſame as their reſpective periods in their real orbits, there muſt be the ſame difference between the former of theſe as there is between the latter. FIG. 16

641 *The orbits of the comets are in planes different* from one another, and conſequently their heliocentric circles are different alſo: I ſhall not at preſent enter into the detail of their ſeveral inclinations, but leave it to another place. To a ſpectator placed at the ſun every comet, if it could be ſeen during an entire revolution, would appear to deſcribe a great circle on the ſphere of the heaven: for, though its orbit be in reality a long ellipſis, the plane of it extended to the heaven would mark a great circle thereon whereof the eye at the ſun would be the center; only, as the comet moves round the ſun in an ellipſis, its apparent magnitude would increaſe as it came nearer to the ſun, and diminiſh as it went farther off: thus, fig. 17, to a ſpectator 17
at the ſun S, a comet moving round in its orbit *abcd* would appear to go round in a great circle ABCD: its apparent magnitude would increaſe as it went from C to A, where it would be greateſt; and decreaſe as it went from A to C, where it would be leaſt.

CHAP. 5. THE ECLIPTIC: ZODIAC; CIRCLES OF LATITUDE: HELIOCENTRIC LATITUDE OF THE PLANETS: THEIR NODES AND LIMITS.

642 To an inhabitant of any planet the ſun appears to go round in the heliocentric circle of that planet, in the periodical time thereof, and the ſame way the planet does: thus, fig. 16, let S be the ſun, *abcdefghiklm* the orbit 16
of the earth, wherein ſhe goes round the ſun in 12 months, ABCDEFGHIKLM, the heliocentric circle of the earth; I ſay to an inhabitant of the earth the ſun will appear to go round in the circle ABCDEFGHIKLM, in twelve months, according to the order of the letters, from A to B, from B to C, &c. by the earth's going round the ſun in the circle *abcdefghiklm*, in that time:

FIG. thus, when the earth is at *a*, if we draw a line from *a* through the ſun at S,
16 the point G in the ſphere of the heaven where the line terminates is the place where the ſun then appears to an inhabitant of the earth: in a months time the earth will be got from *a* to *b*, draw a line then from *b* through the ſun, and where it terminates, at H, is the apparent place of the ſun at that time: in like manner, if we draw lines from the earth in the 12 ſeveral ſituations in which ſhe is here repreſented for the 12 ſeveral months, we ſhall find that when the earth is at *c*, the ſun will appear at I: when the earth is at *d*, the ſun's apparent place will be at K &c: in like manner if there be any inhabitants in venus, the ſun appears to them to go round in the heliocentric circle of venus in ſeven months: the ſame is to be underſtood of the reſt of the planets, if they have any inhabitants.

643 The heliocentric circle of the earth is called *the ecliptic*, becauſe eclipſes of the luminaries cannot happen but when the moon is in or near that circle, as will appear hereafter, when eclipſes come to be treated of: it is called by ſome greek writers κυκλος ηλιακος the circle of the ſun, becauſe it is deſcribed by his apparent annual motion: it is called κυκλος λοξος[a] the oblique circle, becauſe it is cut by the celeſtial equator at oblique angles: in *Ptolemy* it has the name of ο διαμεσων των ζωδιων κυκλος the circle which paſſes through the midſt of the animals, becauſe the twelve conſtellations through which the ecliptic is drawn were anciently all of them animals or parts of animals; and are all ſo now, except the balance, which takes up the place that formerly belonged to the claws of the ſcorpion. For this reaſon, a belt or hoop taken in the ſphere of the heaven of the breadth of about ten degrees on each ſide of the ecliptic, twenty degrees in all, is called *the Zodiac*; from ζωδιον *zodion* an animal: and the conſtellations through which the ecliptic is drawn are *the conſtellations of the zodiac*.

16 644 The ecliptic which is repreſented by the circle ABCD &c. fig. 16, is of great conſideration to us: *the year* is meaſured by the time wherein the ſun goes quite round the ecliptic, or rather appears ſo to do, by our earth going round him, whilſt he all the while keeps his ſituation: the diſtance of the earth from the ſun is ſo exceedingly great, that if the earth were viewed from the ſun it would appear no bigger than a point, its diameter would be inſenſible: from this point it is that we muſt always view the ſun, and therefore all the inhabitants of the earth who ſee the ſun at the ſame time, having their eyes as to ſenſe in the ſame point, muſt ſee him in the ſame place among the fixt ſtars, or, to be the more expreſs, in the ſame point of the ecliptic; and, if they obſerve him for the ſpace of a year, will ſee him go round in the eclip-

[a] *Hinc Apollo vocatur* Λοξιας; Ariſtoph. *Plut.* 1. 1. v. 8. & Suid.

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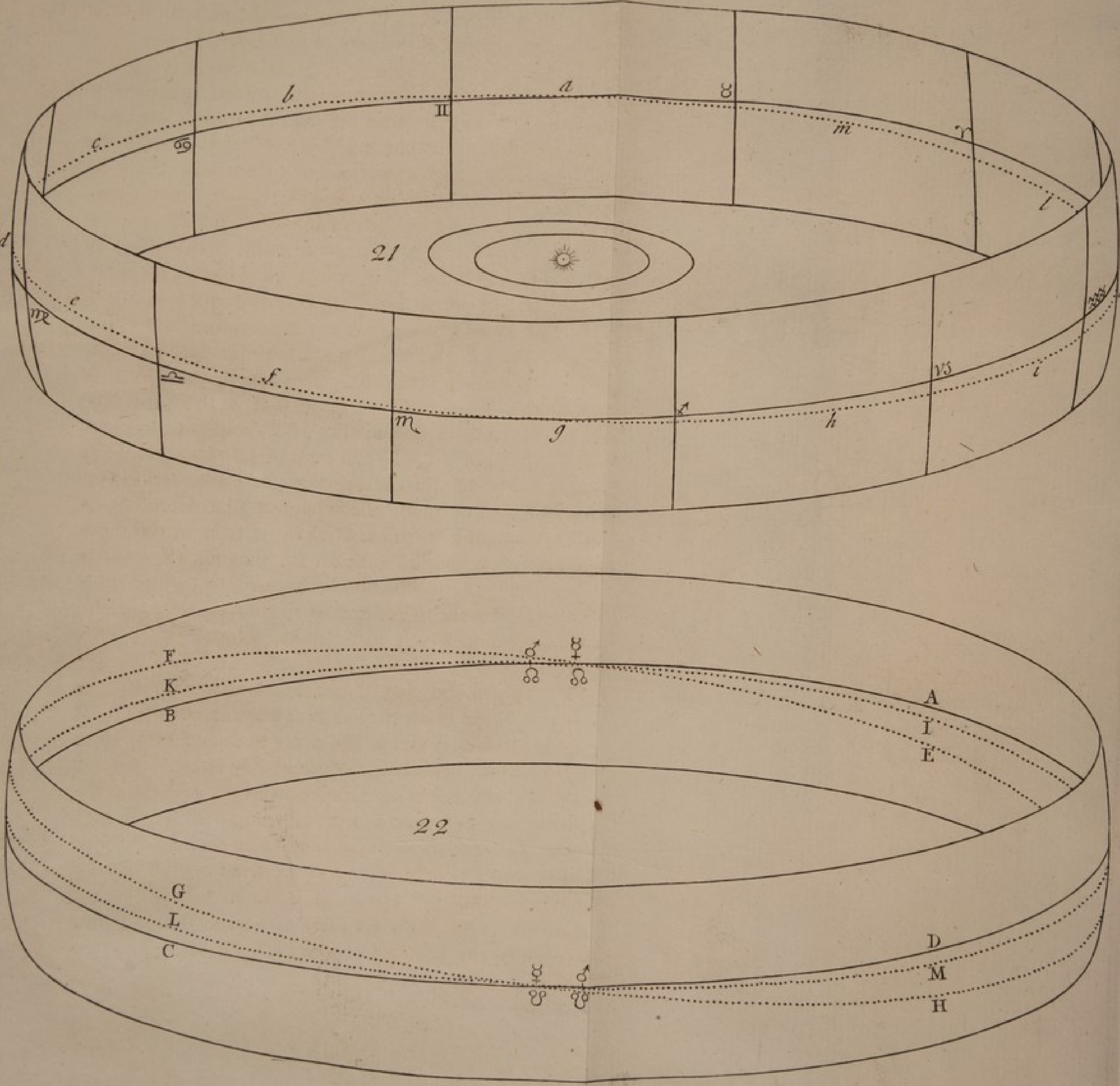

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tic in that time, from A to B, from B to C, &c. —— the periodical time FIG.
wherein any planet goes round the ſun is the year of that planet[a]. 16

645 It appears by § 642, 643, that *the ecliptic* or path of the ſun in the ſphere of the heaven *is a fixt circle*, whoſe place therein is determined by the conſtellations it paſſes through, and the ſtars that are near it on each ſide: we cannot indeed directly ſee the ſun's place among the ſtars, except when he is totally eclipſed, and his light is ſo ſcreened from us by the moon as to let the ſtars appear round him, which otherwiſe would be rendered inviſible by his ſuperior brightneſs; but we may know the ſun's place indirectly, or conſequentially, becauſe we can know at any time what point of the ſphere of the fixt ſtars is diametrically oppoſite to him: thus, fig. 16, ſuppoſe it the 16
time of the year when the earth is in that point of her orbit which is marked here with the letter *g*, if I know the point G is then diametrically oppoſite to the ſun, I know A which is oppoſite to G is the ſun's place: and therefore if I find that in the courſe of the year the points G H I K L M A B C D E F are ſucceſſively oppoſite to the ſun, I may be aſſured that in that time, the ſun's apparent place was ſucceſſively in the oppoſite points A B C D E F G H I K L M: now the point in the heaven oppoſite to the ſun may be known at 12 every night in the year, becauſe he is then in the oppoſite meridian, and his depreſſion below the horizon is eaſily found, and whatever that depreſſion is, that point in the heaven is oppoſite to the ſun which is then in the meridian as much above the horizon as the ſun is below it: thus fig. 18, let C be 18
the earth, S H A N the meridian of the obſerver continued to the ſphere of the heaven, H R his horizon, R B the depreſſion of the ſun, at 12 at night, ſuppoſe it 30°; I ſay the point A which is 30° high above H is oppoſite to the ſun.

646 The ecliptic being thus found, we may imagine as many great circles as we pleaſe to be drawn upon the ſphere of the heaven, perpendicular to the ecliptic, and interſecting each other at the poles of the ecliptic: theſe are called *ſecondaries of the ecliptic*, or *circles of latitude*. *The latitude of a ſtar or planet* or any of the heavenly bodies is its diſtance from the ecliptic in degrees, minutes and ſeconds, meaſured upon a circle of latitude drawn through that ſtar, planet, &c. and may be *northern* or *ſouthern*. The ecliptic is drawn upon the common celeſtial globe, by which we may ſee what conſtellations it paſſes through, there are alſo uſually 6 circles of latitude, which by their mutual interſections ſhew the poles of the ecliptic, as well as divide it into 12 equal parts, anſwerable to the number of months in a year: fig. 19 is 19

[a] *Periodus cujuſvis planetæ iſtius planetæ annus vocatur.* Macrob. *in ſomn.* Scipion. *l.* 2. *c.* 11.

FIG. 19 the picture of a celestial globe, where AG is the ecliptic, N the north, S the south pole of the ecliptic, NAS, NBS, NCS, NDS, &c. are circles of latitude, or rather halves of them, which is as much as can be seen at one view upon the convex of the solid globe: the star H is in so many degrees, minutes and seconds of north latitude as the arc HA amounts to, the star I is in south latitude, the quantity whereof is measured by the arc IB. The different notions of latitude when applied to stars in the heaven or places upon the earth must be carefully distinguished: in the heaven, or upon the celestial globe, latitude is distance from the ecliptic; upon the earth, or upon the terrestrial globe, it is distance from the equator: sometimes indeed we consider the distance of the heavenly bodies from the celestial equator, but this is called declination, as has been already said § 339.

647 The latitude of a planet is either heliocentric or geocentric; the *heliocentric latitude of a planet* at any time is the latitude it would appear in at that time, to a spectator placed in the sun: the heliocentric circles of the planets being all different great circles, any two of them must divide each other in halves, § 177; and consequently intersect one another in two opposite points: if therefore we consider the heliocentric circle of any planet together with the ecliptic, we shall find one half of it is on the north side, the other on the south side of the ecliptic: so that any planet seen from the sun would appear in north latitude, for one half of its period; and in south latitude, for the other. The geocentric latitude of the planets will be treated of in the next chapter.

648 The two points where the heliocentric circle of any planet cuts the ecliptic are called *the nodes* of that planet: and that which the planet passes through as it goes into north latitude is *the ascending node*, whereof this is the character ☊: the opposite point to this, where the planet seen from the sun would appear to cross the ecliptic, going into south latitude, is its *descending node*, exprest by this mark ☋: a line drawn from one node to the other is *the line of nodes*: the common section of the plane of the ecliptic and the plane of the orbit of any planet extended to the sphere of the heaven is the line of nodes of that planet: the planes of the orbits of all the planets pass through the center of the sun, and therefore all their lines of nodes do so too.
20 The 20th figure will make the foregoing particulars very easy to be comprehended, it is the picture of a glass sphere representing the sphere of the heaven, the two small ellipses in the middle of it are the orbits of the earth and of mercury, in a perspective view, which makes them appear ellipses, § 257; of the larger ellipses the black one is the ecliptic, the pointed one the heliocentric circle of mercury in a perspective view also, N is the north, S the south

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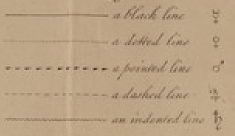

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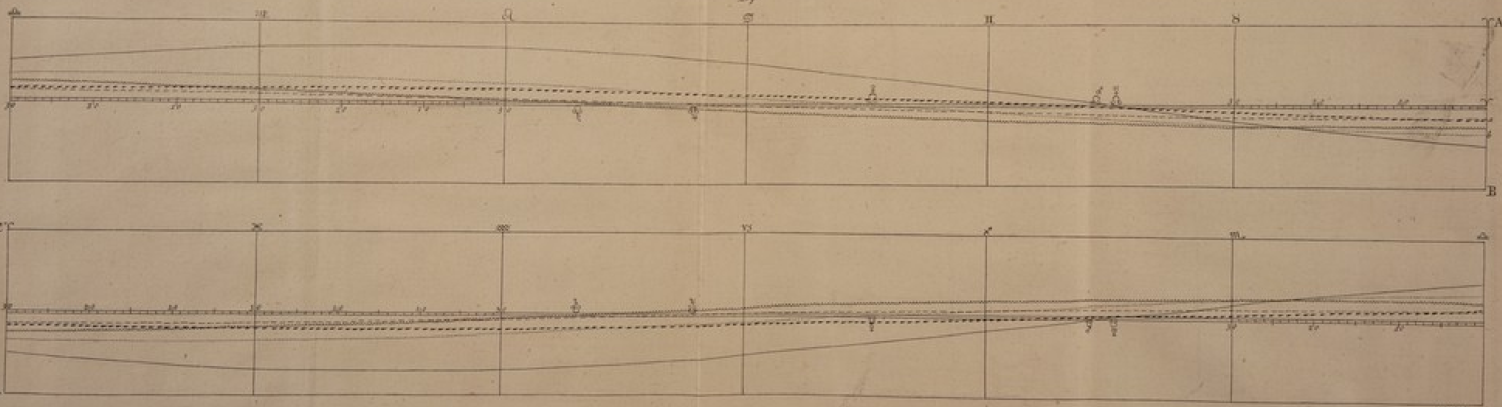

ſouth pole of the ecliptic, the way of mercury's heliocentric motion is ſhewn FIG.
by the order of the letters *abcdefghiklm:* now ſuppoſe the eye at s the center of the ſun, as mercury goes from *a* his aſcending node, he would appear to deviate more and more northwards from the ecliptic, till he comes to *d*, where he is in his greateſt north latitude, or *northern limit:* from thence his latitude gradually diminiſhes, till he comes to his deſcending node *g:* from thence he gradually deviates more and more ſouthward from the ecliptic, till he comes to his greateſt ſouthern latitude or *ſouthern limit k:* from thence he draws nearer to the ecliptic, till he comes again into it, at his aſcending node. the heliocentric latitude and motion of a ſuperior planet may be ſhewn by a
figure like the preceding: fig. 21 is the picture of the zodiac taken out of a 21
glaſs ſphere, the two ſmall ellipſes in the middle of it are the orbits of the earth and of mars, in a perſpective view; of the larger ellipſes the black one is the ecliptic, the pointed one the heliocentric circle of mars, whoſe motion is according to the order of the letters *abcd*, &c. his aſcending node is at *a*, his deſcending at *g*, his northern limit at *d*, his ſouthern at *k*.

649 From the two preceding figures, one of which ſhews the heliocentric motion of a ſuperior the other that of an inferior planet, the heliocentric motions of all the planets are eaſily underſtood: to a ſpectator at the center of the ſun they would appear in the ecliptic only when in their nodes; in all other parts of their orbits their north or ſouth latitude would be greater, the nearer they are to their north or ſouth limits, where their latitude would be greateſt of all: the greateſt heliocentric latitude of each planet is the ſame as the inclination of its orbit to the orbit of the earth: thus, the greateſt heliocentric latitude of mercury is 7°, of venus 3°$\frac{1}{3}$ of mars 2° &c. ſee § 638.

650 The heliocentric circles of the ſeveral planets cut the ecliptic in different places: thus, the aſcending nodes of mercury, venus, &c. are all in different points of the ecliptic; this difference ariſes from hence, that the common ſections of the ſeveral planetary orbits and of the earth's orbit are all different, and conſequently their ſeveral lines of nodes are different alſo. To
make this plain, let fig. 22 be the zodiac taken out of a glaſs ſphere, upon 22
which is drawn the ecliptic ABCD, the heliocentric circle of mercury EFGH, the heliocentric circle of mars IKLM, all appearing ellipſes, as being drawn in a perſpective view, § 257: the figure ſhews their aſcending nodes to be in different points of the ecliptic; the ſame figure ſhews their deſcending nodes and limits to be in different points alſo.

651 I ſhall now ſhew the heliocentric circles of all the planets upon the zodiac: they ſhould have been delineated in different colours, if they could have been printed in that manner from copper plates; but that being impracticable,

FIG. practicable, I have, to avoid confuſion, drawn them in lines of different kinds, to which I have therefore given the different names of black, dotted,
23 pointed, daſhed, indented lines; as may be ſeen fig. 23. This being premiſed, imagine the ecliptic and the heliocentric circles of all the planets to be drawn upon a glaſs ſphere in theſe different ſorts of lines; the zodiac, or an hoop taken in that ſphere of the breadth of ten degrees on each ſide of the ecliptic, would be more than broad enough to contain them all: imagine this hoop to be cut open in a circle of latitude, and to be unbent into a plane; it would then be an oblong parallelogram, whereof one ſide repreſents the zodiac as it appears upon the concave, the other as upon the convex ſurface of the ſphere:
24 the 24 figure ſhews the zodiac drawn upon the concave ſurface of the ſphere, and thus unbent into a parallelogram ABCD[a]: the double line in the middle is the ecliptic, divided into 12 equal parts: every twelfth part has a piece of a circle of latitude drawn through it, which in this view is a ſtrait line perpendicular to the ecliptic: the black curve ſhews the heliocentric circle of mercury: the dotted curve the heliocentric circle of venus: the pointed curve that of mars: the daſhed curve the heliocentric circle of jupiter: the indented curve that of ſaturn: the places of the aſcending and deſcending nodes, and of the north and ſouth limits of the ſeveral planets, are eaſily ſeen upon their reſpective curves.

CHAP. 6. THE GEOCENTRIC LATITUDE OF THE PLANETS: SIGNS OF THE ZODIAC: LONGITUDE OF THE HEAVENLY BODIES.

652 *The geocentric latitude of a ſtar or planet* is the latitude it appears in to an inhabitant of the earth: the ſphere of the fixt ſtars is ſo immenſely great, that compared therewith the orbit of the earth is but as a point: that is, the diameter of the earth's orbit at the diſtance of the fixt ſtars would be inſenſible, too ſmall to be meaſured by aſtronomical obſervation: for this reaſon, whatever part of her orbit the earth is in, the ſtars always appear to us in the ſame poſition as they would do if we were to view them from the ſun; and conſequently there is no difference between the geocentric and heliocentric latitude of the ſtars. The caſe is otherwiſe with regard to the planets: the orbit of the earth bears a conſiderable proportion to their diſtances from us; and therefore their apparent places in the heaven are altered by our change of place, as well as by their own motions: ſo that if a planet were to ſtand ſtill

a No part of a ſpherical ſurface can form a plane, and therefore an hoop taken out of a ſphere would not unbend into an exact parallelogram; but the difference is inconſiderable in the caſe before us.

during

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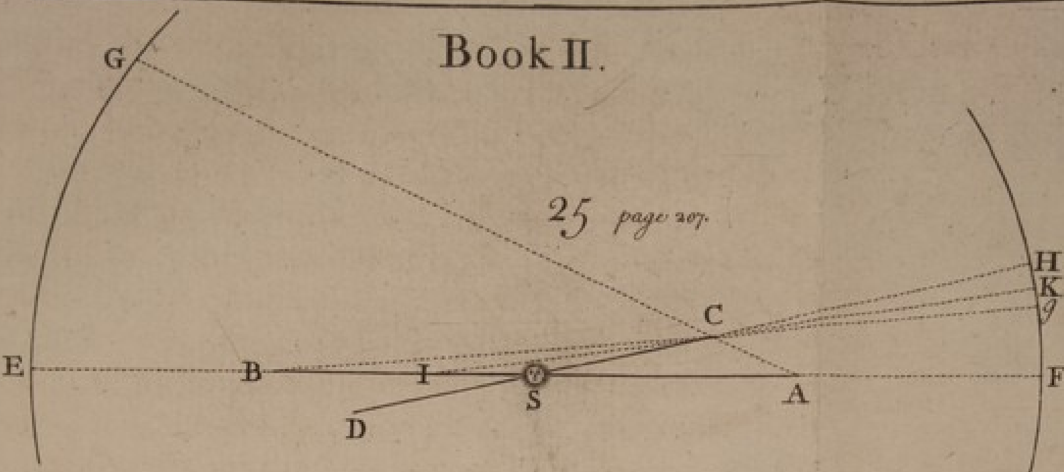
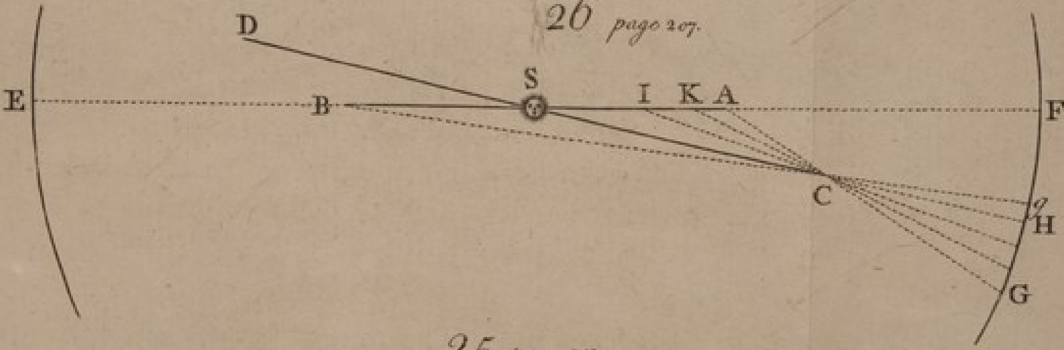
25 page 207.



26 page 207.



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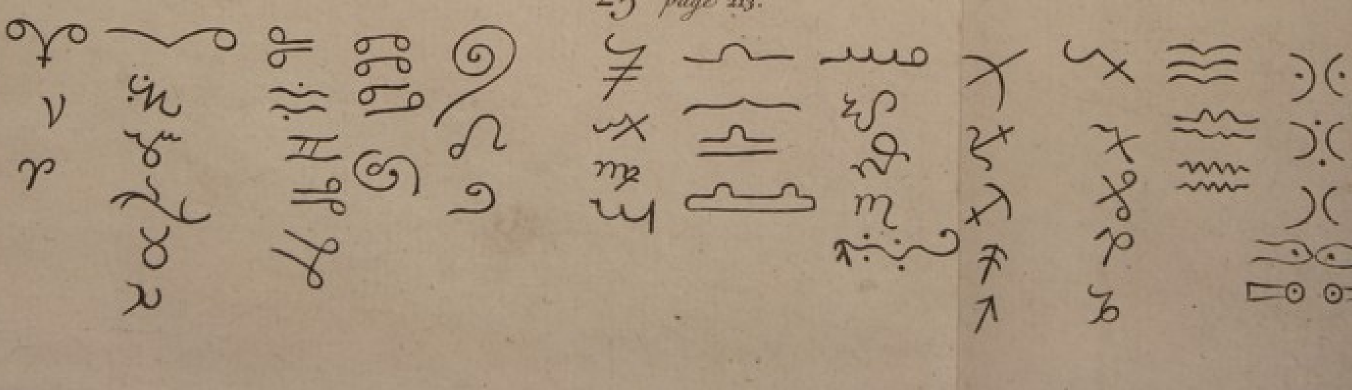

during a whole year, our continual change of place, occaſioned by the earth's going round in her orbit, would cauſe an apparent change of place in the planet: we ſhould be continually viewing it from different ſtations; and conſequently it would continually be ſeen in different points of the heaven. FIG.

653 Since the plane of the earth's orbit is different from the planes of the orbits of every one of the planets, the geocentric latitude of any planet is almoſt always different from its heliocentric latitude, as will appear by the following figure: let A B be the orbit of the earth, C D the orbit of venus, viewed with 25
the eye in their common ſection continued, whereby they appear ſtrait lines, § 258, let E and F be two oppoſite points of the ecliptic: ſuppoſe venus to be in the point C in her utmoſt north limit; if ſhe were at that time viewed from the ſun S, ſhe would appear in the ſphere of the heaven at the point H; her heliocentric latitude then is F H; but let venus in C be viewed from the earth, and ſhe will appear in different places, according as the earth is in different parts of her orbit: for if the earth be at B, a line drawn from thence through C ſhews the apparent place of venus to be at *g*; and her geocentric latitude is then F*g*: if the earth be at A, the apparent place of venus will then be very different, namely in G; and her geocentric latitude E G, if the earth be at I venus would appear at K, &c.

654 By a figure ſimilar to the preceding, the different geocentric latitude of a ſuperior planet, when viewed from the earth in different parts of her orbit, may be ſhewn: thus fig. 26 let A B be the orbit of the earth, C D the 26
orbit of mars, both viewed with the eye in their common ſection continued, whereby they appear ſtrait lines by § 258, let E and F be oppoſite points of the ecliptic: ſuppoſe mars to be in his ſouth limit at C if he were at that time viewed from S the center of the ſun, he would appear in the ſphere of the heaven at the point H; his heliocentric latitude then is F H: but let mars in C be viewed from the earth, and he will appear in different places according as the earth is in different parts of her orbit: for if the earth be at B, a line drawn from B through C ſhews the apparent place of mars to be at *g*; and his geocentric latitude is then F*g*, if the earth be at A, the apparent place of mars will be in G; and his geocentric latitude F G, if the earth be in any other part of her orbit, as at the point I or K, it is eaſy to ſee, by a line drawn from either of thoſe points through mars at C, that he will appear in different places in the ſphere of the heaven, and would be in different geocentric latitudes.

655 *The zodiac* is *aſtral* or *local*[a]: the aſtral zodiac is divided into twelve unequal parts, becauſe it conſiſts of the twelve conſtellations, ſome of which

a Gemini *elementa Aſtronomiæ p.* 1. *ed.* Petav. Caſſini *aſtronomie Indienne. p.* 37. *ed.* Par.

are

are larger and take up more room in the heaven than others; as will appear upon a view of the common celeſtial globe: the aſtral zodiac always continues invariably the ſame, becauſe the ſame ſtars go now to the making up the figure of the ram, the bull and the reſt, as did anciently; except ſome little alterations already mentioned, § 594. The local zodiac is divided into twelve equal parts, each containing 30°, which are called *ſigns*, or *dodecatemoria* twelfth parts, beginning at the point where the ecliptic is cut by the celeſtial equator near the conſtellation of the ram, of which point this is the mark ♈, and proceeding in order according to the apparent annual motion of the ſun in the ecliptic. The firſt ſign, containing 30° meaſured upon the ecliptic, is called aries: the ſecond, containing alſo 30°, taurus: &c. *ſignum* a ſign is often put to ſignify any conſtellation in ancient writers; but thoſe of the zodiac being thought of principal conſideration, cuſtom has prevailed to reſtrain the name ſign to the parts of the zodiac in the manner juſt now mentioned. *The order, names, and characters of the twelve ſigns* are as followeth: 1 aries ♈, 2 taurus ♉, 3 gemini ♊, 4 cancer ♋, 5 leo ♌, 6 virgo ♍, 7 libra ♎, 8 ſcorpio ♏, 9 ſagittarius ♐, 10 capricornus ♑, 11 aquarius ♒, 12 piſces ♓[a]. Aries is made the firſt ſign of the zodiac, becauſe when the ſun enters the firſt point of aries, which is about the 10th of march old ſtyle, it is the vernal equinox to all who live in north latitude, ſee § 366: this is reckoned the beginning of the aſtronomical year, becauſe it is the entrance into the ſpring, when our earth begins to appear with a new aſpect; the plants growing thereon riſe again from a ſort of death which they ſuffered by the coldneſs of the winter; and the animals, by the returning warmth of the ſun, are invigorated with new life and ſtrength.

656 Any *motion* in the heaven from any part of ♈ towards ♉, from ♉ towards ♊, &c. is ſaid to be *according to the order of the ſigns*, in latin *motus in conſequentia*, ſc. *ſigna*, motion towards the following ſigns: ſuch is the apparent annual motion of the ſun in the ecliptic; ſuch alſo would the motions of all the planets appear to be in their ſeveral heliocentric circles, if we were to view them from the ſun. Any motion the contrary way to this, as from any part of ♈ towards ♓, from ♓ towards ♒, from ♒ towards ♑ is ſaid to be contrary to the order of the ſigns, *motus in antecedentia*, i. e. *ſigna*, motion towards the preceding ſigns: ſuch is ſometimes the apparent motion of the planets ſeen from our earth; as will be more fully ſhewn hereafter.

657 The local zodiac is not always invariably the ſame as to the places of the ſeveral ſigns, though the whole zodiac always takes up the ſame place in the

a These latin names are ſo much in uſe with engliſh writers that they ſeem adopted into our language: the engliſh of them may be ſeen page 174.

the ſphere of the heaven, without any alteration; namely ten degrees on each ſide of the ecliptic, which circle was before ſaid to be fixt and invariable: the points where the celeſtial equator cuts the ecliptic have a retrograde motion of about 50″ in a year: that is, the celeſtial equator every year cuts the ecliptic in two points which are diſtant 50″ contrary to the order of the ſigns from the interſecting points of the year immediately preceding: this change of place of the firſt point of the ecliptic, from whence the ſigns begin to be reckoned, occaſions a like change of place in the ſigns themſelves; which, though not ſenſible in a few years, in a long tract of time becomes very conſiderable: thus, ſince the firſt cultivating of aſtronomy by the Greeks above 2000 years ago, the firſt point of the ecliptic is removed backward above a whole ſign; and, whereas it was then about the middle of the conſtellation of the ram, is now about the middle of the conſtellation of the fiſhes: notwithſtanding this, it retains its ancient mark ♈; and the ſigns keep their ancient names, though they be every one of them got into different conſtellations from what they were in anciently, when they received theſe denominations: thus, the firſt ſign is ſtill called aries, though it be now in the conſtellation of the fiſhes: the ſecond ſign is called taurus, though in the conſtellation of the ram: the third ſign gemini, though in the conſtellation of the bull: and ſo of the reſt.

658 The local zodiac is generally meant, when we ſpeak of the zodiac: the ancients made the breadth of the zodiac but twelve degrees[a], ſufficient to take in the moon in her greateſt deviations on either ſide of the ecliptic, which amount to near ſix degrees of latitude; as will be ſhewn when the moon's motion comes to be treated of: the moderns make the zodiac twenty degrees broad[b], in order to take in mars and venus in their greateſt geocentric latitude, in which they appear to us near ten degrees north or ſouth from the ecliptic. See fig. 22 and 24.

659 *The longitude of a phenomenon in the heaven* is the number of degrees, minutes and ſeconds contained upon the ecliptic, between the firſt point thereof and the point where it is cut by a circle of latitude drawn through the phenomenon: the longitude is reckoned beginning at the firſt point of the ecliptic, and proceeding according to the order of the ſigns.

660 Some writers, as *Copernicus* and *Streete*, make the firſt point of the ecliptic invariable: in order to this, they imagine a circle of latitude to be drawn through a ſtar in the head of the ram, which is marked by *Bayer* with the letter γ; where that circle cuts the ecliptic is the firſt point from whence they reckon the longitude; and the ſtar, from its uſe, is called the firſt ſtar of the

a Plin. *nat. hiſt. l.* 2. *c.* 15. Manilius *l.* 1. *v.* 680. Proclus *de Sphæra.* Martianus Capella, *l.* 8. *c. de ſignifero.* b Kepler. *epit. aſtronom. p.* 159. Gregor. *aſtron. l.* 2. *prop.* 1.

FIG. ram: when this method is made uſe of, the longitude of a phenomenon is ſaid to be ſo many degrees, or ſo many ſigns, degrees, minutes and ſeconds from the firſt ſtar of the ram: thus, in *Streete*'s Caroline tables, the longitude of jupiter's aſcending node is two ſigns and eight degrees from rhe firſt ſtar of aries: which is thus expreſt, *Long.* ♃ ☊ *à* 1 * ♈ $2^s. 8^\circ$.

661 The common way of reckoning the longitude of a phenomenon in the heaven is, to take ♈ for the firſt point of the ecliptic, and not to number the degrees quite round that circle in a continued ſeries, but to make a new beginning at the firſt point of every ſign, and to reckon from thence, according to the order of the ſigns, only as far as 30, the number of degrees contained in a ſign: the degrees of the ecliptic upon the common celeſtial globe are numbered in this manner; as are alſo the degrees of the ecliptic in
24 the 24th figure. When this method is made uſe of, the longitude of a phenomenon is expreſt by ſaying it is in ſuch a degree and minute of ſuch a ſign: thus, in the picture of the zodiac in the 24th figure, the longitude of the aſcending node of mercury is ♉ $14^\circ \frac{2}{3}$.

662 Any phenomenon in the heaven, in whatſoever part it be, whether near
19 the ecliptic or not, is referred to ſome ſign: thus, fig. 19, all the ſpace contained upon the celeſtial globe between the ſemicircles of latitude NGS and NFS is within the ſign aries; all between the ſemicircles NFS and NES belongs to the ſign taurus, &c: in what degree of the ſign any phenomenon is, a circle of latitude drawn through it determines, as was ſaid before: thus, fig. 19, the ſtars *a*, *b*, *c*, are in 15° of ♊.

663 The place of a phenomenon in the heaven is expreſt by ſetting down its longitude and latitude; ſaying it is in ſuch a degree and minute of ſuch a ſign, and in ſuch a degree and minute of north or ſouth latitude: in this manner the places of the ſtars are ſet down in the catalogues; as are alſo the places of the heavenly bodies in the common almanacks: —— by the place of any of the heavenly bodies is meant the place of its center.

664 Since the ecliptic is a fixt circle, § 645, the latitudes of the fixt ſtars, and of all phenomena in the heaven whoſe places are fixed, continue always invariably the ſame: ſince the point ♈ hath a retrograde motion of 50″ a year, the longitudes of the fixt ſtars and of all phenomena whoſe places are fixed are altered 50″ a year, in the common way of beginning to reckon the longitude from ♈: and this is the reaſon why, in the ſeveral catalogues of ſtars calculated for different times, we find the longitudes of the ſame ſtars to be different; but their latitudes to be the ſame: as was mentioned § 607.

Remarks

Remarks upon the ſigns of the zodiac in the foregoing chapter.

665 The ancient Egyptians had ſeveral diviſions of the heavens, and particularly of the zodiac, to which the reſt of the heaven was ſuppoſed to have relation; and accordingly aſſigned a greater or leſs number of deities to preſide therein, all under the direction of the ſupreme being: one diviſion of the heaven was into two hemiſpheres, one on the north, the other on the ſouth ſide of the ecliptic: one diviſion of the zodiac was into the four parts which the ſun occupies during the four ſeaſons: another was into the twelve ſigns, wherein they imagined ſome of the moſt powerful genii to reſide; I ſuppoſe becauſe their principal deities the ſun moon and planets are always to be found among thoſe ſigns: obſerving that the earth with the plants and inhabitants thereof are differently affected at different times of the year, they imagined this to be owing to the different natures and influences of the ſigns through which the ſun paſſes; and therefore they repreſented thoſe ſigns by hieroglyphical figures expreſſing their ſuppoſed natures and influences: they did not think this enough, but ſubdivided every ſign into three parts, ſo as to make thirty ſix parts in all, every one of theſe parts alſo was ſuppoſed to have its particular genius of a lower order, upon which account the influences of the heavenly bodies were thought to be different in different parts of the ſame ſign [a]: they had alſo another way of dividing ſo much of the heaven as was referred to one ſign into four parts, ſo as to make 48 in all; which was therefore the number of the conſtellations; to this number the Greeks long after ſuperſtitiouſly adhered, though the figures of the conſtellations are of ſuch different dimenſions, as by no means to anſwer to the original regular diviſion of the heaven into 48 parts: I ſhould not have mentioned theſe particulars, but only to ſhew upon what kind of notions judicial aſtrology ſeems to have been originally founded; namely upon a belief that the ſtars were miniſterially concerned in the government of this ſublunary world, by virtue of their influences, which were under the direction of inferior deities; to whom therefore the ancients uſed to addreſs themſelves, in prayers, ſacrifices, and other ſuperſtitious rites, in order to draw down their benevolent influences, or avert thoſe that were hurtful and unfortunate.

Remarks upon the characters of the ſigns.

666 Theſe characters are thought to be very ancient [b]; they are moſt of them drawn ſo as in ſome meaſure to reſemble the figures they are intended

a Kircher. *Oed. Æg. T. 2. part. 2. c.* 2, 3, & 5. Scalig. *in* Manil. *p.* 371. b Scaliger. *ap.* Kirch. *loco citat.*

FIG. to signify[a], as may be seen fig. 25, where I have given, chiefly from *Kircher*[b],
25 such pictures of the constellations of the zodiac, or of parts of them, as serve best to shew the likeness of the characters to the originals from whence they were taken: ♈ represents the horns of the ram: ♉ the head and horns of the bull: ♊ the figure of the twins, as drawn according to some authors joyning hands and feet, or rather as thus described by *Plutarch*[c]; the Spartans, says he, call the ancient statues of the *Dioscuri* δόκανα beams, they are two pieces of wood joyned together by two cross pieces—these words are plainly a description of the character ♊, as others have also observed[d]. The character ♋ is a little different from what we find it in manuscripts, transcribers have brought it pretty near to the numeral figures 6 and 9; it is not unusual for people to alter characters as well as words which they do not understand to something that is familiar to them; *Kircher* thought the Egyptians intended by this mark to represent the head of the ibis and the tail of the crab; I have given his pictures of them, though I am not of his opinion: I rather think it was the intention of the inventor of this character to represent the change of the sun's declination from north to south, by two lines drawn so as to point contrary ways: ♌ is the tail of the lion, a symbol of his courage, for he is said to lash himself with his tail when he is angry[e]: ♍ was originally the three ears of corn which virgo used antiently to be drawn holding in her hand: ♎ is the beam of the balance: ♏ was at first a picture of the scorpion which hasty transcribers have gradually changed into the figure now in use: ♐ is the arrow of the archer; in manuscripts we often meet with the bow and arrow: ♑, which is the character for capricorn used by the Italian, French, and most European writers, represents in some measure the figure of the constellation; for which reason I have chosen it here, rejecting ♑ in common use with us, as a barbarous character, which owes its original to a bad imitation of the other: ♒ is a natural representation of the wavy surface of water: ♓ is the picture of two fishes tyed together back to back: in manuscripts we have sometimes instead, of this, two fishes heads. I shall only add that ♎ and ♒ are to be met with upon the ancient Egyptian obelisks now at Rome, whereof *Kircher* has published the draughts[f]: that ano-

a Salmas. Plin. *exercit. p.* 1236. b *Oed. Æg. T.* 2. *part.* 2. *c.* 3. c *De fraterno amore, initio,* δόκανα *paragogice a* δοκὸς. δοκὸς παρὰ τὸ δέκεσθαι, ἰωνικῶς, ἢ δέχοιτο ὀκλαδὴ τὰ ἐπικείμενα Eustath. *in Il.* ε. *v.* 744. *ubi & hunc locum* Plutarchi *laudat.* d Xylander *in locum.* Palmerius *exercitat. in* Plut. Shuckford *sacr. and proph. hist. vol.* 1. *p.* 348. It may be observed here that before sculpture was in use the ancient idolaters made use of rough hewn logs of wood or stone for images of their gods; by degrees they gave them human shape, but still with their legs joyned together: *Dedalus* was the first who attempted to form them with their legs asunder, and was therefore said to make walking statues. Gorius *Musei Etrusci vol.* 2. *p.* 32. e Homer. *iliad.* Υ. *v.* 170. Plin. *nat. hist. l.* 8. *c.* 16. f *Obelisc. Pamphil. & Oed. Æg. T.* 3.

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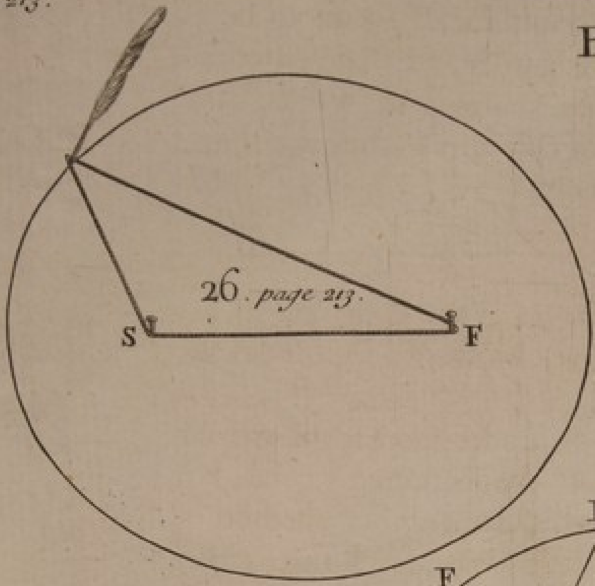
page 213.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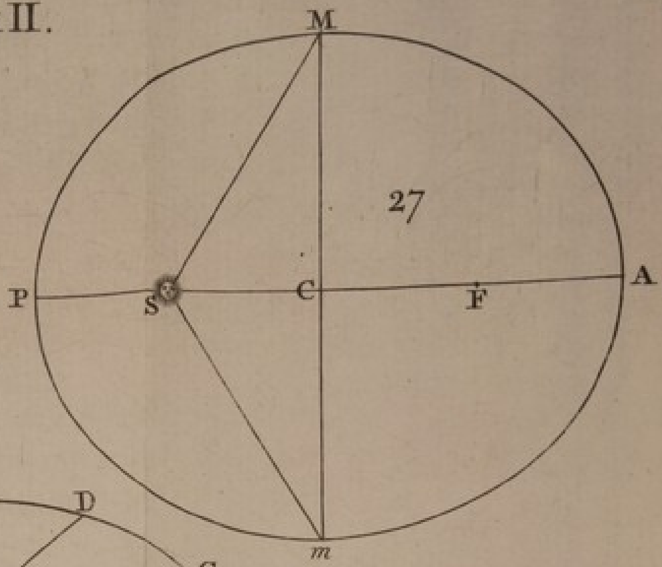
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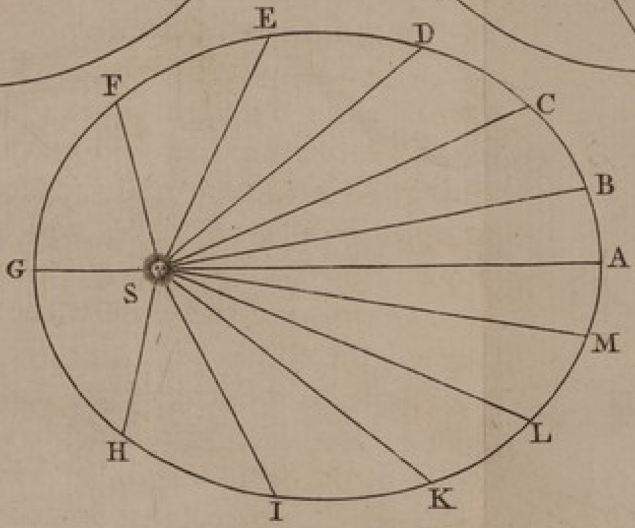
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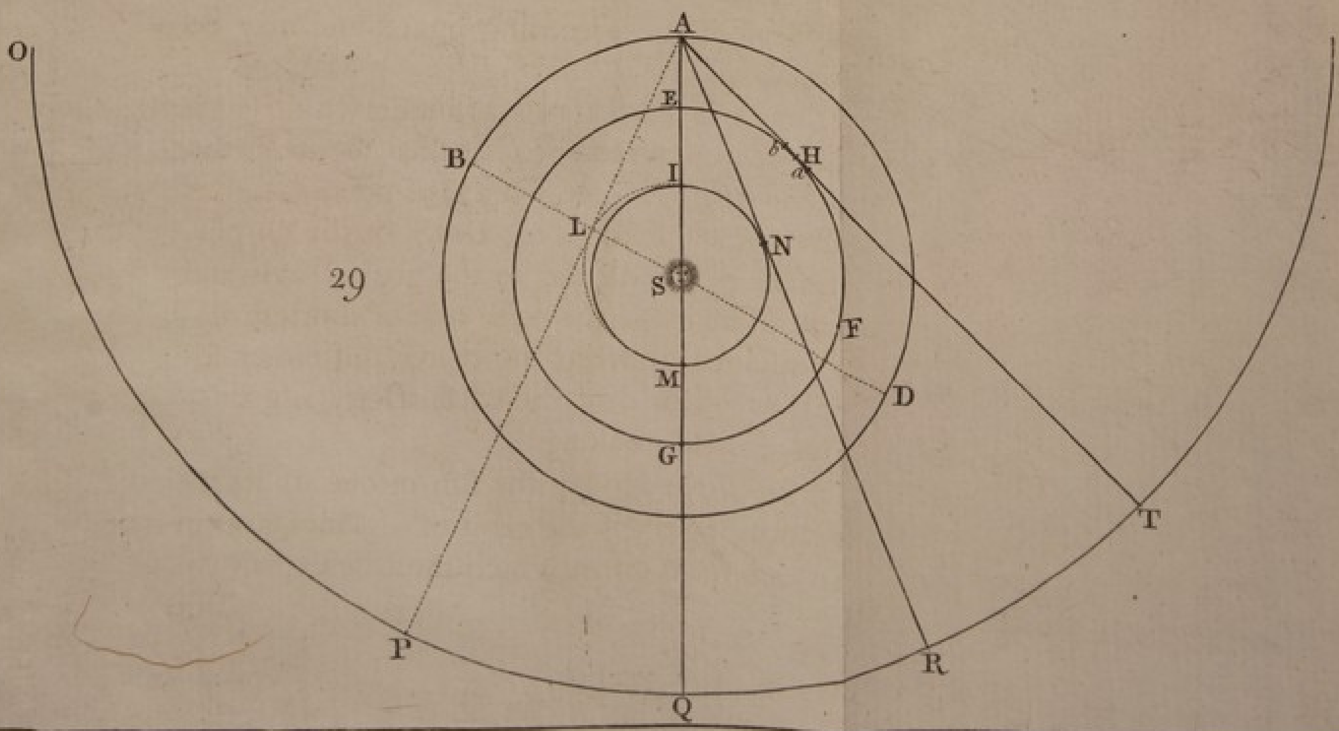
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ther character which sometimes occurs in manuscripts for ♉ seems to be an FIG.
attempt to express the head and fore-legs of the bull: and that sometimes instead of the characters ♉ and ♏ we meet with abbreviated words. The 25th figure, wherein I have given the characters of the signs as they are found 25
in ancient manuscripts, will illustrate these remarks.

CHAP. 7. THAT THE ORBITS OF THE PLANETS AND COMETS ARE ELLIPTICAL: THEIR MOTIONS IN THEIR ORBITS NOT EQUABLE.

667 What *an ellipsis* is may in some measure be understood from the introduction, § 190, where it was shewn to arise from the section of a cone; but it will be necessary for our present purpose to consider another method of drawing or generating that figure, which is as followeth: let a thread tied together at both ends be put over two pins fixed upright upon a plane, at any distance from each other less than the string thus tied will reach; a pen or pencil carried round within the string, so as to keep it always stretched out to its utmost tension, will describe upon the plane a curve, which is the periphery or circumference of an ellipsis, fig. 26: each of the points S F wherein 26
the pins are fixed is called a *focus* or *umbilicus* of the ellipsis: the farther the focuses are asunder the more oblong will the ellipsis be, the nearer the focuses are together the nearer will the ellipsis be to a circle, if the same thread be made use of: if the focuses coincide or meet in a point, the string will then go round it continuing all the while of the same length, and consequently the curve described will be a compleat circle whereof that point is the center: all this is easily apprehended by a view of the preceding figure, and may be tried with a string and two pins as above.

668 When an ellipsis is drawn, there arise these terms; a line drawn through the focuses both ways till it reaches the circumference is called *the axis*, the *greater axis* or longest diameter *of the ellipsis*, as P A, fig. 27: a point taken in 27
the greater axis equally distant from each focus is *the center* of the ellipsis, as C: a line drawn through the center perpendicular to the greater axis and terminated at each end by the circumference is the *lesser axis* or shortest diameter of the ellipsis, as M *m*: the distance between the center and either focus is *the excentricity* of the ellipsis, as C S or C F: the excentricity is greater or less according as the ellipsis is more or less oblong.

669 *The orbit of every planet is an ellipsis* having the sun in one of its focuses: we may now consider the ellipsis fig. 27 as the orbit of a planet, and in 27
this view there will arise some astronomical terms which must be explained:

The

FIG. 27 The axis of any planets elliptic orbit, as P A fig. 27 is called *the line of the abſides:* the point A, where the planet is at its greateſt diſtance from the ſun, is called its *aphelion*, *aux*[a], or *higher abſis*[b]*:* the point P where the planet is at its leaſt diſtance from the ſun is its *perihelion*, *oppoſitum augis*, or *lower abſis:* the extream points of the leſſer axis of the elliptic orbit of a planet M and *m* are the places of its *mean* or middle *diſtance:* and a line drawn from either of thoſe points to the ſun as M S or *m* S is the *line of the planets mean diſtance.* When we would expreſs what the excentricity of the orbit of any planet is, we ſuppoſe the line of its mean diſtance to be divided into 1000 equal parts, and ſay to what number of ſuch parts the excentricity is equal.

If we imagin the mean diſtance of	Saturn	to be divided into	1000	equal parts,	the excentricity is	55	of thoſe parts.
	Jupiter		1000			48	
	Mars		1000			93	
	The Earth		1000			17	
	Venus		1000			7	
	Mercury		1000			210	

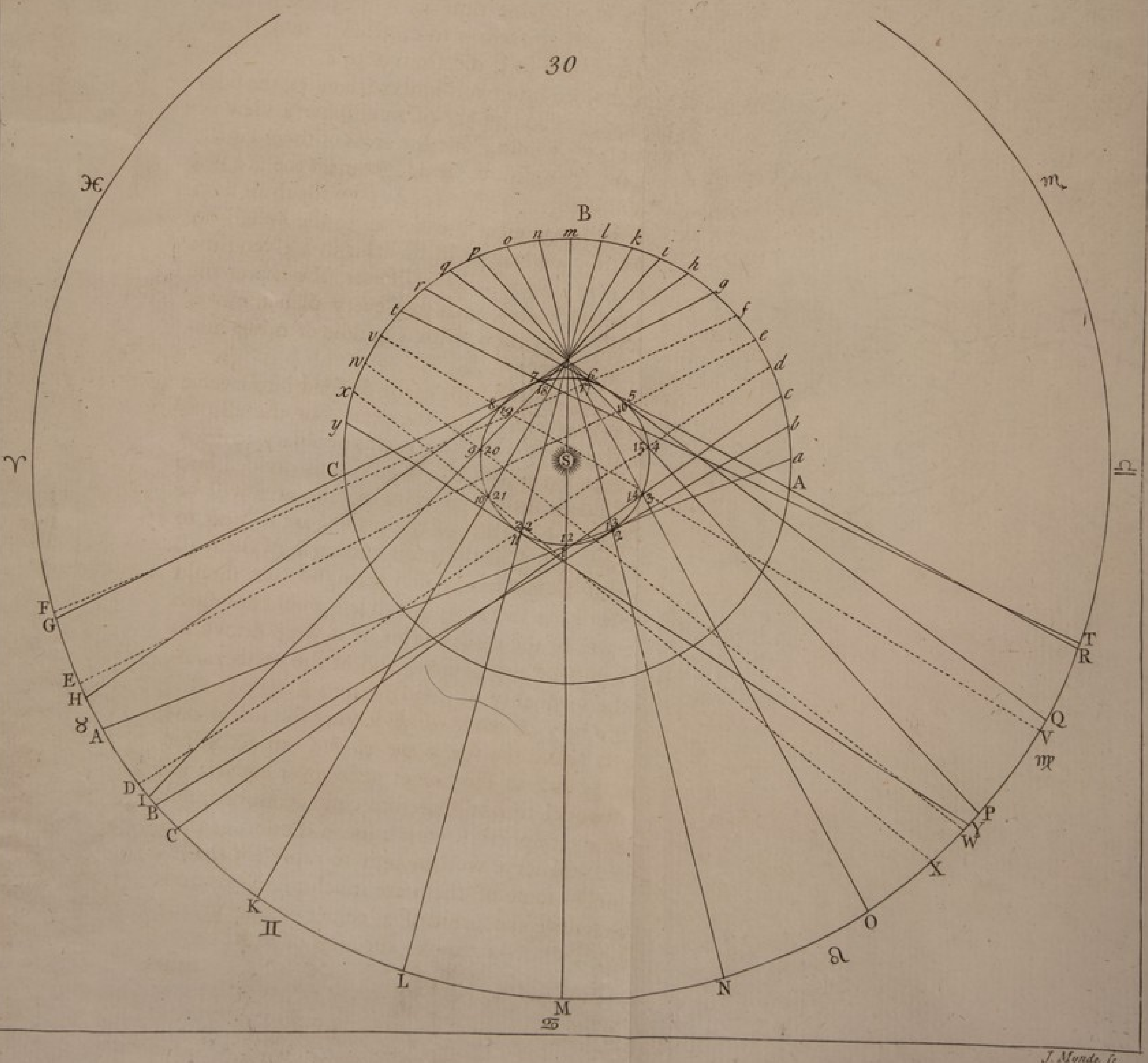
670 The orbits of the planets differ very little from circles, as may be ſeen
11 fig. 11, where they are drawn in their true ſhapes: the orbits of mercury, mars, jupiter and ſaturn, are there expreſt by double lines; the outermoſt of which are the lines of the planets motions; the innermoſt are compleat circles whereof the ſun is the center, and the radius of each circle is the leaſt diſtance of its reſpective planet from the ſun; and conſequently the diſtance between the two lines ſhews how much any planet is farther from the ſun in any other part of its orbit than it is at the perihelion. The excentricities of venus and the earth are ſo ſmall, that inſtead of double ones, their orbits are expreſt by ſingle lines, drawn gradually thicker and thicker from the perihelion to the aphelion; and thinner and thinner from the aphelion to the perihelion: by this means the different diſtances of theſe planets from the ſun in different parts of their orbits is exhibited: thus, the earth is as much farther from the ſun in any point of her orbit than ſhe is at the perihelion, as the thickneſs of the line in that point of her orbit amounts to.

671 *The motion of the planets* in their orbits *is not equable*; but every one of them obſerves this rule, that a line drawn from the ſun to the planet moves over equal areas upon the plane of its orbit in equal times: thus, let the el-
28 lipſis, fig 28, be the orbit of a planet, if the planet moves in a certain time, for example in a month, from the point A to B; we may ſay that in a months time the line S A drawn from the ſun to the planet has ſwept or moved over the triangular area A S B: to this make the triangular area B S C equal, and a line drawn from the ſun to the planet will move over this area in a time equal

a *Aux origine Perſicum, altitudo.* Golii *lexic.* b Plin. *N. H l.* 2. *c.* 15. *al. apſis.*

to

Book II.



J. Mynde sc.

to the former, that is, in another month the planet will move from B to C: FIG.
and ſo for the reſt of the orbit, if the plane of it be divided into the mixt tri- 28
angles CSD, DSE, ESF, &c. in ſuch a manner that the area of every one of them be equal to the area of ASB, a line drawn from the ſun to the planet will ſweep each of theſe triangles in the ſame time as it does the triangle ASB; and conſequently the planet will go from B to C, from C to D, from D to E, from E to F, &c. in the ſame time as it did from A to B.

672 The figure before us being divided into twelve mixt triangles, the ſides 28
of each triangle conſiſt of two ſtrait lines and an arc of an ellipſis: a view of the figure is ſufficient to ſhew, that if we would make the areas of them equal, the ſhorter the two ſtrait lines of any triangle are, the longer muſt the arc be; the longer the ſtrait lines are, the ſhorter muſt the arc be: now the ſtrait lines are ſhorter the nearer to the perihelion, longer the nearer to the aphelion; and conſequently the arcs deſcribed by any planet in its orbit in a given time are longer, the nearer the planet is to its perihelion; ſhorter, the nearer the planet is to its aphelion. From hence it followeth that every planet moves ſwifteſt in its perihelion, ſloweſt in its aphelion, with a middle or mean motion at its mean diſtances.

673 The 28th figure repreſents the orbit of the earth divided into twelve 28
parts or arcs, anſwering to the twelve months in the year; but the ellipſis is much more excentric than its true figure requires: it was neceſſary to draw it thus, the better to ſhew the inequality of the arcs of an ellipſis divided into equal triangles: if a circle be divided into equal triangles, the arcs will be exactly equal: as appears by fig. 16: the orbits of the planets are ſo near to 16
circles, that if the orbit of mercury which is the moſt excentric of them all were drawn in its true figure, and divided into equal triangles, we ſhould ſcarcely perceive any difference between the arcs; much leſs would any ſuch difference be perceptible in the arcs of the earth's orbit, if it were drawn in its true proportion. Since the orbits of the planets, and of the earth particularly, are ſo near to circles, the inequality of their motions is very ſmall.

674 *The orbit of every comet is a very excentric ellipſis* having the ſun in one of its focuſes: *the motion of comets* round the ſun is *not equable*, but according to this rule, a line drawn from the ſun to the comet paſſes over equal areas upon the plane of its ellipſis in equal times: therefore comets move much ſwifter at their perihelia than at their aphelia; with a mean motion at their mean diſtances. The 26th figure will ſerve well enough to repreſent the or- 26
bit of a comet, though the orbits of ſome of them are much more excentric than that ellipſis: the more excentric the orbit of a comet is, the greater difference will there be between the arcs it moves through in equal times;

that

FIG. that is, the greater inequality will there be in the motion of the comet: for this reaſon, a comet which moves pretty faſt near its perihelion may move exceedingly ſlow at its aphelion; ſo as to make its entire period to take up a great number of years: the period of the comet which appeared in the year
11 1680 is 575 years; its orbit is a very excentric ellipſis, as appears by the 11th figure, as does alſo the near approach it made to the ſun in its perihelion; in its aphelion it goes to a diſtance from the ſun about eight times as great as the ſemidiameter of the orbit of ſaturn. Comets are viſible to us only when they come as near to the ſun as the orbit of jupiter; when they are farther from the ſun than that, their diſtance from the earth is ſo great that they are inviſible to us[a]: and this is the reaſon we ſo rarely ſee any of them, notwithſtanding they are ſo numerous; becauſe they are for much the greateſt part of their periods moving very ſlowly at immenſe diſtances from us.

CHAP. 8. THE ASPECTS OF THE INFERIOR PLANETS WITH THE SUN: THEIR GEOCENTRIC MOTIONS: THEIR APPEARING DIRECT, STATIONARY, RETROGRADE.

675 I have ſufficiently explained in what manner the planets would appear to move, if they were to be viewed from the ſun; I have alſo ſhewn how their apparent latitude is varied, by their being viewed from the earth in different parts of her orbit: I ſhall now enter into a more particular detail of their geocentric motions, which ariſe from a combination of theſe two cauſes, 1 the motions of the planets themſelves in their orbits, and 2 the motion of the earth, by which the ſtation of the obſerver is continually changing.

676 A planet is ſaid to be *in conjunction* with the ſun, when its geocentric place is the ſame with the geocentric place of the ſun: a planet is ſaid to be in *oppoſition* to the ſun, when its geocentric place is oppoſite to the geocentric place of the ſun: an exact or central conjunction or oppoſition can happen only when a planet is in one of its nodes at the ſame time that the earth is in the line of nodes of that planet; but it is generally called a conjunction or oppoſition, when the ſame circle of latitude paſſes through the
24 ſun and the planet: thus, fig. 24, if the geocentric place of the ſun be at ♈, of a planet at *a* or *b*, the planet is ſaid to be in conjunction: if the ſun appears at ♎, the point oppoſite to ♈, and the planet at *a* or *b*, it is in oppoſition: when the geocentric place of a planet is 90°, or a quarter of a circle, diſtant from the ſun's place, the planet is ſaid to be in *quadrature*, or in a quartile aſpect,

a v. Newtoni *Princip. l. 3. lemma 4.*

or

Book II.

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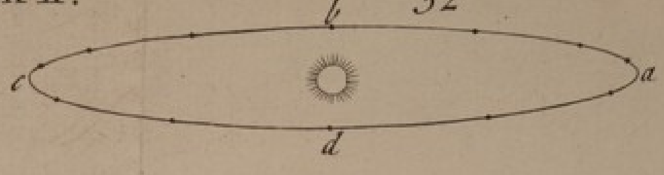

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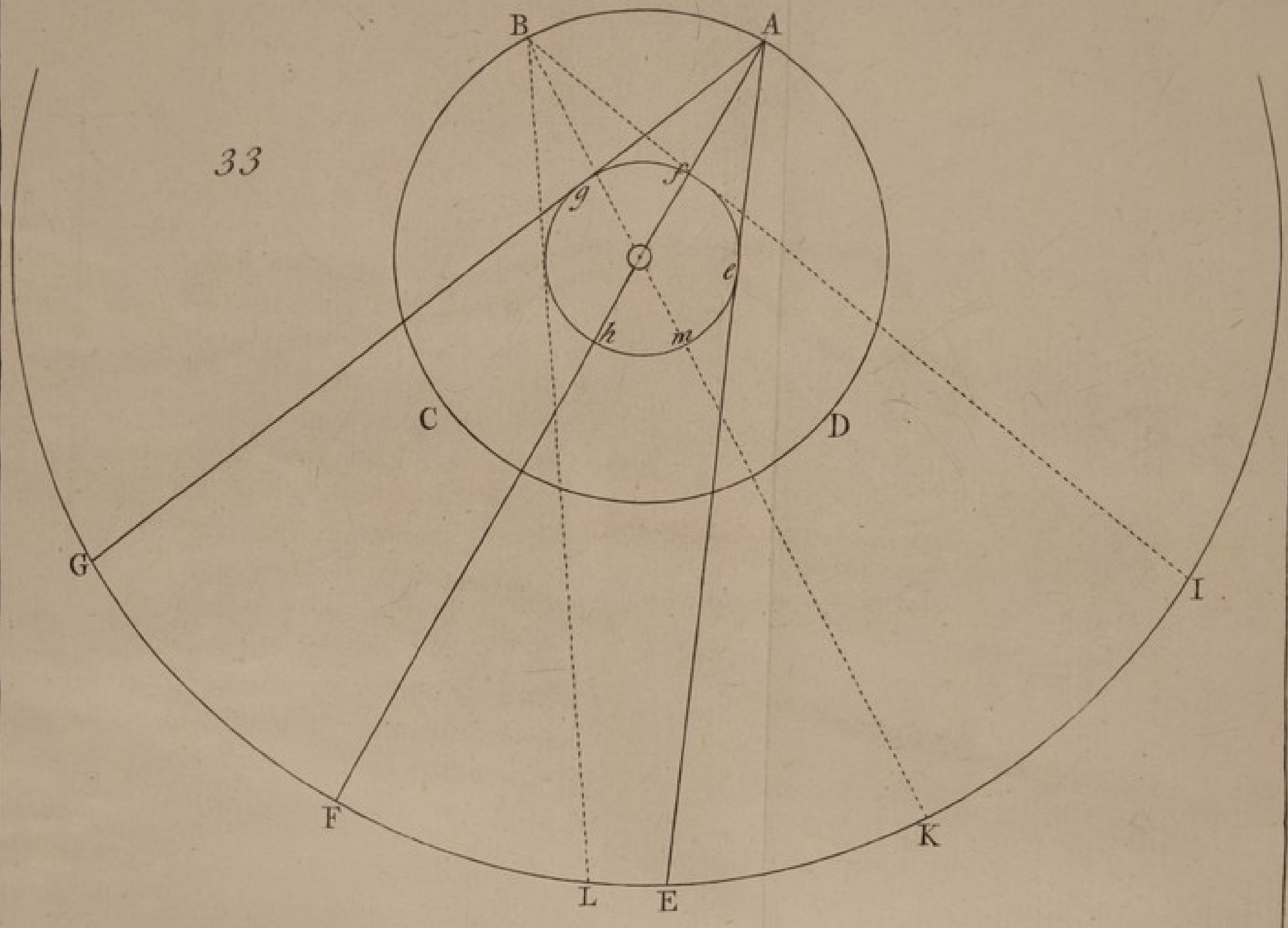

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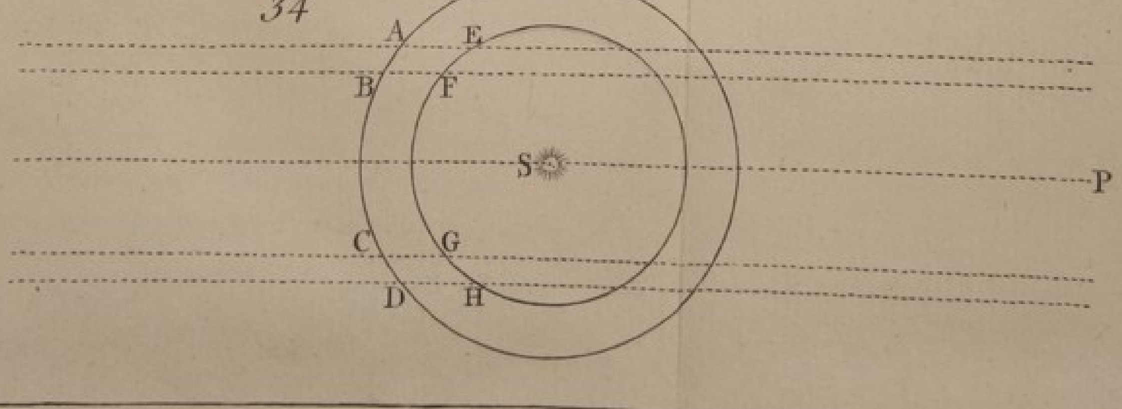

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or to be in ſquare with the ſun: theſe terms are uſed in a like ſenſe when applied to any two of the heavenly bodies: thus, the ſun and moon, or the moon and any planet, or two planets may be in conjunction, oppoſition, or quadrature. Theſe configurations of the heavenly bodies, ariſing from their mutual ſituations with regard to their different longitudes meaſured on the ecliptic, are called *aſpects*; as if they looked at one another in a different manner according to their different poſitions: the word ſeems to be taken from the ancient notion of the ſun, moon and planets being animated, as do alſo ſome other expreſſions uſed by the aſtrologers; as when they talk of the planets afflicting and oppreſſing, or of their aiding and ſtrengthening one another. It has been already obſerved, § 626, that the favourers of judicial aſtrology would have us believe ſome of the heavenly bodies to be of a benign, others of an hurtful nature; they teach moreover that planets of the ſame nature in ſome ſituations cooperate, and joyn their influences; and thoſe of a contrary nature obſtruct one another in their ſeveral effects; and that they exert theſe powers in different manners and degrees, according to their ſeveral aſpects: and therefore, according to *Kepler*'s definition, an aſpect is an angle formed by the rays of two planets meeting upon the earth, having a power to influence ſublunary beings. The ancients reckoned only five aſpects, which are often repreſented by characters, as may be ſeen in the common almanacks: they are theſe that follow, conjunction ☌, oppoſition ☍, quartile □, trine △, ſextile ✶: with regard to their ſuppoſed influences, the oppoſition and ſquare are held to be malevolent, the trine and ſextile benevolent aſpects: the conjunction is ſaid to be of an indifferent nature: ſome of the moderns take in a greater number of aſpects; as the decile, when the difference in longitude between thoſe two of the heavenly bodies which are under conſideration is a tenth part of the ecliptic; the octile, when an eighth part; the quintile, when a fifth part, &c. *Kepler. epit. aſtronom. p.* 842.

677 The conjunction of an inferior planet with the ſun is of two ſorts; 1 in its inferior ſemicircle, or that part of its orbit which is nearer to our earth than the ſun is; 2 in its ſuperior ſemicircle[a], or that part which is farther from our earth than the ſun is: in the former of theſe conjunctions the planet is between our earth and the ſun; in the latter the ſun is between our earth and the planet: thus, fig. 29, let O P Q R T be part of the ecliptic, S the ſun, the three circles round him the orbits of mercury, venus and the earth, ſuppoſe the earth to be at A, the ſun's geocentric place will be at Q, if mercury be then at I, his geocentric place alſo is at Q, and he is in conjunction in his inferior ſemicircle: if mercury be at M, his geocentric place is Q, and he is in con-

FIG. 29

[a] See § 270.

FIG. junction in his ſuperior ſemicircle: in like manner venus at E is in conjunction in her inferior ſemicircle; at G in her ſuperior.

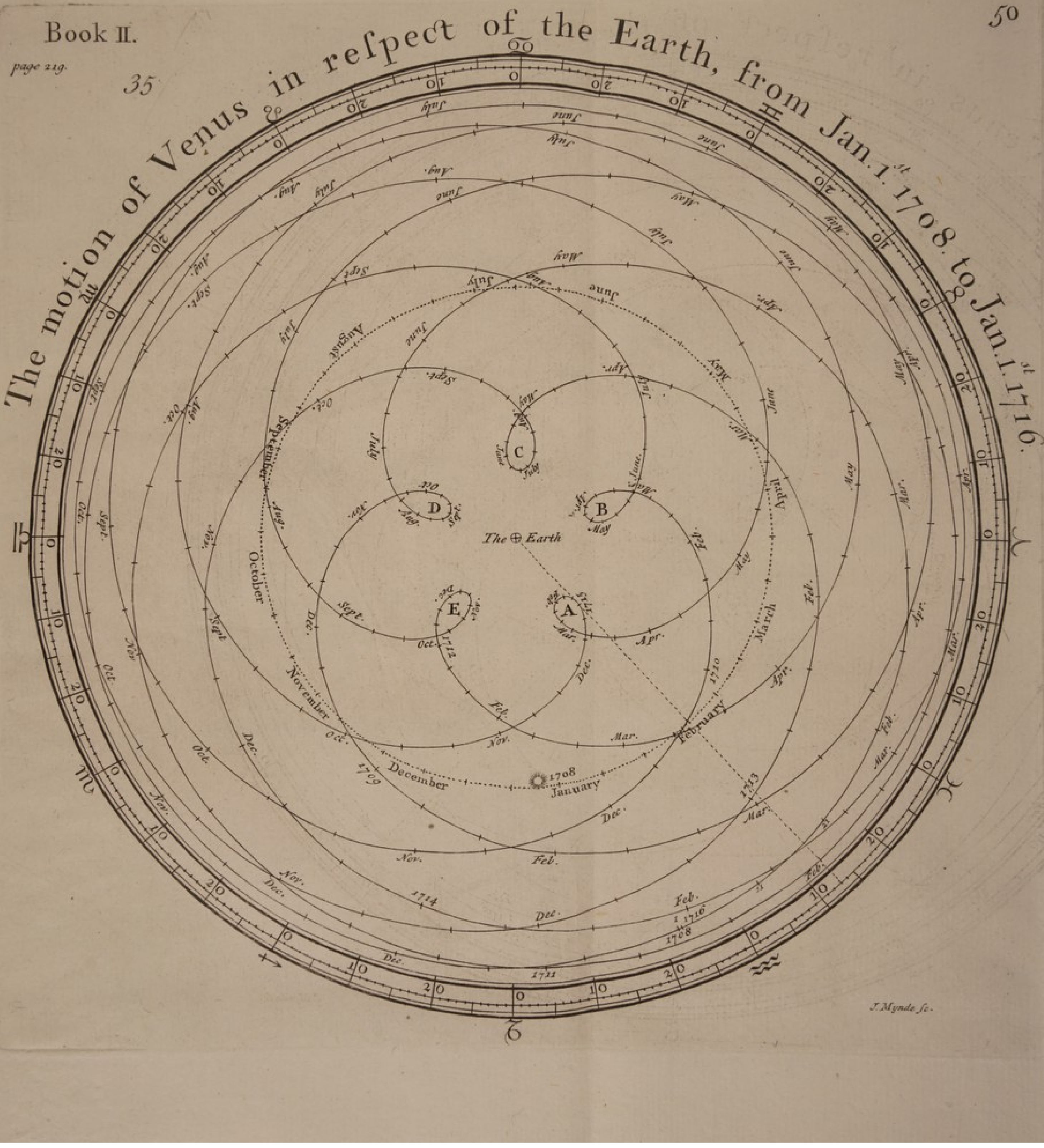
678 The inferior planets can never be in oppoſition to the ſun, nor indeed can they ever appear at a great diſtance from him: this diſtance is called their
29 *elongation:* thus, fig. 29, if the earth be at A, venus at H, her geocentric place is T, her elongation QT: the greateſt elongation of an inferior planet is when the viſual line, that is a line drawn from the earth to the planet, is a tangent to its orbit: thus mercury at N and venus at H are in their greateſt elongations: this is ſpeaking in a general and inaccurate way; for the elongation of a planet is then greateſt of all when the planet is in its aphelion at the time when the viſual line is a tangent to its orbit: thus the greateſt poſſible elongation of mercury is QP, when he is in aphelion, as at L: it is found by obſervation that the greateſt elongation of mercury is about 28°, of venus 48°[a]. The inferior planets in their elongations are ſometimes eaſtward, ſometimes weſt-
29 ward from the ſun: thus, the earth being at A, when venus appears in any part of the arc QO ſhe is weſtward from the ſun, and therefore riſes before him, is ſeen in the morning, and is called *the morning ſtar:* when ſhe appears any where in the arc QT, ſhe is eaſtward from the ſun, and therefore ſets after him, is ſeen in the evening, and is then *the evening ſtar.*

679 If the planets were to be viewed from the ſun they would always appear direct, going on in their heliocentric circles, according to the order of the ſigns, as was ſhewn § 640; and their motions, though not exactly ſo, would be nearly equable: whereas, to us who view them from the earth, they appear ſometimes *direct*, ſometimes *retrograde*; and both theſe with great inequality of velocity: ſometimes they are *ſtationary*, for a little while not ſenſibly changing their geocentric places in the ſphere of the heaven: this diverſity of their appearances is owing to the ſeveral combinations of the motions of the earth and of the planets in their orbits; and therefore, in order to a full explanation, both theſe motions muſt be taken into the account: but it will not be amiſs firſt to conſider them ſeparately; and, ſince the earth is longer in going round the ſun in her orbit than either of the inferior planets in theirs, let us conſider the earth as at reſt in ſome part of her orbit, whilſt an inferior planet, for example, mercury, goes round in his; and ſee what his appearances would be upon this ſuppoſition.

680 Whilſt an inferior planet is moving in its ſuperior ſemicircle its geocentric motion is direct; whilſt it is moving in its inferior ſemicircle its geo-
29 centric motion is retrograde: thus, fig. 29, ſuppoſe the earth at reſt at A, whilſt mercury is going in his orbit from N to I, from I to L, his motion appears to

a *Mem. d' Acad. Royale ann.* 1709. 7 *Aouſt.*

an


The motion of Venus in respect of the Earth, from Jan. 1st 1708 to Jan. 1st 1716.
The ⊕ Earth
A
B
C
D
E
1708
January
February
March
April
May
June
August
September
October
November
December
J. Mynde sc.

an inhabitant of the earth to be retrograde, contrary to the order of the ſigns; FIG.
namely from R to Q, from Q to P: when mercury is moving from L to M, 29
from M to N his geocentric motion is direct, according to the order of the ſigns; namely from P to Q, from Q to R.

681 When our earth is in the line of nodes of an inferior planet its orbit in a perſpective view appears a ſtrait line, as fig. 31; becauſe the plane of it paſſes through the eye of an obſerver upon the earth, § 258; and therefore the planets apparent motion is then in a ſtrait line: thus, let the earth be in the line of nodes of mercury, the projection of his orbit is, as in fig. 31, a 31
ſtrait line A C, extended on each ſide of the ſun B, to the diſtance of the planets greateſt elongation: if mercury be then in his ſuperior ſemicircle, his apparent motion is direct, from A to C, in a ſtrait line, but unequal, going the unequal diviſions of the line in equal times, faſter the nearer to the ſun by § 268[a], if a conjunction happens, he paſſes behind the ſun, from *a* to *b*. If when the earth is in the line of his nodes, mercury be in his inferior ſemicircle, his apparent motion is retrograde, in the ſame ſtrait line as before, from C to A, but more unequal than in the preceding caſe, § 268[b]; going faſter the nearer to the ſun, and in conjunction he paſſes between the ſun and our eye, and appears to go over the ſun's diſk from *b* to *a*: in this manner mercury has often been ſeen to paſs over the ſun's diſk, venus was never obſerved to do ſo but once, Novemb. 24. 1639. When the earth is out of the line of nodes of an inferior planet its orbit appears an ellipſis more or leſs excentric according as our eye is differently elevated above its plane, § 268[c]: the apparent motion therefore of the planet is then in an elliptic curve: thus, let the earth be as far as poſſible, that is 90°, out of the line of nodes of mercury, the projection of his orbit will be ſuch an elliptic curve, as fig. 32, wherein he will appear to move according to the order of the letters, 32
direct when in his ſuperior ſemicircle, from *a* to *b*, from *b* to *c*, being above the ſun at *b*, in conjunction: but in his inferior ſemicircle his apparent motion will be retrograde, from *c* to *d*, from *d* to *a*; and in conjunction he will be below the ſun at *d*: in theſe caſes alſo his apparent motion will be unequal, faſter the nearer to conjunction, but moſt unequal in the inferior ſemicircle, going through the unequal arcs into which the elliptic curve is divided, in equal times. See § 268, 269.

682 The geocentric motion of the inferior planets both direct and retrograde is ſometimes ſwifter and ſometimes ſlower; ſwifter the nearer to the ſun, ſlower the nearer to their greateſt elongations: the inequality now ſpoken of is not owing to the ſmall inequality of their motions in their orbits,

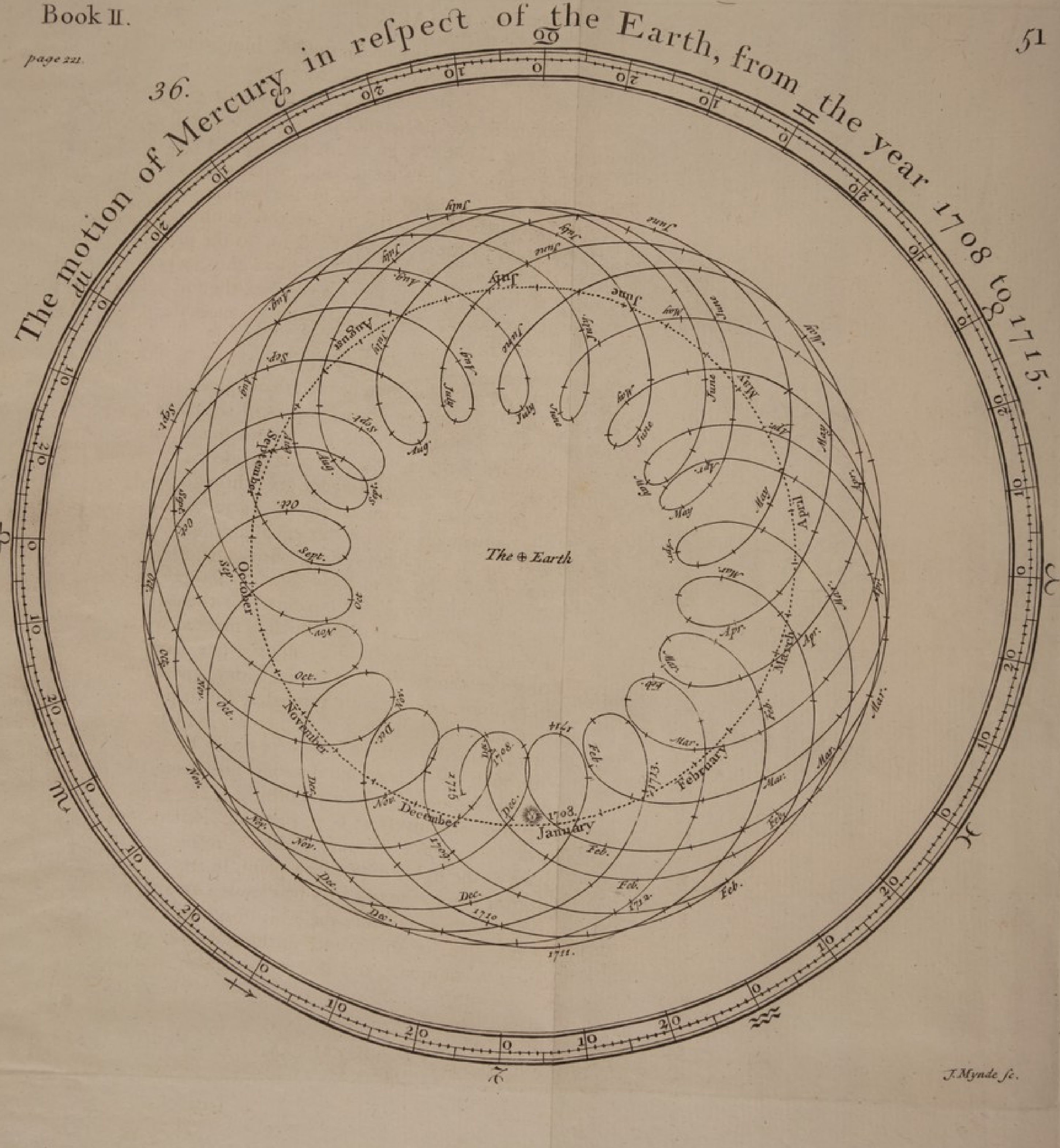
a *Introduct. fig.* 153. b *Introduct. fig.* 154. c *Introduct. fig.* 152.

which

FIG. which was mentioned § 672, but to their orbits being viewed obliquely, and by that means projected into oblong ellipſes or ſtrait lines with the ſun
31 in the middle of them, as fig. 31 and 32; in which projections a body mo-
32 ving with an uniform velocity round a circle will appear to move irregularly, ſwifter the nearer to the middle; ſlower the nearer to the extremities *ac* or A C: ſee this more fully explained in the introduction, § 268, 269.

683 An inferior planet is ſtationary while its motion is changing from direct to retrograde, or from retrograde to direct; that is it will appear not to change its place ſenſibly for ſome time: now if the earth ſtood ſtill the places of being ſtationary would be at the planets greateſt elongation; for though it be the nature of a tangent to touch its circle only in a point, yet when the circle is large the receding of the circle from the tangent is not perceptible
29 in the parts very near the point of contact: thus, fig. 29, ſuppoſe the earth to be at reſt at A venus would appear ſtationary, her geocentric place continuing at T, all the while ſhe is going in her orbit from *a* to *b*: becauſe her deviation from the viſual line A T would ſcarce be perceptible ſo near the point of contact H. Thus to an inhabitant of the earth the inferior planets appear always near the ſun, alternately going from him and returning to him, in ſtrait lines or elliptic curves, firſt on one ſide and then on the other: ſometimes ſo near the ſun as to be rendred inviſible by his ſtronger light: ſometimes, when in or near their nodes, they paſs behind the ſun, in their ſuperior ſemicircles; or come between the ſun and our eyes, in their inferior ſemicircles: and in this laſt caſe appear like ſpots moving over the diſk of the ſun.

684 Hitherto, for the more eaſy comprehenſion of them, I have conſidered the geocentric motions of the inferior planets, ſuppoſing the earth to ſtand ſtill in ſome part of her orbit, while they go round the ſun in theirs; the motion of the earth makes ſome alterations which ſhall now be ſhewn: if the earth were to ſtand ſtill in any point of her orbit as at A, the places of conjunction both in the inferior and ſuperior ſemicircle, as alſo of great-
29 eſt elongation, and conſequently the places of direct and retrograde motion and of the ſtations of an inferior planet would be always in the ſame parts of the heaven: thus, fig. 29, upon this ſuppoſition, the places of mercury's ſtations would be always the points P and R, the arc of his direct motion P R, and the arc of his retrograde motion R P: whereas now, the places wherein theſe appearances happen are continually advancing forward, in the ecliptic, according to the order of the ſigns, by the motion of the earth in her or-
33 bit: thus, fig. 33, let A B C D be the orbit of the earth, *efgh* the orbit of mercury, ☉ the ſun, G K I an arc of the ecliptic; when the earth is at A the ſun's geocentric place is at F, and mercury in order to a conjunction muſt be in the


36.
The motion of Mercury in respect of the Earth, from the year 1708 to 1715.
The ⊕ Earth
January
February
March
April
May
June
July
August
September
October
November
December
1708.
1711.
1712.
1713.
1714.
1715.
J. Mynde sc.

the line AF, that is, in his orbit he muſt be at *f* or *h*; ſuppoſe him to be at FIG.
f in his inferior ſemicircle, if the earth ſtood ſtill at A, mercury's next con- 33
junction would be when he is in his ſuperior ſemicircle at *h*, the places alſo of mercury's greateſt elongation from the ſun would in his orbit be *e* and *g*, and in the ecliptic E and G, but let the earth go on in her orbit, ſuppoſe from A to B, the ſun's geocentric place is now at K, and mercury in order to be in conjunction ſhould be in the line BK at *m*. As by the motion of the earth the places of mercury's conjunctions with the ſun are thus continually carried round the ecliptic according to the order of the ſigns, ſo the places alſo of his utmoſt elongation muſt go forward the ſame way: thus, when the earth is at A the places of mercury's greateſt elongation from the ſun are in the ecliptic E and G; the motion of the earth from A to B advances them forward, from G to L, from E to I.

685 But the geocentric motion of mercury will be better ſeen in the following figure, which is much eaſier to be comprehended than upon a tranſient view it may appear to be. In figure 30 we have part of the ecliptic 30
marked ♈ ♉ ♊ &c, in the center of which is the ſun S, and round him the orbits of mercury and the earth: the orbit of mercury is divided into 11 equal parts, each part containing ſuch an arc as mercury goes through in 8 days, the points of diviſion are marked with numeral figures 1 2 3 4 &c, part of the orbit of the earth ABC is likewiſe divided into 22 equal arcs, each arc being ſo much as the earth goes through in 8 days time, the points of diviſion are marked with the letters *abcdef* &c, and ſhew ſo many ſeveral ſtations from whence mercury may be obſerved by an inhabitant of the earth: ſuppoſe then mercury to be at that point of his orbit which is marked with the figure 1, and at the ſame time the earth to be at *a*; draw a line from *a* through 1 and it ſhews mercury's geocentric place at A: in 8 days mercury will be got to 2, the earth to *b*; draw a line from *b* through 2 and it points out mercury's geocentric place at B: in another 8 days mercury will be at 3, the earth at *c*; a line drawn from *c* through mercury at 3 ſhews his place at C: in this manner going through the figure, and drawing lines from the earth at *d*, *e*, *f*, *g*, &c, through the figures in mercury's orbit 4, 5, 6, 7, &c, we ſhall find his geocentric places ſucceſſively at D, E, F, G, &c; where we may obſerve that from A to B, from B to C mercury is direct, from C to D from D to E retrograde. I have in the figure marked 22 points in the earth's orbit, for ſo many ſtations from whence mercury may be viewed; to anſwer to theſe ſtations, there muſt be 22 places taken in the orbit of mercury: for this purpoſe I have marked the place of that planet at the end of every 8 days, for two of his periodical revolutions; and this is the reaſon of two

numeral

FIG. numeral figures being placed at each diviſion, to ſhew that we are to go over 30 his orbit twice in conſidering the ſcheme before us.

686 The geocentric motion of venus may be explained by a figure ſimilar to that made uſe of to ſhew the motion of mercury; only, as mercury goes through his orbit quicker than venus, conjunctions, oppoſitions, elongations, ſtations, and the changes of motion from direct to retrograde or from retrograde to direct are all more frequent in mercury than in venus.

687 In order to an explanation of the ſtations of the planets, it may be remembred that I have before laid down this poſition, § 636, that, in compariſon of the diſtance of the ſtars, the orbit of ſaturn is but as a point; much more may the ſame be ſaid of the orbit of the earth; and conſequently, if we conſider any two parallel lines which are not at a greater diſtance from one another than the diameter of the orbit of the earth amounts to, ſuch lines continued would, as far as could be perceived by obſervation, terminate in the ſame point of the ſphere of the heaven: this being premiſed, let the

34 two circles fig. 34 repreſent the orbits of venus and of the earth, let the lines AE, BF, CG, DH, be parallel to SP, I ſay they will all, if continued, terminate in the ſame point in the heaven, as to ſenſe, as the line SP extended thither would do: now ſuppoſe venus at E when the earth is at A, the viſual ray by which venus is ſeen is the line AE: ſuppoſe while venus goes from E to F the earth goes from A to B, the viſual ray in which venus is now ſeen is BF, parallel to AE; and therefore venus will be all that time ſtationary, appearing in that point of the heaven where SP extended would terminate: this ſtation is at her changing from direct to retrograde: again, ſuppoſe when the earth is at C venus is at G, the viſual line is CG; if while the earth goes from C to D venus goes from G to H, ſo that ſhe is ſeen in the line DH parallel to CG, venus will be all that time ſtationary, appearing in that point where a line drawn from S through P would terminate: this ſtation is at her changing from retrograde to direct: both ſtations are in her inferior ſemicircle.

688 An inferior planet in conjunction with the ſun in its inferior ſemicircle is ſaid to be in *perigee*, in conjunction in its ſuperior ſemicircle it is ſaid

29 to be in *apogee*[a]: thus fig. 29, if when the earth is at A venus be at E, mercury at I, they are in perigee; if venus be at G, mercury at M, they are in apogee. The diſtance of each of the inferior planets from the earth when the planet is in perigee is variable; as is alſo its apogee diſtance: the variation of theſe diſtances of the inferior planets is owing partly to the excentricities of their orbits and of the orbit of the earth; and partly to the motions of thoſe planets and the motion of the earth; by which it comes to paſs that they are

a The word *perigee* ſignifies near the earth; *apogee* diſtant from the earth.

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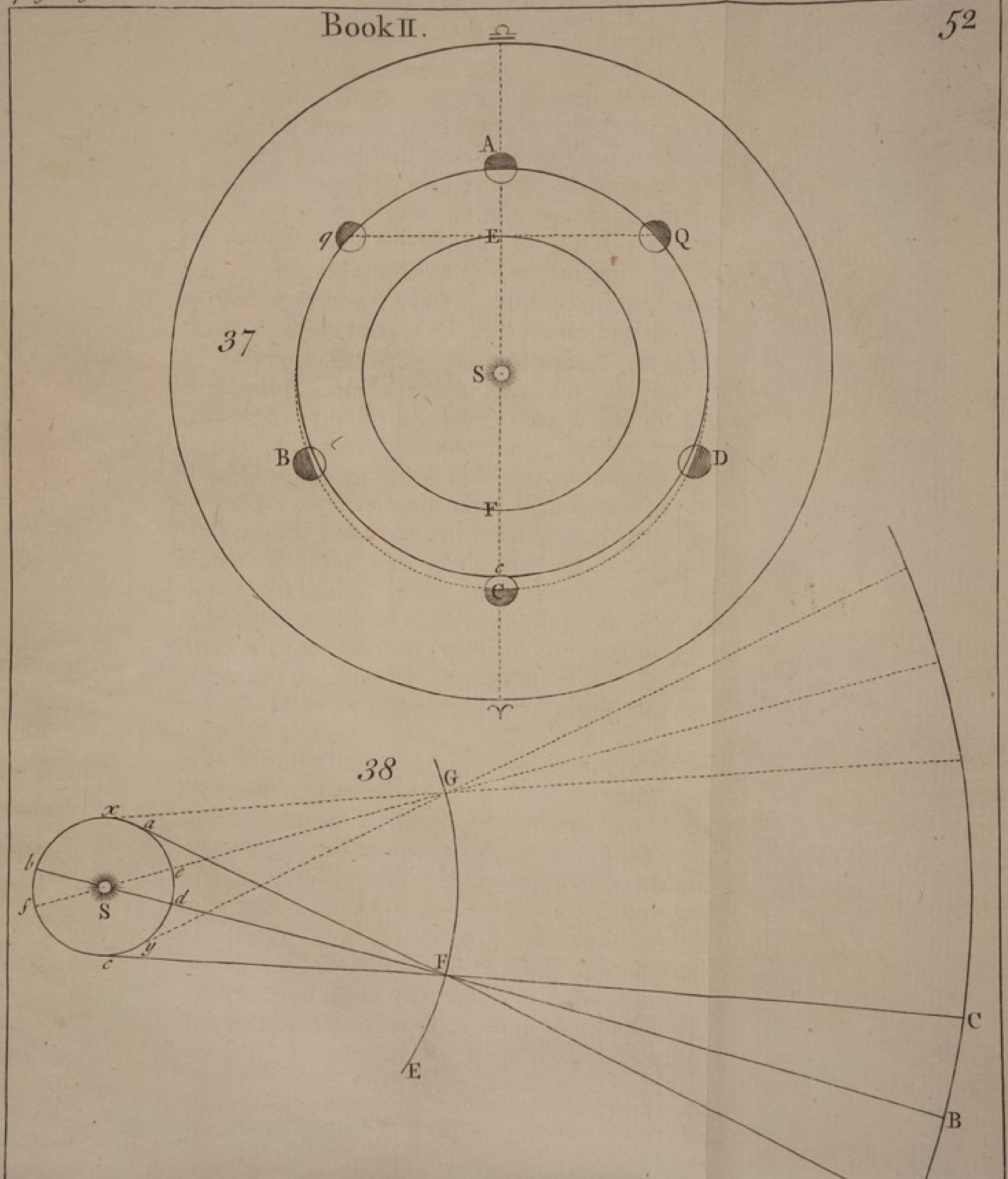

in perigee when they are in different parts of their orbits, as well as when the earth is in different parts of her orbit—Since the difference between the perihelion and aphelion diſtances from the ſun is greater in the orbit of mercury than in the orbit of the earth[a], mercury will be at the leaſt poſſible diſtance from the earth when he is in perigee at the time that he is in aphelion: becauſe, mercury being then between the earth and the ſun, his running out to his greateſt diſtance from the ſun brings him the neareſt to the earth that ever he can be: again, mercury is at the greateſt poſſible diſtance from the earth when he is in apogee at the time that he is in aphelion; becauſe, the ſun being then between the earth and mercury, his running out in that ſituation to his greateſt diſtance from the ſun carries him the fartheſt from the earth that ever he can be: thus, fig. 29, ſuppoſe mercury to be at his aphelion L, 29
if the earth be then at B mercury is at the leaſt poſſible diſtance; if the earth be at D he is at the greateſt poſſible diſtance from the earth.—Since the difference between the perihelion and aphelion diſtances is greater in the orbit of the earth than in the orbit of venus[b], venus will be at the leaſt poſſible diſtance from the earth when ſhe is in perigee at the time that the earth is in perihelion; becauſe, venus being then between the earth and the ſun, the earth by approaching in that part of her orbit the neareſt to the ſun that is poſſible, comes the neareſt to venus that ever ſhe can be: again, venus is at the greateſt poſſible diſtance from the earth when ſhe is in apogee at the time that the earth is in aphelion; becauſe, the ſun being then between the earth and venus, the earth by running out, in that part of her orbit, to her greateſt diſtance from the ſun, goes the fartheſt from venus that is poſſible for her ever to do.

689 The inferior planets, going round the ſun in orbits leſs than the orbit of the earth, are ſometimes nearer to us than at other times, as has been ſhewn, §688; and conſequently their apparent diameters are ſometimes greater than at other times[c]: thus, fig. 29, ſuppoſe the earth to be at A, if venus 29
be at E ſhe is the whole diameter of her orbit, *viz.* EG, nearer to us than if ſhe were at G; and conſequently her diſk appears much larger at E than at G: in other places, as F or H, her diſtances are intermediate; and conſequently her diameters are between the leaſt and the greateſt. Thus alſo mercury is neareſt to the earth, and appears largeſt, when in conjunction in his inferior ſemicircle at I; as he goes to L his diſtance from the earth is greater, and his diſk appears leſs: at M his diſtance is greateſt of all, and therefore the apparent

a § 669. b § 669. c Since the apparent diameters of an object at different diſtcanes are reciprocally as the diſtances, the apparent diameter of venus in perigee is to her diameter in apogee, as 17 to 3; the apparent diameter of mercury in perigee to his diameter in apogee as 14 to 6.

FIG. diameter of his diſk is then leaſt. As by the different diſtances of the inferior planets from us, at different times, their apparent diameters are different; ſo the difference of their apparent diameters ſhews their diſtances to be different[a]: how the apparent diameters of the planets are meaſured will be ſhewn hereafter.

690 A common ſpectator may obſerve an inferior planet alternately to approach nearer and nearer to the ſun, till it is in conjunction with him; and recede farther and farther from the ſun, till it is at its greateſt elongation; and this will be firſt on one ſide of the ſun and then on the other: but if we obſerve the change of the apparent place of an inferior planet in the ſphere of the heaven, its direct motions, ſtations, and retrogradations, and moreover frequently meaſure its diſk with the micrometer, we ſhall find, by the difference of its apparent diameter at different times, that the planet at ſome times comes nearer and nearer to us, and at other times recedes farther and farther from us; in ſuch a manner that, taking the whole of its apparent motion into the account, its courſe round the earth appears to be in a complicated curve, which for its reſemblance thereto may be called *a ſpiral:* and in ſuch a curve muſt the real motion of the planet be, to account for all its appearances, if the earth remained perpetually fixed in the ſame place.

691 The 35th and 36th figures, taken from *Caſſini*[b], ſhew in what kind
35 36 of ſpirals the motions of venus and mercury muſt be, upon this ſuppoſition that the earth does not change her place: an explanation of the 35th figure will be ſufficient to make the other eaſily underſtood. The outermoſt circle is the ecliptic, the earth ⊕ is in the center of it, as it always appears to be, § 248, 249: the ſpiral line marked with the names of the months abbreviated ſhews the motion of venus, ſuch as it appears to an inhabitant of the earth, for eight years ſucceſſively; the time for which *Caſſini* drew theſe figures was from the firſt of january 1608 to jan. 1, 1716: the ſhort ſtrokes croſs the ſpiral ſhew the places of venus for the firſt day, as alſo for the 10th and 20th day of every month, during that time: the months and years are ſet down in their proper places: thus the ſpiral exhibits the direct motions, ſtations and retrogradations of venus, with the times of them: it ſhews alſo her neareſt approaches to the earth, and her receding to the greateſt diſtances from the earth, together with her ſeveral intermediate diſtances: a thread ſtretched from ⊕ through any of the places of venus in the ſpiral to the ecliptic will ſhew her geocentric longitude at that time; thus, the pointed line ⊕A ſhews the longitude of venus, january 1. 1715, to be in 13° of ♒: that line appears to touch the ſpiral for ſome length on each ſide the point

a § 237, 239, 242. b *Memoires d' Acad. Royale, ann.* 1709.

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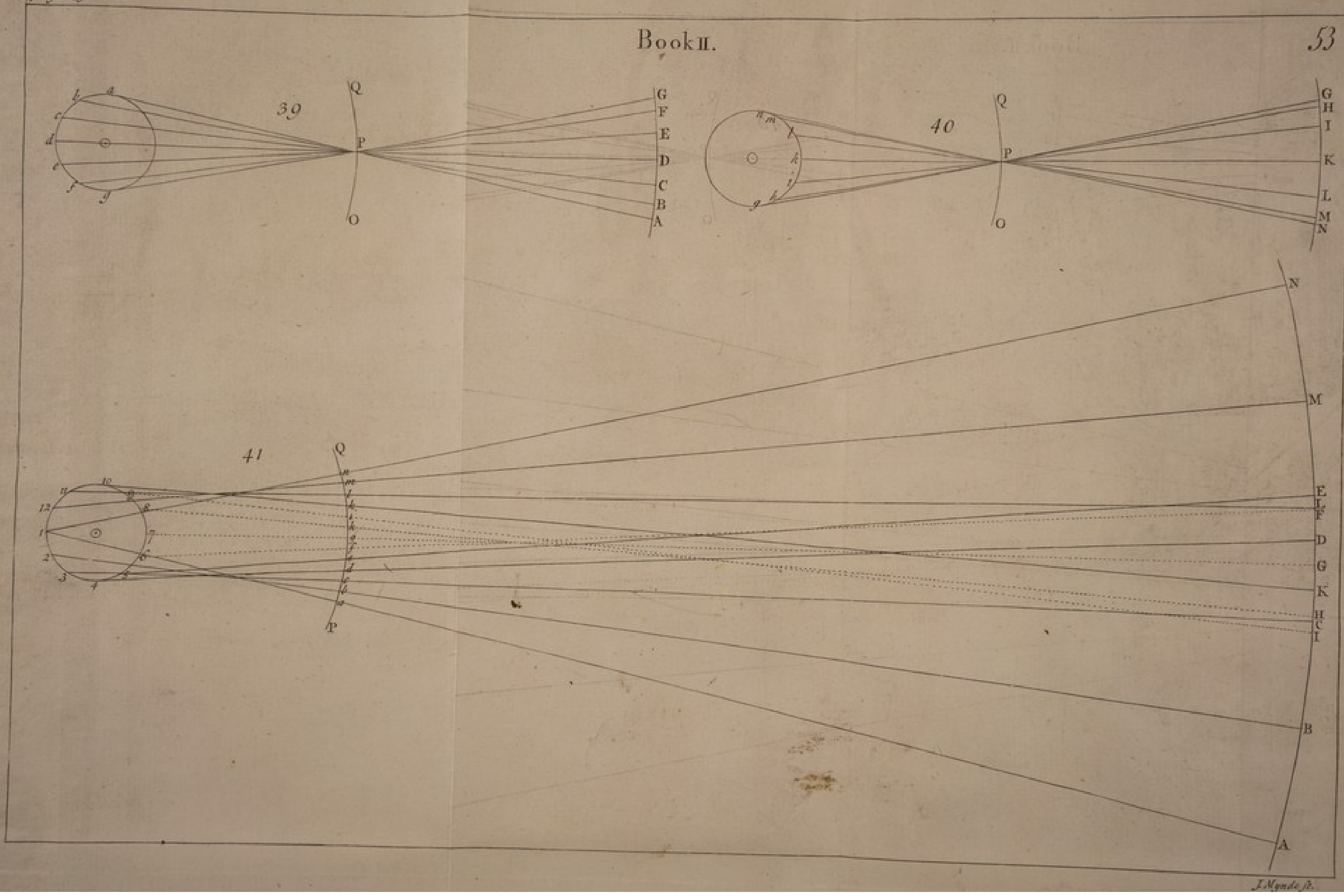

of contact, venus therefore then appeared ſtationary: her other ſtations are FIG.
eaſily ſeen by ſtretching a thread from ⊕ in the ſame manner, ſo as to touch, 35
on either ſide, the curve that encloſes thoſe little oval ſpaces marked A, B, C, D, E: the pointed circle with the names of the months at length ſhews the apparent annual motion of the ſun, which is not ſenſibly different in 8 years time: by means of this circle it may be ſeen, for any part of the time here ſpecified, which was neareſt to the earth venus or the ſun; and how much one was nearer to the earth than the other: the elongations of venus from the ſun for any part of that time may alſo be ſeen by the ſame figure; if two threads be ſtretched from ⊕ to the ecliptic, in ſuch a manner that one of the threads may paſs over the place of venus, the other over the place of the ſun at the time given, the arc of the ecliptic between the two threads ſo ſtretched will ſhew the elongation of venus from the ſun.

CHAP. 9. THE ASPECTS OF THE SUPERIOR PLANETS WITH THE SUN, THEIR APPEARING DIRECT, STATIONARY, RETROGRADE.

692 A ſuperior planet, going round the ſun in a larger orbit than the earth does, can only be in conjunction with the ſun when the ſun is between the earth and the planet: thus, let fig. 37 repreſent the orbits of the earth and of 37
mars, if when the earth is at E mars be at C, mars is in conjunction with the ſun; for the geocentric place of both is at ♈. A ſuperior planet is in oppoſition to the ſun when the earth is between the ſun and the planet: thus, fig. 37, if when the earth is at E mars be at A, he is in oppoſition to the ſun; 37
for the place of the ſun is ♈, the place of mars ♎. A ſuperior planet is in quadrature with the ſun when the geocentric place of it is 90° from the geocentric place of the ſun: thus, fig. 37, if when the earth is at E mars be at *q* 37
or Q, he is in quadrature with the ſun; for the lines QE and SE form a right angle, as do alſo *q*E and SE.

693 As the earth goes round the ſun in leſs time and in a leſs orbit than any of the ſuperior planets, it will not be amiſs to ſuppoſe a ſuperior planet to ſtand ſtill in ſome part of its orbit, while the earth goes once round the ſun in hers; and conſider the appearances the planet would then have: which are theſe that follow, 1. while the earth is in her moſt diſtant ſemicircle, the apparent motion of the planet would be direct: 2. while the earth is in her neareſt ſemicircle[a], the planet would be retrograde: 3. while the earth is near the

[a] What is here called the neareſt ſemicircle is a little leſs, what is called the moſt diſtant ſemicircle is a little more than half a circle: the deficiency and exceſs are greater in mars than in jupiter, greater in jupiter than in ſaturn.

FIG. points of contact of a line drawn from the planet ſo as to be a tangent to the
38 orbit of the earth, the planet would be ſtationary: thus, fig. 38, let the circle *abcd* be the orbit of the earth, S the ſun, EFG an arc of the orbit of jupiter, ABC an arc of the ecliptic, ſuppoſe jupiter to continue at F while the earth goes round in her orbit according to the order of the letters *abcd*; I ſay while the earth is in the ſemicircle moſt diſtant from jupiter, going from *a* to *b*, from *b* to *c*, his motion in the heaven would appear direct; from A to B from B to C: but while the earth is in her neareſt ſemicircle *cda*, the motion of jupiter would appear retrograde, from C to B from B to A: for *a*, *b*, *c*, *d* may be conſidered as ſo many ſeveral ſtations from whence an inhabitant of the earth would view jupiter, at different times of the year; and a ſtrait line drawn from each of theſe ſtations through F the place of jupiter, and continued to the ecliptic, would ſhew his apparent places there to be ſucceſſively at A, B, C, B, A. While the earth is near the points of contact *a* and *c*, jupiter would appear ſtationary, becauſe the viſual ray drawn from the earth through jupiter does not ſenſibly differ from the tangent F*a* or F*c*. When the earth is at *b*, a line drawn from *b* through S and F to the ecliptic ſhews jupiter to be in conjunction with the ſun at B: when the earth is at *d*, a line drawn from *d* through S continued to the ecliptic would terminate in a point oppoſite to B; which ſhews jupiter to be then in oppoſition to the ſun: thus it appears that jupiter's motion is direct when he is in conjunction; retrograde when in oppoſition.

694 The direct motion of a ſuperior planet is ſwifter the nearer it is to
39 conjunction, ſlower the nearer to quadrature with the ſun: thus, fig. 39, let ☉ be the ſun, the little circle round it the orbit of the earth, whereof *abcdefg* is the moſt diſtant ſemicircle, OPQ an arc of the orbit of jupiter, ABCDEFG an arc of the ecliptic; if we ſuppoſe jupiter to ſtand ſtill at P, by the earth's motion from *a* to *g*, jupiter would appear to go direct from A to G, deſcribing the unequal arcs AB, BC, CD, DE, EF, FG, in equal times: when the earth is at *d* jupiter is in conjunction with the ſun at D, and there his direct motion is ſwifteſt; when the earth is in the point of contact of a line drawn from jupiter tangent to her orbit, as in the points *a* or *g*, jupiter is nearly in quadrature with the ſun, and the nearer the earth is to either of thoſe points the ſlower is the geocentric motion of jupiter: for the arcs CD and DE are greater than BC or EF, the arcs BC and EF are greater than AB or FG.

695 The retrograde motion of a ſuperior planet is ſwifter the nearer it is to oppoſition, ſlower the nearer it is to quadrature with the ſun: thus, fig.
40 40, let ☉ be the ſun, the little circle round it the orbit of the earth, whereof *ghiklmn* is the neareſt ſemicircle, OPQ an arc of the orbit of jupiter, NKG an

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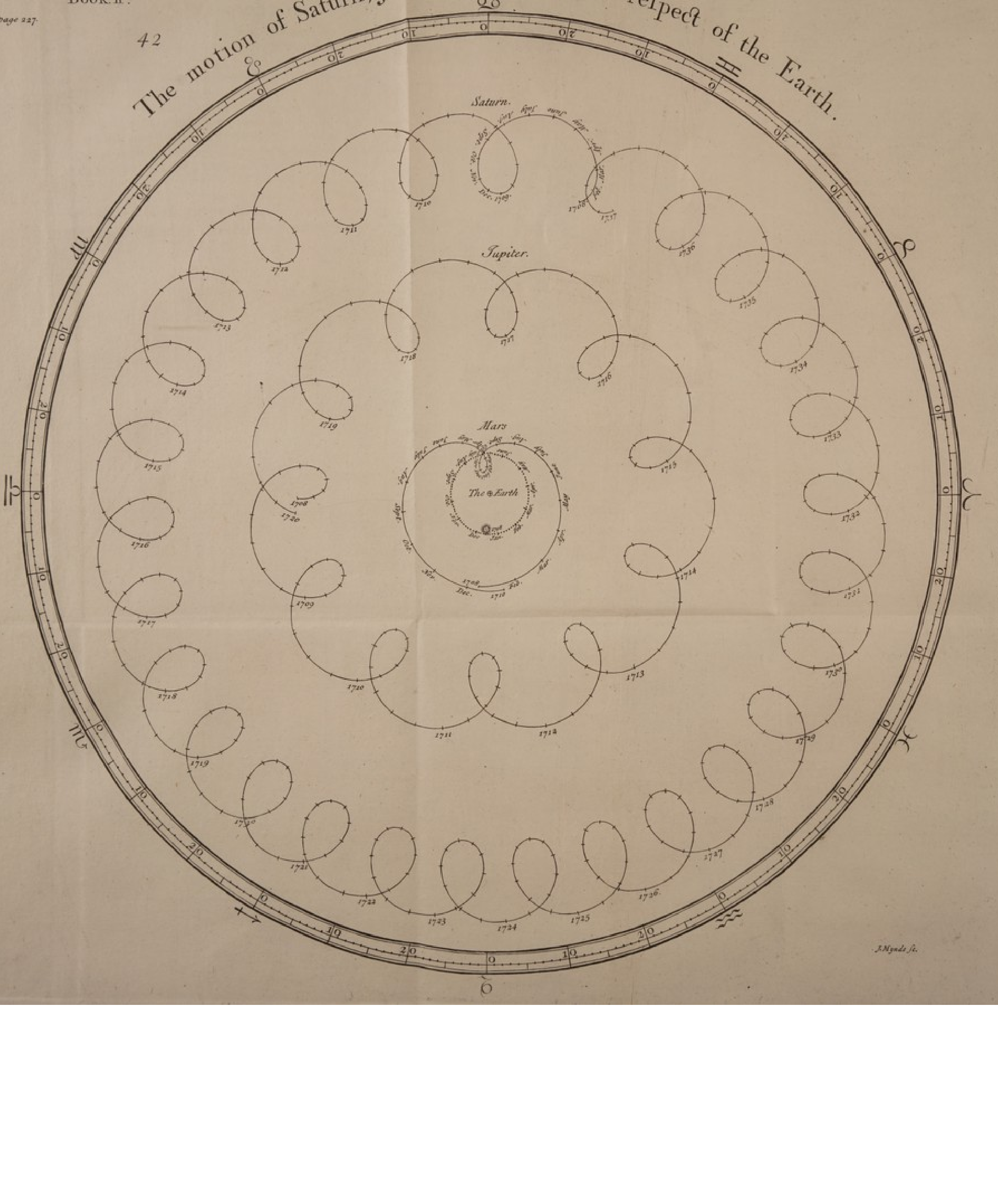
The motion of Saturn, Jupiter and Mars in respect of the Earth.



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an arc of the ecliptic: if we ſuppoſe jupiter to ſtand ſtill at P, by the earth's FIG.
motion from *g* to *n*, jupiter would appear to go retrograde from G to N, de- 40
ſcribing the unequal arcs GH, HI, IK, KL, LM, MN in equal times: when
the earth is at *k* jupiter appears at K, in oppoſition to the ſun, and there his
retrograde motion is ſwifteſt; when the earth is at either *g* or *n*, the points
of contact of the tangents P*g* and P*n*, jupiter is nearly in quadrature with the
ſun; and the nearer he is to either of thoſe points the ſlower is his retrogra-
dation: for the arcs IK and KL are greater than HI or LM, and the arcs
HI and LM are greater than GH or MN. Since the direct motion is ſwifteſt
when the earth is at *d*, and continues diminiſhing till it changes to retro- 39
grade; near the time of change it muſt be inſenſible: in like manner, the
retrograde motion, being ſwifteſt when the earth is at *k*, and diminiſhing 40
gradually till it changes to direct, muſt alſo at the time of that change be
inſenſible: for any motion gradually decreaſing till it changes into a contra-
ry motion gradually increaſing muſt at the time of the change be inſenſible.

696 All theſe changes in jupiter's apparent motion, cauſed by the earth's
going round in her orbit, will happen in the ſame manner if we now ſup-
poſe jupiter to go on ſlowly in his orbit; only they will every year fall out
when the earth is in different parts of her orbit, and conſequently at different
times of the year: thus, fig. 38, ſuppoſe while the earth goes round her 38
orbit jupiter goes from F to G, the points of the earth's orbit from whence
jupiter muſt be viewed to appear ſtationary will now be *x* and *y*; and conſe-
quently his ſtations muſt be at a time of the year different from the former:
moreover, the conjunction of jupiter with the ſun will now be when the
earth is at *f*; and his oppoſition when ſhe is at *e*: and therefore theſe alſo will
fall out at different times of the year from thoſe of the conjunction and oppo-
ſition immediately preceding. As to the other two ſuperior planets, ſaturn's
motion is ſo very ſlow, that it alters but little the times when, and conſe-
quently the places where he is in conjunction, in oppoſition, or ſtationary:
the motion of mars is ſo much ſwifter than that of jupiter, that the times
when, and places where he is in conjunction, in oppoſition, or ſtationary,
are much more changed thereby than the times and places of the ſame ap-
pearances are in jupiter.

697 But the geocentric motion of jupiter, ariſing from the combination
of his motion in his orbit with the motion of the earth in hers, is beſt exem-
plified by the 41ſt figure; where ☉ is the ſun, the circle 1 2 3 4 &c. is the 41
orbit of the earth, divided into twelve equal arcs for the twelve months of
the year, PQ an arc of the orbit of jupiter, containing ſo much as he goes

through

FIG. through in a year, divided into 12 equal arcs, each of them ſo much as ju-
41 piter goes through in a month's time: now ſuppoſe the earth to be at the numeral figure 1 when jupiter is at *a*, a line drawn from 1 through *a* ſhews jupiter's place in the ecliptic to be at A: in a month's time the earth will be got from 1 to 2, jupiter from *a* to *b*, a line drawn from 2 through *b* to the ecliptic ſhews his geocentric place to be at B: in another month the earth will be at 3, jupiter at *c*, a line drawn from 3 through *c* points out his geocentric place at C: it is eaſy to go through the figure in the ſame manner, and find jupiter's geocentric places, for the reſt of the months, at D, E, F, &c: it is eaſy alſo to obſerve jupiter's geocentric motion to be direct in the arcs AB, BC, CD, DE; retrograde in the arcs EF, FG, GH, HI; direct again in IK, KL, LM, MN: the figure ſhews likewiſe the inequality of the arcs of the geocentric motion of jupiter.

698 A ſuperior planet in conjunction with the ſun is ſaid to be in *apogee*;
37 in oppoſition to the ſun it is ſaid to be in *perigee:* thus, fig. 37, if when the earth is at E mars be at C, he is in apogee; if when the earth is at E mars be at A, he is in perigee: the diſtance of each of the ſuperior planets from the earth in apogee is variable, as is alſo its perigee diſtance: the variation of theſe diſtances of the ſuperior planets is owing partly to the excentricities of their orbits, and of the orbit of the earth, and partly to the motions of thoſe planets and of the earth; by which it comes to paſs that they are in perigee or in apogee when they are in different parts of their orbits, as well as when the earth is in different parts of her orbit.

699 Since the excentricity of every one of the ſuperior planets is greater than the excentricity of the earth, § 669, every ſuperior planet will be at the leaſt poſſible diſtance from the earth when he is in perigee at the ſame time that he is in his perihelion; becauſe, the earth being between the ſun and a ſuperior planet in perigee, the planet coming then neareſt to the ſun
37 approaches the neareſt to the earth that ever he can be: thus, fig. 37, if when mars is at A in perihelion the earth be at E, mars is in the neareſt perigee that is poſſible: it is true, if when mars is at C the earth be at F, mars is in perigee; but the perigee diſtance CF exceeds the perigee diſtance AE ſo much as the difference between the perihelion and aphelion diſtances of mars from the ſun amounts to: which in the figure before us is the ſhort line *c*C. For the ſame reaſon, of their excentricities being greater than that of the earth, every ſuperior planet is at its greateſt diſtance from the earth when he is in apogee at the ſame time that he is in aphelion: becauſe, the ſun being between the earth and a ſuperior planet in apogee, the planet then running out to the greateſt diſtance from the ſun will be at the greateſt diſtance alſo from

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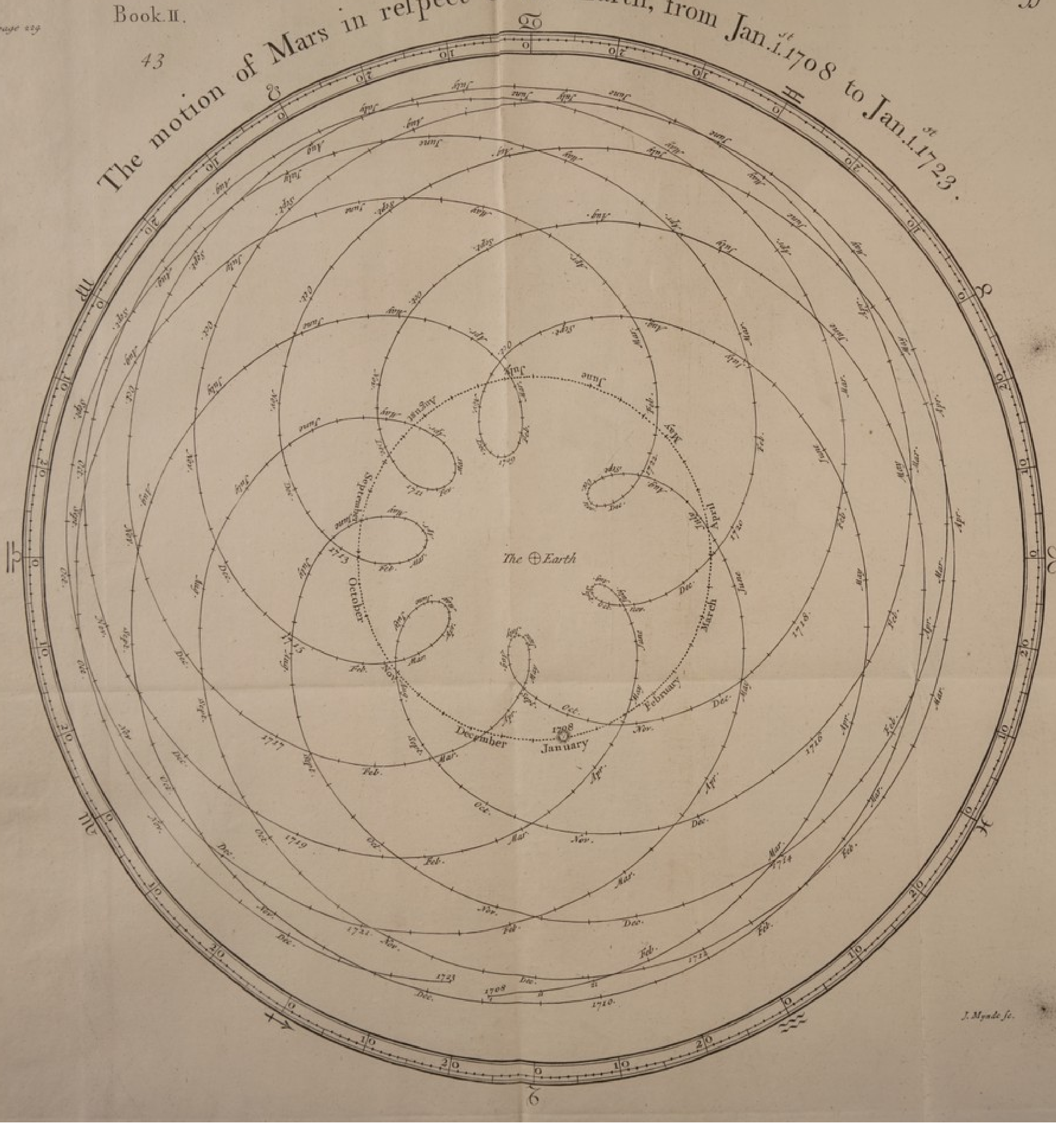
The motion of Mars in respect of the Earth, from Jan. 1st 1708 to Jan. 1st 1723.



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from the earth that ever he can be: thus, fig. 37, if when the earth is at E FIG.
mars be at C, he is in the moſt diſtant apogee that is poſſible: indeed if when 37
the earth is at F mars be at A, he is then alſo in apogee, but the apogee diſtance F A is leſs than the apogee diſtance E C by ſo much as the length of the line c C amounts to.

700 The ſuperior planets, going round the ſun in larger orbits than our earth does, are ſometimes nearer us than at other times, as was ſhewn § 698; and conſequently their apparent diameters are variable: thus, fig. 37, ſuppoſe 37
the earth to be at E, if mars be at A, he is the whole diameter of the earth's orbit E F nearer to us than if he were at C; and conſequently his diſk muſt appear much larger at A than it would if he were at C: in other places, as at q, B, P, Q, the diſtances of mars from the earth at E are intermediate; and conſequently his apparent diameters are between the greateſt and the leaſt. The diameter of the earth's orbit bears a greater ratio to the diameter of the orbit of mars than it does to the diameter of the orbit of jupiter; and a greater ratio to the diameter of the orbit of jupiter than it does to the diameter of the orbit of ſaturn, § 619: and conſequently the difference between the greateſt and leaſt apparent diameters is greater in mars than in jupiter, greater in jupiter than in ſaturn.

701 Since the apparent diameters of an object at different diſtances are reciprocally as the diſtances, the apparent diameter of mars in perigee is to his apparent diameter in apogee as 25 to 5: the apparent diameter of jupiter in perigee to his apparent diameter in apogee as 62 to 42: of ſaturn as 105 to 85. See § 619.

702 Since the areas of circles are as the ſquares of their diameters, the apparent magnitude of the diſks of the planets in perigee to their apparent magnitudes in apogee are as followeth,

of	Mercury	as	196	to	36	or as	$5\frac{1}{2}$	to 1 nearly.
	Venus		289		9		32	
	Mars		625		25		25	
	Jupiter		3844		1764		$2\frac{1}{4}$	
	Saturn		11025		7225		$1\frac{1}{2}$	

703 What was ſaid of the inferior planets, § 690, is applicable alſo to the ſuperior; if we obſerve the changes of their apparent places in the ſphere of the heaven, their direct motions, ſtations, and retrogradations, and meaſure their diſks with the micrometer, we ſhall find, by the difference of their apparent diameters at different times, that, taking the whole of their appa-

rent

FIG. rent motion into the account, their courſes round the earth appear to be in complicated curves, which for their reſemblance thereto may be called *ſpirals:* and in ſuch curves muſt the real motions of the ſuperior planets be, to account for all their appearances, if the earth remained perpetually fixed
42 in the ſame place: the 42d and 43d figures ſhew in what kind of ſpirals
43 the motion of the ſuperior planets muſt be, upon this ſuppoſition that the earth does not change her place: they want no explanation, if what was ſaid § 691 be attended to.

CHAP. 10. THE GEOCENTRIC MOTIONS OF THE INFERIOR AND SUPERIOR PLANETS FARTHER EXPLAINED.

704 The geocentric motions of the planets, both inferior and ſuperior, being ſome of the moſt difficult appearances in aſtronomy to repreſent to the imagination, I ſhall endeavour to illuſtrate them farther, by the following familiar examples, of ſhips in motion upon the ſea; premiſing to each inſtance a proper *lemma*, or general poſition taken from optics; lemma 1, A body moving along the ſame way with the eye, with a velocity equal to the velocity of the eye, will appear to be at reſt: thus, if two ſhips are ſailing eaſtward in parallel lines, at the ſame rate, to a ſpectator in one of the ſhips the other ſhip will continually appear in the ſame ſituation, and he will all along have the ſame view of it, as if both the ſhips ſtood ſtill. 2 A body moving the ſame way with the eye, with a greater velocity than that of the eye, will appear to go forward the way that it is really carried, but with a leſs velocity than if the eye were at reſt: thus, if two ſhips ſail in parallel lines, eaſtward, with unequal velocities, the ſwifter ſhip will to a ſpectator in the ſlower ſhip appear to go eaſtward, but with a ſlower motion than if he ſtood upon land. 3 A body moving along the ſame way with the eye, with a leſs velocity than that of the eye, will appear to go the contrary way to what its real motion is: thus, if two ſhips ſail with unequal velocities, eaſtward, to a ſpectator in the ſwifter ſhip the ſlower ſhip will appear to go weſtward. 4 If a moving body be carried one way and the eye the contrary way, that body will appear to go the ſame way that its real motion is, with a greater velocity than if the eye were at reſt: thus, if two ſhips ſail in parallel lines, one eaſtward, the other weſtward, to a ſpectator in the ſhip ſailing eaſtward the other ſhip will appear to go weſtward, with a greater velocity than it would do if he ſtood upon land. 5 If a body at reſt be viewed by the eye carried along, the body will appear to move with a velocity equal

to

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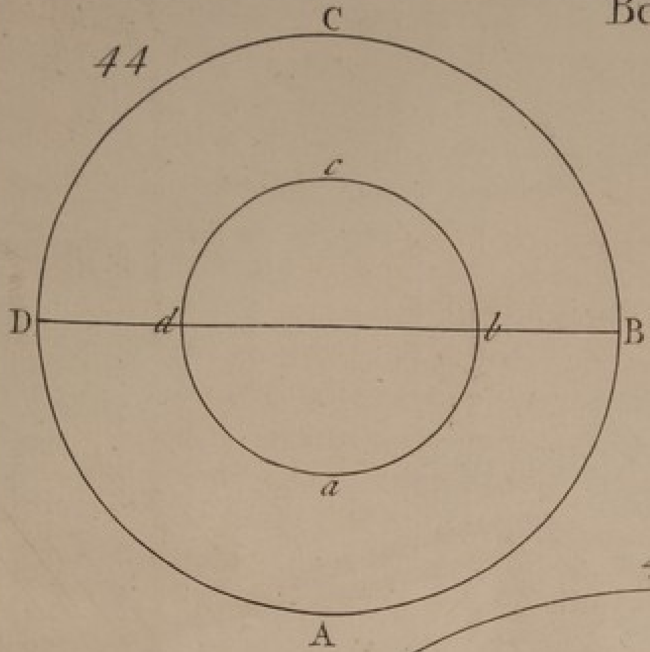

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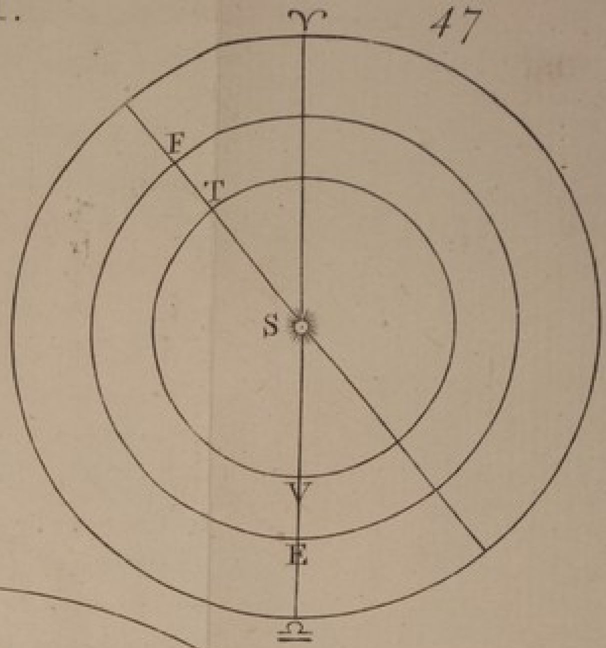

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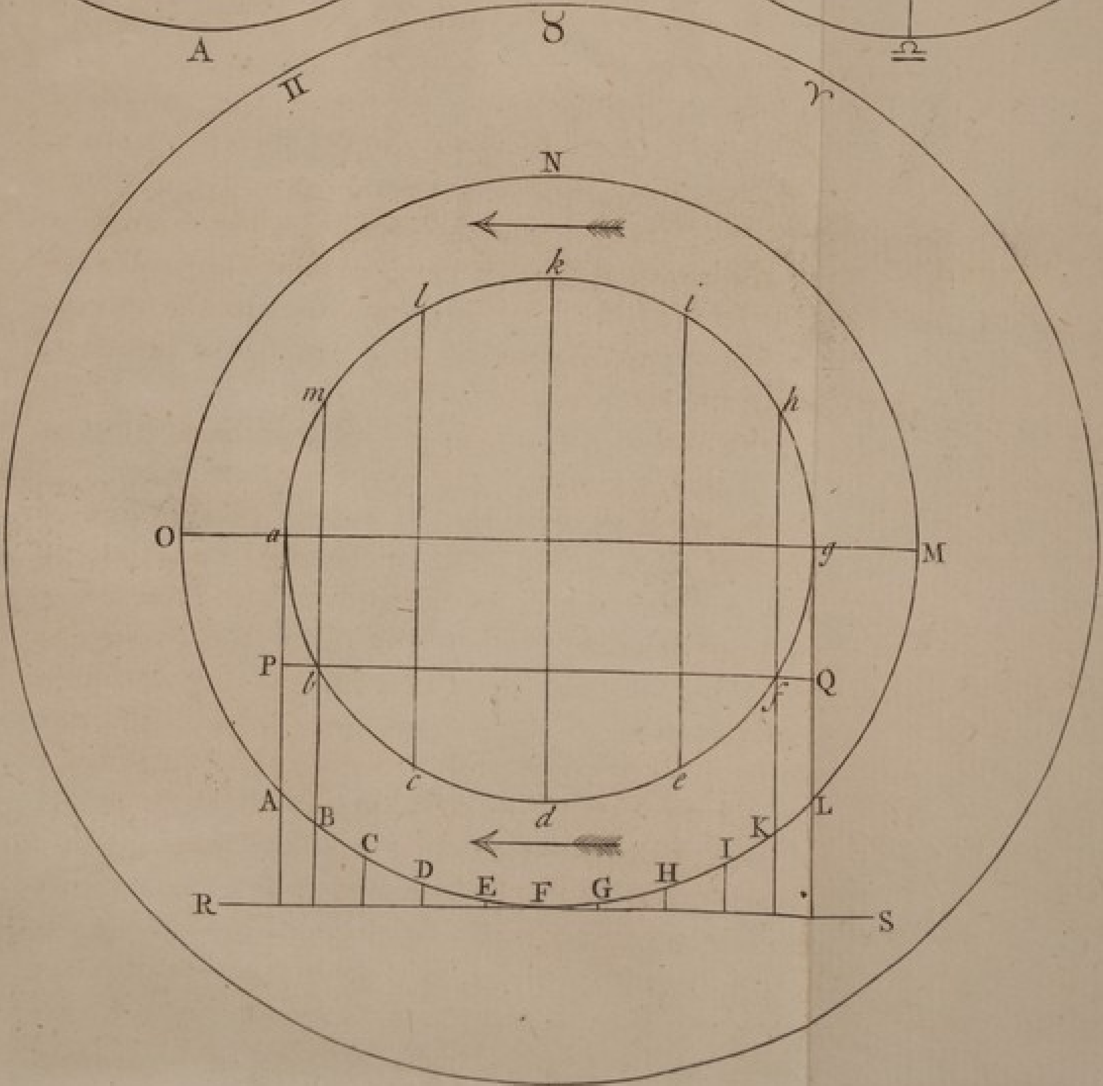

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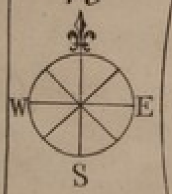

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to that of the eye, but in a contrary direction: thus, to a spectator in a ship which sails eastward the shore seems to go westward, with a velocity equal to that of the ship. FIG.

705 Let there be two concentric circles *abcd* and ABCD, fig. 44, if there be drawn any where through the biggest circle a diameter as BD, the semicircles *bcd* and BCD considered together may be called semicircles on the same side; as may also the semicircles *dab* and DAB. The semicircles *dab* and BCD may be called opposite; as may also the semicircles *dcb* and DAB. 44

706 If a body be moved round in one circle and the eye be carried round the same way in another concentric circle, when the eye and the moving body are in the semicircles on the same side, they may be considered as both going in parallel lines, in the same direction; but when the eye and the moving body are in opposite semicircles, they may be considered as going in parallel lines, in contrary directions: thus, suppose fig. 45 to shew the points 45
of the compass, the flower de luce being the north point, if two ships sail round in the concentric circles *abcd* &c. and ABCD &c, fig. 46, according 46
to the order of the letters, while the ships are in the semicircles, *abcdefg* and OFM, they may be considered as both going in parallel lines PQ and RS, eastward; while they are in the semicircles *ghiklmn* and MNO, as going both in parallel lines QP and SR, westward: when the two ships are in opposite semicircles, they may be considered as going in parallel lines, one eastward the other westward: it must be here observed, that equable circular motion thus reduced to rectilinear will appear unequable, as in the figure before us, by § 262. See fig. 148 of the introduction.

707 If we suppose the velocities of the two ships sailing in these concentric circles to be unequal, and the ship which sails in the least circle *abc* &c. 46
to be the swifter of the two, we shall have all the variety of appearances which are mentioned § 704, of ships sailing in parallel lines: thus, suppose one ship at *a* the other at A, and that whilst one goes from *a* to *b* the other goes from A to B, to a spectator in either of them the other ship would appear to stand still, by lemma 1; because, as to appearance, they are both carried eastward with equal velocities, in the parallel lines PQ and RS: the like appearance will again happen, when one ship goes from *f* to *g* in the same time that the other goes from K to L; because there also they appear to advance with equal velocities eastward, in the lines PQ and RS.

708 The same suppositions of the motions of the ships being made, since whilst the ship in the less circle goes from *b* to *c* from *c* to *d* the ship in the 46
greater circle goes from B to C from C to D, &c, it is plain the two ships are both carried eastward with unequal velocities; and therefore to a spectator carried

FIG. carried in the ſlower ſhip from B to C from C to D the other ſhip will ap-
46 pear to be carried eaſtward, but more ſlowly than if he ſtood upon land, by lemma 2: to a ſpectator in the ſwifter ſhip who is carried from *b* to *c* from *c* to *d* the other ſhip being carried really eaſtward from C to D from D to E will appear to go weſtward, by lemma 3: if the ſhips are in oppoſite ſemicircles, as if whilſt one is going from B to C, from C to D, the other is going from *b* to *i*, from *i* to *k*, to a ſpectator in the ſhip going eaſtward the other ſhip will appear to go weſtward, with greater velocity than if he ſtood upon land, by lemma 4.

709 What has been ſaid of two ſhips ſailing in concentric circles will help the imagination, in conceiving the geocentric motion of the planets; to in-
46 ſtance firſt in one of the inferior planets, let fig. 46 repreſent the orbits of the earth and of venus, wherein they are carried perpetually round, according to the order of the letters, with different velocities, venus going round the circle *abcd* &c. in much leſs time than the earth does in the circle ABCD &c, § 670: whilſt the earth is in any part of the ſemicircle OFM we may conſider her motion as in the line RS, in the direction from R to S; if venus be then any where in her inferior ſemicircle, or that on the ſame ſide *abcdefg*, her motion may be conſidered as in the line PQ, in the direction from P to Q: here, ſince the circular motions of venus and the earth reduced to rectilinear are in the ſame directions, contrary to the way that the arrows in the figure point, which direction referred to the ecliptic and viewed from the earth ſituated in or near F is from ♉ towards ♈, contrary to the order of the ſigns, venus will appear retrograde, but with a ſlower motion than if the earth ſtood ſtill, by § 704, lemma 2.

46 710 If while the earth is going along any of the arcs AB, BC, CD, DE, EF, &c, venus be in her ſuperior or oppoſite ſemicircle *ghiklma*, her motion reduced to rectilinear is now from Q to P, contrary to the direction of the earth's motion, and therefore, by lemma 3, venus will appear to go in the direction QP, according to the pointing of the arrows, and ſwifter than if the earth from whence ſhe is viewed were at reſt: the apparent motion of venus in this caſe referred to the ecliptic is from ♈ towards ♉, according to the order of the ſigns.

711 If venus be near the point of contact of a tangent to her orbit drawn from the earth, her motion does not carry her forward in the ſame direction with the earth nor in a contrary direction; but only brings her nearer to, or carries her farther from the earth: venus may at thoſe times be conſidered as at reſt, and therefore if ſhe be then viewed from the earth ſhe will appear to go in a direction contrary to that of the earth, by lemma 5: thus, if

if while venus is near the point *a* the earth be at A, the motion of the earth FIG.
from A to B will make venus appear to go in a contrary direction, which in 46
the ecliptic will be from ♉ towards ♊ ; the like appearance of venus will
happen, if when venus is at *g* the earth be at L.

712 If when venus is at *a* the earth be at A, and venus goes from *a* to *b* 46
in the ſame time the earth goes from A to B, venus and the earth appear to
be carried in the ſame direction, with equal velocities; *venus* will therefore
appear *ſtationary*, by lemma 1: by the ſame lemma, venus will have the
like appearance, if while ſhe is going from *f* to *g* the earth be going from
K to L.

713 Since when venus is at her utmoſt eaſtern elongation going into her
inferior ſemicircle her apparent motion in the ſame direction as the earth's
is as nothing, § 706, and from thence increaſes till ſhe comes into conjun-
ction with the ſun, where ſhe is carried with her greateſt velocity in the ſame
direction as the earth is; there muſt be an intermediate place wherein the
motion of *venus* thus increaſing comes to equal the motion of the earth, and
conſequently where ſhe appears *ſtationary*; as when venus goes from *a* to *b* 46
while the earth goes from A to B: again, ſince the motion of venus is ſwift-
eſt at her inferior conjunction, in the ſame direction with the earth's motion,
and from thence decreaſes till venus is at her utmoſt weſtern elongation,
where it is again as nothing; there muſt be ſome intermediate place as *f*,
where the motion of venus thus decreaſing comes to be equal to the earth's
motion: as when venus is at *f* the earth at K, and venus goes through the
arc *fg* whilſt the earth goes through the arc KL. Thus we ſee one ſtation of
venus is a little after her utmoſt eaſtern elongation, when ſhe begins to be
retrograde; the other a little before her utmoſt weſtern elongation, when ſhe
begins to be direct: as was ſaid § 687.

714 Since *the times of the conjunctions, utmoſt elongations, direct or retro-
grade motions* as alſo of the *ſtations of the inferior planets* depend upon the
combinations of their motions in their orbits with the motion of the earth
in her orbit; any of theſe appearances will be more frequent in mercury than
in venus: becauſe mercury, going with a ſwifter motion through his orbit
than venus, will in any given time paſs more frequently than venus through
the places where he is in conjunction, utmoſt elongation, direct, retrograde,
ſtationary. How to find the time when an inferior planet will come again
into a given ſituation with reſpect to the ſun and the earth, may be ſeen by
the following examples; let fig. 47 repreſent the orbits of venus and the earth, 47
let the earth be at E venus at V, venus is then in her inferior conjunction
with the ſun in ♈ : from the ſun S venus and the earth would appear in con-

FIG. junction in ♎: let venus go round her orbit and return to V, the earth, ta-
47 king longer time to go round the ſun than venus, will in the mean time go from E through only a part of her orbit, and venus muſt overtake the earth before ſhe can have another inferior conjunction, that is ſhe muſt, beſides an entire revolution in her orbit, which is equal to four right angles, § 42, go through as much more angular motion round the ſun as the earth has done in the mean time, ſo as to be in a right line drawn between the ſun and the earth; ſuppoſe this to happen when the earth is got to F and venus to T: the angular motions of the earth and venus performed in the ſame time are reciprocally as their periodical times: and therefore as the periodical time of the earth is to the periodical time of venus, ſo is the angular motion of venus, which is equal to four right angles added to the angular motion of the earth in the time between two like conjunctions of venus, to the angular motion of the earth in the ſame time; and therefore, by diviſion of proportion[a], as the difference between the periodical times of venus and the earth is to the periodical time of venus, ſo are four right angles or 360 degrees to a fourth quantity, namely to the angular motion or number of degrees which the earth goes in her orbit from the time of one conjunction of venus to the next conjunction of the ſame kind: now the periodical time of the earth is 365 days 6 hours, or 8766 hours: the period of venus 224 days 16 hours, or 5392 hours: the difference is 3374 hours: ſay then, as 3374 is to 5392, ſo are four right angles or 360 degrees to a fourth number, which will come out 575°: this number of degrees the earth goes through in a year and 218 days: if therefore venus were this day in an inferior conjunction, it would be a year and 218 days before ſhe came again into another inferior conjunction: and this alteration of the time occaſions a proportionable change in the place, ſo that if one conjunction be in ♈ the next like conjunction will be in ♏.—The time between any ſituation of mercury with reſpect to the ſun and the earth and another like ſituation may be found by the ſame method: the periodical time of the earth is 8766 hours: the period of mercury 87 days 23 hours, or 2111 hours: the difference 6655 hours: ſay then, as 6655 hours is to 2111, ſo are four right angles or 360° to a fourth number, which comes out 114°: this number of degrees the earth goes through in 116 days: if therefore mercury were to be this day in his inferior conjunction, it would be 116 days before he would be again in a like conjunction[b].

715 This problem is commonly reſolved by aſtronomers in another manner; for they compute the diurnal heliocentric motions of venus and of the

a Euclid. *elem. l.* 5 *prop.* 17. b *See* Keil's *aſtronomy, lecture* 15.

earth;

earth; the difference of theſe motions is the diurnal motion of venus from the earth, or the quantity by which venus would be ſeen to recede from the earth every day by a ſpectator placed in the ſun: thus the middle motion of the earth is every day about 59 minutes and 8 ſeconds; the middle motion of venus in a day is 1 degree 36 minutes and 8 ſeconds, the difference is 37 minutes: ſay therefore as 37 minutes is to 360 degrees, or to 21600 minutes, ſo is one day to the ſpace of time wherein venus having left the earth recedes from her 360 degrees; that is, to the time in which ſhe returns to the earth again, or the time between two conjunctions of the ſame kind: this will be found to be about 583 days, as before § 714 [a]. FIG.

716 Theſe times are here computed according to the middle motions of the planets, ſuppoſing them to move always equably, this is therefore called *a mean conjunction:* but becauſe venus and the earth are really carried in elliptic orbits, in which their motions are conſtantly variable, ſometimes faſter, and ſometimes ſlower; it may be, that the true conjunction ſhall happen ſome few days ſooner or later than by this computation. *The time of the true conjunction* is to be computed from the time of the mean conjunction in this manner: find by aſtronomical tables the true places of the earth and venus in the ecliptic; from whence we ſhall have the diſtance of the earth and venus ſeen from the ſun: compute alſo for the ſame time the angular motions of theſe two planets for any given time; ſuppoſe 6 hours; the difference of theſe two motions will give the acceſs of venus to the earth, or her receſs from it in 6 hours: then ſay, as this difference is to the arc between the places of venus and the earth at the time of the mean conjunction, ſo is 6 hours to the time between the mean conjunction and the true; this time added to, or ſubtracted from the time of the mean conjunction, according as venus is in antecedence or conſequence from the earth, ſhews the time of their true conjunction [b].

717 If we would apply what was ſaid in the beginning of this chapter to *the geocentric motions of the ſuperior planets*, we may make uſe of the 46th figure in the following manner: ſuppoſe *abcde* &c. to be the orbit of the earth and ABCDE &c. to be the orbit of mars; when the earth and mars are in ſemicircles on the ſame ſide, as when the earth is going in the ſemicircle *abcde* while mars is going in the ſemicircle OFM, the earth and mars may be conſidered as going in the ſame direction, the earth in the direction PQ, mars in the direction RS; but the earth being carried with greater velocity than mars, to a ſpectator upon the earth mars will, by lemma 2, appear to go in the direction SR, contrary to his true direction, which refer- 46.

a Keil's *aſtronomy, lecture* 15. b Keil. *ibid.*

FIG. red to the ecliptic is retrograde: when the earth and mars are in oppofite femicircles, as when the earth is in the femicircle *ghiklma* while mars is in the femicircle OFM, the earth and mars are carried in contrary directions; mars will therefore, by lemma 3, appear then to be carried the way he really goes, which referred to the ecliptic is direct: and he will appear to go fafter than if the earth were at reft.

718 *The ftations of the fuperior planets* may alfo be *explained* by the 34th
34 figure, which was made ufe of, § 687, for the inferior planets, premifing as was there done, that parallel lines which are not at a greater diftance from one another than the diameter of the earth's orbit terminate, as to appearance, in the fame point of the fphere of the heaven: let the two circles fig. 34, now reprefent the orbits of mars and of the earth, let the lines AE, BF, CG, DH, be parallel to SP; I fay, they will all, if continued, terminate in the fame point of the heaven, as to fenfe, as the line SP would do: now fuppofe mars at A when the earth is at E, the vifual ray by which mars is feen is EA; fuppofe while mars goes from A to B the earth goes from E to F, the vifual ray in which mars is now feen is FB; parallel to EA; and therefore mars will be all that time ftationary, appearing in that point of the heaven where SP extended would terminate: this ftation of mars is at his changing from retrograde to direct: again, fuppofe when mars is at C the earth is at G, the vifual line is GC; if while the earth goes from G to H, mars goes from C to D, he will be ftationary, appearing in that point where a line drawn from P through S extended to the heaven would terminate: this ftation of mars is at his changing from direct to retrograde.

719 Since *the times of the conjunctions, oppofitions, direct and retrograde motions*, as alfo of the *ftations of the fuperior planets* depend upon the combinations of their motions in their orbits with the motion of the earth in her orbit; any of thefe appearances will be more frequent in faturn than in jupiter, in jupiter than in mars: becaufe, the flower the motion of the planet is, the fooner will the earth overtake it, fo as to have it again in any given fituation: thus, fuppofe faturn to be in conjunction with the fun in ♈, if faturn were to ftand ftill, in one revolution of the earth, that is in one year, faturn would be again in conjunction in ♈; but as faturn goes on flowly according to the order of the figns, at the rate of about twelve degrees in a year, § 620, the earth muft go through almoft thirteen degrees more than an entire revolution, fo that there will be a year and about thirteen days, between any conjunction of faturn with the fun and the conjunction immediately following: as jupiter goes fafter in his orbit than faturn, the earth in going from one conjunction of jupiter to another muft have a proportionably

nably longer time added to the year: the motion of mars being ſtill ſwifter than that of jupiter, the time muſt be ſtill longer between any two conjunctions immediately following one another.

720 The time when a ſuperior planet will come again into a given ſituation with reſpect to the ſun and the earth, may be found by the methods before uſed for the inferior planets, § 715: thus, the mean diurnal motion of the earth is about 59 minutes and 8 ſeconds; the mean motion of *ſaturn* in a day is 2 minutes, the difference is 57 minutes 8 ſeconds: ſay therefore as 57 minutes 8 ſeconds is to 360 degrees, or to 21600 minutes, ſo is one day to the ſpace of time wherein the earth having left ſaturn recedes from him 360 degrees, that is, to the time wherein ſhe returns to ſaturn again, or the time between two conjunctions, oppoſitions, or other like aſpects &c: this time will be found to be 378 days, or 1 year and 13 days; ſo that if ſaturn were to be in oppoſition to the ſun this day, it would be a year and 13 days before he would be again in oppoſition.—The middle motion of *jupiter* in a day is 4 minutes 59 ſeconds; the difference between this and the earth's diurnal motion is 54 minutes and 9 ſeconds: ſay then as 54 minutes 9 ſeconds is to 360 degrees, or to 21600 minutes, ſo is one day to the ſpace of time wherein the earth having left jupiter recedes from him 360 degrees, that is, to the time wherein ſhe returns to jupiter again, this time will be found to be 398 days, or 1 year and 33 days; ſo that if jupiter were to be in oppoſition to the ſun this day, it would be a year and 33 days before he would be again in oppoſition.—The middle motion of *mars* in a day is 31 minutes 27 ſeconds; the difference between this and the earth's diurnal motion is 27 minutes 41 ſeconds: ſay then as 27 minutes 41 ſeconds is to 360 degrees or to 21600 minutes, ſo is one day to the ſpace of time wherein the earth having left mars recedes from him 360 degrees, that is to the time wherein ſhe returns to him again, this time will be found 780 days, or 2 years and 50 days; ſo that if mars were to be in oppoſition to the ſun this day, it would be 2 years and 50 days before he would be again in oppoſition to him. The true conjunctions &c. may be found from the mean, as § 716.

721 Since the planets are all nearer to us than the fixt ſtars, they may ſometimes come between us and ſome of thoſe ſtars which lie near their heliocentric orbits: ſeveral ſuch *occultations of fixt ſtars by the planets* are recorded by aſtronomers both ancient and modern: an inferior planet may alſo ſometimes paſs between us and a ſuperior planet, and cover it for a little while: but theſe appearances are very rare. *Ariſtot. meteor. l.* 1. *c.* 16. *Ptolem. almageſt. l.* 10. *c.* 4 & 9. *l.* 11. *c.* 3. *Kepler. aſtron. part. optic. p.* 304. *Streete aſtronomia Carolina p.* 107. *Ricciol. l.* 7. *c.* 10.

CHAP.

CHAP. II. THAT THE PLANETS ARE OPAKE BODIES AND BORROW ALL THEIR LIGHT FROM THE SUN.

722 The planets are globular opake rough bodies which receive all their light from the ſun: it is owing to the roughneſs of the ſurfaces of the planets that they reflect light to us from every part in the manner they do; optical writers ſhew that the image of any object reflected from a globular *ſpeculum* or looking-glaſs is diminiſhed more and more, the greater the diſtance of the eye is from the ſpeculum: if therefore the ſurfaces of the planets were ſmooth and poliſhed they would be inviſible to us, the image of the ſun reflected by any of them would be too ſmall to ſtrike our eye ſenſibly, or if it did it would appear only a lucid point: whereas now their diameters are of a ſenſible magnitude, becauſe, their ſurfaces being rough, every point of that hemiſphere which is enlightened by the ſun reflects light every way, § 223; and conſequently makes the body of the planet viſible in its proper dimenſions. What I have now ſaid may be illuſtrated by the following experiment, place a ſilver globe perfectly poliſhed of about 2 inches diameter in the ſun, the rays which fall thereon being reflected variouſly according to their ſeveral incidences upon the convex ſurface, we ſhall have them come to our eye only from one point of the globe, which will therefore appear a ſmall bright ſpot, but the reſt of its ſurface will appear dark; let this globe be boyled in the liquor made uſe of to whiten ſilver, and placed in the ſun, and it will then appear of its full dimenſions all over white or luminous: for the effect of that liquor is to take off the ſmoothneſs of the poliſh, and make the ſurface rough, ſo that every point of it ſhall reflect the rays of light of every kind every way.

723 Every planet has one half of its ſurface illuminated; this illuminated hemiſphere is always that which is turned towards the ſun, the other hemiſphere of the planet is dark: if we would ſpeak accurately the ſun, being larger than any of the planets, illuminates a little more than half of every planet: thus, in fig. 136 of the introduction, let ABCD be the ſun, EFGI a planet, the illuminated part EIG will be a little bigger than EFG; but this difference between the enlightened and the obſcure part is inſenſible, becauſe the diſtance of the ſun from any of the planets is ſo great that his light may be conſidered as coming to them in lines phyſically parallel, having the ſame effects as if it came in lines exactly parallel.

724 *The inferior planets*, going round the ſun in leſs orbits than our earth does, will ſometimes have more ſometimes leſs of their illuminated hemi-

ſpheres

Book II.

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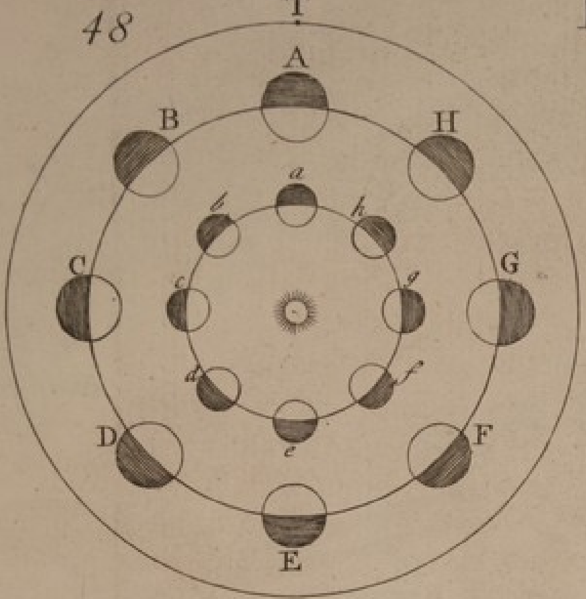

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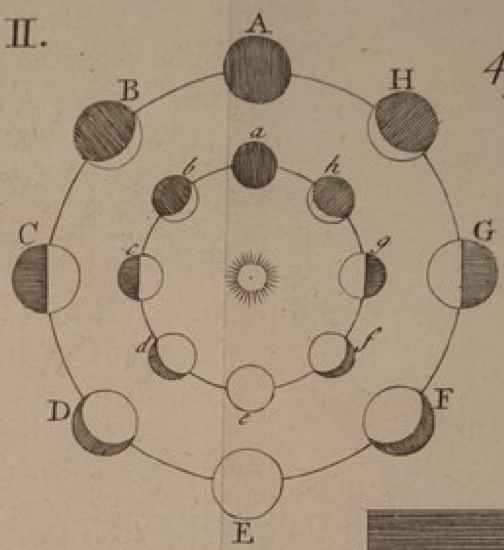

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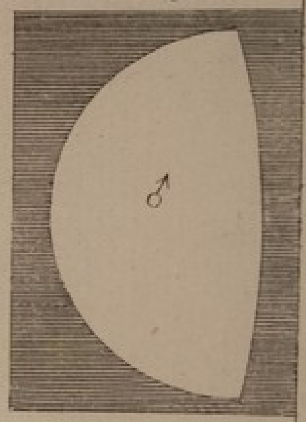

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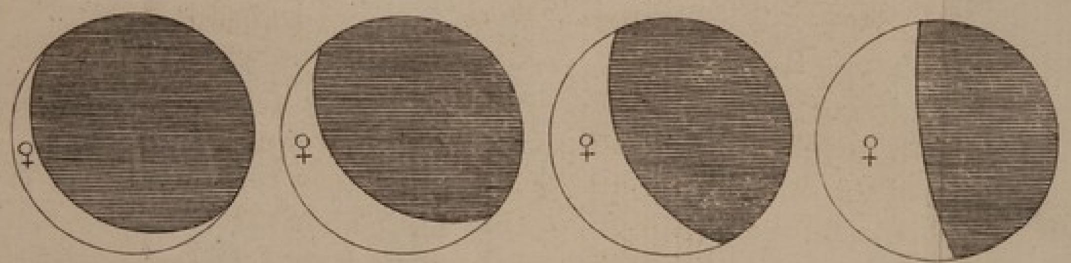

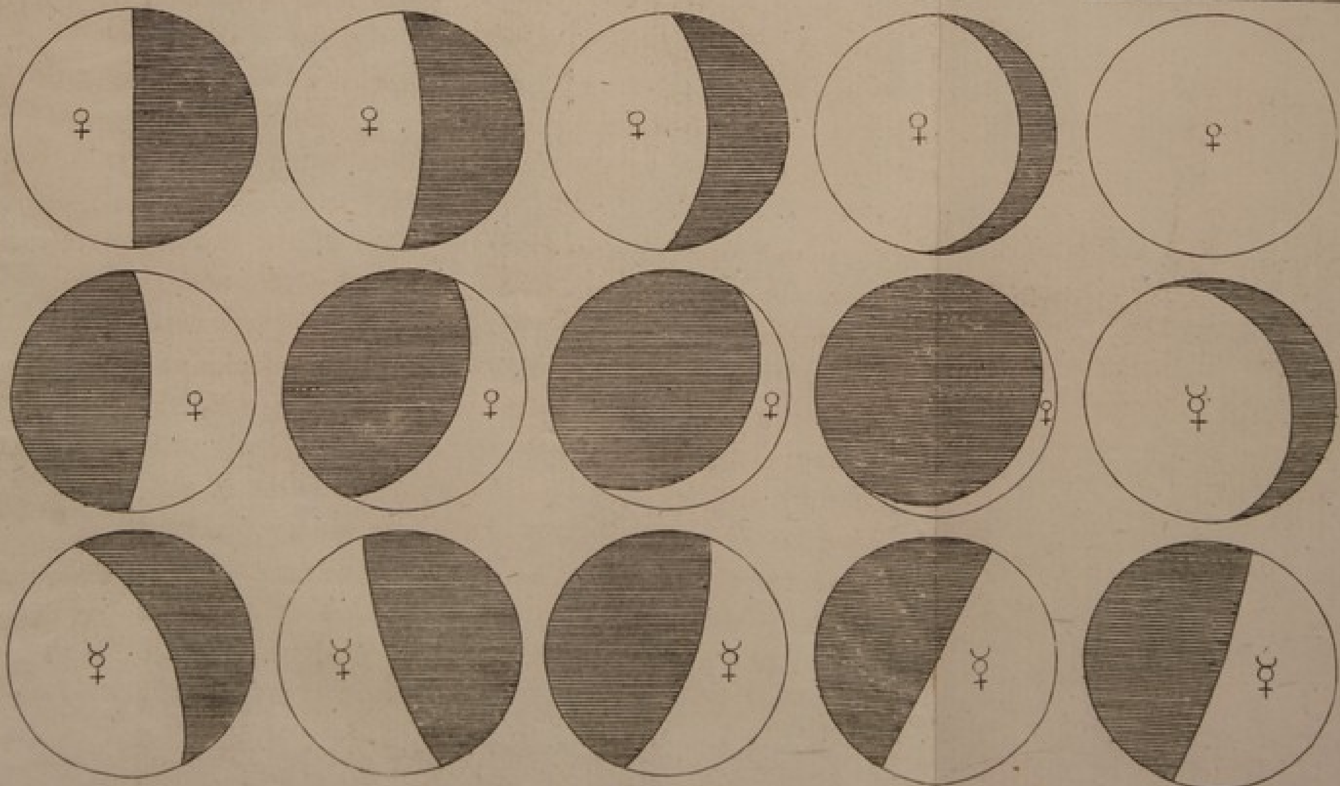

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ſpheres turned towards us, and conſequently, ſince the illuminated part only FIG.
is viſible to us, through a good teleſcope they will appear to *go through all the*
changes which we ſee in the moon, being ſometimes horned like the new
moon, like a half-moon, like the moon nearer the full &c: the 48th figure
repreſents the orbits of mercury, venus and the earth, with the ſun in the
the center of them; the planets mercury and venus are drawn in eight different
ſituations, with their illuminated hemiſpheres towards the ſun; if we ſup-
poſe the earth to be all the while at T, when venus is at A her dark hemi- 48
ſphere is towards the earth, and ſhe is therefore inviſible, except this con-
junction happens in her node, for then ſhe appears like a dark ſpot upon the
diſk of the ſun, as has been already ſaid § 681: when venus is at B a little
of her enlightened hemiſphere is turned towards the earth, and therefore ſhe
appears ſharp horned: when ſhe is at C about half her enlightened hemi-
ſphere is towards our earth, and ſhe appears like an half moon: at D more
than half her enlightened hemiſphere is towards the earth, and ſhe appears
like the moon about 3 days before ſhe is at the full: at E the whole enlighten-
ened hemiſphere is towards the earth, venus is then either behind the ſun
or ſo very near him that ſhe can hardly be ſeen, but if ſhe could ſhe would
appear round, like the full moon: at F venus will appear like the moon a-
bout 3 days after the full: at G like a half moon again: at H ſharp horn-
ed again, but the points of the horns are turned the contrary way to what
they were in B: all this is applicable to mercury. The 49th figure exhibits 49
the appearances of venus and mercury correſponding to their ſeveral ſitua-
tions in the 48th figure; thus when venus is at A in fig. 48th, ſhe is quite 48
dark, as at A in fig. 49: when ſhe is at B in fig. 48, ſhe appears as at B fig. 49
49, &c: ſo when mercury is at *a* fig. 48, he appears as at *a* fig. 49, &c: fig.
50 exhibits ſeveral views of mercury and venus actually taken with the te- 50
leſcope, and delineated by the accurate *Hevelius*: *ſelenograph. p.* 70.

725 The inferior planets appearing with the ſeveral phaſes of the moon is a proof of their going round the ſun in leſs orbits than our earth does: when *Copernicus* firſt publiſhed his account of the ſolar ſyſtem, it was objected to him that it could not be true, becauſe if it were the inferior planets muſt have different phaſes, according to their different ſituations with reſpect to the ſun and the earth; whereas they always appear round to us: the anſwer made by him was, that they appear round to the eye by reaſon of the great diſtance, but that, if we could have a nearer and more diſtinct view, we ſhould ſee in them the ſame variety of ſhapes as we do in the moon: the teleſcope invented ſince the death of *Copernicus* has verified this ſolution of the objection, to the ſatisfaction of every body. The diſtance of objects, e-

ſpecially

FIG. ſpecially ſuch as are luminous, hinders us from ſeeing their true ſhapes; the flame of a torch or a candle, though really of a conic figure, has at a diſtance the round appearance of a ſtar or planet.

726 *The ſuperior planets*, going round the ſun in larger orbits than our earth does, always turn much the greateſt part of their enlightened hemiſpheres towards the earth; and therefore *appear round like the full moon*, except *mars* who ſometimes appears like the moon at a little diſtance from the full, and in quadrature almoſt biſected; according to *Hevelius*[a], from
51 whom the picture of mars fig. 51 is taken. For when mars is in quadrature
37 as at *q* or Q, fig. 37, a good deal of his dark hemiſphere is towards the earth at E: when mars is in conjunction at C, or in oppoſition at A, his whole enlightened hemiſphere is towards the earth; and therefore he muſt in both thoſe caſes appear exactly round: in other ſituations, which are at any diſtance from being in quadrature, as at B and D, there is ſo little of the dark hemiſphere of mars towards the earth that he wants very little of appearing round. The orbit of the earth is ſo ſmall in compariſon of the orbits of jupiter and ſaturn, that they turn very nearly the ſame hemiſpheres towards us as they do towards the ſun; for which reaſon thoſe planets always appear round through the teleſcope.

727 The inferior planets do not ſhine brighteſt when they are full or round viewed through the teleſcope: thus, *venus* does not appear *in her*
47 *greateſt brightneſs* in her ſuperior conjunction at A, fig. 47, though we then ſee her illuminated hemiſphere entire: the reaſon is this, the light which comes from venus to us in that ſituation is more diminiſhed by her being then at her greateſt diſtance from us[b], than it is increaſed by her turning her whole enlightened diſk towards us: Dr. *Halley* has ſhewn[c], that venus is brighteſt when her elongation from the ſun is about 40 degrees; ſhe does indeed in that ſituation ſhew but about a fourth part of her enlightened diſk to the inhabitants of the earth, ſo that ſhe would through the teleſcope look like the moon about 3 days old; but ſhe is then ſo near us that this fourth part contains a larger area and ſends us more light than her whole enlightened diſk does when ſhe is at her greateſt diſtance from us: in this ſituation with reſpect to the ſun venus is often ſeen in the day time, in ſunſhine, and is by the vulgar ſometimes taken for a new ſtar; and in the night her light is ſo ſtrong that ſhe caſts a ſhadow, which none of the reſt of the heavenly bodies ever do, except the ſun and moon. By the method made uſe of by *Halley* for venus, it will be found that *mercury* is *in his greateſt brightneſs* when very near his utmoſt elongation.

a *Selenographia pag.* 42 & 67. b §. 88. c Jones *Phil. Tranſ. abr. vol.* 4. *p.* 300.

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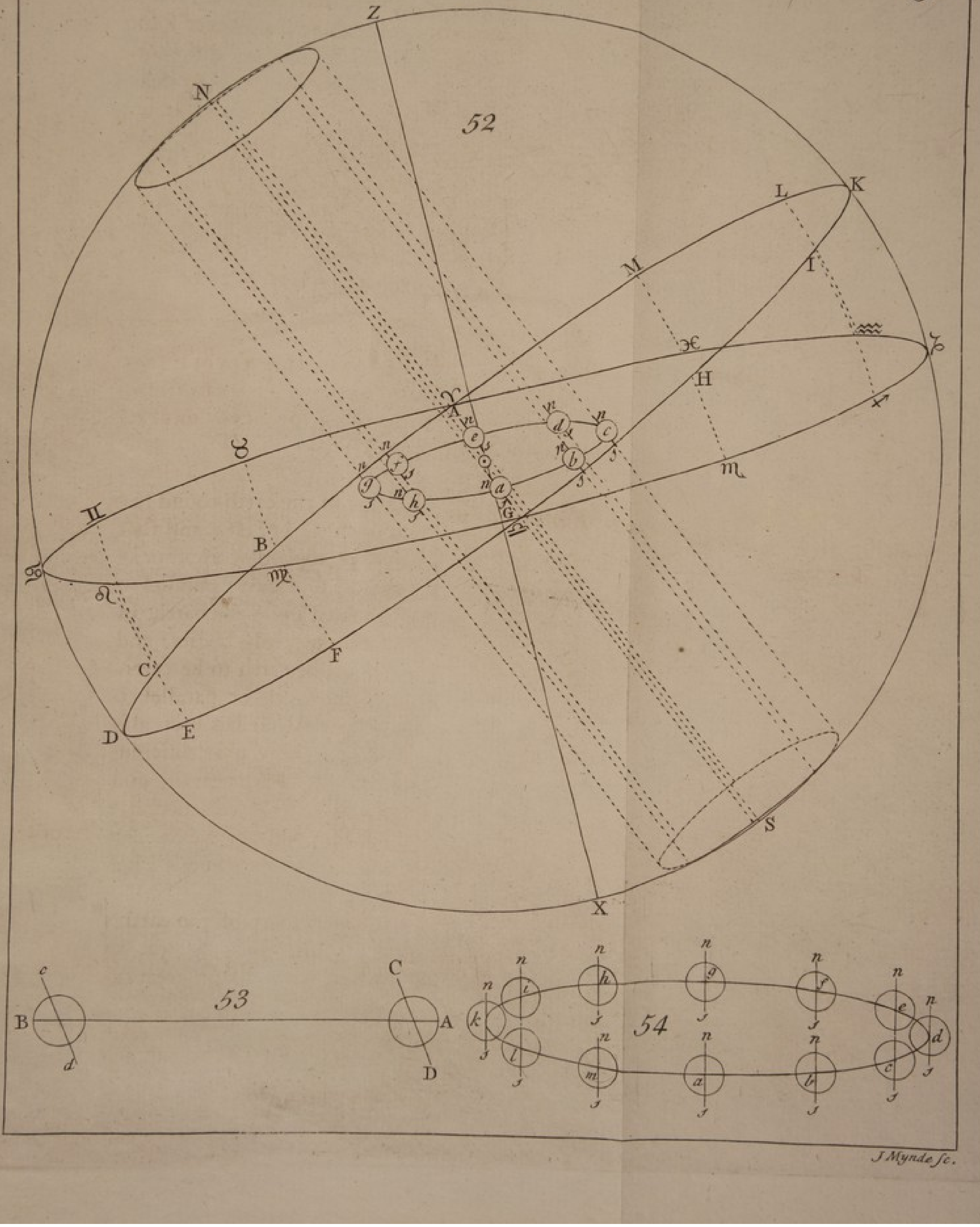

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728 All the planets appear white or luminous, becauſe their ſurfaces re- FIG.
flect the rays of light of all kinds, red, yellow, green, &c together; for it is the mixture of all theſe which produces whiteneſs[a]: there is however ſome little difference in *the colours of the planets*, as their ſurfaces are differently modifyed, ſo as to reflect the rays of one colour in greater quantity than others: thus mars appears of a reddiſh hue, the light of venus is a little inclined towards yellow, that of jupiter very white, ſaturn a little livid, and more dim than the reſt, one reaſon of which may be his great diſtance from us. We may alſo obſerve ſome difference in *the colours of the fixt ſtars*: aſtrologers tell us ſuch ſtars are of the nature of mars, ſuch of venus &c, the ground of theſe fancies ſeems to be the different colours of the ſtars, wherein ſome reſemble one planet and ſome another[b]. *Kepl. aſtr. opt. p.* 261.

CHAP. 12. THE ROTATION OF THE EARTH AND HER REVOLUTION ROUND THE SUN CONSIDERED TOGETHER: THE INCLINATION OF THE EARTH'S AXIS TO THE PLANE OF HER ORBIT THE CAUSE OF THE DIVERSITY OF SEASONS.

729 It has been already ſhewn, that by the rotation of the earth round her axis all the heavenly bodies appear to turn round us in 24 hours[c]: and that from the ſame cauſe every point in the heaven except the poles appears in the natural day to deſcribe either the celeſtial equator, or a circle parallel to it[d]: and that according as any place is differently ſituated upon the earth, in a parallel, right or oblique ſphere, every one of the heavenly bodies, and amongſt the reſt the ſun, appears to the inhabitants of the earth to be carried round them either in a circle coincident with the horizon, or parallel to it, or that cuts the horizon at right, or at oblique angles[e]. It has been alſo obſerved, that the ſun appears in different points of the heaven at different times of the year, ſometimes in the equator, ſometimes very near it, and ſometimes farther off from it, either north or ſouth; and that this declination from the equator is within certain limits, which the ſun never exceeds[f]: the cauſe of all this is the inclination of the earth's axis to the plane of her orbit, which is now to be more particularly conſidered.

730 *The axis of the earth's diurnal rotation* is in every part of the earth's
orbit *parallel to it ſelf* in every other part of her orbit: thus, fig. 52, let 52
N D S K be a glaſs ſphere, or the ſphere of the heaven, viewed at a great di-

a § 222. b *Chaldæi, ab elementis eorumque commixtionibus ad ſtellas progredientes, naturas earum per colores judicant:* Albumaſar, *introduct. l.* 1. *c.* 2. c § 296. d § 343. e *book* 1 *chap.* 8. f *book* 1 *chap.* 8.

FIG. ſtance, ſo as to have the eye a little elevated above the plane of the ecliptic,
52 which circle, marked with the characters of the ſigns ♈ ♉ ♊ &c, is here ſeen in a perſpective view, as is alſo the plane of the equator, ABCDEFGH IKLM, and the orbit of the earth, *abcdefg*, in the middle whereof is the ſun ☉; *ns* is the axis of the earth, if the poſition of it be obſerved when the earth is at *a*, and a line drawn parallel to it as NS, I ſay that when the earth is at *b* or *c* or *d* &c, her axis is in every one of theſe places parallel to NS, as it is repreſented in the figure. Some writers, in explaining the Copernican ſyſtem, mention this paralleliſm of the earth's axis as cauſed by a third motion of the earth, which they call *the motion of inclination*, as if, beſides the diurnal rotation and annual motion, another motion were impreſſed upon the earth, whereby the inclination of her axis to the plane of her orbit were continued in the ſame angle; whereas this is only the conſequence of the diurnal and annual motions continuing independent upon one another, the one no way diſturbing the other: ſuppoſe a globe to be carri-
53 ed along ſo that the center of it goes in the line AB, when the globe is at A, among the infinite number of diameters of the globe imagine ſome one inclined to the line AB in any angle to be marked out, ſo as to be diſtinguiſhed from the reſt, as CD; if the globe has no other motion impreſſed upon it but a progreſſive one in the line AB, when it is come from A to B the diameter CD will be in the ſituation *cd*, parallel to its former ſituation: if at the ſame time with the progreſſive motion a rotation round the axis CD be impreſſed upon the globe, theſe motions are independent upon one another and one will have no effect upon the other, but the axis of rotation will at B, as alſo at all the intermediate places between A and B, be parallel to CD. If inſtead of a rectilinear motion we ſuppoſe the globe to go in a curve, as in a circle or ellipſis, as the earth does round the ſun, the axis of rotation will then alſo continue parallel to it ſelf, undiſturbed by the circular motion: theſe motions of a globe are here ſuppoſed to be *in vacuo*, and not in a medium where they meet with any friction or reſiſtance, for then the axis of rotation might be changed, according to the different impulſe of the medium upon its ſurface: now this is the caſe of the earth and planets in their revolutions round the ſun, that they move in ſpaces void of all reſiſting matter; or if it has any reſiſtance it is ſo ſmall as not to have any ſenſible effect in many ages.

731 *The axis of the earth extended* both ways *terminates* as to ſenſe, *in the ſame points of the heaven, throughout the year:* in reality the axis of the earth extended deſcribes in the heaven round each of the points N and S a circle equal to the circumference of the earth's orbit; but the ſphere of the heaven is ſo immenſely large, that in compariſon of it the orbit of the earth is

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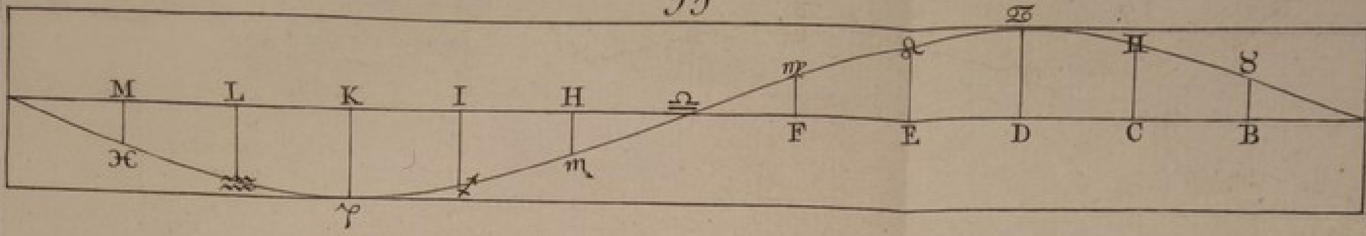

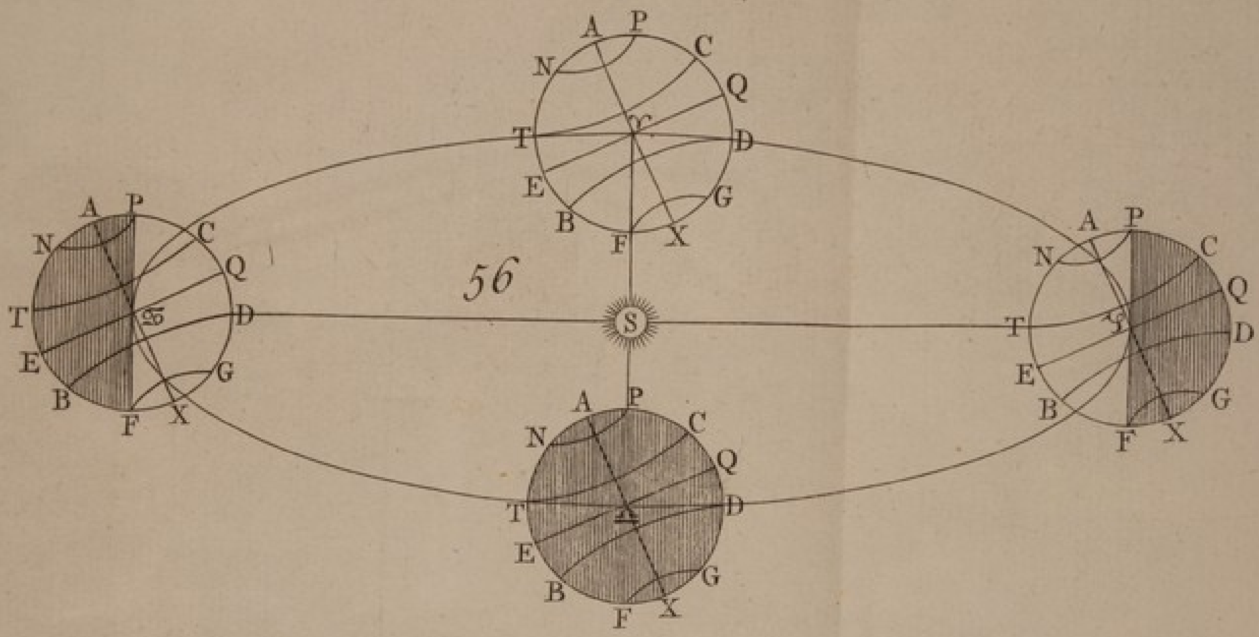

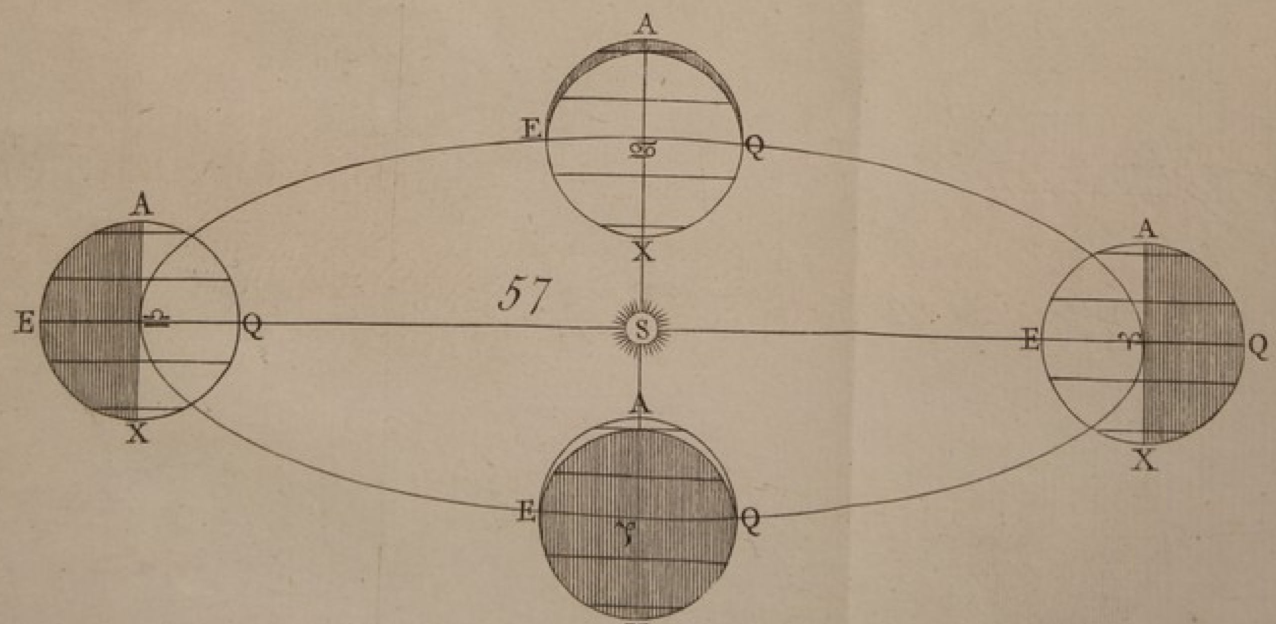

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is but as a point: and confequently the axis of the earth extended both ways FIG.
terminates, as to fenfe, throughout the year in the points N and S; and thofe 52
points are the poles round which the heaven appears every day to turn. From hence it comes to pafs, that every point in the heaven appears to defcribe either the equator or a parallel to the equator, in the fpace of a natural day. It has already been obferved, § 359 and 366, that the fun is but twice a year in the equator, at the two equinoxes; and that every other day of the year he is more or lefs in north or fouth declination: and accordingly appears to defcribe a parallel more or lefs north or fouth of the equator: what diverfity the declination of the fun thus varying occafions in the length of the days and nights, at different times of the year in the fame horizon, or at the fame time of the year in different horizons, has been before explained, book I. chap. 8. and 10. I fhall now fhew from whence this difference in the fun's declination arifes.

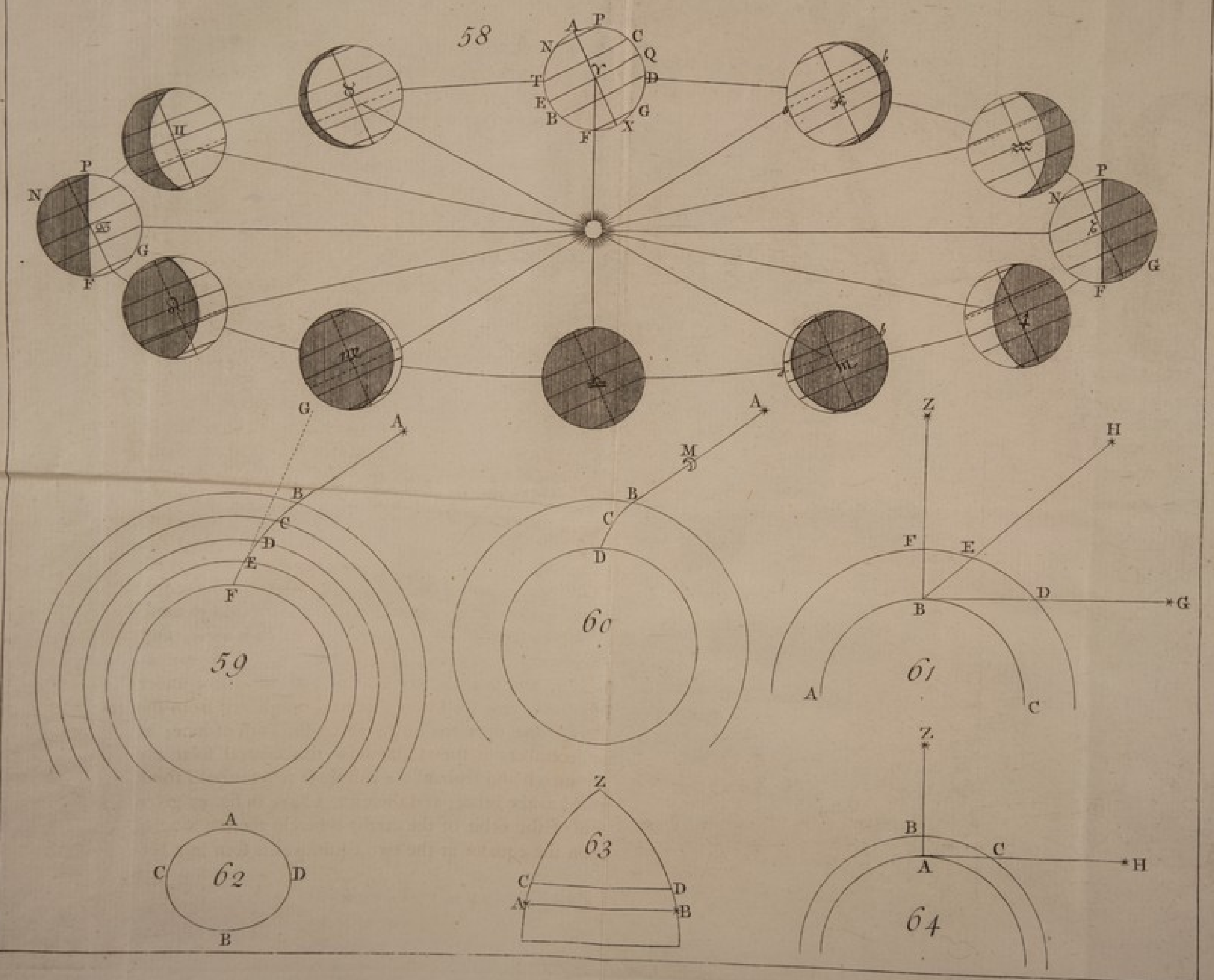
732 *If the axis of the earth were perpendicular to her orbit*, the planes of the earth's equator and of her orbit would be coincident; and then, fince the fun is in the center of the earth's orbit, the plane of the earth's equator extended would pafs through the fun, and the fun would appear to be carried
round in the celeftial equator every natural day in the year: thus, fig. 54 ex- 54
hibits the orbit of the earth in a perfpective view, the eye being at a great diftance and a little elevated above the plane of it: if the axis of the earth *ns* were perpendicular to it, as it is here reprefented, the plane of the earth's equator in every one of the fituations *a*, *b*, *c*, *d*, &c would pafs through the fun; and then the fun's apparent place in the heaven muft be in the celeftial equator; and confequently we fhould have perpetual equinox: the fun indeed would, by the progrefs of the earth through her orbit, appear every day in a different point of the equator, fo as to go through that circle in the fpace of a year; but this would make no difference in the feafons of the year: for every place of the earth would then enjoy the light and heat of the fun every day alike, and that in the fame manner as it does now at the equinoxes.

733 *The axis of the earth is inclined to the plane of the earth's orbit*, fo as to make an angle with it of 66° 31′: hence the plane of the earth's equator makes with the plane of her orbit an angle of 23° 29′, the complement to 66° 31′: and confequently the celeftial equator and ecliptic interfect each other in an angle of 23° 29′. The ecliptic is cut by the celeftial equator in the points ♈ and ♎, and therefore when the fun appears in either of thofe points he appears in the celeftial equator alfo; in every other point of the ecliptic he is in north or fouth declination: let fig. 52 be the glafs fphere, or 52
the fphere of the heaven reprefented as feen at a great diftance in a perfpec-

FIG. tive view, ABCD &c is the celeſtial equator, ♈ ♉ ♊ ♋ &c the ecliptic, *abcde*
52 *fg* the orbit of the earth, N the arctic, S the antarctic pole, Z the north, X the ſouth pole of the ecliptic: about the 10th of march, the earth being at *a*, the ſun's place to an inhabitant of the earth is at ♈; and the rotation of the earth for that natural day makes him appear to be carried round in the celeſtial equator: the next day, by the earth going about one degree in her orbit from *a* towards *b*, the ſun's place will appear to be advanced about one degree from ♈ towards ♉; this carries him a little into north declination, and he that day appears to go round in a parallel a little north of the equator. As the earth goes on from *a* to *b*, from *b* to *c*, from *c* to *d*, &c, the ſun appears to proceed in the ecliptic; changing his declination according as that circle deviates from or approaches to the celeſtial equator: thus, from ♈ towards ♉ and ſo on according to the order of the ſigns, his northern declination every day increaſes; for about the 10th of april when the ſun is at ♉ his declination is ♉B; about the 10th of may when he is at ♊ it is ♊C; about the 10th of june when he is at ♋ it is ♋D; and this is his greateſt north declination, amounting to 23° 29′: that day the ſun appears to be carried round in the tropic of cancer, and is vertical at noon to thoſe who live in a correſponding parallel upon the earth, namely in the northern tropic, in 23° 29′ north latitude: from thence the ſun's declination continually decreaſes; ſo that about the 10th of july his place is at ♌, his declination is ♌E: about the 10 of auguſt he is at ♍, his declination ♍F: about the 10th of ſeptember he is again in the celeſtial equator at ♎: for the remaining months he is in ſouth declination; in october at ♏: in november at ♐: in december at ♑, in his greateſt ſouth declination, when he deſcribes the tropic of capricorn, and is vertical at noon to thoſe who live under that circle, or in 23° 29′ ſouth latitude: in january the ſun is at ♒: in february at ♓: and about the returning 10th of march in ♈ again.
55 In the 55th figure we have the celeſtial equator and ecliptic in another view; it repreſents an hoop containing all that part of the ſphere of the heaven which is between the tropics; ſuppoſing it to be cut open and unbent into a plane, in the ſame manner as we conſidered the zodiac, § 651: it ſhews the change of the ſun's declination in his progreſs through the twelve ſigns: in april it is ♉B; in may ♊C; &c.

52 55 734 The 52 and 55 figures ſhew how it comes to paſs that the ſun's declination changes faſter the nearer he is to one of the points ♈ and ♎, where the equator and ecliptic interſect one another; for there thoſe circles recede faſteſt from one another: the ſame figures ſhew alſo why the ſun's declination changes more ſlowly the nearer he is to one of the ſolſtitial points ♋ and ♑; becauſe there the ecliptic touching the two tropics does not recede ſenſibly

page 245.



J. Mynde sc.

bly from them for ſome ſpace: and therefore all the while the ſun is near ei- FIG.
ther of the ſolſtitial points the parallels in which he every day appears to be carried round by the earths rotation are not ſenſibly different from one another, but are in a manner coincident with the neareſt tropic: and ſo long the change of the ſuns declination is ſcarce perceptible.

735 *The change of the ſeaſons*, ariſing from the inclination of the earth's axis to the plane of her orbit, may be very well ſhewn in another manner: the 56 figure, which is commonly made uſe of for this purpoſe is taken o- 56
riginally from *Galileo*[a]; the ellipſis ♈ ♋ ♎ ♑ repreſents the orbit of the earth in a perſpective view, the earth with ſuch circles as are requiſite for the preſent occaſion is pictured in the four ſeveral ſituations which ſhe is in at the beginning of the four ſeaſons of the year, AX is the axis of the earth, parallel to it ſelf in all the ſituations, EQ is the equator, TC the northern tropic, NP the north polar circle, BD the ſouthern tropic, FG the ſouth polar: now if we imagine a line to be drawn from S the center of the ſun to the center of the earth in each ſituation, this *central ſolar ray*, as it may be called, will about the 10th of june, when the earth is at ♑, terminate upon the ſurface of the earth at the northern tropic TC; and conſequently, by the earth's rotation round her axis, the inhabitants of every part of the circle TC will ſucceſſively have the ſun in their zenith, or in other words he will be vertical[b] to them that day at noon, and the ſun appears that day to be carried round in the tropic of cancer: about the 10th of ſeptember the earth is at ♈, the central ſolar ray S♈ terminates upon the ſurface of the earth in the equator; and therefore the ſun appears to be carried round in the celeſtial equator, and is ſucceſſively vertical to thoſe who live under that circle: about the 10th of december, when the earth is at ♋, the central ſolar ray S♋ terminates on the ſurface of the earth in the ſouthern tropic BD; and for that day the ſun appears to be carried round in the tropic of capricorn, and is vertical to thoſe who live under that circle: about the 10th of march the earth is at ♎, and the ray S♎ points at the equator again; and conſequently the ſun appears again in the celeſtial equator, and is again vertical to thoſe who live under
the line.—The 56 figure ſhews very well how a central ray drawn from the 56
ſun points at the northern tropic upon the earth, about the 10th of june; at the ſouthern tropic, in december: it ſhews alſo how this central ſolar ray points at the equator, in march and ſeptember: but theſe two ſeaſons I think
are not ſo well repreſented as the other; and therefore I have in fig. 57 given 57
another perſpective view of the orbit of the earth, wherein the pointing of the central ſolar ray upon the equator at the two equinoxes is ſeen in a better manner. 736

a v. Galilei *Syſtema coſmicum dialog* 3. b *See* § 388 *to* § 395.

Fig. 736 Fig. 58 exhibits the orbit of the earth in another perſpective view; the
58 earth is drawn in the twelve ſeveral places which ſhe is in about the 10th day of each of the twelve months, keeping the paralleliſm of her axis in thoſe ſeveral ſituations: now if a line be drawn from the center of the ſun to the center of the earth in each ſituation, in march when the earth is at ♎, it points at the equator: in april it points at the parallel here expreſt by the dotted line *ab*, which is a little in north latitude: in may at a parallel farther north, which is alſo expreſt in the figure by a dotted line: and in june at the northern tropic: in july and auguſt the line points at parallels leſs and leſs north, marked here by dotted lines: in ſeptember it points at the equator again: for the reſt of the months the line points at parallels in ſouth latitude, marked in the figure by dotted lines; going more and more ſouth from ſeptember till december, when it points at the ſouthern tropic: from thence it points every day at a parallel nearer and nearer to the equator; till about the 10th of the returning march it points at the equator again: it is eaſy to ſee that according as the central ſolar ray points any day of the year, at the equator, or at ſome parallel upon the earth more or leſs north or ſouth, the ſun appears to be carried round that day either in the equator, or in ſome celeſtial parallel more or leſs north or ſouth, correſponding to the terreſtrial parallel.

737 The ſun is not only twice a year vertical to the inhabitants under the line, namely at the two equinoxes; but alſo to the inhabitants of any parallel ſituated between the tropics: thus the ſun is vertical to the inhabitants
58 of the parallel *ab* in april, as the earth is going from the equinoctial point ♎ towards the ſolſtitial point ♑; and in auguſt, as ſhe is going from the ſolſtitial point ♑ towards the equinoctial point ♈: in like manner, the figure ſhews the central ſolar ray to point at the ſame parallel in july as in may: in october as in february: in november as in january: from hence appears the reaſon why the days are of the ſame length with us, as alſo in any place in an oblique ſphere, in auguſt as in april: in july as in may: in november as in january: in october as in february: the only difference is that in april, may, january, and february, the days are increaſing; but in july, auguſt, october, and november, they are decreaſing.

56 738 If we imagine a plane perpendicular to the line drawn from the cen-
57 ter of the ſun to paſs through the center of the earth, the ſection of the globe
58 of the earth by that plane will be a great circle, which may be called *the circle of illumination*; becauſe it marks out that half of the earth which is towards the ſun and is enlightened by him, wherein it is day, and divides it from the other half which is in darkneſs, wherein it is night: the circle of illumination always divides the equator into two equal parts, § 177; and therefore

therefore all who live under the equator have the days and nights equal FIG.
throughout the year.

739 About the 10th of march, when the earth is at the point ♎, and the 56
10th of ſeptember, when ſhe is at ♈, the plane of the circle of illumination 57
paſſes through the axis of the earth, and divides not only the equator but 58
every parallel alſo both north and ſouth into two equal parts; and conſequently every point of the earth's ſurface is by her rotation carried juſt as long in light as in darkneſs: thoſe times therefore are the *two equinoxes*, when the nights and days are equal over the face of the whole earth[a], and the circle in which the ſun then appears to be carried round is called *the equinoctial.*

740 In every other ſituation of the earth, every parallel through which the plane of the circle of illumination paſſes is divided by it unequally, and more unequally the farther the earth is from the equinoctial points ♈ and ♎; 58
and conſequently, at all other times of the year except the equinoxes, the *days and nights are unequal*, in every place ſituated in an oblique ſphere: and the greater the diſtance of time is from the equinox, the greater is this inequality of the day and night: the greateſt inequality therefore is at the *two ſolſtices*; when the earth is at ♋ or ♑.

741 In every ſituation of the earth except at the two equinoxes at ♈ and 58
♎, there may be taken parallels near each pole which are not cut by the circle of illumination, but are ſome of them entirely in the light, others entirely in the dark: ſo long as any parallel is entirely in the light it is *continual day* without night in every place of the earth in that parallel; as it is alſo in every place ſituated between that parallel and the neareſt pole: ſo long as any parallel continues entirely in the dark it is *continual night* without day to all the inhabitants therein; as it is alſo in every place ſituated between that parallel and the neareſt pole.

742 About the 10th of june, in the ſummer ſolſtice, when the earth is 56
at ♑, the largeſt parallel N P which can be taken entirely in the light is the 58
north polar circle; the largeſt parallel F G which can be taken entirely in the dark is the *ſouth polar circle:* at that time therefore it is continual day every where within the north polar, and continual night in all places within the ſouth polar circle: about the 10th of december, at the winter ſolſtice, when the earth is at ♋, the reverſe of this happens; the north polar circle N P is then entirely in the dark, the ſouth polar F G entirely in the light, as appears by

a In a parallel ſphere the ſun is in reality then carried round in the horizon, half his body being above and half below the plane of that circle: notwithſtanding, to a ſpectator under either of the poles his whole body would be ſeen all the while above the horizon; becauſe refraction always makes him appear higher than his true place.

the

FIG. the 56 and 58 figures: at that time therefore it is continual day, within the
56 ſouth polar, and continual night within the north polar circle.

58 743 From the ſummer ſolſtice, when the earth being at ♑ fig. 58, the north polar NP is entirely in the light, the ſouth polar FG entirely in the dark, the greateſt north parallels which can be taken entirely in the light and the greateſt ſouth parallels which can be taken entirely in the dark daily grow leſs and leſs, till the earth comes to ♈, at the autumnal equinox; when, the circle of illumination cuts all the parallels equally, and every point of the earth's ſurface is by her rotation continued as long in the light as in the dark. From the autumnal equinox the parts about the north pole begin to go entirely into the dark, and the parts about the ſouth pole entirely into the light; and the circle of illumination cuts the ſurface of the earth in ſuch a manner as to encreaſe every day the darkneſs about the north pole, and the light about the ſouth, till the winter ſolſtice; when, the earth being at ♋, the whole north polar is in the dark, and the whole ſouth polar in the light. From the winter ſolſtice the greateſt entirely dark northern parallels and the greateſt entirely light ſouthern parallels grow every day leſs and leſs, till the vernal equinox; when, the earth being at ♎, all the parallels are again divided into equal parts by the circle of illumination. From the vernal equinox the parts about the north pole come every day more and more entirely into the light, and the parts about the ſouth pole more and more entirely into the dark, till at the ſummer ſolſtice the earth is again at ♑; and the circle of illumination cuts the ſurface of the earth in ſuch manner as to throw the whole north polar into the light, and the whole ſouth polar
58 into the dark. The 58 figure makes what I have now ſaid eaſy to be comprehended; ſhewing the gradual ſucceſſive gaining and loſing of light and darkneſs, in different months, upon the parts about each of the poles.

744 From the 10th of march to the 10 of ſeptember, whilſt the earth is going in her orbit through ♎ ♏ ♐ ♑ ♒ ♓, and by that motion makes the ſun appear to go through the northern ſigns ♈ ♉ ♊ ♋ ♌ ♍, the circle of illumination divides the parallels through which it paſſes, unequally, in ſuch a manner that the greater part of every north parallel is in the light, and the greater part of every ſouth parallel in the dark: during that time therefore the days are longer than the nights to all who live in north latitude; and the nights are longer than the days to thoſe who live in ſouth latitude. In the other half year, from the 10th of ſeptember to the 10th of march, when the earth is going in the other part of her orbit through ♈ ♉ ♊ ♋ ♌ ♍, and the ſun is in the ſouthern ſigns ♎ ♏ ♐ ♑ ♒ ♓, the parallels through which the plane of the circle of illumination paſſes are ſo divided by it that the greater part

part of every north parallel is in the dark, and the greater part of every ſouth parallel in the light: during all that time therefore all who live in north latitude have the night longer than the day; but all who live in ſouth latitude have the day longer than the night.

CHAP. 13. OF THE ATMOSPHERE, REFRACTION, THE TWILIGHT.

745 Our earth is ſurrounded every way with a ſphere of air wherein various kinds of particles are continually floating; the whole taken together is called *the atmoſphere*, from its ſpherical ſhape, and from the greek word *atmos* which ſignifies a miſt, vapor or ſmoke: The *air* is a fluid *ſui generis*, having ſome properties not to be found in other fluids; it is compreſſible, and elaſtic, capable of having its parts ſqueezed cloſer together, or of expanding it ſelf ſo as to take up a greater ſpace: a cubic foot of air may be compreſſed into a 60th part of that dimenſion; on the other hand, a cubic inch of air, if all preſſure were taken off, would expand it ſelf ſo as to fill a ſpace many millions of times as large[a]. Air has this in common with all other material ſubſtances that it is weighty, though in a leſs degree than moſt bodies with which we are acquainted; a glaſs bottle filled with air weighs ſomething heavier than it will do if the air is exhauſted out of it by the air-pump; we may alſo make a bottle filled with air in its natural ſtate ſtill heavier, by forcing more air into it.

746 The gravity of the air makes the loweſt parts of the atmoſphere to be the heavieſt as well as the moſt denſe, becauſe they are preſſed upon by the weight of all above them; and for the ſame reaſon the higher the air is the thinner it grows, till at the extream or higheſt parts of the atmoſphere it is exceedingly thin and light: and this is the reaſon why clouds and vapours can riſe but to a certain height, the higher air being ſpecifically lighter; and conſequently unable to ſupport them. What the texture is of the particles of which air conſiſts we muſt be contented to be ignorant of; ſome have thought they might reſemble the ſpring of a watch, which unbends its coils when left to it ſelf, but may be forced to wind them up into a narrow compaſs. Sir *Iſaac Newton*[b] ſuppoſes that ſome bodies may have their ſmalleſt parts endued with a repulſive power, which makes them recede from one another, and that air may be of this ſort. How the upper and lower air come to be of a different denſity may be illuſtrated by a familiar inſtance of an heap of wool or ſpunge, or the like compreſſible matter, where the preſſure of what is above will

a Newt. *princip. l.* 3 *prop.* 41. opt. book 3 qu. 28. Gregor. *aſtron. l.* 5 *prop.* 3. b Opt. book 3 qu. 31.

make the lower parts lye more compact and close together, in proportion to the weight which lies upon them: thus the atmosphere may be considered as consisting of an indefinite number of spheres of different densities, enclosing one another as the several coats of an onion do.

747 The atmosphere is not only admirably fitted for the respiration and nourishment of animals, the growth of vegetables, the production and propagation of sounds &c; but helps also to make our habitable earth that beautiful scene of variety which it now is. If it were not for the atmosphere the sun and stars would give us no light but just when we turn our eyes upon them, the brightness of the sun would indeed be greater than it is, but if we turned our eyes from him towards any other part of the heaven, it would appear as dark and full of stars as in a bright star-light night in winter. As for the various bodies which are upon the earth, they would all, without the atmosphere, appear to us as dark as at midnight; except only those parts of them which happened to be in such a position that the rays of the sun falling upon them were reflected to our eyes. It is easy to imagine how much of the beauty of the visible creation would be lost in these circumstances, besides the insupportable prejudice to the eyes of all creatures, by passing so suddenly from pitchy darkness to excessive light. The numberless small particles of various kinds which float in the air receive the light from the sun, and like so many small *specula* or looking-glasses reflect and scatter it through the air[a], and this occasions that light which we see in the day-time, by which our eyes are affected so strongly as to render the fainter light of the stars insensible. By this means the sky is illuminated all round us by the sun, not only whilst he is above our horizon, but also for some time before his rising, and after his setting; so long as any of his rays can either directly or by refraction reach any part of the atmosphere within our visible horizon: for the air, as well as all other mediums which transmit light, refracts or bends the rays of it, if they come into it from a different medium: this property of the air is exceedingly beneficial to the inhabitants of the earth, as it lengthens the days by the addition of the twilight, but it gives astronomers some trouble, as it changes a little the places of all the heavenly bodies, and makes them appear higher than they really are, and must therefore be taken into the account, if we would be exact: the ancients were not well acquainted with the refraction of the air, which renders many of their observations of the heavenly bodies, especially near the horizon, liable to uncertainty.

a Thus if the sun shines into a dark room through an hole in a door or shutter of a window, we perceive it in a long stream of light: which appears brighter the fuller the room is of dust or smoke.

748

748 *The rays of light* coming out of a thinner medium into a thicker are *refracted* towards the perpendicular, whether the ſurface of the thicker medium be plane or curve; as has been already obſerved, § 213 and 215: a ray of light coming from any of the heavenly bodies to the eye of an inhabitant of the earth paſſes firſt through a ſpace either perfectly void of all matter, or very nearly ſuch, in a ſtrait line, till it reaches the top of our atmoſphere; upon the ſpherical ſurface of which if it falls obliquely, it will be a very little bent or refracted, at its entrance into the exceedingly thin air, and will be continually more and more bent as it paſſes through thicker and thicker air, till it arrives at the earth. FIG.

749 If we imagine the atmoſphere to be divided into any number of concentric ſpherical ſpaces of different denſities, for example into four, as is done in fig. 59 by a like number of ſpherical ſurfaces, a ray of light coming 59
from a ſtar at A would proceed in a ſtrait line till it falls upon the outward ſurface at B[a], there it would be a little bent, and go on from thence in a ſtrait line to C, where, falling upon a ſurface of thicker air, it would receive a greater refraction, and go on in the ſtrait line CD, at D ſtill thicker air would give it a new and greater refraction, into the line DE, at E the air being more denſe would give it the greateſt refraction, into the line EF: as all viſion is made in a right line, a ſpectator upon the earth at F would ſee the ſtar in the line FE continued; ſo that its refracted or apparent place is G, higher or nearer to the zenith than its true place A: refraction therefore makes all the heavenly bodies appear higher than their true places.

750 If inſtead of four we imagine the atmoſphere to be divided into an indefinite number of ſpherical ſpaces containing air of different denſities, it is eaſy to ſee that, inſtead of going in four ſeveral ſtrait lines, a ray of light paſſing through the atmoſphere will go in a curve line, whoſe curvature continually increaſes till it falls upon the earth, as is repreſented by the curve
ABCD, fig. 60. 60

751 If a ſtar be in the zenith of a ſpectator upon the earth, a ray coming from it to his eye falls perpendicularly upon the ſpherical ſurface of the atmoſphere, and will therefore proceed in a ſtrait line, without being refracted, by § 212: if a ſtar be in the horizon of an obſerver, a ray coming from it to his eye ſuffers the greateſt refraction of all, for two reaſons, 1 the ray falls upon the ſurface of the atmoſphere with the greateſt obliquity, 2 it paſſes through the largeſt ſpace of the lower and denſer part of the air: thus, fig.

a I call that the outward ſurface of the atmoſphere where the air begins to be denſe enough to cauſe a ſenſible refraction; the height of this is about 40 or 50 miles above the earth: how much higher the thinner air may reach is difficult to determin.

Fig. 61, let A B C be part of the ſurface of the earth, B the place of an obſerver, 61 if a ſtar be in his zenith at Z, the line Z B drawn from the ſtar to his eye falls perpendicular upon the ſpherical ſurface of the atmoſphere at F, and conſequently will be perpendicular to all the concentric ſpherical ſurfaces which we can imagine in the atmoſphere: if a ſtar be in his horizon at G, the ray G D, by which the ſtar is ſeen, falls more obliquely upon the atmoſphere at D, than the ray H E from a ſtar at H does at E; or than a ray coming from any ſtar between G and Z to the eye at B: moreover the line D B is longer than F B, or E B, or than any other line which can be drawn from the out ſide of the atmoſphere to the eye at B, between D B and F B.

752 The *refraction* of the heavenly bodies is not only *greateſt in the horizon* and *none* at all *in the zenith*, but decreaſes from the horizon as their altitudes increaſe, till near the zenith it becomes ſcarcely ſenſible: aſtronomers give us tables of refraction, which ſerve chiefly for the country where they were made: the air is condenſed, and conſequently refraction increaſed by cold; and therefore refraction is greater in cold countries than in hot: it is alſo greater in cold weather than in hot, in the ſame country, and the morning refraction is greater than the evening; becauſe the air is rarified by the heat of the ſun in the day, and condenſed by the coolneſs of the night: refraction is alſo ſubject to ſome ſmall variation, at the ſame time of the day in the fineſt weather; ſee § 483: but theſe niceties are, I ſuppoſe, not conſidered in the tables, or rather they give us the mean refractions between the greateſt and the leaſt.

753 The *refraction of all the heavenly bodies is the ſame* at the ſame apparent height above the horizon: thus the refraction of the ſun, moon, or any ſtar is the ſame, at the ſame apparent altitude; becauſe the rays come from them all in ſtrait lines till they enter our atmoſphere: if the moon which is the neareſt to our earth be of the ſame apparent altitude with a ſtar, a ray coming from the moon goes through the ſame ſpace of air as a ray from the
60 ſtar does: thus, fig. 60, if a ſtar be at A, the moon at M, a ray from either comes alike in the line A B and is alike refracted into the line A B C D.

754 The horizontal refraction being the greateſt is the cauſe of *the ſun* appearing *of an oval form, at his riſing and ſetting:* for the lower edge of the
62 ſun B is more refracted than the upper edge A, by which means they are brought nearer together, that is the perpendicular diameter A B is ſhortened: whereas refraction does not ſhorten the tranſverſe diameter C D: moreover, the lower edge ſuffering the greateſt refraction, the horizontal ſun does not appear a compleat ellipſis, but the lower half C B D is part of a more oblong oval than the upper half C A D. What I have now ſaid of the ſun is applicable

cable alſo to the riſing and ſetting moon. For the ſame reaſon, if we take with an inſtrument the diſtance of two ſtars when they are in the ſame vertical and near the horizon, we ſhall find it conſiderably leſs than if we meaſure it when they are both at ſuch an height as to ſuffer little or no refraction; becauſe the lower ſtar is more lifted up than the higher. There is alſo another alteration made by refraction in the apparent diſtance of ſtars: if two ſtars are in the ſame almicantarah, or circle parallel to the horizon, their apparent diſtance is leſs than the true; for ſince refraction makes each of them higher in the vertical or azimuth in which they appear, it muſt bring them into parts of the vertical where they come nearer to one another: thus, let the ſtar A be in the vertical A Z, the ſtar B in the vertical B Z, their true diſtance is A B, an arc of a great circle: ſuppoſe A to be lifted up by refraction to C, and B to be lifted up to D, their apparent diſtance is now C D, leſs than A B; for ſince all verticals converge ſo as to meet in the zenith Z, it is manifeſt the diſtance between any two verticals is diminiſhed as they grow nearer the zenith: this contraction of diſtance, according to Dr. *Halley* [a], is at the rate of at leaſt one ſecond in a degree; ſo that, for example, if the diſtance between two ſtars in a poſition parallel to the horizon meaſures 30°, it is at moſt to be reckoned but 29° 59′ 30″.

FIG. 63

755 I have here ſet down four *tables of refraction*, that of *Tycho Brahe* [b], which is the oldeſt we have, was made from his own obſervations; it goes no higher than to 45°, becauſe at greater altitudes the author tells us he did not find any ſenſible refraction: *Tycho*'s table of the refraction of the ſtars is not much different from thoſe of *Flamſteed* and *Newton*, except near the horizon; he makes the refractions of the ſun and moon about 4′ greater than that of the ſtars, probably from ſome falſe hypotheſis [c], for by comparing his own obſervations in his *hiſtoria cæleſtis*, they come out the ſame, making allowance for the ſmall unavoidable errors to which obſervations are liable. The table of *Caſſini* is taken from *les elemens d' aſtronomie verifiez*, *p.* 21: *Flamſteed*'s from his *hiſtoria cæleſtis*, *vol.* 1 *p.* 396, and is the reſult of his own obſervations: Sir *Iſaac Newton*'s table was firſt publiſhed in the tranſactions, n. 368, may 1721.

756 The *uſe of the* following *tables*: the apparent altitude of any of the heavenly bodies being given, take from thence the refraction, and what remains is the true altitude: thus, if the altitude of the ſun, moon, or a ſtar be obſerved 15°, take from thence, by *Flamſteed*'s table, 3′, the true altitude is 14° 57′.

a Phil. tranſact. n. 368, may &c. 1721. b *v.* Tychonis *progymnaſmata. p.* 79, 124, & 280.

c Perhaps from his making the parallaxes of the ſun and moon about 3 minutes too great.

A TABLE

A TABLE OF REFRACTIONS.

Appar. Altit.	Refraction according to					
	Newt.	Flamst.	Cassini	Tycho		
				☉	☽	*
° '	' ″	' ″	' ″	' ″	' ″	' ″
0 0	33 45	33 0	32 20	34 0	33 0	30 0
0 15	30 24					
0 30	27 35	26 38				
0 45	25 11					
1 0	23 7	23 22	27 56	26 0	25 0	21 30
1 15	21 20					
1 30	19 46	20 17				
1 45	18 22					
2 0	17 8	17 26	21 4	20 0	20 0	15 30
2 30	15 2	15 15				
3 0	13 20	13 23	16 6	17 0	17 0	12 30
3 30	11 57	11 53				
4 0	10 48	10 39	12 48	15 30	15 20	11 0
4 30	9 50	9 38				
5 0	9 2	8 48	10 32	14 30	14 20	10 0
5 30	8 21					
6 0	7 45	7 26	8 55	13 30	13 50	9 0
6 30	7 14					
7 0	6 47	6 25	7 44	12 45	12 45	8 15
7 30	6 22					
8 0	6 0	5 37	6 47	11 15	12 0	6 45
8 30	5 40					
9 0	5 22	5 2	6 4	10 30	11 20	6 0
9 30	5 6					
10 0	4 52	4 33	5 28	10 0	10 45	5 30
11 0	4 27	4 6	4 58	9 30	10 10	5 0
12 0	4 5	3 45	4 32	9 0	9 35	4 30
13 0	3 47	3 29	4 12	8 30	9 0	4 0
14 0	3 31	3 13	3 54	8 0	8 30	3 30
15 0	3 17	3 0	3 36	7 30	8 0	3 0
16 0	3 4	2 48	3 24	7 0	7 30	2 30
17 0	2 53	2 38	3 11	6 30	7 0	2 0
18 0	2 43	2 29	3 0	5 45	6 30	1 15
19 0	2 34	2 21	2 49	5 0	6 0	0 30
20 0	2 26	2 14	2 39	4 30	5 30	0 0

A TABLE OF REFRACTIONS.

ap. alt.	Refraction according to New.		Fla.		Cass.		Tycho ☉		☽	
°	′	″	′	″	′	″	′	″	′	″
21	2	18	2	7	2	31	4	0	5	0
22	2	11	2	1	2	25	3	30	4	35
23	2	5	1	55	2	18	3	10	4	10
24	1	59	1	50	2	12	2	50	3	45
25	1	54	1	45	2	6	2	30	3	20
26	1	49	1	40	2	0	2	15	3	0
27	1	44	1	36	1	55	2	0	2	40
28	1	40	1	31	1	51	1	45	2	20
29	1	36	1	27	1	46	1	35	2	0
30	1	32	1	23	1	42	1	25	1	45
31	1	28	1	20	1	38	1	15	1	30
32	1	25	1	17	1	34	1	5	1	20
33	1	22	1	14	1	30	0	55	1	10
34	1	19	1	11	1	27	0	45	1	0
35	1	16	1	9	1	23	0	35	0	50
36	1	13	1	7	1	20	0	30	0	45
37	1	11	1	5	1	18	0	25	0	40
38	1	8	1	2	1	15	0	20	0	35
39	1	6	1	0	1	12	0	15	0	30
40	1	4	0	58	1	10	0	10	0	25
41	1	2	0	56	1	7	0	9	0	20
42	1	0	0	54	1	5	0	8	0	15
43	0	58	0	52	1	3	0	7	0	10
44	0	56	0	50	1	1	0	6	0	5
45	0	54	0	48	0	59	0	5	0	0
46	0	52	0	46	0	58				
47	0	50	0	45	0	56				
48	0	48	0	44	0	54				
49	0	47	0	42	0	52				
50	0	45	0	40	0	50				
51	0	44			0	49				
52	0	42			0	47				
53	0	40			0	45				
54	0	39			0	43				
55	0	38	0	34	0	41				

ap. alt.	Refraction New.		Fla.		Cass.	
°	′	″	′	″	′	″
56	0	36			0	40
57	0	35			0	38
58	0	34			0	37
59	0	32			0	35
60	0	31	0	29	0	34
61	0	30			0	33
62	0	28			0	31
63	0	27			0	30
64	0	26			0	28
65	0	25			0	27
66	0	24			0	26
67	0	23			0	25
68	0	22			0	24
69	0	21			0	22
70	0	20	0	19	0	21
71	0	19			0	20
72	0	18			0	19
73	0	17			0	18
74	0	16			0	17
75	0	15			0	16
76					0	14
77					0	13
78					0	12
79					0	11
80			0	9	0	10
81					0	9
82					0	8
83					0	7
84					0	6
85					0	5
86					0	4
87					0	3
88					0	2
89					0	1
90			0	0	0	0

Ricciolus, beſides treating largely of refraction, in his *almageſt*, gives us there and in his *aſtronomia reformata*, another table; wherein, from his own obſervations and thoſe of *Tycho* and others corrected, he ſets down the different refractions of the heavenly bodies, at three different times of the year, ſummer, winter, and the equinoxes.

757 Refraction lengthens the day and ſhortens the night; by making the ſun appear above the horizon a little before his riſing, and a little after his ſetting: refraction alſo makes the moon and ſtars appear to riſe ſooner and ſet later than they really do. The apparent diameter of the ſun or moon is about half degree; the horizontal refraction is a little more than that, as appears by the tables; this makes both ſun and moon appear entire above the horizon when they are entirely below it.

758 The rays of the ſun being ſcattered over ſome of thoſe parts of the air which are within our viſible horizon cauſe *the twilight* [a], both morning and evening: the morning twilight begins when the ſun is not more than about 18° below our rational horizon, for then his rays firſt reach the eaſtern parts of the air within our viſible horizon: as he grows nearer riſing, his light ſpreads farther round, and enlightens a larger portion of our air, and it grows lighter and lighter, till ſun-riſe: in like manner, after ſun-ſet the light gradually decreaſes, till the ſun is got ſo low that none of his rays can reach the weſtern parts of the air within our viſible horizon, or not enough to cauſe any ſenſible light there; and then the evening twilight ends: this happens when the ſun's depreſſion below the rational horizon is about 18°.

759 There is ſome little difference in *the duration of the twilight*, ariſing from the different denſity and height of the atmoſphere; by which the vapours and other particles that reflect the light of the ſun are carried up to a greater height at ſome times than at others; for the higher the reflecting particles are raiſed, the lower may the ſun be depreſt and yet have his rays reach them. For this reaſon the evening twilight ends at a lower depreſſion of the ſun than the morning twilight begins at; becauſe the heat of the day, by rarifying the air, raiſes the reflecting particles to a greater height, whereas the coolneſs of the night, by condenſing the air, brings them down nearer to the earth: this cauſes the evening twilight to be longer than the morning, at the ſame time of the year in the ſame place. For the ſame reaſon the twilight is longer in hot weather than in cold, as alſo in hot countries than in cold, o-

a It is called the twilight as being between or partaking of two lights, the light of the ſun and that of the ſtars; *v.* Skinneri *etymolog.* The latin word *crepuſculum* is from its being doubtful whether it be day or night: *res dubiæ creperæ vocantur*, Cenſorinus: *v.* Voſſii *etymolog.* The begining of the morning twilight is commonly called the day-break, day-ſpring, or dawning of the day.

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ther circumſtances being the ſame: *Ricciolus* at Bologna obſerved, at the equinoxes, the duration of the twilight in the morning to be 1 hour and 47 minutes; in the evening 2 hours: and that the evening twilight did not end till the ſun was above 20° below the horizon[a]: however the differences in the ſame country ariſing from this cauſe are ſo ſmall that they are generally not taken notice of.

760 Beſides theſe *phyſical differences*, as they may be called, in the duration of the twilight, ariſing from the different conſtitution of the air, there are other *aſtronomical differences*; which are owing to the different ſituations of places upon the earth, or to the difference of the ſun's place in the heaven: if a place is ſituated in a parallel ſphere, or near to it, the apparent motion of the ſun being parallel to the horizon or nearly parallel, he will be carried round for ſome months at a leſs depreſſion than 18°; and therefore ſo long will the twilight laſt: in a right ſphere, the twilight is ſhorteſt; becauſe, the ſun riſing and ſetting at right angles to the horizon, the changes of his depreſſion are made in the ſhorteſt times: in any place in an oblique ſphere, the nearer the place is to one of the poles the longer are the twilights; becauſe the caſe comes the nearer to that of a parallel ſphere. As to the different places of the ſun, the twilights are longeſt in all places which are in north latitude, when the ſun is in the tropic of cancer; in ſouth latitude, when he is in the tropic of capricorn: the time of the ſhorteſt twilight is different in different latitudes: with us in England, the ſhorteſt twilights are about the latter end of ſeptember, and the latter end of february[b].

761 *Ricciolus*[c] gives us *a table of the duration of the twilight*, at different times of the year, in different latitudes: but, as the differences of latitude are therein ſet down in no orderly progreſſion, I have here inſerted a new and more methodical table, calculated upon a ſuppoſition that the twilight begins and ends when the ſun is 18° below the horizon: the letters c. d. ſignify that it is then continual day without night: c. n. continual night without either day or twilight: w. n. that the twilight then laſts the whole night: thus for inſtance, when the ſun is in ♓ or ♏, that is, about the 10th of february, and about the 10th of october; the twilight, in the latitude of $52\frac{1}{2}°$ is 2 hours: in the latitude of 70° it is 3 hours 41′.

The table ſhews how the duration of the twilight increaſes as the latitude is greater; which is a very providential relief to the inhabitants of the countries near the pole, in their very long winter nights.

a *almageſt. l.* 1 *c.* 31. b How to find the ſhorteſt twilight, may be ſeen in *Gregory*'s aſtronomy book 2 prop. 41: and *Keil,* lect. 20. c *almageſt. l.* 1 *c.* 31.

A table of the duration of the twilight in different latitudes.

Alt. Pole	0	10	20	30	40	45	50	52½
☉ enters	H. ′	H. ′	H. ′	H. ′	H. ′	H. ′	H. ′	H. ′
♋	1 18	1 21	1 28	1 41	2 8	2 39	w. n.	w. n.
♊ ♌	1 16	1 19	1 25	1 36	1 58	2 19	3 3	w. n.
♉ ♍	1 13	1 15	1 20	1 28	1 43	1 55	2 12	2 25
♈ ♎	1 12	1 13	1 17	1 24	1 35	1 44	1 55	2 2
♓ ♏	1 13	1 14	1 18	1 24	1 35	1 43	1 54	2 0
♒ ♐	1 16	1 17	1 21	1 28	1 40	1 49	2 1	2 8
♑	1 18	1 19	1 23	1 30	1 43	1 53	2 6	2 15

The table continued.

Alt. Pole	55	60	65	70	75	80	85	90
☉ enters	H. ′	H. ′	H. ′	H. ′	H. ′	H. ′	H. ′	H. ′
♋	w. n.	w. n.	w. n.	c. d.	c. d.	c. d.	c. d.	c. d.
♊ ♌	w. n.	w. n.	w. n.	c. d.	c. d.	c. d.	c. d.	c. d.
♉ ♍	2 41	3 55	w. n.	w. n.	w. n.	c. d.	c. d.	c. d.
♈ ♎	2 10	2 33	3 8	4 18	w. n.	w. n.	w. n.	w. n.
♓ ♏	2 8	2 27	2 56	3 41	5 2	17 32	w. n.	w. n.
♒ ♐	2 18	2 43	3 26	11 38	11 14	10 32	8 38	c. n.
♑	2 26	2 57	4 4	10 24	9 30	7 46	c. n.	c. n.

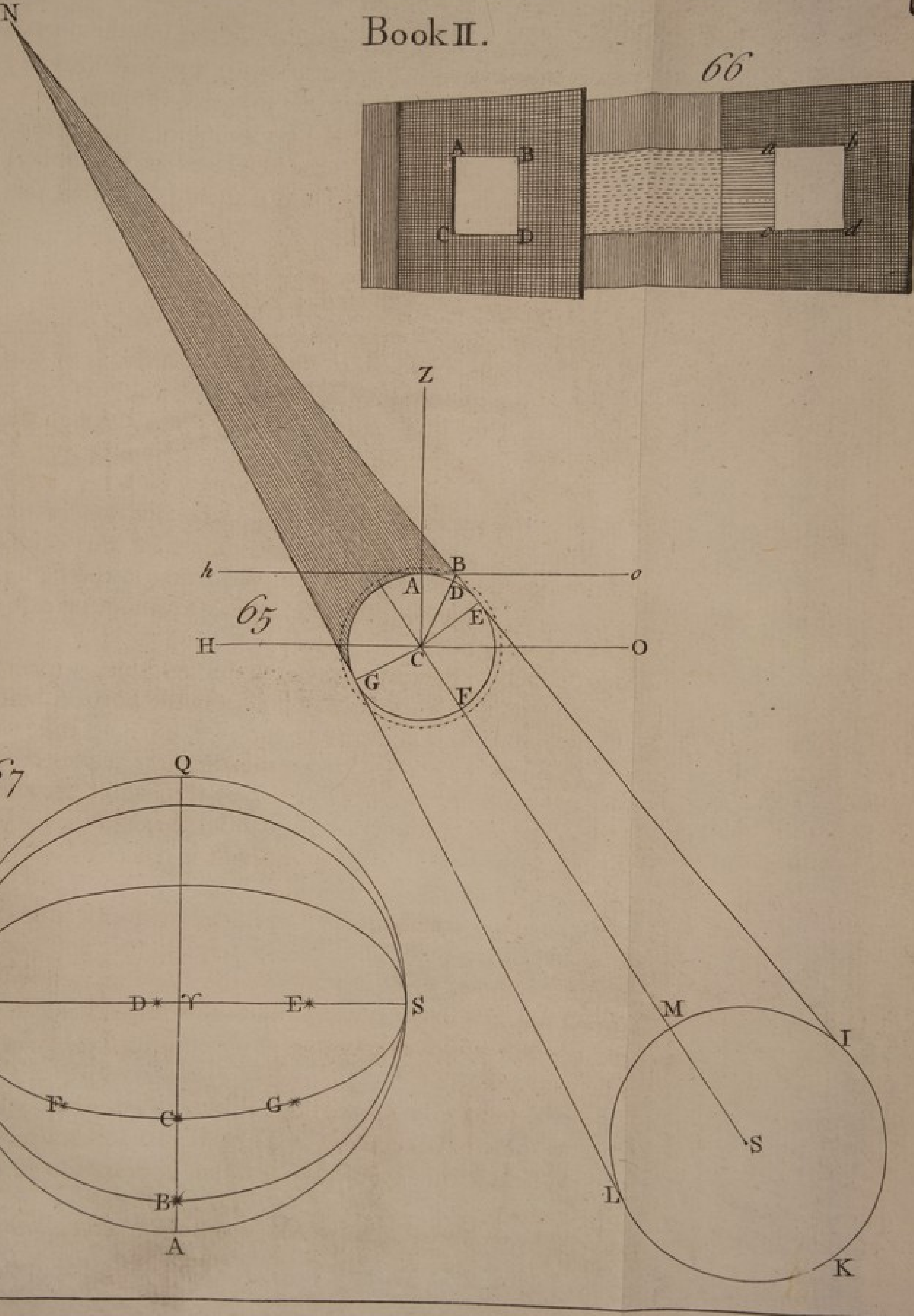
762 The twilight has hitherto been confidered only as it is caufed by the light of the fun himfelf reflected to us; but, befides this, the body of the fun is encompaffed with a fphere of light, which is either the *ether* that immediately furrounds him heated to fuch a degree as to become luminous, or *the fun's atmofphere*, confifting of fiery particles emitted from his body, but retained near him by attraction: this, being of larger dimenfions than the fun, muft rife before him, and fet after him; and confequently lengthens the twilight, by illuminating our air, when the fun is at too low a depreffion to reach it with his own light: this is alfo the caufe that the rifing fun is preceded by a luminous fegment of a circle, in the eaft, different from the light which the atmofphere reflects from the body of the fun: the like to this may be obferved in the weft, juft after fun-fet. *Greg.* aftr. book 2 prop. 8.

763 *The height of the atmofphere*, that is of fuch parts of it as are denfe enough to reflect the fun's light, may be determined, by knowing at how low a depreffion of the fun the twilight begins or ends: *v. Ricciol. almageft. l.* 1 *c.* 31. fuppofing that depreffion of the fun to be 18°, the height of the atmo-

fphere

Book II.

61



J. Mynde sc.

ſphere is about 40 miles[a]. *Caſſini*[b] is of opinion that, in ſettling the durati- FIG.
on of the twilight, aſtronomers have made it too long; by miſtaking for part of it a light which accompanies the ſun in his progreſs through the ecliptic[c]: he aſſerts the depreſſion of the ſun at the beginning of the morning and end of the evening twilight to be but 17°: the height of the atmoſphere would from this ſuppoſition be but 37 miles: and it ſhould ſeem that this is ſtill leſs, becauſe of the ſun's atmoſphere, § 762.

Additions to the foregoing chapter.

764 There are three reaſons why the horizontal refraction is the greateſt: 1 a ray from any of the heavenly bodies when they are in the horizon falls with the greateſt obliquity upon the ſpherical ſurface of the atmoſphere: 2 an horizontal ray paſſes through the thickeſt vapours: 3 it paſſes through the largeſt ſpace of thick vapours: thus, fig. 64, a ray coming from a ſtar at Z in 64
the zenith paſſes only through the line B A of the atmoſphere, whereas a ray coming from a ſtar at H in the horizon paſſes through the line C A of the atmoſphere, which is almoſt 14 times as long as the line B A: this exceſs of C A above B A is not repreſented in any tolerable proportion in the figure, nor indeed can be; becauſe in ſo ſmall a compaſs the earth cannot be exhibited large enough for the atmoſphere.

765 The great length which an horizontal ray goes through thick vapours is the reaſon that the ſmall ſtars are ſometimes inviſible near the horizon; and that the ſun may be looked upon without hurting our eyes, at riſing and ſetting; becauſe much of his light is reflected back: the ſun near the horizon looks red, becauſe the red-making rays which are leaſt refrangible are alſo leaſt reflexible; and therefore paſs in the greateſt quantity through thoſe vapours by the particles of which the reſt of the ſun's light is reflected back again into the *ether*.

766 In § 757 I ſaid refraction lengthens the days: this it does a little in every place, but near either of the poles this effect of refraction is very conſiderable; cauſing the ſun to appear ſome days above the horizon, when he is really below it: almoſt every body who writes upon this ſubject takes notice of that extraordinary refraction, amounting to ſeveral degrees, which gave ſome Hollanders who wintered A. D. 1596 in Nova Zembla, in the latitude of 76°, a ſight of the ſun 17 days ſooner than by the theory he ought to have appeared to them: ſome have thought, that the Hollanders miſreckoned either their latitude or their time; but their account appears too accu-

a See § 767. b *Decoverte de la lumiere celeſte &c pag.* 52 *ed. Par.* c Of which I ſhall treat hereafter.

FIG. rate to admit of ſuch a ſuſpicion: the cauſe of ſo great a refraction was probably the very great condenſation of the air, in that extreamly cold region, during a night of above three months continuance. *Kepl. aſtr. opt. p.* 138.

Remarks upon § 763.

65 767 In the 65th figure let A E F G be the earth, the pointed circle ſurrounding it the outward ſurface of the atmoſphere, the height of which D B is to be found: let A be the place of an obſerver, *h o* his ſenſible, H O his rational horizon: let I K L M be the ſun, E N G the ſhadow of the earth, I B a ray from the upper edge of the ſun, touching the earth in E, and falling upon the outward ſurface of the atmoſphere at B, from whence it is reflected to the eye of the obſerver at A, in the line of his ſenſible horizon B A; the ſun, being larger than the earth, illuminates a little more than an hemiſphere thereof, repreſented by the arc E F G, which is 180° 32′ *, whoſe half E F is 90° 16′, as is alſo the angle E C S: O C S is the ſun's depreſſion, which is 18° by obſervation, this being taken from E C S leaves E C O 72° 16′: now ſince Ż C O or A C O, by the definition of the horizon, is 90°, A C E complement to E C O is 17° 44′: and the half of A C E *viz.* D C A † is 8° 52′: here then is a right-angled triangle B A C, with one acute angle B C A and one ſide A C known; and therefore, by § 143, the ratio of any one ſide to any other may be found. If A C be made radius B C will be the ſecant of the angle B C A of 8° 52′, ſay then as 10000000 to 10120948, ſo is $3967\frac{1}{2}$ the number of miles contained in the earth's ſemidiameter to a fourth number, which is $4015\frac{1}{2}$, the number of miles from the center of the earth to the outward ſurface of the atmoſphere; from which take the earth's ſemidiameter $3967\frac{1}{2}$ miles, the remainder 48 miles is the height of the atmoſphere above the ſurface of the earth. In this calculation no allowance is made for refraction, which in the horizon is about 34′, ſo much therefore muſt the angle B C A be diminiſhed,

65 * The angles E C F and E C N together are equal to two right angles or 180°, *Eucl. l.* 1 *prop.* 13. E C F muſt therefore exceed 90° as much as E C N wants of 90°: now in the right angled triangle C E N the angle E C N muſt want as mnch of a right angle as C N E amounts to, § 55, that is as much as the apparent ſemidiameter of the ſun I N S viewed from N the vertex of the cone of the earths ſhadow would be: the ſhadow of the earth reaches but a little farther from the earth than the moon, which diſtance from the earth is in a manner inſenſible, compared with the vaſt diſtance of the ſun from the earth; ſo that we may aſſume the ſun's apparent ſemidiameter viewed from N the ſame as we find it viewed from the earth at F, this by obſervation is at the ſun's middle diſtance 16′; therefore E C F is 90° 16′.

65 † The triangles B A C and B E C are right angled by § 28, the ſides A C and E C are equal by § 25, the ſide B C is common, and hypotenuſe in both, whoſe ſquare is equal to the ſquares of B E and E C and to the ſquares of B A and A C by *Eucl.* book 1 prop. 47, but A C and E C being equal their ſquares are equal, wherefore the ſquares of B E and B A muſt be equal; and conſequently the ſides B E and B A themſelves are equal: ſo that the triangles B E C and B A C are mutually equilateral, and therefore mutually equiangular, by *Eucl* book 1 prop. 8; that is, the angle B C E is equal to the angle B C A.

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this brings it to 8° 18′, the ſecant of which is 10105851; from whence the height of the atmoſphere comes out 42 miles.

CHAP. 14. THE SUN'S DISTANCE FROM THE EARTH VARIABLE; THE SUN'S APOGEE AND PERIGEE: THE CAUSES OF THE HEAT IN SUMMER: THE SUN'S APPARENT DIAMETER VARIABLE.

768 How the earth goes round the ſun in an ellipſis, in one of the focuſes of which the ſun is placed, has been explained, book 2 chap. 7; one conſequence of this is, that the ſuns apparent annual motion is the ſame as if he were carried round the earth in an ellipſis, in one of the focuſes of which the earth were placed. As we call the point of the earth's elliptic orbit where ſhe is fartheſt from the ſun her aphelion, ſo we call the point in the ecliptic wherein the ſun then appears *the ſun's apogee*; becauſe he is then fartheſt from the earth: in like manner, when the earth is in her perihelion, or neareſt to the ſun, we call the point of the ecliptic wherein the ſun then appears *the ſuns perigee*; becauſe he is then at his leaſt diſtance from the earth: it is eaſy to ſee that the ſun's apogee is oppoſite to the earth's aphelion; and the ſun's perigee oppoſite to the earth's perihelion. As the longitude of the ſun's apogee is reckoned from the point ♈, § 661, it muſt increaſe 50″ in a year; becauſe the point ♈ moves ſo much backwards contrary to the order of the ſigns, as was ſaid § 657[a]. The place of the ſun's apogee is this preſent year 1740 in 8° 25′ of ♋; the place of his perigee in 8° 25′ of ♑: the ſun is therefore in apogee in june; in perigee in december: thus it appears that the ſun is nearer the earth in our winter than in our ſummer. The ſun being nearer to the earth in winter than in ſummer, it may ſeem ſtrange to ſome perſons that the winter ſhould be colder than the ſummer; the cauſes of this are now to be enquired into.

769 One cauſe of the heat of the ſun being greater with us in ſummer than in winter is, his having then a greater altitude above our horizon; ſo that his rays fall nearer to a perpendicular upon thoſe parts of the earth which are round about us: we may conſider the heating particles that come from the ſun as an innumerable multitude of inconceivably little balls, continually ſhot from his body, every way: if they cauſe heat in the bodies upon which they fall, by ſtriking upon their ſurfaces, the more directly they

a Whether the place of the earth's aphelion, and conſequently of the ſun's apogee, be invariable in reſpect of the fixt ſtars or not, is controverted by aſtronomers. *v.* Ricciol. *alm. l.* 3. *c.* 25.

ſtrike

FIG. ſtrike upon them, the greater is the force of the percuſſion; and the more intenſe will the heat be: on the other hand, the more obliquely they fall upon the ſurfaces of bodies, the weaker is the ſtroke; and the leſs the heat cauſed thereby. See the remarks § 777.

770 Another reaſon why any body is leſs heated the more obliquely the heating particles fall upon its ſurface is, that they are the more thinly ſpread
66 thereon, by ſuch obliquity: thus, let A B C D be an hole of a foot ſquare in a board placed ſo as to receive the ſun's rays perpendicular upon it; if a plane of larger dimenſions be placed behind the board, near it and parallel to it, ſo as to receive the rays coming through the hole perpendicular alſo, they will cover an area a foot ſquare, as *a b c d:* if the plane be held obliquely to the rays, they will cover an area of the ſame breadth as before, but of a greater length; ſuppoſe the plane to be held ſo as to receive the rays with ſuch obliquity that they ſhall cover an area one foot in breadth, and two feet in length, in this caſe it is manifeſt the heating particles falling upon an area twice as large muſt be ſpread proportionably thinner thereon; and conſequently they will cauſe but half ſo much heat.

771 Another reaſon why the weather is hotter in ſummer than in winter is this, that heat is not produced in bodies by the ſun inſtantaneouſly, or all at once, nor do the effects of the heat of the ſun ceaſe immediately, upon his rays being intercepted; as is the caſe of light, which is ſpread or ſtopped in a moment: the heating particles operate gradually, and their force decreaſes alſo gradually; and therefore the longer any body is expoſed to the rays of the ſun the hotter it grows; and the hotter any body is the longer it is in cooling: now in ſummer there are more hours in the day for the ſun to heat the earth in, than the night has to cool it again; in the winter, on the contrary, the nights are long, and the days ſhort: and this will account for a good deal of the difference as to heat and cold between thoſe two ſeaſons.

772 Since the heating power of the ſun is greateſt when his rays fall moſt directly upon us, § 769, 770, and when the days are longeſt, § 771, it may be imagined that the hotteſt weather ought to be about the 10th of june, when the ſun is in the tropic of cancer; for then the ſun comes neareſt to our zenith, and continues the longeſt above our horizon: but we find by experience that our greateſt heats are generally above a month after this, about the end of july, when the ſun's altitude is a little diminiſhed, and the days ſenſibly ſhortened: this time is called *the dog-days*, becauſe the dog-ſtar, the largeſt and brighteſt ſtar in the firmament, riſing with the ſun at that time, was by moſt of the ancients believed to be the cauſe of the extraordinary heats of that ſeaſon; though ſome of them, with better judgement, thought his thus riſing

rising only pointed out the time of the year when the weather is usually hottest. I shall treat farther of the dog-days hereafter.

773 To find the true cause of this, we must remember what was said § 771, that the earth is not heated by the sun instantaneously, nor is it cooled all at once: but the heating particles streaming from the sun fall upon the parts of any solid body, or penetrate into its pores, in a continual succession; and therefore every moment an addition is made to the heat before excited: this addition is made, by the heating particles coming on faster than they fly off, or than their heating power is destroyed; or by their continuing to communicate farther degrees of motion to the already agitated particles of the heated body: perhaps both these causes combine to increase heat. In the absence of the sun, the heat of the earth gradually decreases; because some of the heating particles fly off, and are reflected back: others are absorbed into the pores of the bodies heated by them, and attracted by and closely united to their solid parts; and so gradually lose their motion, which, by being continually communicated to more and more particles of matter, becomes at last insensible. Now in whatever degree the parts of the earth round the place where we inhabit are heated, at the summer solstice, by the days continually lengthening from the preceding winter to that time, their heat will continue to be still farther increased for so long time as there is every day an addition of a greater quantity of heat than is lost in the night immediately preceding; though the additions are every day less and less: this is usually for above a month after the longest day. From the foregoing reasoning, we may see also how it comes to pass that the hottest time of the day is not at noon, though the sun be then highest; but about two hours after.

774 When I speak of the heating particles streaming from the sun, I know that some imagin fire to be a subtle matter, diffused through the universe; and that the action of the sun upon it causes the heat which we feel in sun-shine: I have no occasion to enter into this controversy, the force of the sun will be greater the higher he is, and the longer he is above our horizon; whether he pours upon us heating particles thrown off from his own body, or only impells the particles of fire diffused through our air.

775 The sun's apparent diameter is greater the nearer he is to the earth; and consequently greatest in december, least in june, by § 768.

The following table shews the sun's apparent diameter for every 10th day throughout the year: it is taken from *conoissance du temps*, only I have set down the days of the month in old style. *v. & Cassini observat. astronomiques, p.* 22, *& Flamsteed. histor. cælest.*

A table

A table of the apparent diameters of the sun.

d.	′ ″	d.	′ ″	d.	′ ″	d.	′ ″
Jan. 9	32 40	April 9	31 56	July 9	31 40	Octo. 9	32 24
19	32 38	19	31 50	19	31 44	19	32 30
30	32 36	29	31 46	30	31 46	30	32 34
Feb. 9	32 30	May 9	31 44	Aug. 9	31 50	Nov. 9	32 36
19	32 24	19	31 42	19	31 56	19	32 38
27	32 18	30	31 40	30	32 0	29	32 42
Mar. 9	32 13	June 9	31 38	Sept. 9	32 6	Dec. 9	32 44
19	32 8	19	31 38	19	32 12	19	32 44
30	32 2	29	31 38	29	32 18	30	32 42

Remarks upon § 768.

776 In computing the sun's place in the ecliptic, astronomers often reckon his distance from the point of his apogee; which distance is called *the sun's anomaly*[a]: and is either the mean or the true. *The sun's mean anomaly* is his distance from his apogee, computed upon a supposition that his motion has been all the while equable: *the suns true anomaly* is his true distance from his apogee, computed by making allowance for the unequability of his motion: the sun's true motion being sometimes swifter sometimes slower than his mean motion; in order to find his true from his mean anomaly, we must sometimes add to his mean motion, and sometimes subtract from it: this operation is called *prosthaphæresis*, a greek compound word which signifies addition and subtraction.

Remarks upon § 769.

777 If two equal bodies strike upon a plane with equal forces, but in different angles, the strength of their strokes will be as the sines of those angles: now the radius or whole sine is the greatest of all the sines, and therefore a perpendicular stroke is the strongest; and the strength of any oblique stroke, *cæteris paribus*, decreases in the same ratio as the sine of the angle does: the meridian height of the sun at the summer solstice is with us at *Cambridge* 61° 19′, his height at the winter solstice is 14° 21′[b], the sine of 61° 19′ is 8772858,

a The word signifies irregularity, or unequability, in greek ανωμαλια, and is used in this case because the sun's apparent motion is more or less equable according to his distance from his apogee; for it is slowest in his apogee, quickest in perigee, and mean at his mean distances from the earth.

b I here suppose the latitude of Cambridge 52° 10′, as found by late observations; that in the table § 331 was from *Streete's astronomia Carolina*, but he does not tell us his author.

the

the ſine of 14° 21′ is 2478445; the ſun's heat then at noon at the ſummer ſolſtice is to his heat at noon at the winter ſolſtice as 8772858 to 2478445; that is nearly as 100 to 28.

CHAP. 15. THE COLURES: RIGHT ASCENSION: OBLIQUE ASCENSION: ASCENSIONAL DIFFERENCE: THEIR USES.

778 We have already ſeen, that many of the motions of the heavenly bodies are not equable; we may however reaſonably ſuppoſe the rotation of the earth round her axis to be equable: no diſcovery having been hitherto made to the contrary. *Kepler*[a] imagined the earth's rotation was quicker in her perihelion than in her aphelion; this opinion was owing partly to his believing the ſun's rotation round his axis to be the cauſe of the rotation of the earth, and partly to ſome irregularities in the motions of the moon, which he could not otherwiſe account for: but theſe irregularities will appear to belong to the moon herſelf, when we come to treat of her motions. Since *Kepler*'s time, clocks have been brought to ſuch a degree of perfection, by the inventions of *Huygens*, as to prove that the rotations of the earth are all performed throughout the year in equal times[b]. It may perhaps admit of ſome doubt, whether, ſince the parts of the earth towards her ſurface are not every where of the ſame denſity, the attractions of the ſun and moon do not cauſe ſome inequality in the rotation of the earth; ſo as to accelerate it when ſome parts of the earth are coming towards the ſun or moon, and retard it when they are turning from them. *Hook*[c] ſeems to have thought he had diſcovered ſome inequality in the diurnal motion of the earth; but refers the matter to farther experiments, to be made by obſerving with an accurate clock, whether ſtars, when very near the zenith, and conſequently out of the reach of ſenſible refraction, go through equal arcs of the parallel of their apparent diurnal motion in equal times, or not: if there be any ſuch inequality it would, how ſmall ſoever, hinder the ſettling the places of the ſtars exactly by their tranſits.

779 From the equability of the rotation of the earth it follows, that the apparent diurnal motion of the heaven is equable alſo: this motion therefore, which is ſometimes called the motion of the *primum mobile*, and is made in the plane of the equator and circles parallel to it, is very proper for

a Kepl. *epit. aſtron. p.* 108, 286, 550, 574, 722. b Halleius *in tractatu de emendatione lunaris theoria.* c See *Hook's* poſthumous works, p. 545.

a ſtandard, by which other motions in the heaven may be meaſured: for this reaſon, and others that will appear in the ſequel, the celeſtial equator is of great account, in our enquiries into the places and motions of the heavenly bodies: that circle is ſuppoſed to be divided into 360 degrees, beginning at the point ♈, or the point of the vernal equinox, proceeding round according to the order of the ſigns; and each degree to be ſubdivided into minutes and ſeconds, &c.

780 We may imagine a ſecondary of the equator, or circle of declination, to be drawn through any point of the equator: the principal ſecondaries of the equator are the two *colures*, one of which is drawn through the equinoctial points ♈ and ♎, and called *the equinoctial colure*; the other is drawn through the ſolſtitial points ♋ and ♑, and called *the ſolſtitial colure*: the uſe of the colures is to mark out the four cardinal points of the ecliptic; at which when the ſun arrives the four ſeaſons of the year begin. Since the point ♈ changes its place 50″ every year, the other cardinal points muſt alſo change their places as much; and conſequently the colures alſo change their ſituations in the ſphere of the heaven; and this change, though not ſenſible in a few years, becomes in a great number of years very conſiderable: thus the ſituation of the colures, is found to be very different now from what it was 2000 years ago[a]. The colures have that name from the greek word κολος maimed, and ουρα a tail; becauſe, in every place in north latitude, their lower parts that are within the antarctic circle, deſcribed § 348, are cut off by the horizon; ſo as never to be ſeen. *Achilles Tatius cap.* 27 *de coluris.*

781 The motion of the equinoctial points, deſcribed § 657, is called *the preceſſion of the equinoxes*[b]; becauſe it is in *antecedentia*, that is from a following ſign towards a preceding one, as from aries towards piſces, &c: by ſome it is called the *regreſſion* or going back of the equinoxes, becauſe it is contrary to the order of the ſigns: this retrograde motion, by carrying the equinoctial points to meet the ſun as he comes along the ecliptic in his apparent annual motion, makes him arrive at them and cauſe the general equinoxes, a little ſooner every year than he would do if thoſe points continued immoveable: thus, the arc of regreſſion being 50″ a year makes the equinoxes happen 20′ in time ſooner than they otherwiſe would do.

782 Another conſequence of the preceſſion of the equinoxes, and what is chiefly to be conſidered in this place is, that the celeſtial equator and its poles are continually changing their ſituations among the fixt ſtars; and therefore,

a *Newton*'s chronology p. 88, 91. b Hipparcho *apud* Ptolemæum, μεταπτωσις των σημειων ισημεριων· Copernico, *anticipatio vel præceſſio æquinoctiorum.*

whenever

whenever we ſpeak of the diſtance of any ſtar from the equator or poles, we muſt be underſtood to mean the equator and poles as they are ſituated at the time of the obſervation: but, the change now mentioned is ſo very ſlow, that, in moſt caſes of common uſe, we may conſider the equator and poles as if for a ſmall number of years they continued immoveably the ſame.

783 The uſe of ſecondaries of the equator is to ſhew the places of ſtars, or of any points in the heaven, in reſpect of the equator; in the ſame manner as the ſecondaries of the ecliptic ſhew their places in reſpect of the ecliptic: the arc of a ſecondary of the ecliptic, or circle of latitude, contained between a ſtar and the ecliptic is called the latitude of that ſtar; the arc of a ſecondary of the equator, or circle of declination, contained between a ſtar and the equator is called the declination of that ſtar: an arc of the ecliptic reaching, according to the order of the ſigns, from the point ♈ to the point where the ecliptic is cut by a circle of latitude drawn through a ſtar is called the longitude of that ſtar; an arc of the equator reaching, according to the order of the ſigns, from the point ♈ to the point where the equator is cut by a circle of declination drawn through a ſtar is called the *right aſcenſion* of that ſtar: thus we ſee that declination and right aſcenſion are the ſame in reſpect of the equator, as latitude and longitude are in reſpect of the ecliptic[a]. Latitude of ſtars has been treated of, § 646: longitude, § 659: and declination, § 340: right aſcenſion only remains to be farther explained.

784 When aſtronomers conſider what point of the equator comes to the eaſtern part of the horizon, and conſequently riſes at the ſame time with a ſtar, they ſay, the *aſcenſion* of a ſtar is an arc of the equator which, proceeding from the point ♈, or the point of the vernal equinox, according to the order of the ſigns, is contained between the point ♈ and the point of the equator that riſes with that ſtar: aſcenſion is, according to the different poſition of the ſphere, right, or oblique.

Scholium. This is a compendious way of ſpeaking, as *Kepler epit. aſtron. p.* 240, obſerves: the greek words συνανατολη and συγκαταδυσις, which may be tranſlated coaſcenſion and codeſcenſion, are more properly applicable to a point of the equator, than to an arc of it which is terminated at one end by that point: however we muſt be content to take commonly received terms of art as we find them.

785 The *right aſcenſion* of a ſtar is an arc of the equator which, proceeding according to the order of the ſigns, reaches from the point ♈, the point

a Declination is called latitude from the equator by *Ptolemy:* right aſcenſion might have been called longitude upon the equator. *Veteres longitudinem et latitudinem ſtellarum penes æquatorem conſideraſſe, oſtendit* Petavius, *variar. diſſert. l.* 2. *c.* 2.

FIG. of the vernal equinox, to the point of the equator that riſes with the ſtar in
67 a right ſphere: let fig. 67 be a projection or picture of the eaſtern half of the concave ſphere of the heaven, let E Q be the equator, S N the horizon, which, in a right ſphere as is here drawn, is cut by the equator at right angles, by § 346; let N be the arctic, S the antarctic pole, which in a right ſphere are in the plane of the horizon; the curves N A S, N B S, &c, and the ſtrait line N D S are projections of ſemicircles of declination: now if we imagin the ſphere to move upon the poles N S according to the order of of the letters A B C D, a ſtar at D or at E or any point in the ſemicircle of declination N D S comes to the horizon and riſes above it at the ſame time with the point ♈; and therefore we ſay its right aſcenſion is o: a ſtar at F or G or any point in the ſemicircle of declination N C S riſes at the ſame time with the point C, and its right aſcenſion is the arc ♈ C, or ſo many degrees minutes and ſeconds as that arc contains: a ſtar in the ſemicircle N B S riſes with the point B, and its right aſcenſion is the arc ♈ B, &c.

786 The term right aſcenſion is taken from a right ſphere[a], as is alſo the common definition of it given § 785: but we are not therefore neceſſitated to go under the line, in order to find the right aſcenſions of the heavenly bodies; they may be obſerved in any place, by an inſtrument fixed in the plane of the meridian, as deſcribed § 408, and a good clock, to obſerve the times of their *tranſits:* ſee § 409. For, ſince the plane of every meridian extended paſſes through the celeſtial poles, § 299, &c; and ſince, in a right ſphere, the plane of the horizon extended paſſes alſo through the poles, it follows, that every meridian is coincident with the horizon of ſome place or other in a right
67 ſphere: thus, fig. 67, the plane of the meridian, N A S is coincident with the horizon of the place under the line which, in the ſituation of the heaven here repreſented, has E for its zenith: for this reaſon, the point of the equator which comes to the plane of any meridian[b], at the ſame time with a ſtar gives us the right aſcenſion of that ſtar[c].

787 It is true, the point ♈, as well as every other point of the equator, is inviſible; and therefore the right aſcenſions of ſtars, which muſt be reckoned from ♈, cannot be found directly and immediately; but they may by the help of the ſun; becauſe the theory of his motion is ſo well aſcertained, that his place in the ecliptic at any time is eaſily known, from whence his right aſcenſion may be calculated; and this being given, *the right aſcenſion of*

a *Ptolemy* calls it aſcenſion in a right ſphere. b § 303. c Since all ſecondaries of the equator and all meridians are drawn through the poles; when any one point of a ſecondary of the equator is in the plane of the meridian, every other point of that ſecondary is alſo in the plane of the meridian: and therefore the definition of right aſcenſion in § 783, expreſſes the thing very well.

any

any ſtar may be thus *found by obſervation:* let the motion of a clock be ſo adjuſted that the hand may go round the 24 hours exactly in the time of a rotation of the earth, that is, in the time which paſſes between any fixt ſtar leaving the plane of the meridian and retuning to it again: ſet the hand of the clock thus regulated at 12 when the ſun is in the meridian; obſerve the hour minute and ſecond when the fixt ſtar whoſe right aſcenſion is required comes to the meridian; and the intermediate time, turned, by the table § 316, into degrees minutes and ſeconds of the equator, is the difference between the right aſcenſions of that ſtar and of the ſun when before obſerved in the meridian: add to this difference the right aſcenſion of the ſun at that time, and you have the right aſcenſion of the ſtar: thus, this preſent year 1740, june the firſt at noon, the right aſcenſion of the ſun is 80° 54′ 53″, Arcturus comes to the meridian at 8ʰ 40′ 16″ * in the evening, this turned into degrees minutes and ſeconds is 130° 4′ 0″, which added to the right aſcenſion of the ſun gives the right aſcenſion of Arcturus 210° 58′ 53″.

If the hour circle of a clock be divided into 360°, and, when the ſun is in the meridian, the hands be ſet at the degree minute and ſecond which mark the right aſcenſion of the ſun; they will, when a ſtar comes to the meridian, point out its right aſcenſion directly, without the trouble of reducing time to degrees minutes and ſeconds of the equator.

788 The foregoing ſection ſhews how to find the right aſcenſion of a ſtar, by the time of its tranſit; the converſe of this is *to find the time of the night*, by obſerving the tranſit of a ſtar whoſe right aſcenſion is known: this is done by turning the arc of difference between the right aſcenſions of the ſun and the ſtar into time: thus, I find by an ephemeris, that june the firſt 1740, the right aſcenſion of the ſun is 80° 54′ 53″, the right aſcenfion of Arcturus 210° 58′ 53″, the difference 130° 4′ 0″, the time anſwering to 130° 4′ 0″ is 8ʰ 40′ 16″: ſo much then does Arcturus come to the meridian after the ſun*. The time of the night may alſo be found by the height of a ſtar whoſe right aſcenſion and declination is known, if we have firſt the latitude of the place of obſervation: but this requires trigonometrical calculation. By either of theſe methods *a clock* may be *corrected.* The *latitude* of the place where we are may be *found* by the meridian altitude of a ſtar whoſe declination is known; or of the ſun, if his declination be known for the time of obſervation: ſee § 411 to 415. This is of uſe at ſea, ſee § 568.—We have in ſome almanacks a *table of the declination of the ſun*, for every day of the year: and *a table of the right aſcenſions and declinations* of the principal ſtars; which, will ſerve, for the uſe of ſailors, for ſeveral years, without ſenſible error.

* The time uſed § 787, 788, & 789, is ſydereal time, which I ſhall ſhew how to reduce to common time, hereafter.

FIG. 789 The *difference of right aſcenſions of* two *ſtars* is *found*, by turning the time between their coming to the meridian into degrees minutes and ſeconds
67 of the equator, by the table § 316: thus, fig. 67, if the ſtar B comes two hours later to the meridian than the ſtar C, the difference of their right aſcenſions is 30°; and ſo much does the right aſcenſion of B exceed that of C.—It is eaſy to ſee, that all ſtars in the ſame ſemicircle of declination come to the meridian at the ſame time; and conſequently have the ſame right aſcenſion. The *right deſcenſion* of a ſtar is the ſame with its right aſcenſion; for, in a right ſphere, the ſame point of the equator that riſes with a ſtar ſets with it alſo.

790 *Oblique aſcenſion* of a ſtar is an arc of the equator reaching, according to the order of the ſigns, from the point ♈ to the point of the equator which riſes with the ſtar, in an oblique ſphere: the difference between the right and oblique aſcenſion of a ſtar is called its *aſcenſional difference*. Oblique aſcenſion and aſcenſional difference are relative to ſome given latitude: for the farther any place is removed from a right ſphere, the greater is the aſcenſional difference of any ſtar in that place. *Oblique deſcenſion* of a ſtar is an arc of the equator reaching, according to the order of the ſigns, from ♈ to the point that ſets with the ſtar, in an oblique ſphere: oblique deſcenſion is alſo relative to ſome latitude, in the ſame manner as oblique aſcenſion is. The oblique aſcenſion or deſcenſion of a ſtar may be found by calculation, for any place, if the latitude of the place and the right aſcenſion and declination of the ſtar be firſt known.

791 We have in ſome books of aſtronomy *tables of oblique aſcenſions* for the ſeveral degrees of the ecliptic, for ſeveral latitudes[a]: by means of theſe, ſince the ſun's place in the ecliptic is known for every day in the year, we may find what his oblique aſcenſion is, any day of the year, in any of the latitudes for which the tables are made: ſome authors give us alſo *tables of aſcenſional differences*[b]: The arc of aſcenſional difference of the ſun for any day of the year in a given latitude, turned into time, ſhews, for that latitude, how many hours and minutes before or after ſix the ſun riſes that day: the ſame arc, turned into time, ſhews alſo, for the ſame day and latitude, how many hours and minutes before or after ſix the ſun ſets: it is eaſy from hence to find the length of the artificial day, that is, how many hours and minutes the ſun is above the horizon; and if this time be taken from the natural day of 24 hours, the remainder is the length of the night: but this is ſpeaking aſtronomically, without regard to refraction; for that lengthens the day and ſhortens the night, as was before obſerved, § 757.

a Ricciol. *l.* 10. *pag.* 562. b Ricciol. *ib. pag.* 561. Gregory's aſtronomy book 2. prop. 60.

792

792 The right aſcenſions and declinations of the ſtars being known, their longitudes and latitudes may be found by calculation; and converſely, their longitudes and latitudes being known, their right aſcenſions and declinations may be found by calculation. In order *to make a catalogue of the ſtars*, their right aſcenſions and declinations are found by obſervations made with proper inſtruments; and from thence their longitudes and latitudes are calculated, and ſet down in the catalogue. The places of ſtars are ſet down in the catalogues according to their longitudes and latitudes, rather than according to their right aſcenſions and declinations; becauſe their latitudes continue invariably the ſame, and their longitudes change regularly, at the rate of 50″ in a year, ſee § 607, and 657, ſo that the longitude of any ſtar is eaſily found for any year paſt preſent or to come, by any catalogue: whereas both the right aſcenſions and declinations of ſtars are, by the preceſſion of the equinoctial points altering the ſituation of the celeſtial equator, changed every year a little, and that irregularly; the change not being the ſame in all the ſtars, but greater in ſome than in others, according as they are differently ſituated in reſpect of the ecliptic and the equator.

793 When I ſay *the latitudes of the ſtars* are *invariable*, it is upon a ſuppoſal that two poſitions are true, which are both controverted amongſt the aſtronomers: one of theſe is, that the ſtars are ſo fixed as to keep their places immoveably; the other, that the orbit of the earth continues unalterably in the ſame plane, and conſequently that the ecliptic is invariable: as to the firſt of theſe poſitions, *Ptolemy*[a] has a chapter on purpoſe to prove that the ſtars are fixed, and for that end inſtances in a conſiderable number of ſtars which he found to lye in right lines with one another, or to form triangles and other figures, exactly in the ſame manner as *Hipparchus* had deſcribed them, above 260 years before him. *Tycho*[b] not only found thoſe ſtars to keep their places in reſpect of one another, but ſeveral others alſo to anſwer ſo exactly to that deſcription, that he declares it to be his opinion, that all the differences, which he found between the diſtances of ſome ſtars from one another, as they were obſerved by himſelf and as they are ſet down by the ancients, are owing, either to the inaccuracy of the obſervations of the ancients, and the imperfections of their inſtruments; or to the miſtakes of tranſcribers, who, in ſome inſtances, have manifeſtly given us wrong numbers, and very probably in many more. On the other hand, Dr. *Halley*[c] has obſerved, that the Bull's eye, Sirius, and Arcturus are now found to be above half a degree

a *almageſt. l. 7. c.* 1. b *epiſt. aſtronom. p.* 43. *progymnaſmat. p.* 234. c Philoſ tranſact. n. 355. *Jones*'s abridg. p. 225.

more

more ſoutherly than the ancients reckoned them: that this difference cannot ariſe from the errors of tranſcribers; becauſe the declinations of theſe ſtars, ſet down by *Ptolemy*, as obſerved by *Timocharis*, *Hipparchus* and himſelf, ſhew their latitudes given by him are ſuch as thoſe authors intended: that it is ſcarce to believed, that thoſe three obſervers could be deceived in ſo plain a matter. To this he adds, that the bright ſtar in the ſhoulder of Orion has in *Ptolemy* almoſt a whole degree more ſoutherly latitude than at preſent: that an ancient obſervation, made A. D. 509, at Athens, as *Bullialdus* ſuppoſes, of an appulſe of the moon to the Bull's eye, ſhews that ſtar to have had leſs latitude at that time than it now has: that as to Sirius, it appears by *Tycho*'s obſervations that he found him 4 minutes and an half more northerly than he is at this time. All theſe obſervations, compared together, ſeem to favour an opinion, that *ſome* of the *ſtars have a motion of their own*, which changes their places in the ſphere of the heaven: this change of place in the ſtars, if there be any ſuch, may, as Dr. *Halley* obſerves, ſhew it ſelf in ſo long a time as 1800 years, though it be entirely imperceptible in the ſpace of one ſingle century: and it is likely to be ſooneſt diſcovered in ſuch ſtars as thoſe juſt now mentioned; becauſe they are all of the firſt magnitude, and may therefore probably be ſome of the neareſt to our ſolar ſyſtem.

794 As to the ſecond poſition, that *the ecliptic is invariable*, *Tycho*[a] brings ſeveral inſtances of ſtars whoſe latitudes he found to be different from what they were in *Ptolemy*'s catalogue; and ſays that, according to his obſervations, the latitudes of the northern ſtars has increaſed, and the latitudes of the ſouthern ſtars decreaſed; and that this increaſe and decreaſe of latitude is greater or leſs in different ſtars, according as they are nearer to or farther from the ſolſtitial colure. This would imply ſuch a change in the plane of the earth's orbit as cauſes the northern parts of the ecliptic to recede from the north pole, and the ſouthern parts to recede from the ſouth pole: *Tycho*[b] indeed confeſſes, that his own obſervations of ſome of the biggeſt ſtars, and particularly of the Bull's eye and Sirius, compared with the numbers of *Ptolemy*, were againſt this opinion of the change of the ecliptic; but, to ſilence this objection, he has recourſe again to the inacuracy of the ancient obſervations, and the miſtakes of tranſcribers. *Ricciolus* takes notice that *Tycho* ſeems to allow the obſervations of the ancients to be good, or reject them as faulty, according as they favour, or ſtand againſt his opinion about the change of the ecliptic[c]. If we conſider the mutual attraction of the heavenly bodies,

a *epiſt. aſtronom. p.* 30, 65, 66, 69, 70, 86. *progymnaſm. p.* 233, *ad* 240. b *progymnaſm. p.* 246.
c *almag. l.* 6. *c.* 15.

of

of which more in another place, we cannot think it impoſſible that both the plane of the earth's orbit, and the planes of the reſt of the planets ſhould be ſubject to ſome alterations; but that there has been an actual change in any of theſe, we cannot reaſonably conclude, without proof from obſervations: in this enquiry, there are four things to be conſidered in the orbit of every planet; 1 its excentricity, 2 the place of its aphelion, 3 the place of its aſcending node, 4 the inclination of its plane to the plane of the orbit of any of the other planets: it has been the opinion of many great aſtronomers[a], that all theſe continue invariable in reſpect of the fixt ſtars: ſome aſſign to the nodes and aphelia a very ſlow motion, but this opinion ſeems to have been built upon ſome preconceived hypotheſis, rather than any actual diſcovery of ſuch motion[b]: perhaps the aphelion of ſaturn may be excepted from this remark, which, according to *Maraldi*, has a motion of about a minute in a year, according to the order of the ſigns[c]; and the nodes of jupiter, which the ſame author makes to go backwards at the rate of about 37″ in a year[d]. As to the planes of the planetary orbits, we have no obſervations to ſhew that any of them was ever inclined to the reſt in a different angle from what it is at preſent: the change of latitude of ſome ſtars ſuppoſed by *Tycho* does not appear to be made out clearly enough to conclude from thence any change of the plane of the ecliptic: on the other hand, two occultations of the ſame ſtar by the planet mars, with a ſpace of 1934 years between, the earth being at the time of both obſervations very nearly in the ſame place of her orbit, make it extreamly probable that the planes of both the orbit of mars and of the earth have continued in the ſame ſituation during that long interval[e].

795 For the excentricities of the orbits of the planets ſee § 670 and 669: their aphelia and perihelia are marked in the 11th figure, by the letters A and P. The inclinations of the planetary orbits to the plane of the ecliptic have been given in round numbers, § 638; and, together with their aſcending nodes, are ſhewed in the 24th figure, explained § 651: I ſhall now ſet them down to a greater exactneſs, with the place of the aphelion and aſcending node of each planet, for the year 1700; they are all taken from the tables of *De la Hire*, except thoſe of mercury, in which I follow the accurate determination of Dr. *Halley*[f].

a Streete, *aſtronomia Carolina*, p. 45. Du Hamel, *Reg. ſcientiar. Acad. hiſtor. l.* 4. *c.* 4. Newton. *princip. lib.* 3. *prop.* 14. *Jones*'s Phil. tranſ. abridg. vol. 4. p. 305 & 320. *v. et* Ricciol *l.* 3. *c.* 26.
b Kepler. *tabb. Rudolphin.* c *Memoires d'Acad. Royale* 26 *novemb. ann.* 1704, d *Mem. d'Acad.* 20 *fevrier* 1706. e The firſt of theſe occultations is mentioned by *Ptolemy almag. l.* 10. *c.* 9. the ſecond is in the Phil. tranſ. *Jones*'s abr. vol. 4. p. 305. f Phil. tranſ. n 386.

	Aphelion.	☊	Inclination.
♄	♐ 29° 15′	♋ 21° 56′	2° 33′ 30″
♃	♎ 10 17	♋ 7 12	1 19 20
♂	♍ 0 35	♉ 17 25	1 51 0
♀	♒ 6 56	♊ 13 54	3 23 5
☿	♐ 12 44	♉ 14 42	6 59 20

CHAP. 16. WHETHER ANY OF THE STARS CHANGE THEIR PLACES OR NOT: THE OBLIQUITY OF THE ECLIPTIC VARIABLE.

796 The ſubject of § 793 in the foregoing chapter is of ſo curious a nature, that I thought it would deſerve a farther diſcuſſion, if we could find materials for it: if the diſtances of ſeveral ſtars from one another were at any time to be taken exactly, and, after a conſiderable number of years, the ſame diſtances were to be carefully meaſured again, it ſeems to be a likely way to diſcover whether the ſtars ſo obſerved change their places or not: the ancients have given us nothing of this kind; *Tycho* [a] and the *Prince* of *Heſſe* [b] were the firſt who left us any diſtances taken with good inſtruments, and their accounts agree ſo well together, as to give us reaſon to believe they are as exact as could be expected from plain ſights. I have compared a great number of their diſtances, particularly thoſe of the brighteſt ſtars, with obſervations of the ſame diſtances taken by later aſtronomers, eſpecially *Hevelius* [c] and *Flamſteed* [d], and can find no ſuch change in any of them as will ſhew that either Capella, Lyra, the Bull's eye, the bright ſtar in the ſhoulder of Orion, the Lyon's heart, Spica ♍, or Sirius have, in the interval of time between the obſervations of *Tycho* and *Flamſteed*, which is about 100 years, gone out of their places: but in Arcturus the caſe at firſt appeared to be different; *Hevelius* ſets down the diſtance of that ſtar from Lyra 4′ greater than *Tycho* had obſerved it, 72 years before him; and *Flamſteed*, 22 years after, meaſured the diſtance between the ſame two ſtars ſtill 3′ greater than *Hevelius* found it; ſo that, if Lyra ſtood ſtill all the while, there was an appearance of Arcturus having gone 7′ out of his place in 100 years: it ſeemed ſome confirmation of this motion of Arcturus, that *Flamſteed* found his diſtance from the head of Hercules 3′ greater than it is ſet down by the *Prince* of *Heſſe*;

a *epiſt. aſtron. p.* 50 *&* 51, *progymnaſm. p.* 229 *&* 230, *& in* Tychon. *hiſtor. cœleſt. paſſim.*

b *v. lib.* 12 *hiſtor. cœleſt.* Tychon. *a* Lucio Barretto (*i. e.* Alberto Curtio) *edit. nam hoc anagrammate cum nomen ſuum texiſſe ait* Ricciol. *aſtron. reformat. l.* 4. *c.* 8. *p.* 219.

c *machin. cœleſt. part.* 4.

d *hiſtor. cœleſt. vol.* 1.

and

and that his distance from the Lyon's tail was a little decreased: to make these observations consistent with one another, Arcturus must have gone almost directly towards the ecliptic, so as to decrease his latitude about 7′; and indeed his latitude in *Flamsteed*'s catalogue is $5'\frac{1}{2}$ less than in that of *Tycho*: thus far every thing favoured the opinion of Arcturus having a motion almost directly towards the ecliptic; upon this, I considered several other stars to the north of Arcturus, from which he must have grown more distant, if he had really had any such motion; and several stars to the south of him, to which such a motion would have made him approach nearer: the distances of Arcturus from these stars being calculated from their longitudes and latitudes in the different catalogues of *Tycho*, the *Prince* of *Hesse*, *Hevelius* and *Flamsteed*, I found that very few of them agreed with the supposed motion of Arcturus, but that the greatest part of them came out such as shewed he had kept his place; for I seldom found the difference of the distances computed from the several catalogues to exceed 2′, and these differences fell out so, that they could not all be true; since from some of them Arcturus appeared to have gone towards the south, and from others towards the north: so that, upon the whole, after a pretty long and careful enquiry, I am inclined to think the *stars keep their places immoveably*, and this will appear the more probable, if we consider the fixt stars as so many suns: see § 625.

797 It has been a subject of controversy amongst astronomers, whether *the obliquity of the ecliptic* be *variable* or not; that is, whether the angle between the planes of the ecliptic and equator, mentioned § 733, continues always unchangeably the same, or is subject to alteration: it is also disputed among those writers who hold it liable to change, whether that change be regular or irregular. It is certain that the obliquity of the ecliptic is at present found to be above a third part of a degree less than *Ptolemy* has given it us: if we enter into a detail of all the observations of it which were made from *Ptolemy*'s time down to *Tycho*, we shall find that later observers have generally found it less than those who went before them; but this has not always been the case: for there are some instances where, on the contrary, later observations have made it a few minutes greater than some preceding ones. They who will have the obliquity of the ecliptic to have been always the same that it is at present get rid of all these difficulties, by throwing upon the inaccuracy of the observations of the ancients, and the imperfection of their instruments, all the differences that are found between them and the moderns in this affair: others think this is treating the ancients with too little respect; for, though it appears by *Ptolemy* that they did not pretend to observe more nicely than to a 6th part of a degree, and their instruments, as far as we

 have

have any account of them, fall far ſhort of thoſe made uſe of by the moderns; yet it can hardly be imagined they could be ſo greatly miſtaken in a matter ſo eaſy to be known, and ſo well deſerving their attention. As for thoſe who ſuppoſe that the obliquity of the ecliptic is ſubject to a ſort of libration, increaſing in ſome ages and decreaſing in others, they certainly attribute a greater degree of exactneſs to the obſervations upon which they ground this fancy, than there is any good reaſon to do. Some have thought that the obliquity of the ecliptic has been always gradually decreaſing, the planes of the ecliptic and equator growing continually nearer to coincidence: this opinion, beſides its being grounded upon a compariſon of ancient and modern obſervations, receives a good deal of ſupport from the conſideration of the ſhape of the earth, as we ſhall ſee by and by, § 802.

798 The obliquity of the ecliptic is equal to the diſtance of either tropic from the equator, which is the ſame with half the diſtance between the two tropics: the beſt way of finding it, becauſe leaſt liable to error from refraction, is to take the height of the ſun when he is in the ſummer tropic; the height of the pole, and conſequently the complement thereof, the height of the equator, being firſt known in the place of obſervation: this gives us the diſtance of the tropic from the equator directly. There is another way of finding this, the only one made uſe of by the ancients, and that is, to obſerve the meridian height of the ſun in each tropic: but then refraction muſt be taken into the account; for refraction increaſes the meridian altitude of the ſun, when he is low in the winter ſolſtice, more than it does when he is high and more out of the reach of vapours in the ſummer ſolſtice; thus the tropics are in appearance brought nearer to one another by refraction, in the ſame manner as the upper and lower edge of the ſun's diſk were ſhewn to be, § 754; for want of being aware of this, the ancients meaſured the diſtance of the tropics leſs than it really was: they fell alſo into another miſtake of ſuppoſing the parallax[a] of the ſun too great, which operated the ſame way, and diminiſhed alſo the diſtance between the tropics, and that about twice as much as they leſſened it by not conſidering refraction[b]; theſe errors of the ancients, of ſuppoſing a falſe parallax, and neglecting refraction, are no hindrance to our making uſe of their obſervations, in this diſquiſition; becauſe we know what conſequences they draw after them, and can therefore tell how to make proper allowances for them: now upon the whole, after proper allowances, the obliquity of the ecliptic comes out from the obſervations of the ancients above a third part of a degree greater than the modern aſtronomers have found it. *Louville*, after having compared all the ancient obſerva-

a Parallax will be explained in the next chapter. b See the remarks.

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tions he could meet with, was of opinion that the obliquity of the ecliptic decreaſed at the rate of 1′ in an hundred years, and from a great number of obſervations made by himſelf about the year 1711, ſet it down 23° 28′½[a], which is half a minute leſs than *Flamſteed* and *De la Hire* made it: he goes ſtill farther and thinks he diſcovered it to be 5 ſeconds leſs in the year 1720 than he had obſerved it in the year 1714: but, notwithſtanding the great care with which his obſervations appear to have been made, it ſeems hardly credible that any one can, in an affair of this nature, be certain he has arrived to ſuch a degree of exactneſs as is here pretended.

Louville, for the farther ſupport of his opinion, fetches arguments from the times of fabulous antiquity, upon a preſumption however that fable has generally ſome truth for its foundation. He cites *Herodotus* as ſaying that the ancient Egyptians had a tradition among them, that the ecliptic had once been perpendicular to the equator; this is ſo odd a fancy, that he thinks it hard to imagin how it ſhould ever have come into their heads, except they had actually found by obſervation that thoſe two circles were grown nearer to one another than they had formerly been: if they had made ſuch a diſcovery, it was natural for them to ſuppoſe that there had been a time when the ecliptic and equator were at the greateſt diſtance from coincidence that was poſſible; they might then ſet down what they had only thus ſuppoſed, as a fact which had been obſerved by them: but this is all miſtake; *Herodotus* only ſays that the Egyptians affirmed the ſun, in the ſpace of 11340 years, during the reigns of their ancient kings, to have altered his courſe four times, twice riſing where he then ſet and ſetting where he roſe[b]: which cannot be explained by the change of the obliquity; and ſeems to be only an idle amuſing ſtory, invented to ſupport their vain pretenſions to antiquity, but fit to paſs only among perſons ignorant of aſtronomy[c].

He goes on to tell us from *Diodorus Siculus*, that the Chaldeans pretended to have aſtronomical obſervations of 403000 years before the time of *Alexander* the great: this extravagant account will have ſome foundation, if we allow the Chaldeans to have found out that the obliquity of the ecliptic diminiſhed at the rate juſt now mentioned, of one minute in 100 years; for, this being ſuppoſed, if we run back 402942 Chaldean years from the time of *Alexander*'s entry into Babylon, we ſhall come to the time when the ecliptic and equator muſt have interſected each other at right angles: and this is but 58 years ſhort of the time from which the Chaldeans pretended to date their firſt ob-

a *Hiſtoire d'Acad. Royale pour l'ann.* 1714 *ſur l'equinoxe du printemps de* 1714. *Hiſtoire d'Acad. ann.* 1716. *v. & memoires pour l'ann.* 1721. b in Euterpe. c See the remarks.

ſervations

ſervations. It is remarked upon this occaſion, that there cannot be given a more probable account of the fabulous antiquity of the Egyptians and Chaldeans than this, that, from obſerving ſome very ſlow motions in the heaven they calculated the periods of ſuch motions, and fixed upon ſome time when they ſuppoſed them to begin, and dated from thence the origin of the world, and of their own nation, which they were willing to have believed to be of equal antiquity with the world it ſelf: we have ſome thing like this fanciful way of reaſoning among ſome Chriſtian aſtronomers, who have been of opinion that the ſun's apogee was in the point ♈ at the time of the creation, and pretend from thence to fix the age of the world, which by that method comes out not many years different from the numbers in the tranſlation of the bible called *the ſeptuagint.*

799 We are told[a] that, notwithſtanding theſe reaſons of *Louville*, the reſt of the aſtronomers of the French academy were of the contrary opinion: it was alledged by *De la Hire*, that *Ptolemy* thought the obliquity of the ecliptic unchangeable; and that therefore in determining it he had leſs regard to his own obſervations than to thoſe aſtronomers who preceded him, as *Hipparchus* and *Eratoſthenes:* that he was more attentive to the theory than to the practical part of aſtronomy; and more a mathematician than an obſerver; and that therefore he ſettled the obliquity, manifeſtly upon the credit of the ancients[b]. In anſwer to this, it muſt be owned that *Ptolemy* paid ſuch a deference to *Hipparchus*, whom he commends greatly for his fidelity and induſtry, as to take his obliquity, and calculate his tables according to it; but the queſtion here is not what was *Ptolemy*'s opinion in this matter, but what is the reſult of his obſervations: which, as to this particular, appear to have been made with a good deal of care and exactneſs. He deſcribes two inſtruments proper for that purpoſe, he recommends one of them as more commodious than the other; he tells us, he took meridian altitudes of the ſun, and that, from ſuch altitudes, and eſpecially thoſe obſerved by him at many returns of the ſolſtices, he found the diſtance between the tropics to be 47 degrees and more than half but leſs than three fourths of a degree; which he ſays is nearly the ſame as *Eratoſthenes* had determined it, and *Hipparchus* had made uſe of[c]. Now, according to them, if the ſolſtitial colure be divided into 83 equal parts, the diſtance between the tropics contains 11 of thoſe parts: thus the obliquity of the ecliptic comes out from the obſervations of *Eratoſthenes* $23^\circ\ 51'\ 20''$, from thoſe of *Ptolemy* $23^\circ\ 48'\ 45''$.

a *Hiſtoire d' Acad. pour l' annee* 1716. b *memoires pour l' annee* 1716. c *almogeſt l.* 1. *c.* 10.

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800 I here follow the greek text of *Ptolemy*, and his commentator *Theon*[a], who lived alſo at Alexandria: there are, in this and many other places, faults and omiſſions in the tranſlation of *Trapezuntius*, which it is evident *De la Hire* made uſe of, without conſulting the original: and this may be one reaſon of his having ſo mean an opinion of the above mentioned obſervations of *Ptolemy*; for who ever looks only into the latin tranſlation will imagin his quadrant with which he took the meridian altitudes of the ſun was divided only into 90 degrees; whereas it is manifeſt, by the greek, and by *Theon*'s comment, that each degree was ſubdivided, though we are not told into how many parts: *Theon* ſays, into as many parts as poſſible; from *Ptolemy*'s determining the diſtance between the tropics, to have exceeded the number of whole degrees, more than half and leſs than three fourths, as above, I am apt to think each degree was divided at leaſt into 4 equal parts: and ſurely with ſuch an inſtrument a careful obſerver could not eaſily be miſtaken a quarter of a degree. But to give us an inſtance of *Ptolemy*'s want of accuracy, we are told that he ſettled the latitude of Alexandria, his own obſervatory, 13′ leſs than *Chazelles*, who went thither on purpoſe in the year 1700 with proper inſtruments, found it to be; and leſt it ſhould be thought this difference might ariſe from the ſituation of Alexandria being different now from what it was formerly, it is ſaid that the contrary to this appears from the ruins of the ancient buildings ſtill remaining[b]: now in anſwer to this, not to mention that *Greaves* took the latitude of that place 7′ leſs than *Chazelles*, and therefore differed but 6′ from *Ptolemy*, it may be remarked, that though it appears from *Ptolemy*'s *almageſt*, *l.* 1 *c.* 10, that he knew a much better way of obſerving the latitude than *De la Hire* fancies he made uſe of, yet he might more eaſily miſtake 13′ therein, than be out two thirds of a degree in the diſtance between the tropics.

801 It is objected, that *Pappus* of Alexandria[c], 270 years after *Ptolemy*, ſuppoſes ſuch a ratio between the diameters of the ecliptic and of the tropic as brings out the obliquity of the ecliptic but 23° 30′, and it is concluded from hence that this was the well known meaſure of it in the time of *Pappus*, and that conſequently *Ptolemy*'s meaſure muſt have been then found to be erroneous by ſome later aſtronomers; ſince it is not likely it ſhould have decreaſed from 23° 51′ to 23° 30′ in ſo ſhort a time: but this is an haſty concluſion, for *Pappus* ſays nothing of any obſervations of the obliquity, nor does his ſubject lead him to it, he had only occaſion to prove that the diameter of the ecliptic was leſs than double the diameter of the tropic; and, in

a *edit. Baſil. anno* 1538. b *memoires pour l'ann.* 1716. c *In collectionib. mathemat. l.* 6. *prop.* 35.

order

order to this, he aſſumes, that the diſtance between the centers of the ecliptic and of the tropic is to the ſemidiameter of the tropic as 10 to 23: now theſe numbers are probably the ſame as he would have made uſe of if he had acquieſced in *Ptolemy*'s meaſure of the obliquity, being ſufficient for his purpoſe, which did not require larger or more exact numbers; ſo that no conſequence can be drawn from hence of *Pappus* being of a different opinion from *Ptolemy:* but, to put the matter out of all doubt, we have extant great part of the comment of *Pappus* upon the 5th book of *Ptolemy*'s *almageſt*[a], wherein he mentions the ſame obliquity of the ecliptic that *Ptolemy* made uſe of, 23° 51′, without any hint of his diſſenting from it: this deſerves the more to be taken notice of, becauſe not only *De la Hire*, but other writers alſo, lay a great ſtreſs upon the paſſage quoted out of *Pappus* in the beginning of this ſection: add to this, that *Theon*[b], who wrote after *Pappus*, and *Proclus* called *Diadochus*[c] uſed the ſame meaſure; which the Alexandrian aſtronomers ſeem ſo long to have taken from *Eratoſthenes*, without any ſuſpicion of its being ſubject to alteration.

802 *De la Hire* objects farther againſt *Ptolemy*'s obſervations, that he has in many inſtances, given us the latitudes of ſtars above a quarter of a degree different from what they are now found to be: but theſe errors are eaſily accounted for, if we conſider that his obſervations of the ſtars were made with a zodiacal *armilla*, an inſtrument that by its conſtruction muſt be liable to great errors; and accordingly we find that *Tycho*, having made ſuch an inſtrument at a great expence, was induced, after a little experience of it, to lay it aſide as uſeleſs: whereas the meridian altitudes of the ſun were taken by *Ptolemy* with a quadrant drawn upon a ſmooth ſtone, (marble I ſuppoſe) placed in the plane of the meridian, divided into degrees with thoſe degrees farther ſubdivided as has been ſaid: they who are for the immutability of the obliquity will alledge, that, though *Tycho* ſettles it 23° 31′ 30″, greater by 2′$\frac{1}{2}$ than it is at preſent, *Flamſteed*, from the obſervations of *Tycho*, after proper allowances, brings out the ſame obliquity as he does from his own obſervations made 100 years after: in anſwer to this it may be remarked, that, according to the theory juſt now mentioned, the obliquity ought to decreaſe but 1′ in the time between *Tycho* and *Flamſteed*, and it may very well be ſuppoſed that *Tycho*, with his plain ſights, might miſtake as much as that; nay it is certain that, in his meridian altitudes of the ſun taken the ſame day with different inſtruments there is often a difference of above one, and ſometimes of more than two minutes. *Tychon. hiſt. cœleſt. paſſim.*

a *inter* Theonis *commentar. edit. Baſil. ſupra citat. pag.* 258. b *edit. Baſil. p.* 60. c about A. D. 500.

A TABLE

A TABLE OF THE OBLIQUITY OF THE ECLIPTIC.

	Authors Names.	Years before Christ	Obliquity.
L	*Pytheas*	320	23° 49′ 23″
	Eratosthenes	230	23 51 20
		after Christ	
	Ptolemy	140	23 48 45
F	*Almamon*	832	23 35
	Albatennius	890	23 35
F	*Thebet*	911	23 33 30
F	*Abul Wafi* and *Abu Hamed*	999	23 35
F	Persian tables in *Chrysococca*	1004	23 35
F	*Albatrunius*	1007	23 35
F	*Arzakel*	1104	23 33 30
F	*Almeon*	1140	23 33 30
F	*Chojah Nassir Oddin*	1290	23 30
F	*Prophatius* the Jew	1300	23 32
F	*Ebn Shatir*	1363	23 31
	Ulug Beigh	1437	23 30 17
R	*Purbachius* and *Regiomontanus*	1460	23 28
R	*Waltherus*	1476	23 30
R	*Wernerus*	1510	23 28 30
	Copernicus	1525	23 28 24
R	*Egnatio Danti*	1570	23 29
	Prince of *Hesse*	1570	23 30
	Tycho Brahe	1584	23 31 30
	Wright	1594	23 30
	Ricciolus	1646	23 30 20
F	*Hevelius*	1653	23 30 20
L	*Cassini*	1655	23 29 15
	De la Hire	1686	23 29
	Flamsteed	1690	23 29
L	*Bianchini*	1703	23 28 25
*	*Roemer*	1706	23 28 41
	Louville	1715	23 28 24
	Godin	1730	23 28 20

* Godin. *mem. d' Acad. ann.* 1734.

The foregoing table, taken chiefly from *Ricciolus*[a], *Flamſteed*[b] and *Louville*, ſhews what the obliquity of the ecliptic was obſerved to be, by different aſtronomers, in the ſeveral ages of the world, from the moſt ancient times wherein we have any records of its having been meaſured, down to the lateſt obſervations thereof: a view of it may induce us to think, that the angle between the planes of the equator and ecliptic is leſs now than formerly, and that it is continually decreaſing; *Louville*, having corrected the obſervations of the ancients, by making proper allowances for refraction not conſidered, and for parallax ſuppoſed to great, finds them very favourable to his opinion mentioned § 798, that the decreaſe of the obliquity is about 1′ in 100 years; his diſſertation, which is very curious, is publiſhed in latin, in the *acta eruditor. Lipſiæ*, A.D. 1719: the hiſtory of the academy of ſciences for the year 1716 gives a ſhort view of it; but at the ſame time tells us that the other aſtronomers of the academy were ſtill of opinion the obliquity of the ecliptic was invariable: perhaps this was the reaſon why this diſſertation did not find a place in their *memoires*.

803 M. *Godin* another member of the French academy of ſciences reſumed this ſubject, in the *memoires* of the year 1734: he remarks that *Louville*, notwithſtanding his great exactneſs, made uſe of the table of refractions for Paris, to correct the obſervations of the ancient aſtronomers who lived in places where refraction might be different; and that the height of the pole at Marſeilles, which is one of the chief grounds he goes upon, is not even now accurately enough determined; ſince *Gaſſendus*, *Caſſini*, and *de la Hire* differ about 4′ in ſettling it: this induced him to make uſe of ſuch modern obſervations only in this enquiry as may be depended upon for their exactneſs, and which were made in places where the refraction is well known: he proceeds in this manner; in the year 1655 the obliquity of the ecliptic came out 23° 29′ 15″, from the obſervations of *Caſſini* by the gnomon at Bologna: now it is certain, by all the obſervations made at Paris and other places, that ſince 1730 the obliquity is no more than 23° 28′ 20″; and that there cannot be an error of 5″ in this determination of it: it has therefore grown 55″ leſs in 80 years; which is very near 1′ in 90 years: and this agrees, within 5″, with the obſervations of *Richer*, *De la Hire*, *Roemer*, and *Bianchini*. Whatever may be thought of *Godin*'s objection to correcting the obſervations made at Alexandria and other places by the table of refractions for Paris, I ſee no reaſon for his queſtioning *Louville*'s determination of the height of the

a *almageſt. l. 3. c. 27, & aſtronom. reformat. l. 1. c. 6.* b *prolegom. in hiſtor. cœleſt. vol. 3.* See alſo Philoſ. tranſact. n. 163.

pole

pole at Marſeilles; ſince it appears by his diſſertation to have been very carefully taken, with a quadrant of 3 feet radius furniſhed with teleſcopic ſights.

804 *Godin* will have it that the ecliptic approaches nearer to the equator, and that the equator is immoveable: he ſuppoſes the axis of this motion to paſs through the equinoctial points, he does not ſay whether he means the places of them as now ſituated, or as they are continually changing by the preceſſion; but ſeems to mean the latter: he ſuppoſes alſo that the orbits of all the reſt of the planets are invariable, whilſt the orbit of the earth only is perpetually changing: theſe are ſuppoſitions not very eaſy of digeſtion: if they be granted, it is certain the latitudes of ſtars muſt change in proportion to the motion of the ecliptic; but their declinations no otherwiſe than from the preceſſion of the equinox: he thinks he has, from the declinations of ſtars ſet down by *Ptolemy* compared with what they are at preſent, found that the greateſt part of them have changed their latitudes, ſince the time of that aſtronomer, as much as his ſuppoſed motion of the ecliptic would cauſe them to do; but owns at the ſame time that ſeveral ſtars favoured the contrary opinion[a]: he goes on to ſhew that this motion of the ecliptic would cauſe that circle to cut the orbits of the planets ſucceſſively in different points, but different orbits in a different manner; by reaſon of their different inclinations: the conſequence of this is that their inclinations to the ecliptic muſt be changed, and their nodes muſt have a retrograde motion, a little different from one another, as well as different from what ariſes from the motion of the equinoctial points.

805 If there be any change in the obliquity of the ecliptic, which I think to be very probable, it may be cauſed either 1 by a change in the inclination of the earth's axis, the plane of the earth's orbit continuing immoveable: or 2 by a change in the plane of the earth's orbit, the axis of the earth continuing parallel to it ſelf: or 3 by a change both in the inclination of the axis and in the ſituation of the orbit of the earth. The firſt of theſe ſeems moſt likely to be the caſe; for if we conſider the ſhape of *the earth*, that it is *an oblate ſpheroid*, or a globe a little flatted like a turnep, having its diameter at the poles a little ſhorter than at the equator; and that, by reaſon of this figure of the earth, the attraction of the heavenly bodies will act upon it in the ſame manner as if it had a ring round the equator; and that the ſun, being in the plane of the ecliptic, is perpetually pulling this ring, or the protuberant parts about the equator of the earth, towards a coincidence with the plane of the ecliptic; which action of the ſun, together with the like attraction of the moon, is the cauſe of the preceſſion of the equinoxes, as I ſhall

a See § 794.

ſhew more at large when I come to treat of the cauſes of the planetary motions; if I ſay we conſider all this, it will not appear improbable, that theſe actions of the ſun and moon, which have a continual tendency to bring the plane of the earth's equator nearer to the plane of the ecliptic, ſhould gradually diminiſh the angle between thoſe planes. The moon indeed, being nearer to the earth, contributes more than the ſun towards this effect, by her attraction; for though ſhe is but twice a month in the ecliptic, yet ſince ſhe is always near it, never deviating much above 5° from that circle, and theſe deviations are as much towards the north in one half of her period round the earth as they are towards the ſouth in the other, they will ſo balance one another, that the effect of the whole attraction of the moon will be pretty much the ſame as if ſhe were carried round the earth exactly in the plane of the ecliptic. I do not here abſolutely exclude all change in the poſition of the ecliptic[a]; for, as the planets move round the ſun in different planes, their mutual attractions muſt have a tendency to change the ſituation of all their planes, and bring them nearer to a coincidence with one another: but then the diſtances of the planets from each other is ſo great, that the change here mentioned may be ſo exceedingly ſmall as not to become ſenſible in many ages.

Remarks upon § 798 note [b] pag. 276.

806 Moſt of the ancient obſervations, which are come down to us, were made at Alexandria in Egypt, where, to ſpeak in round numbers, which are ſufficient in this caſe, the height of the pole is 31°; the height of the equator 59°; the height of the ſun in the winter ſolſtice 35°, at which height refraction is about $1'\frac{1}{4}$; the height of the ſun at the ſummer ſolſtice 82°, at which height refraction is about $7''$; ſo that refraction, in that latitude, by increaſing the ſun's apparent meridian altitude above $1'$ more at the winter than at the ſummer ſolſtice, diminiſhes the diſtance between the tropics as much; and conſequently leſſens the obliquity about half that quantity: we know that *Ptolemy* determines the ſun's horizontal parallax to be very near $3'$; whereas it does not amount to above $10''$, as we ſhall ſee in the following chapter: if the ancients conſidered *Ptolemy*'s parallax in this affair, as I believe they did not[b], this at the altitude of 35° is almoſt $2'\frac{1}{2}$, and at the altitude of 82° not more than $21''$; and then theſe miſtakes about the parallax and refraction, would occaſion their ſettling the obliquity of the ecliptic about $1'\frac{1}{2}$ leſs than they would otherwiſe have done.

a See § 794.   b It is certain *Ptolemy* did not; ſee his *almageſt l.* 1 *c.* 10.

Remarks

Remarks upon § 798 note [c] pag. 277.

807 It is impoſſible to explain this tradition of the Egyptians of the diurnal riſing and ſetting of the ſun; but if they meant it of his annual riſing and ſetting, and by that expreſſion underſtood his entrance into the points of the vernal and autumnal equinox, ſome ſenſe may be made of it[a]: they ſuppoſed the equator immoveable, and, if they had found by obſervation that the obliquity of the ecliptic gradually diminiſhed, they might naturally conclude the ecliptic, or circle of the ſun's apparent annual motion, would in time be coincident with the equator; at which time there would be a perpetual equinox over the face of the whole earth: that thence forward the ecliptic would decline from the equator the contrary way; ſo that the ſemicircle of the ecliptic which is now on the north, would be then on the ſouth ſide of the equator: this would change the ſeaſons of the year, in ſuch a manner that the ſummer would happen, in Egypt, when the ſun was in north, the winter when he was in ſouth declination; the ſpring would begin when the ſun entered into ♎, and the autumn when he entered into ♈: it is eaſy to ſee that, ſuppoſing this motion of the plane of the ecliptic to be conſtant, it would cauſe the viciſſitudes of the ſpring beginning alternately, though with a very long interval of time between, when the ſun was in ♈ and ♎: the Egyptians, reſolving to raiſe their pretenſions to antiquity high enough, gave it out that four ſuch changes had been actually obſerved by their nation.

Remarks upon the table.

808 The moſt ancient obſervation here mentioned is that of *Pytheas* of Marſeilles, not that he was the firſt who is recorded to have obſerved the obliquity of the ecliptic, for we are told *Thales*[b] and *Anaximander*[c] did it near 300 years before him; but we are not informed what they found it to be: the only ancient account of the obſervation of *Pytheas* is in *Strabo l.* 2, where he is ſaid to have found that, at Marſeilles, at the ſummer ſolſtice, the length of the gnomon was to the length of its ſhadow, as 120 to 42 wanting a 5th: by the 5th I ſuppoſe, with *Gaſſendus* and *Louville*, is meant a 5th of one of the 120 parts into which the gnomon was divided; the gnomon then was to the ſhadow, in whole numbers, as 600 to 209: ſay then, as 600 to 209, ſo is radius to the cotangent of the height of the ſun's upper edge; which comes out $70° 47' 41''$: this corrected by taking away for refraction $20''$, the ſemidiameter of the ſun $15' 49''$, and adding parallax $3''$, gives the true height of

a Fracaſtorius *in homocentricis*, § 3 c 8. b Laertius *in* Thalete. c Laertius *in* Anaximandro.

the

the ſun's center 70° 31′ 35″: from whence take away the height of the equator at Marſeilles, obſerved by *Louville* 46° 42′ 12″, there remains the obliquity of the ecliptic in the time of *Pytheas* 23° 49′ 23″.

809 Since *Ptolemy* all aſtronomers ſeem, after his example, to have retained the obliquity ſettled by *Eratoſthenes*, till the time of *Almamon*: that Prince, aſſiſted by many learned men, found the greateſt meridian height of the ſun at Bagdat to be 80° 15′; the leaſt 33° 5′: the leaſt being ſubtracted from the greateſt, the remainder 47° 10′ is the diſtance between the two tropics; half of which, 23° 35′, is the obliquity. *Albatennius*, about the ſame time, brought out the ſame obliquity, from his own obſervations: I have ſet down his own words[a] becauſe his book is not common; it appears from them, that he did not conſider the parallax of the ſun at all, though ſome writers tell us the contrary. *Arzakel*, who is much commended for his abilities by *Aben-Ezra*[b], found the obliquity 1′ leſs than *Albatennius*, for his numbers are 23° 34′, according to moſt writers, though *Flamſteed* ſets them down half a minute leſs: from thence forward we find the obliquity leſſening, till the time of *Tycho*, when refraction came firſt to be conſidered in this affair; though *Walther* and even *Regiomontanus*[c] had before obſerved refraction to alter the altitudes of the heavenly bodies.

The letter F on the ſide of the table intimates the obſervation to be taken from *Flamſteed*, R from *Ricciolus*'s *almageſt* or *aſtronomia reformata*, L from *Louville*, thoſe which have no letter prefixed are from the authors themſelves: the meaſure of *Eratoſthenes* as well as that of *Ptolemy* is from *Ptolemy*'s *almageſt l.* 1 *c.* 10. As to the years ſet down in the table, I have followed the authors from whence I took the obſervations: there are in the table a few inſtances where the angle of the obliquity of the ecliptic ſeems to increaſe, being greater by a ſubſequent obſervation than more ancient ones had determined it; but this increaſe never riſes much above 2′, and ſo ſmall a difference may very well be attributed to the inaccuracy of the obſervers: whereas the difference of above 20′ between the moſt ancient and the lateſt obſervations is too great to be accounted for any other way, than by an actual diminution of the angle between the equator and ecliptic: if we will allow

a *Nos autem in hoc noſtro tempore cum Albidada longiſſima, & latere, quorum opus & doctrina in Almageſti libro docetur, poſt partium diminutionem (i. e. diviſionem) & poſitionis inſtrumenti verificationem, tam optimam quam eſſe poſſit, frequenter obſervavimus, ſoliſque propiorem aſcenſum puncto zenith capitis in medij diei circulo in Aracta civitate* 12 *graduum, &* 26 *minutorum, remotiorem autem ejus elongationem* 59 *graduum &* 36 *minutorum eſſe deprehendimus. Per hoc ergo probatum eſt quantitatem arcus inter duo ſolſtitia* 47 *graduum, &* 10 *minutorum exiſtere, declinationemque circuli ſignorum ab æquinoctiali circulo, non niſi harum partium medietatem quod eſt* 23 *graduum &* 35 *minutorum obtinere. De ſcientia ſtellarum c.* 4.

b *apud* Scaliger. *de emendat. tempor.*

c Snellius *in appendice ad obſervationes* Haſſiacas.

the

page 287.

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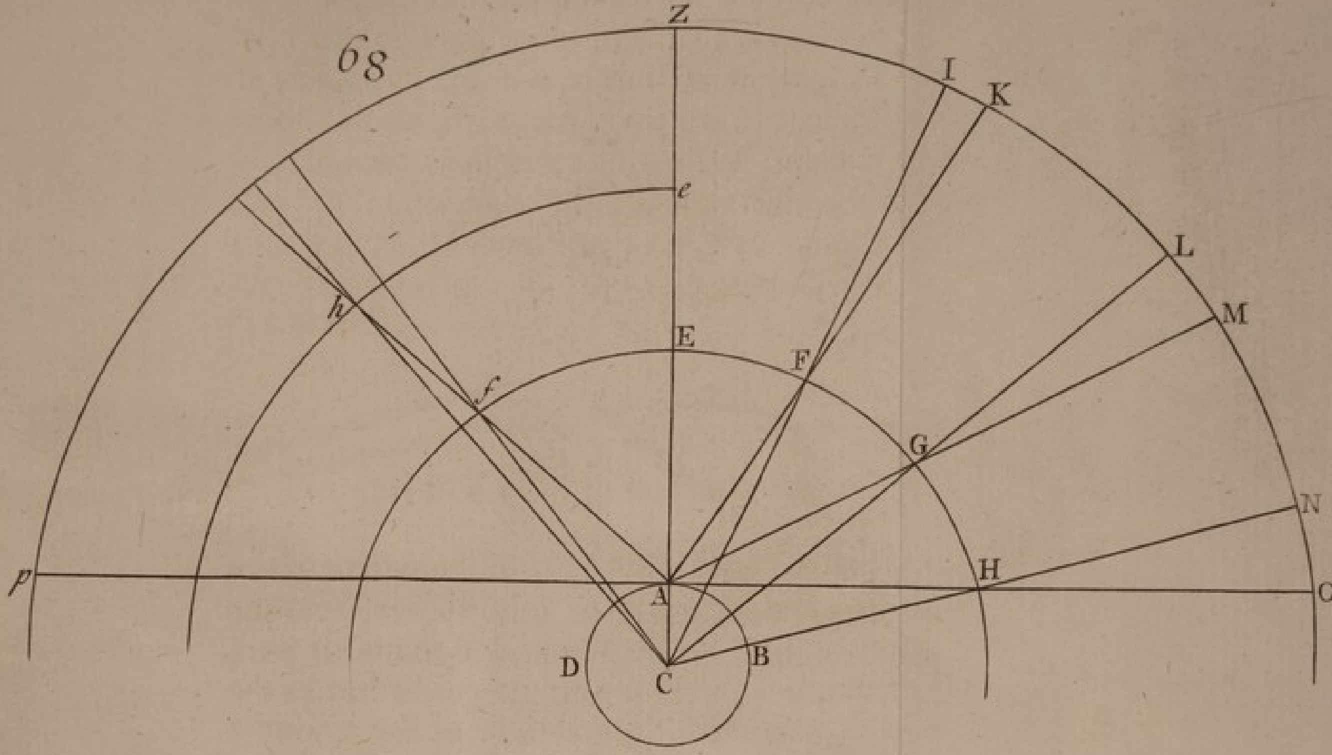
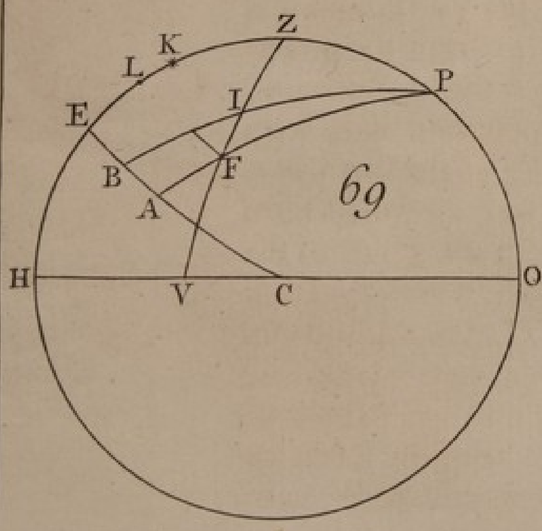
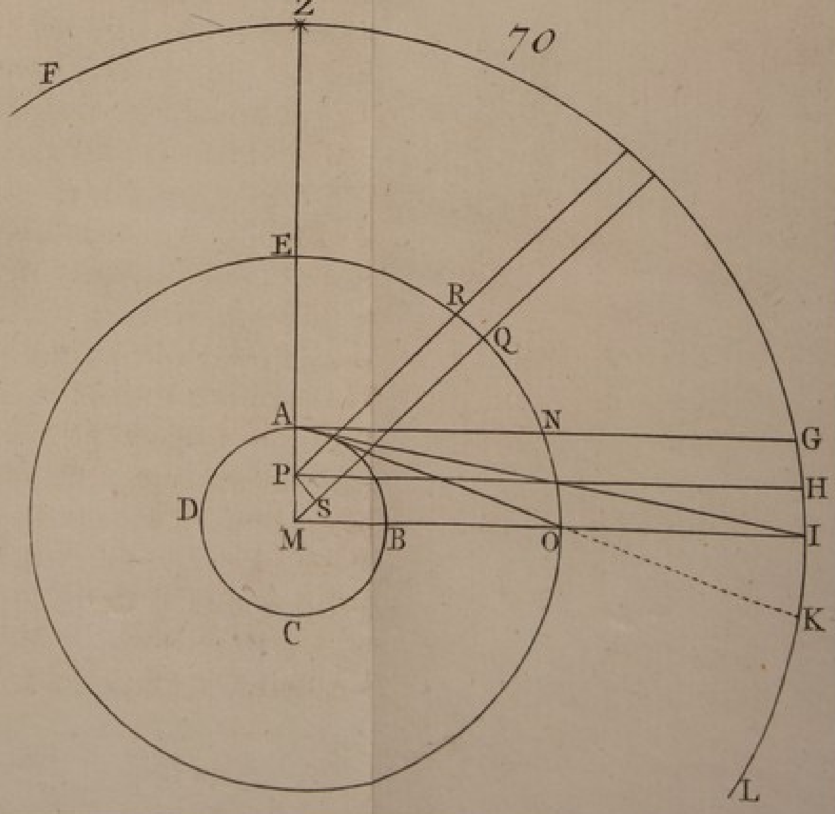
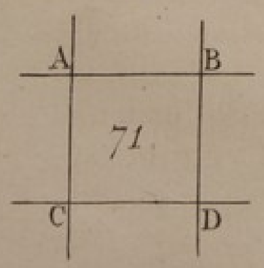








J. Mynde sc.

the ancients to have had eyes and inſtruments, and to have uſed any tolera- FIG.
ble care in their obſervations. I ſhall here give ſome of the numbers corrected by the parallax of the ſun, ſuppoſing his horizontal parallax 10″, and allowing for refraction according to *Newton*'s table of refraction § 765; where it muſt be owned we cannot be ſo accurate as is to be wiſhed, by reaſon of the difference of refraction in different places upon the earth, and at different times of the year in the ſame place. With this correction, the obliquity of the ecliptic comes out from the obſervations of *Eratoſthenes* 23° 51′ 51″, of *Ptolemy* 23° 49′ 16″, of *Albatennius* 23° 35′ 35″, of *Arzakel* 23° 34′ 42″, of *Prophatius* 23° 32′ 42″, of *Ulug Beigh* 23° 30′ 58″, of *Copernicus* 23° 30′ 7″, of *Walther* 23° 29′ 15″, of the *Prince* of *Heſſe* 23° 30′ 20″, of *Tycho* 23° 29′ 0″, of *Hevelius* 23° 29′ 0″.

CHAP. 17. OF THE PARALLAX OF THE HEAVENLY BODIES.

810 In ſpeaking of the places of the heavenly bodies in the ſphere of the heaven, we have hitherto conſidered them as if they were viewed from the center of the earth; or, which would be the ſame thing, as if the earth were but a point; that is, as if the diſtance between the center and ſurface of the earth were inſenſible, when compared with the diſtances of the heavenly bodies from us: this is true with regard to the fixt ſtars, ſee § 274, and in a great meaſure alſo in reſpect of the ſun, and all the planets except the moon: in fig. 68, let A B D be the earth, *p* Z O part of the ſphere of the heaven, now, 68
though we are ſure, by geometrical reaſoning, that if two ſtrait lines were to be drawn from any two different points of the ſurface of the earth as A and B to the center of the ſun or any of the planets at H, they would form an angle A H B; and if they were prolonged from thence to the ſphere of the heaven they would croſs one another and terminate in two points thereof N and O, which would be at ſome diſtance from one another; yet this diſtance is, for the moſt part, too ſmall to be taken by any inſtrument: this diſtance between the points N and O is called the *parallax*, which is ſaid to be *ſenſible* when great enough to be diſcoverable by obſervation; *inſenſible* when too ſmall to be meaſured by any inſtrument: the word parallax in greek ſignifies any kind of change in general; but, in aſtronomy, *the parallax of a phenomenon* is the change of its apparent place in the ſphere of the heaven, cauſed by its being ſeen from different points of view.

811 *The diurnal parallax* of a phenomenon, which is generally underſtood when the word is uſed without any epithete, is the arc of a great circle

FIG. cle in the ſphere of the heaven, contained between the point wherein it appears to a ſpectator upon the ſurface of the earth and the point wherein it would appear if it were viewed by a ſpectator at the center of the earth: the former of theſe points is called *the apparent place*, the latter *the true place* of the phenomenon: it is called diurnal parallax to diſtinguiſh it from the annual, and becauſe it ariſes from the ſemidiameter of the earth whoſe revolution round her axis cauſes the viciſſitude of day and night, or becauſe it is alterable by the diurnal rotation of the earth which changes the apparent altitudes of the heavenly bodies and conſequently their parallax.

812 A phenomenon which at different altitudes continues at the ſame diſtance from the center of the earth has the greater parallax the farther it appears from the zenith of the obſerver: therefore the parallax is greateſt in the horizon. A phenomenon that appears in the zenith, whatever its diſtance
68 from the earth is, has no parallax: thus, if a phenomenon be at H, in the viſible horizon of a ſpectator at A, its parallax is the arc N O; its apparent place is O; its true place N: if it be at ſome height above the horizon, as at G, its parallax is L M; which is leſs than N O: if it be higher, as at F, its parallax is I K; leſs than L M: if it be at E or *e*, it appears in the zenith, at Z; and has then no parallax: for, the lines A Z and C Z coinciding, its apparent place is the ſame with its true place.

813 *Parallax* always *diminiſhes the altitude* of a phenomenon, or makes it appear lower than it would do from the center of the earth: thus, O the apparent place of H is farther from the zenith Z than its true place N is; in like manner, M the apparent place of G is lower than its true place L; and K the apparent place of F is lower than its true place I. This change of the altitude by parallax may, according to the different ſituation of the ecliptic and equator in reſpect of the horizon of the ſpectator, cauſe an apparent *parallax* or change *of* the *latitude*, *longitude*, *declination*, and *right aſcenſion*, of
69 the phenomenon; or it may change only ſome of them: thus, fig. 69, let H O be the horizon, E C part of the ecliptic, P the pole of the ecliptic, Z the zenith, Z V an arc of a vertical drawn through I the true place, and F the apparent place of a planet, let D A be a circle of latitude drawn through the planet's true place, and D B a circle of latitude drawn through its apparent place; it is manifeſt that the parallax of altitude F I, by changing the place of the planet from I to F, alters its latitude from B I to A F; it alters its longitude alſo as much as the arc A B amounts to § 659. If the place of a planet be in a vertical circle which cuts the ecliptic in the ninetieth degree from the horizon, that is which cuts the ecliptic at right angles, the parallax will change the latitude of the planet, but not its longitude: thus, if a planet be in

in the point K of the vertical Z E H, this vertical being perpendicular to the ecliptic, and consequently a circle of latitude, by the definition § 646, the parallax of latitude K L will be the same with the parallax of altitude; but, since the same circle of latitude P E H passes through the true place K and the apparent place L, the parallax of altitude K L does not change the longitude. Let E C, which before represented the ecliptic, be now the equator, P the pole of the equator, P E H the meridian, P I B a circle of declination passing through the true place, and P F A a circle of declination passing through the apparent place of the planet; the point B shews the true, and the point A the apparent right ascension of the planet, and B A is the parallax of right ascension: I B is its true, F A its apparent declination, and their difference is the parallax of declination: if the star be in the meridian as at K, the parallax of declination will be K L the same as the parallax of altitude; but there will be no parallax of right ascension: because the same circle of declination P E H passes through the apparent place L and the true place K. FIG. 69

814 The parallaxes of any two phenomena as *f* and *h* whose distances from the center of the earth are different, and apparent distances from the zenith equal, are reciprocally as their distances from the center of the earth: thus, if the distance of *h* from C be double the distance of *f* from C, the parallax of *f* will be double the parallax of *h*. The converse of this is true; if the parallax of *f* be double the parallax of *h* the distance of *h* is double the distance of *f* from the earth. 68

815 One *use* of the knowledge *of parallaxes* is to find the true place of a phenomenon: in all observations of the heavenly bodies, it is necessary to know how much they are depressed by parallax, that by adding so much to their apparent we may have their true altitudes: indeed in all of them except the moon the parallax is so small, that, in most cases, we need not take any account of it, but then to know it to be thus small is of good use, to prevent our falling into the mistakes, and help us to correct the observations of those who have supposed it too great; as all astronomers till of late have done: thus, *Ptolemy* settled the horizontal parallax of the sun when in perigee about 3′; as *Tycho* did also: *Kepler* diminished it to 1′: but, by the latest and best observations, it is found not to exceed 10″.

Another use of parallaxes is to find the distance of the heavenly bodies from the earth: thus, the horizontal parallax of any one of them being known, its distance from the earth may be found; by § 143: see the moon's distance found by her horizontal parallax, § 147. The parallax of a phenomenon at any given altitude being known its distance from the earth may be found: see the remarks, § 825.

FIG. 816 The moon being the neareſt to the earth of all the heavenly bodies, her parallax is the greateſt, and conſequently the moſt eaſy to be determined; it amounts to about a whole degree, as we ſhall ſee when the moon comes to be treated of. The ſun and all the primary planets, except mars and venus when in perigee, are at ſo great diſtances from the earth, that their parallax is too ſmall to be obſerved. When mars is in oppoſition to the ſun, his diſtance from the earth is but half ſo much as the ſun's diſtance from the earth; and conſequently his parallax is then double to that of the ſun: *Tycho* in the year 1582 endeavoured with incredible diligence to diſcover the parallax of mars in oppoſition; but *Kepler*, having examined *Tycho*'s obſervations, concluded from them that mars's parallax was ſcarcely ſenſible[a].

817 *The* horizontal *parallax* of a phenomenon would be *found* directly, if it were to be ſeen by two obſervers, diſtant from each other 90° of a great circle upon the earth, and ſo ſituated that one of them ſaw the phenomenon in his zenith, the other in his horizon: the diſtance between the two points in the ſphere of the heaven in which the phenomenon appeared to them
68 would be its parallax: thus, fig. 68, let a phenomenon be at H, to an obſerver at B it appears in his zenith at N; to one at A it appears in his horizon at O; its horizontal parallax is N O. This method is mentioned for the eaſineſs of conceiving it, but is not likely to be put in practice, and, if it were, horizontal obſervations are very uncertain, by reaſon of the variableneſs of refraction in or near the horizon: but the parallax of a phenomenon at any known altitude being found, its horizontal parallax may be computed from thence, in the manner ſet down in the remarks[b]. Alſo if two obſervers not ſo far diſtant as 90° obſerve, at the ſame time, meridian altitudes of a phenomenon, the difference of declination which comes out from thoſe altitudes is the parallax owing to the difference of latitude of the places of obſervation, this being known the horizontal parallax which would ariſe from a diſtance of 90° may be computed from it: thus the meridian altitudes of mars in perigee were obſerved at the ſame time at Paris by *Caſſini*, and at Cayenne[c], by *Richer*; and the horizontal parallax of mars computed from thence: the beſt way to have found the parallax of mars, by obſervations made at

a Ricciol. *almageſt l.* 7 *c.* 3. b § 825, corollary 2.

c Cayenne is an iſland on the coaſt of N. America, in the latitude of 4°. 56′. 18″. diſtant from Paris 3h. 39′. in longitude, weſtward, hither *Richer* went by order of the R. Academy of ſciences to make obſervations, amongſt other things, of the meridian altitudes of mars and venus in perigee, and of ſome ſtars near them: the Meſſieurs of the Academy reſolving to do the ſame at Paris and other places in France, in order to diſcover the parallaxes of thoſe two planets. I have here given the reſult of their obſervations, which may be ſeen more at large, in *Obſervations Aſtronomiques & Phyſiques faites en l'iſle de Cayenne par* Richer *p.* 14. *& elemens d'Aſtronomie verifiez, par* Caſſini, *p.* 5. *& ſeqq.*

thoſe

thoſe two places, would have been to have obſerved with the teleſcope an occultation of ſome fixt ſtar by mars[a]; if this had appeared exactly the ſame in both places, it would have ſhewn that mars had no ſenſible parallax; if he had, the moment that the upper edge of mars's diſk appeared at Cayenne to touch the ſtar, it would at Paris have appeared a little lower than the ſtar; and when the lower edge of the planet appeared at Paris to touch the ſtar, it would at Cayenne have appeared a little higher than the ſtar: and theſe diſtances of mars from the ſtar ſeen in one place and not in the other would have been owing to the parallax.

818 As they had not an opportunity of making ſuch an obſervation in both places at the ſame time[b], they took, the ſame day at Paris and Cayenne, meridian altitudes of mars and of a fixt ſtar in aquarius nearly of the ſame declination as that planet then had; in order to find whether the difference between the altitudes of mars and that ſtar, were the ſame at Cayenne, as at Paris: if it were, ſince the ſtar has no parallax, the declination of mars would come out the ſame from the obſervations in both places; and his parallax would be inſenſible: if, on the contrary, the difference between the altitudes of mars and of the ſtar were obſerved to be greater at one place than at the other, this would ſhew a difference between the declination of mars as calculated from the obſervations of him in one place and his declination as it came out from the obſervations in the other place; which difference would be the parallax of mars, ariſing from his being viewed by two obſervers diſtant from each other as much as the arc of a great circle contained between the parallels of Paris and Cayenne amounts to.

Scholium. It is eaſy to ſee that, in order to find whether the declinations of mars would come out the ſame from his meridian altitudes in Paris and Cayenne, the difference between the latitudes of thoſe places muſt be known: but, beſides this, their difference in longitude muſt alſo be conſidered: now this is ſuch, that any of the heavenly bodies comes to the meridian of Cayenne $3^h\,40'$ later than to the meridian of Paris: in this interval of time, mars, by his motion in his orbit, changes his declination; and, though this change be very ſmall, it is neceſſary to know exactly what it is, in an affair of ſo great nicety as that before us; this is known by comparing the meridian height of mars taken the night immediately before with his meridian height taken the night after the obſervation of him from whence the parallax is ſought: for this ſhews what the change of his declination is in the interval of 24 hours; from whence, by the rule of proportion, it is eaſily found what it is in $3^h\,40'$.

a *v. les elemens d'aſtronomie verifiez p.* 34. b *ibid. p.* 35.

819 The three obſervations of the meridian altitudes of mars, made the ſame nights at Paris and Cayenne, by which his parallax was found, were in the month of ſeptember 1672: by the firſt obſervation, ſept. 5, mars appeared 12″; by the ſecond obſervation, ſept. 9, 13″; by the third, ſept. 24, 17″ more ſoutherly, at Paris; than he would have done, at the ſame moment, under the ſame meridian, in the latitude of Cayenne: *Caſſini* ſays that the third number ſhould have been leſs than the ſecond, becauſe mars was a little farther from the earth at the time of the third obſervation, than at the ſecond; and therefore his parallax ſhould have then been leſs: but an error of a few ſeconds is unavoidable in ſuch obſervations: he thought the beſt way was to ſplit the difference between the ſecond and third obſervations, and make the parallax of mars, owing to the difference between the latitudes of Paris and Cayenne, 15″; from whence the horizontal parallax of mars at that time is by calculation $25''\frac{1}{3}$. *v. les elemens d'aſtronomie verifiez p.* 39.

820 Mars is neareſt to the earth and his parallax the greateſt of all, when he is in oppoſition at the ſame time that he is in perihelion; ſuch was his ſituation in the year 1672, when *Caſſini*, by the methods here mentioned, § 817 and 822, from his own obſervations at Paris and thoſe of *Richer* at Cayenne, determined his horizontal parallax to be $25''\frac{1}{3}$: thoſe obſervations of *Caſſini* were confirmed by thoſe of *Maraldi*, made in the year 1704[a], and again in the year 1719[b]; from which he concluded the ſun's parallax to be 10″, as *Caſſini* had ſettled it in ſeveral places of his writings[c]: at the time of *Caſſini*'s obſervations the diſtance of mars from the earth was to the mean diſtance of the ſun from the earth, as $25\frac{1}{3}$ to $9\frac{1}{2}$; the parallaxes of any two phenomena are reciprocally as their diſtances[d], and therefore, if the parallax of mars be $25''\frac{1}{3}$, the ſun's parallax at his mean diſtance comes out $9''\frac{1}{2}$: inſtead of which the round number 10″ is uſually aſſigned for the ſun's parallax. There are other methods of finding the ſun's parallax made uſe of by the ancients and ſome of the moderns, but they are not ſo accurate as thoſe juſt now mentioned; they require alſo ſome knowledge of the moons theory, in order to the more eaſily underſtanding them: I ſhall therefore reſerve the explanation of them to a more proper place.

821 Venus in perigee is ſo near the ſun, that her parallax cannot eaſily be diſcovered by comparing her with any fixt ſtars[e]. Venus in perigee may ſometimes be ſo near one of her nodes as to appear upon the diſk of the ſun; thus ſhe was ſeen nov. 24. A. D. 1639, only at Hoole in Lancaſhire by *Hor-*

a *Hiſtoire d'acad. ann.* 1706. b *Memoires d'acad. ann.* 1722. c *Decouverte de la lumiere celeſte p.* 22. *Elemens d'aſtronomie p.* 21. d § 814. e Hamel. *hiſt. acad. p.* 109 199. Maraldi *memoires d'acad.* 1722.

rox,

rox, and at Mancheſter by his friend *Crabtree*, to whom he had beforehand given notice of that uncommon appearance[a]: venus will not be again viſible upon the ſun's diſk, till may 26. 1761, and then, if the time of her tranſit be obſerved by different perſons, in different parts of the earth, in the manner deſcribed by *Halley* in the philoſophical tranſactions n. 348, her parallax from the ſun, *i.e.* the difference between her parallax and the ſun's, may be determined, to a degree of accuracy not to be hoped for from any other method. Mercury appears oftner upon the diſk of the ſun than venus, but his diſtance from the earth at that time wants ſo little of being equal to the ſun's, that his parallax from the ſun is too little to be eaſily diſcovered.

822 The parallax of a phenomenon, if ſenſible, may be found by one obſerver only, by marking the apparent difference of its ſituation, in reſpect of fixt ſtars that are near it, at different hours of the ſame night: if I make uſe of this method, a fixt ſtar and a clock that beats ſeconds will ſupply the place of another obſerver, diſtant from me any number of degrees upon the earth leſs than a quarter of a circle; for all that he could tell me would be, that at the ſame moment when I viewed the phenomenon at a certain diſtance from the ſtar, it appeared to him at a different diſtance from it; which is the parallax owing to the diſtance of our two places of obſervation: ſuppoſe that diſtance to be 45 degrees, the rotation of the earth, in a certain time which may eaſily be computed in any latitude, ſuppoſe the time 5 hours, will carry me into a ſituation 45 degrees diſtant from that wherein I am at preſent, and conſequently, ſuppoſing the phenomenon and the ſtar to have no motion in the mean time beſides the apparent diurnal motion, I ſhall, at theſe two different times of obſervation, one now the other five hours hence, find the ſame difference between the diſtances of the phenomenon from the ſtar as would be found by two obſervers diſtant 45° from each other, viewing it at the ſame moment of time. By this method, which, from the authors here quoted[a], is more at large explained in the remarks, § 826, *Caſſini* found the parallax of mars nearly the ſame as by that mentioned § 817: by the ſame, *Flamſteed* at one time determined the parallax of mars to be leſs than 30″[b]; and at another time not to exceed 25″[c]: by the ſame method, *Bianchini* makes the parallax of mars to amount to near 40″: ſo difficult is it in obſervations of this nature to be certain we are within a few ſeconds of the truth.

a Caſſini *de la comete ann.* 1680: Bianchini *op. acta erudit. Lipſiæ ann.* 1685: *Whiſton*'s 7th aſtronomical lecture. *Digges* an Engliſh gentleman, invented ſeveral methods of finding out the parallax by one obſerver, publiſhed in his *alæ ſeu ſcalæ mathematicæ* 1573; from whom ſubſequent authors ſeem to have borrowed. b Philoſoph. tranſact. n. 89 and 96. c *ibid.*

FIG. 823 *The annual parallax* of a phenomenon is the change of its apparent place in the ſphere of the heaven, which is cauſed by its being viewed from the earth in different parts of her orbit: the annual parallax of all the heavenly bodies except the fixt ſtars is conſiderable: it is the motion of the earth through the different parts of her orbit that cauſes the ſun to appear every day of the year in a different point of the ecliptic; as was ſhewn § 642: and it is from the ſame cauſe, namely our continually changing our ſtation, that the geocentric places of the planets are almoſt always different from what they would be if they were viewed from any fixt point in the orbit of the earth: as has been ſhewn in the 8th, 9th and 10th chapters of this book. The reaſon of this is plain, the diameter of the earth's orbit, bears a conſiderable proportion to the ſemidiameters of the orbits of the moſt diſtant planets, being more than a 5th part of the ſemidiameter of the orbit of ſaturn; and above a 3d of the ſemidiameter of jupiter's orbit: but it bears ſo ſmall a proportion to the ſemidiameter of the ſphere of the heaven, or the diſtances of the fixt ſtars from us, that if they have any ſenſible parallax it is exceedingly ſmall: what attempts have been made to diſcover it, and with what ſucceſs, ſhall be the ſubject of the next chapter.

Remarks upon § 812.

824 In order to ſee how it comes to paſs that the parallax of a phenomenon is greater the leſs its altitude is, we may take it in the following view;
68 a line A C drawn from the center of the earth to the place of the ſpectator is a ſemidiameter of the earth, which, if we ſuppoſe it to be viewed from the phenomenon whoſe parallax is conſidered, will appear under an angle that may be called the angle of the ſemidiameter: thus, if the phenomenon be at H, the angle of the ſemidiameter is C H A; if at G, it is C G A, &c.—The angle of the ſemidiameter is equal to the angle of parallax, becauſe vertical to it: thus, C H A is equal to N H O; and therefore either of theſe is called the parallactic angle: in like manner, C G A is equal to L G M; and C F A to I F K. The angle of the ſemidiameter is leſs, the more obliquely the ſemidiameter C A is viewed: thus, from H the line C A would be ſeen in the moſt direct view; and then it appears under the greateſt angle C H A: from G the line C A is viewed more obliquely, and therefore appears under a leſs angle C G A: from F it is viewed ſtill more obliquely, and appears under a ſtill leſs angle C F A: from E or *e* the line A C is viewed end-wiſe, and appears a point.

Remarks upon § 815.

825 The diſtance of a phenomenon from the center of the earth is in the ſame

ſame ratio to the ſemidiameter of the earth, as the ſine of its apparent diſtance from the zenith is to the ſine of its parallax: it is a known property of every plane triangle, that the ſines of the angles are as the ſides which ſubtend them: or, converſely, the ſides are as the ſines of the angles ſubtended by them: thus, fig. 68, C G the diſtance of the phenomenon G from the center of the earth is to A C the ſemidiameter of the earth, as the ſine of the angle C A G, or Z A M † which meaſures the apparent diſtance of G from the zenith, is to the ſine of C G A the angle of the parallax of G. FIG. 68

Corollary 1. Hence the parallax of a phenomenon at any altitude being given, its diſtance from the center of the earth may be known: and converſely.

Corollary 2. The ſines of the apparent diſtances of a phenomenon from the zenith are as the ſines of its parallax: therefore as the ſine of any given diſtance of a phenomenon from the zenith is to the ſine of its parallax at that altitude, ſo is the ſine of 90° to the ſine of its horizontal parallax.

Remarks upon § 822.

826 In fig. 70, let A B C D be the equator of the earth, A the place of an obſerver, imagin the plane of the equator to paſs through mars at E, and to be extended every way till it reaches the ſphere of the fixt ſtars, and marks thereon the celeſtial equator, part whereof is repreſented by F H L: ſuppoſe the celeſtial equator divided into 24 equal parts, beginning at Z the zenith of the obſerver, and a plane to be drawn from M the center of the earth to each diviſion: theſe planes will mark 24 hour-circles, whereof M A Z is the meridian of the obſerver, whom we ſuppoſe to ſee mars, when at E, in conjunction with a fixt ſtar Z, in his zenith: if neither mars nor the ſtar had any other motion beſides the apparent diurnal, they would both appear to go round in 24 hours; and, if this diurnal motion be equable, mars and the ſtar would in ſix hours after being in the meridian M A Z be in M O I the plane of the ſixth hour-circle, which is alſo the rational horizon of the place A: now a ſpectator at M the center of the earth would ſee mars and the ſtar go round from Z to I continuing all the while in exact conjunction, but it will happen otherwiſe to the obſerver at A; for he will ſee mars in exact conjunction with the ſtar, only while they are both in the plane of his meridian M A Z, but ſix hours after, when mars is at O, and the ſtar at I, ſo that both of them are in the plane M O I, the ſtar will to him appear to be in the plane A I, and mars in the plane A K: it is to be farther obſerved, that mars, being 70

† The obtuſe angle C A G and the acute angle Z A M have the ſame ſine; becauſe either of theſe angles is ſupplement to the other: § 105.

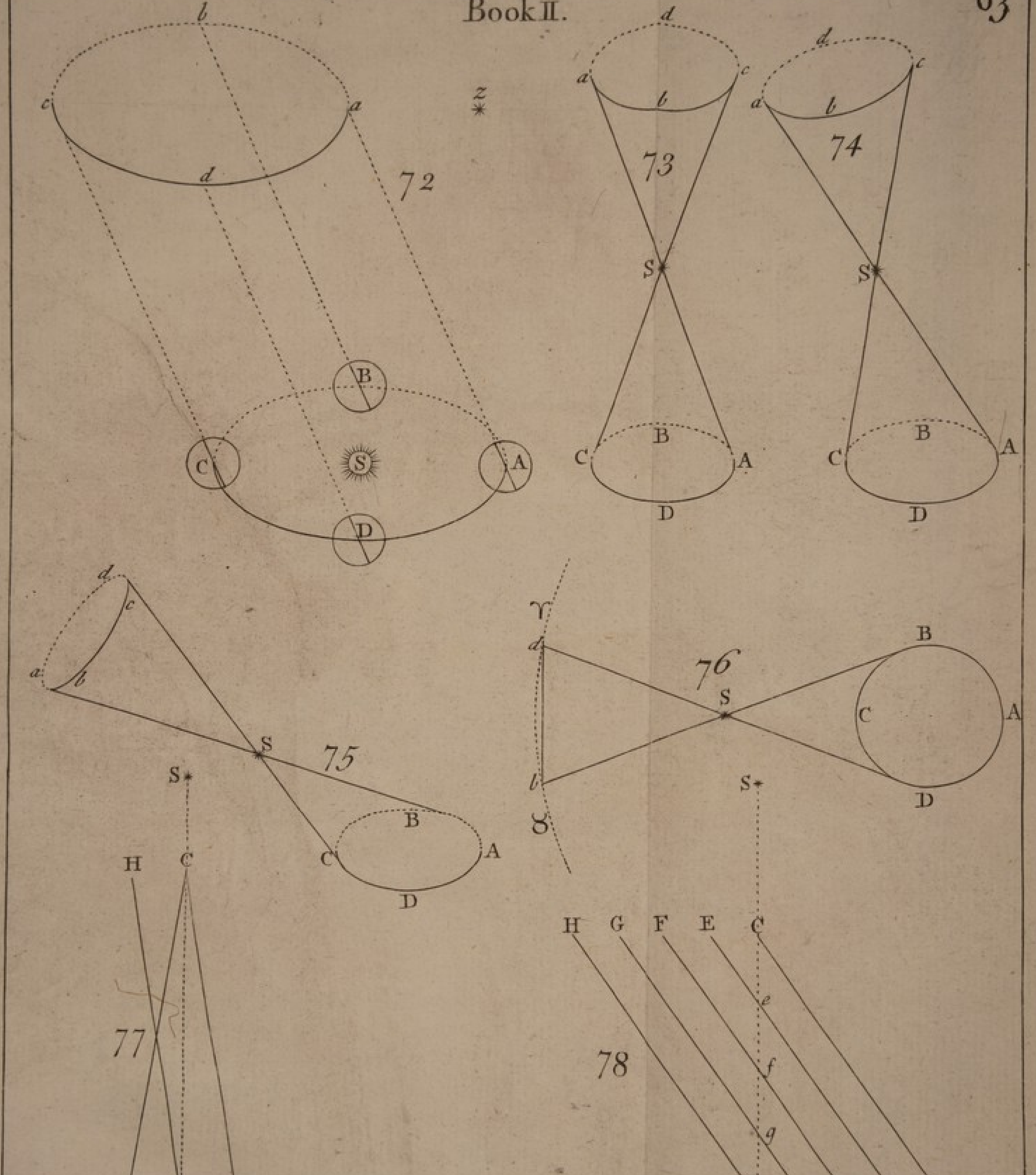
thus

FIG. thus depreſſed by a ſenſible parallax, will appear to come to A N G the ſenſi-
70 ble horizon of A, a few ſeconds before he really comes to the rational hori-
zon M O I; and conſequently before the expiration of ſix hours after his be-
ing in the meridian; whereas, the ſtar will appear to go from the meridian
to the horizon exactly in ſix hours; the ſenſible and rational horizon being
coincident in reſpect of the ſtars § 275: now the time that mars appears to
come to the horizon before the ſtar is his parallax in time; and is equal to
the time mars takes in going the arc N O, from the ſenſible horizon to the ra-
tional: and may be eaſily turned into meaſure, in order to have his parallax
in an arc of a great circle. We ſhall alſo have directly the parallax of mars
in an arc of a great circle, if, when he is in the ſenſible horizon, we take
his apparent diſtance from the ſtar, with the micrometer. The parallax of
mars being thus found to be the arc G K, or the angle N A O, to which the al-
ternate M O A is equal; we have a right angled triangle A M O, whereof the
acute angle at O is known; and conſequently, by § 143, the ratio of A M the
ſemidiameter of the earth to M O the diſtance of mars from the earth may
be known.

827 In order to find the difference of time between the coming of mars
and that of the ſtar to any hour-circle, there muſt be four fine hairs or very
71 ſmall wires croſſing at right angles, as in fig. 71, placed in the focus of the
teleſcope; and the teleſcope muſt be turned round till ſome ſtar near mars
appears by the diurnal motion to paſs along one of the hairs, as A B, which
hair will then be parallel to the equator, and the hairs A C and B D perpen-
dicular to it will then be meridians, by the coming to which the right aſcen-
ſion of any ſtar may be known, ſee § 786: mark the time then when mars
and the ſtar are both in your meridian, and ſix hours after, the ſtar will come
to the ſixth hour circle, but mars will come to it a little ſooner; againſt that
time therefore, having the teleſcope ready with the two croſs hairs A B and
C D parallel to the equator, obſerve the moment that mars comes to one of
the hairs A C or B D, and count how many ſeconds later the ſtar comes to the
ſame hair.

828 It muſt be owned ſeveral circumſtances have been now mentioned to
attend the obſerver, which he may more eaſily ſuppoſe in theory, than be fa-
voured with in practice; but trigonometry will here come in aid: for 1 ſup-
70 poſe the obſerver to be at P in ſome parallel at a good diſtance from the e-
quator, the parallax of right aſcenſion will be found leſs than it would un-
der the equator, but in a ratio eaſy to be known; for it will be in the ratio
of P M to A M or as the ſine of the height of the equator to the whole ſine; 2
horizontal obſervations being difficult, inſtead of the ſixth let the different
appulſes

page 297.



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appulſes of mars and the ſtar to the third hour-line be obſerved; here alſo Fig.
will be two third hour-lines, the true one M Q drawn through the center of 70
the earth, and the apparent one P R drawn parallel to it though P the place of the obſerver: and as P S is to P M, or the ſine of the half right angle Z M Q contained between the meridian and the third hour-circle of the place P is to the whole ſine, ſo is the parallax found at the third hour-circle to the parallax at the ſixth: 3 ſuppoſe mars not to be in the equator, but in ſome parallel; his parallax then found, in order to know what it would be in the equator, muſt be increaſed juſt ſo much as the ſemidiameter of the equator exceeds the ſemidiameter of the parallel wherein mars then is, or as the whole ſine is to the ſine complement of mars's declination: 4 as mars has a motion in his orbit, this muſt be taken into the account; and ſince this is either equable, or equably accelerated or retarded, which of theſe is the caſe may be found by preceding and ſubſequent obſervations of mars, ſo as to enable us to know, with ſufficient exactneſs, at any moment of time, the true place of mars wherein he would appear to a ſpectator at the center of the earth; and, by comparing it with his apparent place, diſcover his parallax as well as if he had no other motion beſides the diurnal.

CHAP. 18. OF THE ANNUAL PARALLAX OF THE FIXT STARS: THEIR DISTANCE FROM US: THE VELOCITY OF LIGHT.

829 Since the revival of the ancient opinion of the earth's annual motion round the ſun by *Copernicus*, ſeveral aſtronomers have endeavoured to find out whether the fixt ſtars are ſubject to any annual parallax or not: this enquiry very well deſerves our attention, upon two accounts; 1 if ſuch parallax could be diſcovered, it would demonſtrate the truth of the *Copernican* ſyſtem: 2 if the quantity of the annual parallax of any of the fixt ſtars could be found, the diſtances of thoſe ſtars from our earth might be known[a].

The axis of the earth extended, being carried parallel to it ſelf during the earth's annual revolution round the ſun, in reality deſcribes a circle in the ſphere of the fixt ſtars equal to the orbit of the earth: thus, fig. 72, 72
let A B C D be the orbit of the earth, S the ſun, the dotted lines the axis of the earth extended, this axis when the earth is at A points at *a* in the ſphere of the heaven; when the earth is at B points at *b*; when at C points at *c*; when at D points at *d*: ſo as in a years time to deſcribe *a b c d*, equal to A B C D: but though the orbit of the earth, and conſequently the circle *a b c d* be

a See the remarks.

FIG. immenſely large, many millions of miles in diameter, it is but a point in compariſon of the ſphere of the heaven; that is, the angle under which its diameter appears to an inhabitant of the earth is inſenſible, leſs than can be meaſured by any obſervation; and therefore the celeſtial poles appear to be in the ſame points of the heaven throughout the year: thus, in the figure be-
72 fore us, though when the earth is at A the place of the celeſtial north pole is *a*, and when the earth is at C the place of the north pole is *c*, and a ſtar at Z is nearer the point *a* than it is to the point *c* by the whole length of the line *a c* yet, if this line *a c* viewed from the earth ſhould take up no ſenſible ſpace in the ſphere of the heaven, as if it ſhould meaſure no more than 2 or 3 ſeconds, which is no more than the errors of the niceſt obſervations may amount to, the ſtar at Z will appear at the ſame diſtance from the pole throughout the year; and conſequently it will have no annual parallax.

830 We have ſeen the parallax of the ſun to be no more than 10″, this ſmallneſs of the ſun's diurnal parallax is owing to this, that the ſemidiameter of the earth bears an exceedingly ſmall proportion to the ſemidiameter of the earth's orbit, being not more than a 20000th part of it, for ſo many ſemidiameters of the earth is the ſun diſtant from us: things are great or little only in compariſon to other things of the like ſort; the diſtance of the ſun may be inconſiderable when compared with the vaſtly greater diſtance of the ſtars: if we ſuppoſe the diſtance of the neareſt ſtar to be 20000 times as great as the ſun's diſtance from us, the annual parallax of that ſtar would be no more than 10″; too little to be diſcovered by any of the methods commonly made uſe of to take the height of the pole by the ſtars: the diſtance of the neareſt ſtars may be much greater than this, and their parallax conſequently much leſs than 10″; it is no wonder therefore that aſtronomers have found the height of the pole in every place to be the ſame throughout the year: but ſome have been too haſty in concluding from thence that the earth has no ſuch annual motion round the ſun as the followers of *Copernicus* ſuppoſe.

831 If the annual parallax of any fixt ſtar were ſenſible, that ſtar would appear to change its place ſo as to deſcribe a very ſmall ellipſis in the ſphere
73 of the heaven, in a years time: thus, fig. 73 and 74, let ABCD be the orbit
74 of the earth, S the ſtar to be obſerved, if we imagin a ſtrait line to be drawn from the earth in any part of her orbit as A through the ſtar to a point in the heaven as *a*, that viſual line A*a*, being carried along with the earth in her annual motion, will deſcribe two conic ſurfaces ASC and *asc*, having their common vertex at the ſtar S; and the motion of the earth round ABCD will make the ſtar appear to go round *abcd*. If the ſtar S were in the pole of the
73 ecliptic, as fig. 73, the ellipſis deſcribed by it would have the ſame excentrici-
ty

ty with the orbit of the earth; and conſequently would differ very little from a circle: if the ſtar be at any diſtance from the pole of the ecliptic, the greater that diſtance is the more oblong will the ellipſis be, ſee fig. 74 and 75: if the ſtar be in the plane of the ecliptic, the ellipſis may be ſaid to be infinitely ſmall in breadth; for it will become a ſtrait line[a], wherein the ſtar will appear to go, according to the order of the ſigns, one half of the year, and contrary to the order of the ſigns, during the other half: ſee fig. 76. FIG. 74 75 76

832 The greater the diſtance of the ſtar S is from the earth the leſs will ASC and *asc* the angles of the cones be; and conſequently the leſs will the ellipſis *abcd* appear: if the diſtance of the ſtar be ſo great that the angles of the cones are too ſmall to be meaſured by aſtronomical obſervation, the ellipſis *abcd* becomes as a point, and the annual parallax is ſaid to be inſenſible; that is no change of place is diſcoverable in the ſtar, throughout the year. It is the opinion of many aſtronomers that the ſtars appearing to us of different magnitudes is in a great meaſure owing to their being placed at different diſtances from us: if this be true, the parallax will be greateſt, and conſequently moſt eaſily to be found, in thoſe ſtars which are of the greateſt apparent magnitude. 73

833 I ſhall not enter into a detail of all the variety of changes which their aberrations in an elliptic curve, mentioned § 831, muſt cauſe in different ſtars, according as they are differently ſituated in the ſphere of the heaven in reſpect of the ecliptic and equator; enough may be ſeen upon this ſubject in the author quoted in the margin[b]: it is ſufficient for our preſent purpoſe to remark, that ſuch aberration of any ſtar muſt change its longitude and latitude; now both theſe are found not directly and immediately, but by its declination and right aſcenſion, as was ſaid § 792: the declination of a ſtar is found by taking its meridian altitude, the height of the equator being firſt known: the right aſcenſion of a ſtar is found by the time of its coming to the meridian, § 787[c]. Thus we have pointed out to us two methods of enquiring into the annual aberration or parallax of the ſtars: one by obſerving whether or no any change can be diſcovered in the meridian altitudes of the ſame ſtar at different times of the year; the other by examining whether the intervals of time between any two ſtars coming to the meridian are equal throughout the year: if there be any ſenſible change of declination in any of the ſtars, it muſt be greateſt, and conſequently moſt eaſily diſcovered, in thoſe

a § 258. b Euſtachius Manfredius *de annuis inerrantium ſtellar. aberrationib. Bononiæ* 1729.

c Both declination and right aſcenſion of ſtars are perpetually changing, by the annual preceſſion of the equinox, § 792: this change, though very ſmall, muſt be taken into the account in our enquiry into the annual parallax of the fixt ſtars.

that are near the pole of the ecliptic: but the change of right aſcenſion here enquired after muſt be greateſt in ſtars in the ſolſtitial colure, and neareſt the pole of the equator: I ſhall treat of both theſe methods in their order.

834 *Galileo* ſeems to be the firſt who thought of trying whether any annual parallax of the ſtars were diſcoverable or not: to this purpoſe, ſuppoſing the ſtars to be at different diſtances from us, and thoſe ſtars to be neareſt to us that appear the biggeſt, he ſuggeſts, that by obſerving with a teleſcope two ſtars very near to each other, one of the greateſt the other of the leaſt magnitude, their apparent diſtance from one another might perhaps be found to vary, as they were viewed, at different times of the year, from the earth in different parts of her orbit[a]. The ſame author propoſes alſo a method whereby we may not only diſcover whether a ſtar has any ſenſible annual parallax or not, but determine the quantity of it alſo, and conſequently know the diſtance of the ſtar from us[b]: the method is this, upon the top of ſome very high building let a ſmall ſtrait bar be fixed parallel to the horizon and perpendicular to the meridian; recede from it towards the north till you can ſee the bar juſt cover or paſs exactly through the center of ſome ſtar when it is in the meridian; then upon a wall or ſome ſtrong poſt well fixed place a mark exactly at the height of your eye; thus you will have in effect a very large inſtrument with ſights placed in the meridian, ſufficient to diſcover the leaſt alteration in the meridian height of the ſtar, by obſerving it from month to month, but chiefly when it is at its utmoſt north and ſouth limits: but in taking meridian altitudes by this or any other inſtrument in order to diſcover the annual parallax, the ſtars obſerved muſt be ſuch as paſs our meridian not far from the zenith; otherwiſe the variableneſe of refraction will render the obſervations too uncertain for that purpoſe: and therefore *Halley* juſtly remarks that, whereas a difference of about 6 ſeconds in the meridian height of Sirius had been obſerved at Paris, no concluſion can from thence be drawn about the annual parallax; becauſe at Paris the meridian height of Sirius is under 25°, at which height refraction will vary 7 or 8 ſeconds, which is more than the whole parallax ſuppoſed to be obſerved amounts to[c].

835 Another way to attempt the diſcovery of the annual parallax by the change of declination of the fixt ſtars is to view, through a teleſcope placed perpendicular to the horizon, ſome ſtar in or near the ſolſtitial colure that paſſes through the zenith or very near to it; if the parallax of the ſtar be ſenſible, there will at different times of the year appear a difference in its me-

a Galilei *Syſtema coſmic. dialog.* 3. b *idem ibid.* c Phil. tranſ. n. 346. abridg. vol. 6. p. 165.

ridian

ridian altitudes; and its altitudes at the two solstices will differ most from each other: thus a star that in june passes through the zenith of any place in north latitude will in december pass southward from the zenith, and a star that in december passes through the zenith will in june pass northward from it, as we shall see by and by[a]: *Hook* was the inventer of this method, and in the year 1669 put it in practice at Gresham College with a telescope 36 feet long, and gave an account of the process in one of his Cutlerian lectures[b]: his first observation was july 6, when he tells us the bright star in the head of draco marked by *Bayer* with the letter γ passed about 2′ 12″ northward from the zenith: the second was july 9, when that star passed at the same distance from the zenith as before: the 3d observation was august 6, when the star passed northward from the zenith about 2′ 6″: the fourth and last was october 21, when the transit of the star was 1′ and 48 or 50 seconds north from the zenith.

836 In 1689 *Flamsteed* began the observations from whence he deduced the annual parallax, a detail whereof we have in a letter of his to Dr. *Wallis*[c]: he there remarks that neither *Tycho* nor *Ricciolus* could discover any annual parallax[d], because their instruments with plain sights were liable to errors of a minute or more, as appears by many places in *Tycho*'s *historia cœlestis:* he describes his own instrument which had fixed to it a telescope of 7 feet, with cross hairs: he says that, by seven years continual observations, he found the pole-star nearer to the pole in december than in the months april, may, july, august, or september: and that its apparent distance from the pole was greater in april than in september, and greater in july and may than in april: he could not observe that star in june, because it then comes to the meridian near the same time the sun does; but concludes, from his observations in other months, that its apparent distance from the pole in june must be different from that in december about 40″ or 45″[e]: we ought here to take notice that, though some writers have laid a great stress upon these observations, as if they were sufficient to demonstrate a sensible annual parallax, *Flamsteed* himself speaks of them with a good deal of diffidence; he says indeed that he could be sure of taking the height of the star so near as 5″, provided he could be certain the divisions of his instrument were accurate enough;

a See the remarks. b *v.* An attempt to prove the motion of the earth from observation, by *R. Hook.*

c *inter* Wallisii *opera vol.* 3. d Neither *Tycho* nor *Ricciolus* thought of endeavouring to find the annual parallax of the stars, both of them believing the earth kept her situation in the center of the solar system.

e The medium of this is about 42″; from hence the annual parallax of a star at the pole of the ecliptic would come out about 47″, supposing its distance from us to be the same with that of the pole-star. See the remarks.

but

but this he justly makes a doubt of[a], and recommends the use of much larger instruments, as necessary for the purpose: he owns that the wall upon which his mural arc was fixed sunk a little out of its true position; and that he could not be certain he was sufficiently exact in the allowance he made for the errors caused thereby: he adds that he thought he discovered an annual parallax in some of the southern stars also; but rightly remarks that the variableness of refraction might occasion all the differences he found in their meridian altitudes: he mentions also some observations of Sirius, from which the annual parallax of that star would come out near 30″; but declares he will not answer for the exactness of those observations which were many of them made by his assistant.

837 Mr. *Whiston*[b], from the observations of *Hook* and *Flamsteed*, computes that the greatest annual parallax, or that which a star in the pole of the ecliptic would have, is 47″; from whence he calculates the distance of the stars to be about 9000 semidiameters of the orbit of the earth, or 500000000000 miles: a prodigious distance this, but Mr. *Bradley* in a letter to Dr *Halley*[c] tells him, he believes he may venture to say that in two of the stars observed by him the parallax does not amount to 2 seconds; and that he is of opinion if it had been so much as one second he should have discovered it, by the great number of observations made by him, especially of the star *γ draconis*: this, instead of 9000 times, makes the distance of the stars from us 400000 times as great as that of the sun; which is above 40 times as great as the distance calculated from *Flamsteed*'s observations.

838 In the year 1725 Mr. *Molyneux*, assisted by Mr. *Bradley*, with a telescope of above 24 feet placed perpendicularly at his house at Kew, began to observe the same star in Draco that *Hook* had done, in hopes of verifying what he had communicated to the public: but their observations came out so contrary to what they expected, as to be matter of great surprise to them, and give them reason to call in question the accuracy of *Hook*'s observations; since they must have been liable to an error of at least 30 seconds: but indeed, besides this, had they been more exact, they were too few to conclude any thing from them, in so nice an affair as the annual parallax.

839 The observations at Kew were as followeth: from december 3, 1725, the star did not sensibly change its distance from the zenith, at the

a He says the subtense of an angle of 5″ was in his instrument no more than the 600th part of an inch, and no instrument can be divided so nicely that we can be certain none of the divisions are the 600th part of an inch too great or too small.

b *Whiston*'s astronomical lectures, lect. 4.

c This letter, which I am now going to make use of, is published in the phil. trans. n. 406. and in the abridgment, vol. 6. p. 167.

time

time of its paſſing over the meridian for ſeveral days: december 17, it paſſed a little more ſoutherly, and ſo continued gradually to paſs more and more ſoutherly at every *tranſit* over the meridian, till about the beginning of march, when it was found to paſs 20″ more ſoutherly than at the time of the firſt obſervation, and ſeemed to have arrived at its utmoſt ſouthern limit; becauſe in ſeveral obſervations made about this time no ſenſible difference was found in its ſituation: by the middle of april it appeared to be returning back towards the north; and about the beginning of june it paſſed over the meridian at the ſame diſtance from the zenith as it had done in december when it was firſt obſerved. From that time the ſtar appeared gradually more and more northerly at every tranſit, till ſeptember following, when it again became ſtationary, being then near 20″ more northerly than in june, and no leſs than 39″ more northerly than it was in march: from ſeptember the ſtar returned towards the ſouth, till it arrived in december to the ſame ſituation it was in at that time twelve months, allowing for the difference of declination on account of the preceſſion of the equinox.

840 The like obſervations were made upon a ſmall ſtar almoſt oppoſite in right aſcenſion to the ſtar γ in the dragon and about the ſame diſtance from the north pole of the equator; this ſtar did not change its declination above half ſo much as the ſtar γ in the dragon did, in the ſame time; which was a ſufficient proof that the apparent change of place in theſe ſtars was not owing to a *nutation of the earth's axis*; ſince, if that had been the cauſe, the alteration in both the ſtars would have been nearly equal, they both being ſituated near the ſolſtitial colure.

841 In the year 1727 Mr. *Bradley*, with a teleſcope of 12½ feet, began the like obſervations at Wanſtead in Eſſex; he tells us, that, not having a place convenient for the uſe of ſo long a teleſcope as that of Mr. *Molyneux*, he contented himſelf with one of but little more than half that length, which by frequent trials he found ſufficient for his purpoſe; ſince its ſituation may be ſecurely depended upon to half a ſecond, when it is carefully adjuſted: that the inſtrument was ſuſpended ſo as to enable him to obſerve ſix degrees and ¼ on each ſide his zenith, which gave him an opportunity of taking in ſeveral ſtars very different in magnitude and ſituation, and among others Capella a ſtar of the firſt magnitude:

842 After a years obſervations *Bradley* conjectured this change of place in ſtars to ariſe from theſe two cauſes, 1 the progreſſive motion of light being in time, 2 the annual motion of the earth in her orbit: he conſidered this affair in the following manner: if the eye be at reſt, or if it be in motion along a ſtrait line directly towards an object, or directly from it, the apparent

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FIG. rent place of the object will continue the same, whether light be propagated in time or instantaneously; but if the eye be in motion in any other direction than in a strait line from the object or towards it, and if light takes up any time in its progress from one place to another, the place of an object will be changed, and that change will be different according as those causes
77 are differently combined: thus, fig. 77 let CA be a ray of light falling perpendicularly from a star at C upon the line BD; if the eye be at rest at A, or moves along the line AC, in the direction AC or CA, the apparent place of the star will continue the same, for it will be seen by the visual ray AC, whether the progress of light be in time or instantaneous: but if the eye be carried in any other direction as BD, and light be propagated in time, with a certain velocity which we will, for example, suppose to be in such proportion to the velocity of the eye that a particle of light runs from C to A, in the same time that the eye is carried from B to A; then that particle of light by which the star is seen by the eye when arrived at A must have been at C when the eye was at B: for joyn the points C and B, and imagin the line BC to be a tube of such a diameter as to let but one particle of light pass through it at a time (or if instead of so small a tube we take the axis of a larger the case will be the same) it is easy to conceive that the particle of light which is at C when the eye is at B and arrives at A at the same time with the eye will pass through the tube carried along with the velocity here supposed all the way parallel to it self, or inclined to BD in an angle equal to DBC; and that it cannot pass through the tube thus carried if it be inclined to BD in any other angle: from hence it follows that, although the star C be perpendicular to the line BD in which the eye is moving, and would be seen in the direction AC if the progress of light were instantaneous, yet by reason of the motion of light being in time, its apparent place will be in the direction of the tube through which it is seen, so that when the eye is arrived at A the star will appear to be at H.

843 This may be farther illustrated, if we imagine the time to be divided into any number of equal parts, as 4, and the lines CA and BA to be each
78 divided into the like number of equal parts, as in fig. 78: let us, for example, suppose light to move from C to A in 4 minutes, and the eye with the tube to be carried from B to A in the same time; it is manifest that at the end of the first minute the tube being carried into the situation EE, the particle of light, having run through one of the equal parts, will be in the tube at *e*; at the end of the second minute the tube will be in the situation FF, and the particle of light at *f*; at the end of the third minute the tube will be in the situation GG, the particle of light at *g*; at the end of the fourth minute the particle

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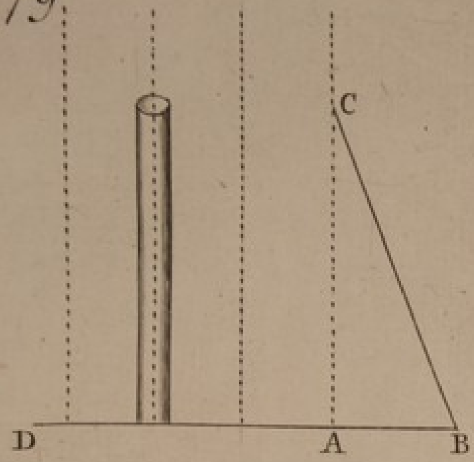

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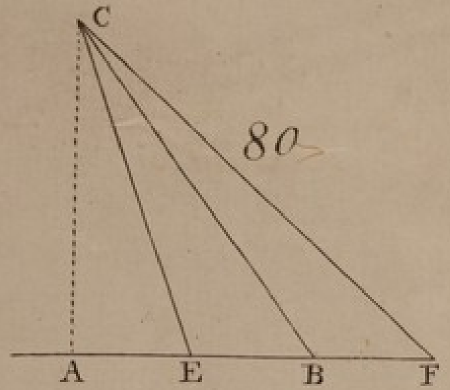

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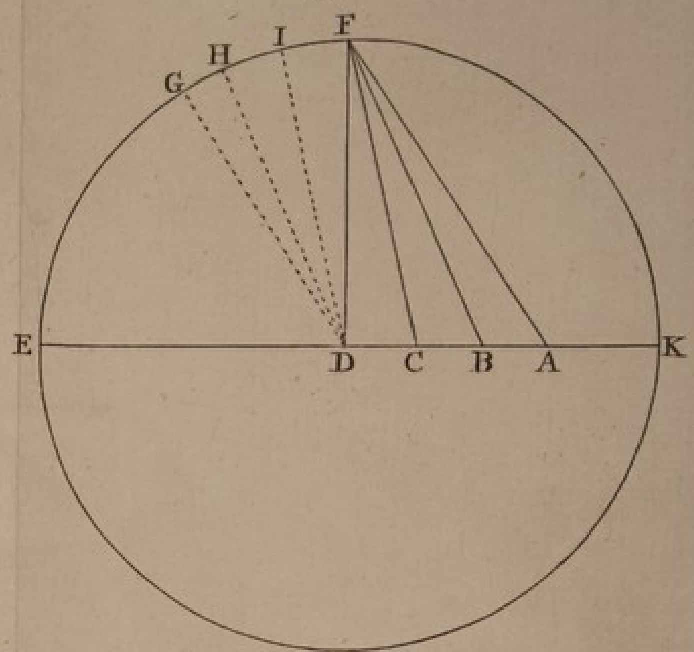

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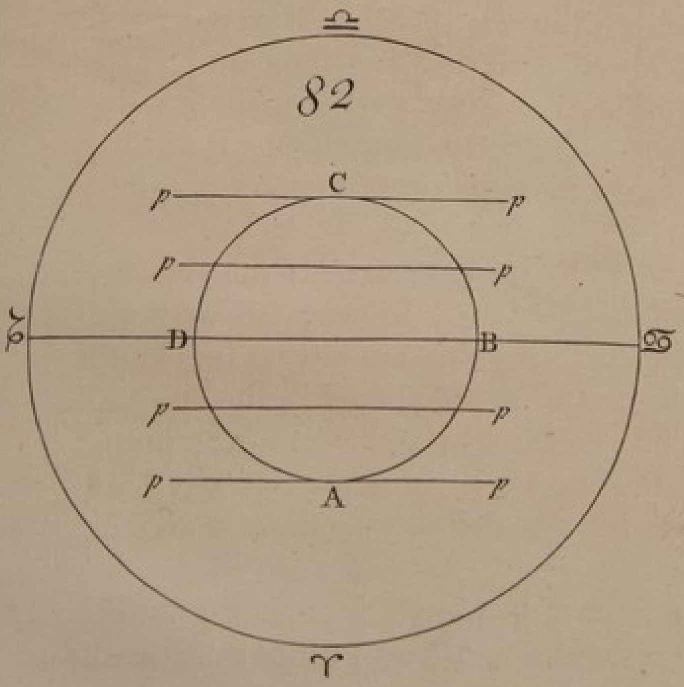

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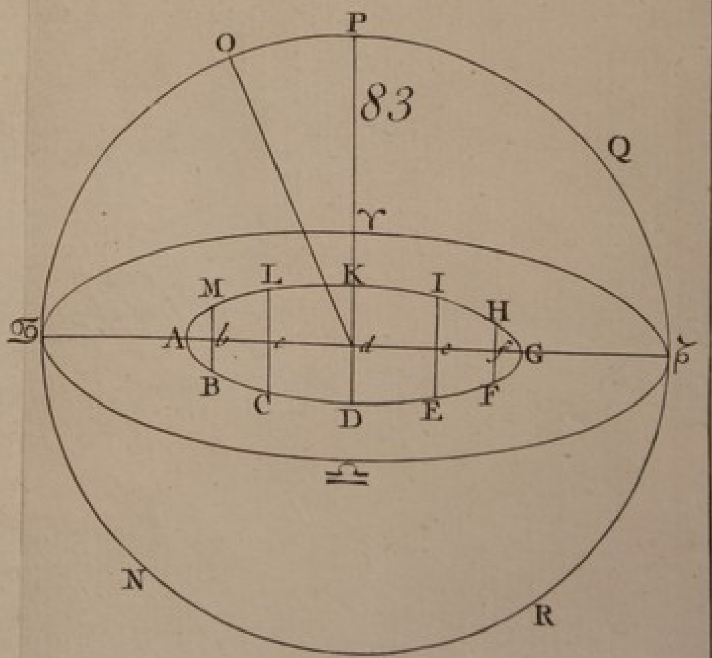

J. Mynde Sc.

particle of light will be at A, the tube in the ſituation AH; and conſequent- FIG.
ly the ſtar which is really at C will appear at H. It is eaſy to ſee that if the 78
eye be moved the contrary way from D towards A with the velocity before ſuppoſed, the tube, to make the ſtar C viſible through it to the eye arrived at A, muſt be carried along parallel to DC, or all the while inclined the contrary way to the line DA in an angle equal to BDC. — We have in this and the preceding ſection ſuppoſed the ſtar to be at C and the tube to be of the length CB; the caſe will be the ſame if we ſuppoſe the ſtar to be at S which is viewed through the tube CB: for the particle of light by which the ſtar is ſeen is ſtill to be conſidered as running through the line CA while the tube with the eye looking through it is carried along the line BA.

844 Perhaps the following familiar inſtance may make the matter before us more eaſy to be conceived: let us ſuppoſe drops of rain to fall, with an uniform velocity, in a continual ſucceſſion, and all in a direction parallel to
CA, upon a plane BD; if we would have a tube at reſt upon the plane to be 79
in ſuch a ſituation that ſome of the rain may paſs ſtrait through it, it is evident that it muſt be ſet in a direction parallel to CA: but if the tube be in motion upon the plane, as if it be carried along the line BD, none of the drops will then paſs through it as before, becauſe the ſides of the tube will meet with them as they are falling; except we give the tube ſuch a different direction as may in a manner compenſate for its motion: what that direction ought to be may be thus found; ſuppoſe a drop at C is falling towards A, take AB to CA as the velocity of the tube is to the velocity of the falling drop, and draw the ſtrait line from C to B; I ſay the tube muſt be carried along with its axis conſtantly parallel to CB in order to have the falling drop paſs directly through it; it is eaſy to apply this to the caſe of the temporary progreſs of light: as before explained.

845 We have hitherto ſuppoſed the velocity of light to be to the velocity
of the eye in a conſtant ratio, or as CA to BA: there is no reaſon why we 77
ſhould not believe the velocity of light to be uniform and always the ſame, but the velocity of the eye which we here conſider as moving in the line BA is not the ſame throughout the year, as we ſhall ſee by and by[a]: in the mean time let us enquire what change of the apparent place of the ſtar C will ariſe from the motion of the eye being ſometimes ſwifter ſometimes ſlower in the line BA.

846 If we ſuppoſe the velocity of light to be always repreſented by the
ſame line CA, and the mean velocity of the eye by BA, a greater velocity of 77

a § 852

FIG. the eye than the mean muſt be repreſented by a longer line than B A; a leſs
77 velocity of the eye by a ſhorter line than B A.

847 If the line by which the velocity of the eye is expreſt be longer than B A, the angle of the tubes inclination through which the ſtar C muſt be view-
80 ed by the eye arrived at A will be leſs than A B C: thus, fig. 80, if to expreſs the velocity of the eye inſtead of B A we take a longer line F A, the tube then will be repreſented by the line F C, and the angle of its inclination will be A F C, leſs than A B C[a]. On the other hand, if the velocity of the eye be expreſt by a ſhorter line than B A, the angle of the inclination of the tube muſt be greater than A B C: thus if inſtead of B A the velocity of the eye be expreſt by a ſhorter line as E A, the tube will be repreſented by E C, and the angle of its inclination will be A E C, which is greater than A B C[b]. It is all along ſuppoſed here that the velocity of light is repreſented by C A.

81 848 If we imagin a great circle E F K, fig. 81, to be drawn in the ſphere of the heaven with its plane paſſing through the ſtar F to be obſerved and the line A D in which the eye is carried according to the order of the letters A B C D, we may call E, that point of the circle towards which the motion of the eye is directed, *the point of the eye's direction.*

The leſs the angle of the tube's inclination is at any time, the more will a ſtar ſeen through it be depreſſed from its true ſituation towards the point of
81 the eye's direction: thus, fig. 81, let E be the point of the eye's direction towards which the eye is carried in the line A B C D according to the order of the letters, F the ſtar to be obſerved; if the tube be carried from A to D inclined to A D in the angle D A F, draw D G parallel to A F, and G will be the place where the ſtar appears through the tube, when the eye is arrived at D: if the tube be inclined in a greater angle as D B F, draw D H parallel to B F, and H will be the ſtars place ſeen by the eye at D; and the diſtance H E is greater than G E: if the angle of the tubes inclination be ſtill greater as D C F, the place of the ſtar will be I, which is ſtill farther diſtant from E. This change of place is called *the aberration of the ſtars*[c].

849 From hence it follows, 1, that the aberration of a ſtar always makes it appear nearer to the point of the eye's direction than its true place: 2, that the aberration of a ſtar is greater or leſs towards any point in the heaven according as the eye is carried towards that point with a greater or leſs veloci-
81 ty: 3, that if the motion of the eye towards any point as E be gradually accelerated and retarded by turns, the aberration towards that point will be gradually increaſed and diminiſhed by turns: 4, that if the direction of the eye's motion be contrary to the former, as from D to B the aberration will be

a Eucl. *l.* 1. *prop.* 16. b Eucl. *ibid.* c *voyez mem. d' Acad. R. ann.* 1737.

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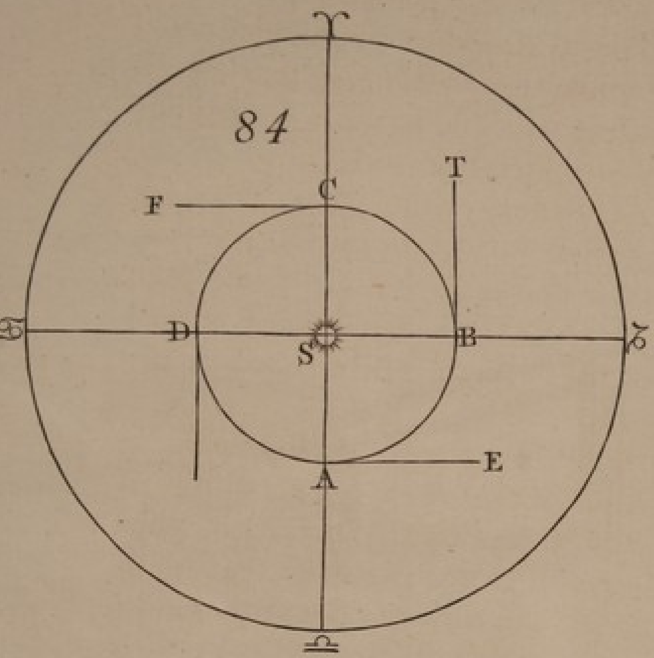
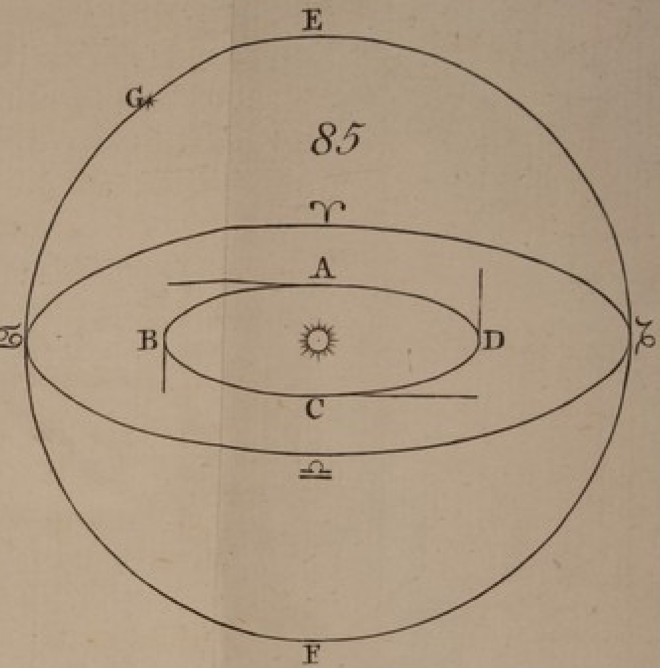
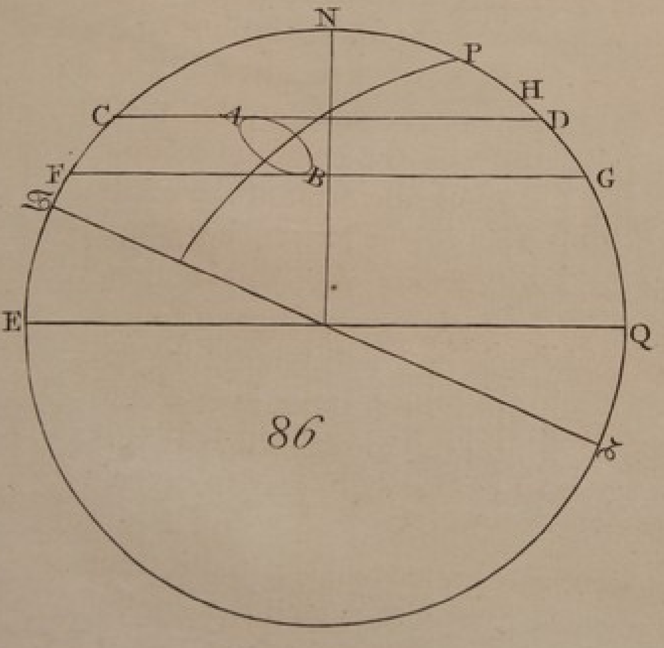
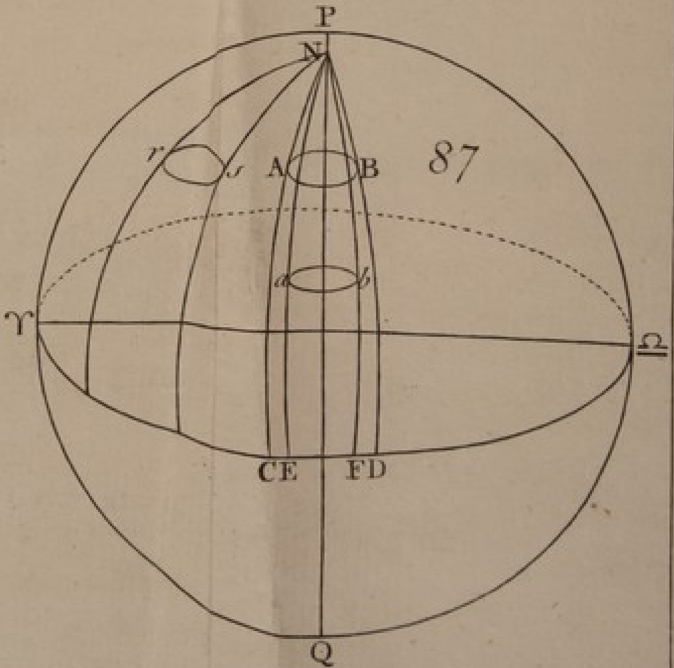








be alſo the contrary way towards the point K which is diametrically oppo- FIG.
ſite to E, fig. 81. 81

850 I ſhall now apply what has been ſaid in the foregoing ſections to the motion of the eye of a ſpectator carried along with the earth in her annual revolution round the ſun, having firſt laid down this *poſtulatum*, that the diameter of the earth's orbit meaſured in the ſphere of the heaven is inſenſible, and therefore all parallel lines the diſtances of which from each other do not exceed that diameter may be look'd upon as phyſically coincident: thus, fig. 82, let ABCD be the orbit of the earth, ♈ ♋ ♎ ♑ the ecliptic, all the lines 82
pp parallel to BD are phyſically coincident with BD, and if continued both ways to the ſphere of the heaven would terminate in the ſame points ♋ and ♑, as to ſenſe, as the line BD does; this is true as far as can be found by obſervation, ſince no annual parallax is yet diſcovered.

851 Firſt let us ſuppoſe that the ſtar whoſe aberration in declination is to be obſerved is ſituated in the pole of the ecliptic; that pole is in the ſolſtitial colure, and it is eaſy to ſee, by inſpecting the celeſtial globe, that when any point of the ſolſtitial colure is in any meridian the planes of that meridian and of the ſolſtitial colure are coincident; the time of obſerving the declinations of ſtars is when they are in the meridian, the method is by their altitudes, § 833; for all change of meridian altitude found in any ſtar is juſt ſo much change in the declination of that ſtar: now the declination of a ſtar in the ſolſtitial colure will be changed in the ſame manner by the motion of the earth in her orbit as it would be if ſhe were carried backward and forward with different velocities in the common ſection of the ſolſtitial colure and the ecliptic, that is in the line ♋ ♑ fig. 83: for let NOPQR be the ſolſtitial 83
colure, P the north pole of the ecliptic, O the pole of the equator, let ♈ ♋ ♎ ♑ be the ecliptic viewed obliquely, the line ♋ ♑ is the common ſection of the ſolſtitial colure and the ecliptic, let ABCD &c be the orbit of the earth wherein ſhe is carried round according to the order of the letters, her place being at A in december, at B in january, at C in february, &c: this motion, ſince it ſometimes makes the eye approach nearer to the point ♑, and ſometimes carries it the contrary way towards the point ♋, will change the declination of any ſtar in the ſolſtitial colure, in the ſame manner as it would do if the earth were carried in the line ♋ ♑, from A to G in the half year from december to june; and from G to A in the other half year from june to december.

852 The motion of the earth thus conſidered is unequable, ſome times faſter than other, as is ſhewn by the unequal parts into which the line A is divided, each part anſwering to the ſame ſpace of time, or one month:

FIG. thus, the motion of the earth from A to B in the firſt month, conſidered with 83 regard to her approach towards the point ♑, is reduced to the line A*b*; her motion from B to C in the ſecond month is reduced to the line *bc*; her motion the third month from C to D is reduced to the line *cd*, &c: now ſince the lines A*b*, *bc*, *cd*, &c, which meaſure the earth's approach to the point ♑, in each month, increaſe in length while the earth goes from A to D, or from december to march; and decreaſe in the ſame ratio as the earth goes from D to G, that is from march to june: it is manifeſt that the earth is carried towards the point ♑, from december to march, with a velocity continually increaſing; from march to june, with a velocity continually decreaſing: in like manner, it is eaſily ſeen by the figure, that the earth is carried towards the oppoſite point ♋, from G to *f*, from *f* to *e*, &c, with a velocity which continually increaſes from june to ſeptember; and decreaſes in the ſame ratio from ſeptember to december: as alſo that in june and december the earth is ſtationary in reſpect of the points ♋ and ♑; becauſe when her place is at A or G the direction of her motion is not towards either of thoſe points, but is at right angles to the line ♋♑.

853 Though the annual motion of the earth be circular, we may at any moment of time conſider it as being in the direction of a ſtrait line which I ſhall here call *the earth's tangent*; that is a line drawn through the center of the earth, at that moment, tangent to her orbit; as the earth is continually going round in her orbit according to the order of the ſigns, the direction of this tangent is continually changing, ſo as to point ſucceſſively round the ecliptic; and therefore the earth goes with her whole velocity towards all the points of the ecliptic ſucceſſively: if we imagin a line to be drawn at any time through the center of the ecliptic parallel to and in the ſame direction with the earth's tangent, it will ſhew the point of the ecliptic wherein the earth's tangent terminates, and towards which the earth is carried with her whole
84 velocity at that time: thus, fig. 84, let A B C D be the orbit of the earth wherein ſhe is carried round according to the order of thoſe letters, at the vernal equinox when the earth is at A ſhe is carried with her whole velocity towards the point ♑ in the direction of the tangent A E parallel to and therefore, by § 850, coincident with S♑: at the autumnal eqninox when the earth is at C ſhe goes with her whole velocity towards the point ♋ in the direction C F coincident with S♋.

854 Thus we ſee the earth is carried with the greateſt velocity towards the
84 point ♑ at the vernal, and towards ♋ at the autumnal equinox: 2, that in december when the earth is at D and in june when ſhe is at B her motion is in a direction perpendicular to the line ♋♑, and conſequently ſhe does not approach

approach to either of the points ♋ or ♑, but, in reſpect of them, may be con- FIG.
ſidered as ſtationary: 3, at the ſummer ſolſtice when the earth is at B her 84
whole velocity is towards ♈; at the winter when at D it is towards ♎.

855 From what has been premiſed it follows, 1, that from december to march the ſtar P appears to recede from the point ♋, and conſequently 83
grows farther and farther from the intermediate point O, the pole of the equator, and is fartheſt from that pole, or has leaſt northern declination in march: 2, from march to june the ſtar approaches gradually to the point ♋ and conſequently to the pole of the equator O, ſo that, its declination continually increaſing during theſe three months in the ſame proportion as it decreaſed in the three months immediately preceding, the ſtar comes to have the ſame declination in june as in the foregoing december; allowance being made for the preceſſion of the equinox in that half year: 3, from june to ſeptember the ſtar, going now a contrary direction, recedes gradually from the point ♑; and in ſeptember is fartheſt from that point, and conſequently neareſt to the pole O, or has greateſt north declination: 4, from ſeptember to december the ſtar approaches to the point ♑, and recedes farther from the pole O, ſo that, its declination continually decreaſing in the ſame ratio as it had before been increaſing, the ſtar appears to have the ſame declination again in december, as it had that time twelve months; allowing always for the change of declination cauſed by the preceſſion of the equinox.

856 Having ſeen what change of declination the motion of the earth and the temporary progreſs of light would cauſe in a ſtar ſituated in the pole of the ecliptic, let us next conſider how theſe cauſes would affect the declination of a ſtar ſituated in any other point of the ſolſtitial colure. If a ſtar were in the point ♋ or ♑, which are in the plane of the ecliptic, the motion of 83
the earth, being conſidered as in the line ♋ ♑, is in a ſtrait line either directly towards the ſtar, or directly from it; and therefore will not cauſe any change in the ſtars declination, as was ſaid § 842.

857 Since the greateſt change of declination would happen to a ſtar in the pole of the ecliptic, and no change to a ſtar in the point ♋ or ♑ in the plane of the ecliptic; it is eaſy to ſee, that the change of declination will be greater or leſs in any intermediate ſtar in the ſolſtitial colure, according as its true place is nearer to the pole of the ecliptic, or to the plane of the ecliptic: the aberrations in declination of any two ſtars in the ſolſtitial colure are as the ſines of their latitudes: therefore the aberration of any ſtar in the ſolſtitial colure whoſe latitude is given being known, the aberration which a ſtar in the pole of the ecliptic would have may be found; and converſely, the aberration in declination of a ſtar in the pole of the ecliptic being known,

the

FIG. the aberration incident to any other ſtar in the ſolſtitial colure may be calculated, if its latitude be given: thus the greateſt change of declination of γ *draconis* which is near the pole of the ecliptic was found by *Bradley* to be 39″, whereas the greateſt change of declination of a ſmall ſtar almoſt oppoſite to it in right aſcenſion and ſituated about 60 degrees diſtant from the pole of the ecliptic, was no more than about 19″. From obſervations made of the change in theſe and ſeveral other ſtars, *Bradley* ſettles the greateſt change in declination which would happen to a ſtar in the pole of the ecliptic at 40,″4; for its aberration from its true place would be 20,″2 towards ♑ at the vernal equinox, and 20,″2 towards ♋ at the autumnal.

858 Hitherto we have taken notice of the aberration of thoſe ſtars only that are in the ſolſtitial colure; in order to ſee what is the aberration of other ſtars, we may conſider the whole affair in another and more general view. The point of the ecliptic towards which the earth's tangent is directed is al-
84 ways 90 degrees behind the ſun's place: thus, fig. 84, let ABCD be the orbit of the earth, ♈ ♋ ♎ ♑ the ecliptic; when the earth is at A the ſun's geocentric place is ♈, the earth's tangent is AE, which being parallel to and therefore coincident with S♑, is directed towards the point ♑; in like manner, when the earth is at B the ſun's place is ♋, the direction of the tangent BT parallel to S♈ is towards the point ♈: when the earth is at C the ſun's place is ♎, the direction of the tangent CF is towards the point ♋, &c.

859 The aberration of ſtars cauſed by the temporary progreſs of light and annual motion of the earth is ſuch, that *a ſtar in the pole of the ecliptic* would at all times appear, nearer to that point of the ecliptic towards which the earth's tangent is directed than its true place is, and juſt ſo much nearer as the aberration amounts to; becauſe the eye is always carried towards that point with the whole velocity of the earth's motion in her orbit, § 853: the earth's tangent is directed towards every point of the ecliptic ſucceſſively according to the order of the ſigns, § 853: we may in this caſe look upon the orbit of the earth as a perfect circle, the excentricity thereof mentioned § 669 being ſo ſmall that it need not be taken into this account; we may alſo ſuppoſe the velocity of the earth in her orbit to be equable, for the ſmall inequability mentioned § 673 may here be diſregarded. From theſe premiſes it follows, that a ſtar in the pole of the ecliptic would annually deſcribe a circle round it, appearing always at the diſtance of 20,″2 from its true place: thus the longitude of a ſtar in that ſituation would be continually changing, ſo as to go quite round the ecliptic according to the order of the ſigns in a year's time, but its latitude would be always the ſame; for it would be always 89° 59′ 39,″8; wanting 20,″2 of 90°, its true latitude.

860 From what has been ſaid it is manifeſt, 1, that the aberration of a FIG.
ſtar in the pole of the ecliptic would be 20,″2 towards the point ♑ at the vernal, and 20,″2 towards the point ♋ at the autumnal equinox; ſo that its place at one equinox would be 40,″4 diſtant from its place at the other: and conſequently its declination would be 40,″4 leſs in ſeptember than in march. 2, for the ſame reaſon, the aberration of a ſtar in the pole of the ecliptic, would at the ſummer ſolſtice, carry it 20,″2 nearer to the point ♈ than its true place; and as much nearer to the point ♎, at the winter ſolſtice: thus
fig. 85, let ABCD be the orbit of the earth, ♈♋♎♑ the ecliptic, F♋E♑ the 85
ſolſtitial colure; at the vernal equinox when the earth is at C, the aberration of a ſtar at E the pole of the ecliptic would carry it 20,″2 from E nearer to the point ♑, towards which the earth's tangent is then directed; but at the autumnal equinox, when the earth is at A, the aberration would carry the ſtar 20,″2 nearer to the point ♋, towards which the earth's tangent is then directed: in june when the earth is at D the aberration is towards ♈; in december when the earth is at B the aberration is towards ♎.

861 The aberration of any *ſtar not in the pole of the ecliptic* is in an ellipſis whoſe longeſt axis is equal to the diameter of the circle which a ſtar in the pole of the ecliptic would appear to deſcribe, and is at right angles to the circle of latitude or ſecondary of the ecliptic drawn through the ſtar; the ſhorteſt axis is to the longeſt as the ſine of the ſtars latitude is to radius: thus, the longeſt axis being parallel to the ecliptic and always the ſame, the ſhorteſt axis is leſs the leſs the latitude of the ſtar is; ſo that the ellipſis of aberration of a ſtar in the ecliptic becomes a ſmall arc of the ecliptic of 40,″4, which ſeen from the earth would appear a ſtrait line, and may be conſidered as ſuch.

862 For ſince the aberration always carries a ſtar nearer to that point in the heaven towards which the earth's tangent is directed, and the earth's tangent is always in the plane of the ecliptic, the aberration of a ſtar in the ecliptic can only be in longitude. The greateſt aberration of *a ſtar in the plane of the ecliptic* is 20,″2 forward, when the earth's tangent points 90 degrees before the true place of the ſtar; and 20,″2 backward, when the earth's tangent is directed towards the point in the ecliptic 90 degrees behind the
ſtar: thus, fig. 84, ſuppoſe a ſtar's true place were in the point ♈, when 84
the earth is at C and the earth's tangent points at ♋, the aberration of the ſtar will be 20,″2 forward, from ♈ towards ♋; when the earth is at A and the tangent points at ♑, the aberration will be 20,″2 backward, from ♈ toward ♑. A ſtar in the plane of the ecliptic has no aberration when the point towards

FIG. towards which the earth's tangent is directed is in quadrature with the ſtar:
84 thus when the earth is at A or C the ſtar at ♈ would appear in its true place.

863 If we enquire how the aberration of a ſtar ſtands with regard to its
place compared with the place of the ſun, we ſhall from § 858, 861, and
862 have the following corollaries: 1, a ſtar in the plane of the ecliptic
84 would appear in its true place when in quadrature with the ſun: thus, fig.
84, if a ſtar were in the point ♈, when the earth is at B, the ſun's place at
♋; the earth's tangent BT coincident with S ♈ is directed towards the ſtar:
when the earth is at D, the ſun's place at ♑, the tangent is directed towards
the point ♎, oppoſite to the ſtar: in both theſe caſes, by § 842, there is no
aberration. 2, A ſtar in the plane of the ecliptic, would have its greateſt ab-
erration forward, or according to the order of the ſigns, when in oppoſition
to the ſun; and its greateſt aberration backward when in conjunction: thus,
84 fig. 84, a ſtar in the point ♈, would have its greateſt aberration from ♈ to-
wards ♋ when the earth is at C, and the ſun at ♎; but its greateſt aberration
from ♈ towards ♑ would be when the earth is at A, the ſun's place at ♈.
3, A ſtar neither in the pole nor plane of the ecliptic, would appear in one
of the extreme points of the ſhorteſt axis of its ellipſis of aberration, when in
quadrature with the ſun: and conſequently it would be in its true longitude,
but in its leaſt or greateſt latitude: in leaſt latitude when the ſun's place is
90 degrees forwarder than the point of the ecliptic which ſhews the longi-
tude of the ſtar; and in greateſt latitude when the ſun's place is 90 degrees
85 behind the ſtar's longitude: thus, fig. 85, if a ſtar be at G and its longitude
marked by the point ♋, when the earth is at A and the ſun's place is ♎, 90°
before ♋, the ſtar will have leaſt latitude; for it will have its greateſt aber-
ration towards ♋: but when the earth is at C and the ſun's place is ♈, 90°
behind ♋, the ſtar will have the greateſt latitude; for it will have its great-
eſt aberration from ♋ towards the pole of the ecliptic. 4, A ſtar neither in
the pole nor plane of the ecliptic would appear in one of the extreme points
of the longeſt axis of the ellipſis of aberration when in conjunction or oppo-
ſition with the ſun; and conſequently would be in its true latitude, but in
85 its greateſt or leaſt longitude: fig. 85, a ſtar at G the longitude of which is
in the point ♋, will have its longitude moſt increaſed or carried forward,
when the earth is at B and the ſun's place in the point ♑; and moſt decrea-
ſed, when the ſun is in ♋: the ſame ſtar G would be in its true longitude
when the ſun's place is ♈ or ♎.

864 If a ſtar be in the ſolſtitial colure, all change of latitude will be ſo
much change of declination; that is the difference between its greateſt and
leaſt declination will be equal to the ſhorteſt axis of the ellipſis of aberrati-
on:

on, see the remarks § 877: in any star not in the solstitial colure, the change FIG.
of declination is equal to the distance between two circles drawn parallel to the equator, and tangents on each side to the ellipsis of aberration: thus, fig. 86, let EQ be the equator, ♋ ♑ the ecliptic, N the pole of the equator, P the 86
pole of the ecliptic, AB the ellipsis of aberration of a star; draw the parallels CD and FG, the distance between those parallels, measured by the arc CF, is the difference between the greatest and least declination of the star.

865 We have seen what change in declination is caused by the aberration of stars; it is time to consider what *change in right ascension* may be expected from the same cause: if a star were in the pole of the equator, or so near it that the pole were surrounded by the ellipsis of aberration; it is easy to see that the star would appear to go round the pole, and consequently its right ascension would be varied through all the points of the equator, according to the order of the signs, in a years time: but we know of no star that is not more than 40″ distant from the pole, and therefore too far off to surround it with its ellipsis of aberration; so that we may say *the aberration in right ascension* of any star is an arc of the equator which measures the angle made at the pole of the equator by two arcs of great circles drawn tangents on each side to the ellipsis of aberration of that star: thus, fig. 87, let PQ be the sol- 87
stitial colure, ♈ ♎ the ecliptic, ♈ CD ♎ the equator, P the pole of the ecliptic, N the pole of the equator, AB the ellipsis of aberration of a star the true place whereof is in the center of that ellipsis, draw the arcs NC and ND touching the ellipsis in A and B, the arc CD is the whole aberration in right ascension of that star; for when the apparent place of the star is A the point of its right ascension is C: when the star appears at B its right ascension is D.

866 Of two stars in the solstitial colure that star will have the greatest aberration in right ascension which is nearest to the pole of the equator: for since the angle made by the tangent arcs is in both cases subtended by the longest axis of the ellipsis of aberration, which is always the same, 40,″4, the angle will be greater the nearer the subtending line is to the vertex of it, that is to the pole of the equator: thus, fig. 87, if the true place of a star be in the 87
center of the ellipsis AB, its aberration in right ascension is the arc CD, or the angle CND; if a star be in the center of the ellipsis *ab*, its aberration in right ascension is the arc EF, less than CD; or the angle ENF less than CND.

867 Of two stars equally distant from the pole of the equator that star will have the greatest aberration in right ascension which is nearest the solstitial colure: for, if a star be in the solstitial colure, the angle made at the pole of the equator by the tangent arcs is subtended by the longest axis of the

FIG. ellipſis of aberration; but if a ſtar be not in the ſolſtitial colure, the angle made by the tangent arcs will be ſubtended by ſome other diameter of the ellipſis; and, the farther the ſtar is from the ſolſtitial colure, the ſhorter will be the diameter of the ellipſis which ſubtends the angle that meaſures the ab-
87 erration in right aſcenſion: thus, fig. 87, if a ſtar were in the ſolſtitial colure PQ in the center of the ellipſis AB, the angle ANB is ſubtended by AB the longeſt axis of the ellipſis: but if the ſtar be in the center of the ellipſis *rs*, the angle of aberration in right aſcenſion *r*N*s* will be ſubtended by ſome other diameter, which is ſhorter than the longeſt axis.

Scholium. Though, *cæteris paribus*, the aberration in right aſcenſion is greateſt in ſtars neareſt the pole of the equator, yet may it more eaſily be obſerved in thoſe that are at ſome diſtance from the pole: for ſtars that are very near it appear to go round in very ſmall circles, and with a very ſlow motion, and therefore the time of their paſſing the meridian cannot be aſcertained with exactneſs, without much longer teleſcopes than are required for ſtars near to the equator: the more the teleſcope magnifies, the more eaſily may the tranſit of a ſtar be determined[a].

868 How to find the right aſcenſion of a ſtar, by comparing it with the ſun, has been ſhewn, § 787; but the method there pointed out, though ſufficient for the common uſes of aſtronomy and navigation, will not ſerve in ſo nice an affair as the aberration of ſtars; for the right aſcenſion of the ſun, which is changing every day of the year, cannot be known for any particular time, within a few ſeconds; the theory of the ſun's motion is not aſcertained accurately enough for that, and if we were to attempt to deduce the ſun's right aſcenſion, by taking his meridian altitude every day, we could not do it with ſuch exactneſs as the preſent caſe requires; as well by reaſon of the unavoidable ſmall errors to which obſervations are liable, as becauſe ſome of the elements of calculation are not determined to a ſufficient degree of certainty. Nor can we, for this purpoſe, take ſome one ſtar from which as from a fixt point we may begin to reckon the right aſcenſion of other ſtars; becauſe that ſtar which we here ſuppoſe fixed will alſo have its aberrations, as well as thoſe ſtars which we compare with it. The beſt method of finding the aberration of ſtars in right aſcenſion is, to chuſe two ſtars which differ conſiderably in right aſcenſion, and obſerve whether the intervals of time between their tranſits croſs the meridian are invariably the ſame throughout the year or not[b].

869 In order to make theſe obſervations, a clock muſt be had that goes as equably as poſſible; or rather two clocks, that they may correct one ano-

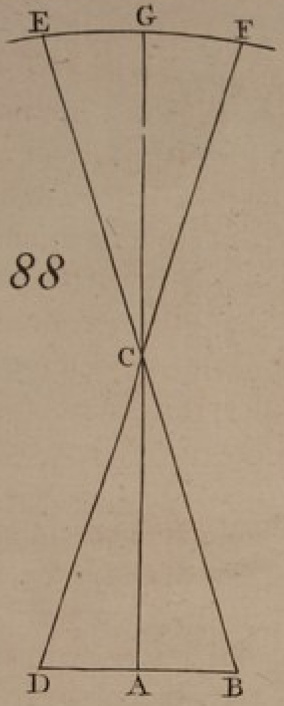
a Manfredius *de annuis inerrantium ſtellarum obſervationib. c.* 9. b *idem ibid.*

ther

page 315.

Book II.

88



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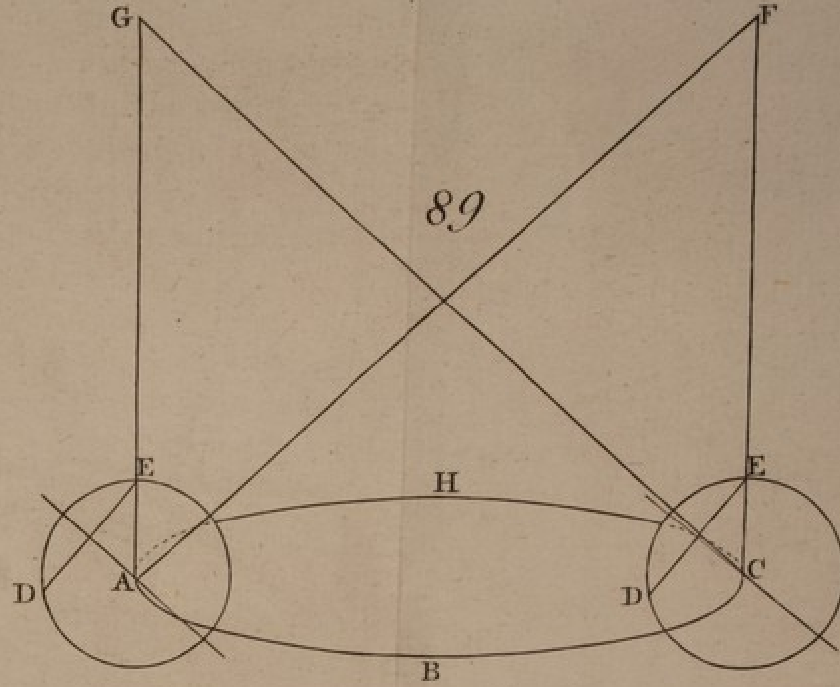

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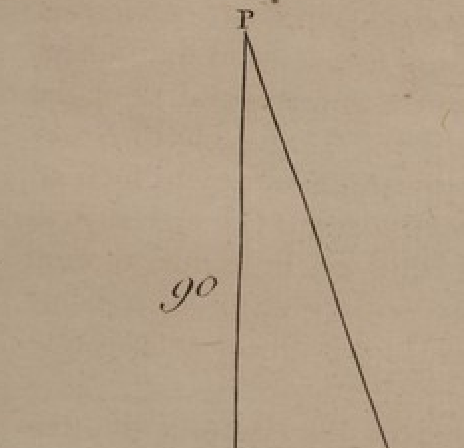

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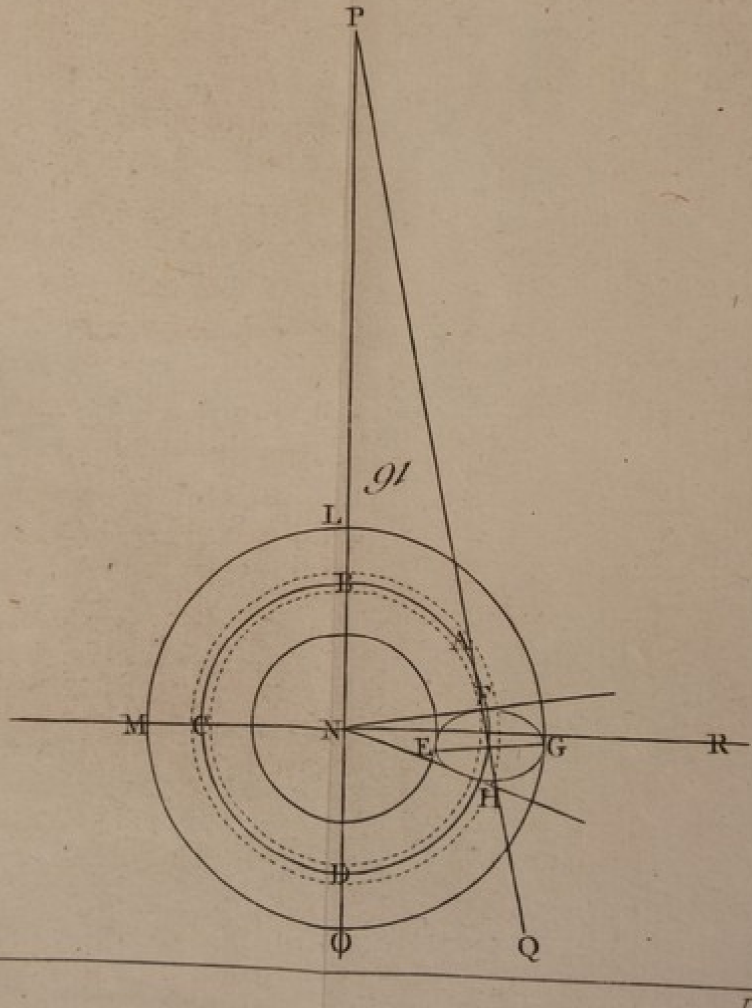


J. Mynde sc.

ther: the intervals between the tranſits of the ſtars are to be turned into mean time[a]: we ſhould be well aſſured that the inſtrument with which we obſerve is always in the ſame plane at the times of obſervation; for this purpoſe, inſtead of one teleſcope moveable upon a mural arc, it would be better to have two, fixed to a ſtrong old-built wall, in ſuch a manner that one of them may point at the parallel of one of the ſtars to be obſerved, the other at the parallel of the other ſtar; each teleſcope being furniſhed with croſs hairs, one of which is to be perpendicular to the horizon. It is of no conſequence whether the mural inſtrument or the teleſcopes be fixed preciſely in the plane of the meridian or not, provided we be ſure they continue all the time immoveable; ſince the intention here is not to find the true right aſcenſion of either ſtar, but to obſerve whether the difference of their right aſcenſions be conſtantly the ſame, throughout the year, or be different at different times of the year[b].

870 Obſervations of this ſort have been made by ſeveral aſtronomers[c]; by ſome with a view of finding out whether any annual parallax of the fixt ſtars could be diſcovered by a variation in their right aſcenſions, or not: thus they have obſerved with great care what number of ſeconds Lyra comes to the meridian after Capella; as alſo how many ſeconds Capella comes to the meridian after Lyra, throughout the year: the like obſervations have been made of the tranſits of Capella and Arcturus, of Arcturus and Aldebaran, of Arcturus and Sirius, and of ſeveral other pairs of ſtars: in all which there has been found an inequality in the intervals of time between their tranſits; and this inequality has been obſerved to have its regular periods of increaſe and decreaſe, which it went through in the ſpace of a year; and that not in ſuch order and degree as was to be expected from the annual parallax of the ſtars, but, in many inſtances, quite the contrary; and ſo agreably to *Bradley*'s hypotheſis, in the greateſt number of ſtars, that *Manfredi* owns ſuch an agreement could by no means be looked upon as accidental[d]: though that aſtronomer at the ſame time declares againſt the belief of the annual motion of the earth, and ſeems unwilling to admit of the progreſs of light being temporary, and is for ſuſpending his judgment till ſome other cauſes can be thought of for the ſolution of theſe appearances.

We may now go on to ſhew in what manner, the aberration of the ſtars

a How to turn apparent into mean or ſydereal time will be ſhewn hereafter.

b *v.* Manfredium *loco citato.*

c Romer, Caſſini, Maraldi, Manfredi: *v.* Horrebovii *baſin aſtronomiæ, cap.* 10, *de parallaxi orbis annui; et* Manfredii *epiſtolam de noviſſimis circa fixorum ſyderum errores obſervationibus, inter Academicorum opuſcula edita Bononiæ* 1731.

d Manfredius *in epiſtola noviſſime citata.*

FIG. being known, the velocity of light may be found; having firſt premiſed the following lemma.

871 The velocity of light being to the velocity of the eye as CA to BA, §
77 842, requires the tube to be carried along always parallel to BC, or conſtantly inclined to BD in an angle equal to ABC, in order to have the ſtar S ſeen through it by the eye arrived at A: the converſe is true, that if the ſtar S be ſeen by the eye at A, through the tube BC carried parallel to it ſelf along with the eye from B to A conſtantly inclined in the angle ABC; then the velocity of light is to the velocity of the eye as CA is to BA, fig. 77.

872 It has been ſhewn, § 857, that the greateſt aberration in declination which a ſtar that were ſituated in the pole of the ecliptic would have amounts
88 to 40,″4; in fig. 88, let G be the true place of a ſtar in the pole of the ecliptic, E its apparent place in march, and F in ſeptember; the arc EF or the angle ECF is the greateſt difference of the ſtar's declination, found to be 40,″4, § 857: the angles BCD and ECF, being vertical, are equal; therefore ACB the half of BCD is 20,″2: the angle BAC is a right one, here then is a right-angled triangle BAC with one acute angle known; and conſequently, by § 141, the ratio of BA to CA, that is the ratio of the velocity of the eye to the velocity of light, may be known: now BA will be found to be to CA, as 1 to 10210, ſo that the velocity of light is to the velocity of the eye (which in this caſe is the ſame as the velocity of the earth in her orbit[a]) as 10210 to 1: the earth runs through her orbit in $365^{d}\ 5^{h}\ 48'\ 57''$, or 31556937 ſeconds, which carries her through a length equal to the ſemidiameter of her orbit in 5022442 ſeconds; but light goes 10210 times as faſt, and therefore paſſes through that ſemidiameter, or as far as from the ſun to the earth, in 492 ſeconds, that is in 8 minutes and 12 ſeconds.

873 *Romer*, who firſt diſcovered the temporary progreſs of light, by apparent inequalities in the times of the returns of the eclipſes of the ſatellits of jupiter, (which will be treated of hereafter) determined the velocity of light to be ſuch that it paſſes from the ſun to us in about 11 minutes; others, from the ſame eclipſes, have concluded that it runs that length in about 7 minutes of time: the velocity of light here deduced from the aberrations of the ſtars is as it were a mean betwixt what has at different times been determined from the eclipſes of jupiter's ſatellits.

874 From what has been ſaid, *Bradley* draws theſe concluſions: 1, that theſe two different methods of finding the velocity of light thus agreeing in the reſult, is a confirmation of the truth of the hypotheſis which accounts for the annual aberration of the ſtars, and inequalities in the times of the re-

a § 853.

turns

turns of the eclipſes of the ſatellites of jupiter, by the temporary progreſs of light and the annual motion of the earth in her orbit: 2, that the light of all the ſtars arrives at the earth with the ſame velocity; for the annual aberration is the ſame in ſtars of the 5th or 6th as in ſtars of the 2d or 3d magnitude, which is a proof that the lights of them all enter the tube of the obſerver upon the earth with the ſame velocity: 3, that light is propagated from all the ſtars with an uniform velocity, ſo as to run through equal ſpaces in equal times, at all diſtances from the ſtars: this follows from the 2d concluſion, ſince the light from ſome ſtars when it arrives at the earth muſt have run through a vaſtly greater length than that from other ſtars, except we ſuppoſe all the ſtars to be at the ſame diſtance from us, which is highly improbable, on account of the difference in their apparent magnitude and brightneſs: 4, if the light of the ſun be propagated with the ſame velocity as that of the ſtars (which we have no reaſon to doubt of) light moves with the ſame velocity after reflection as before it; ſince the light of the ſun reflected from a ſatellit of jupiter traverſes the orbit of the earth in the ſame ſpace of time as the light does which is emitted directly from the ſtars.

875 *Bradley* having found, by comparing the obſervations of ſeveral ſtars, that they all conſpired to prove that the *maximum*, or greateſt aberration of a ſtar in the pole of the ecliptic would be about 40 or 41 ſeconds; ſuppoſes it to be $40''\frac{1}{2}$: this, from the agreement of his obſervations, he was induced to think could not err ſo much as a ſecond from the truth, and that therefore the velocity of light is determined from theſe obſervations within 5 or 6 ſeconds; which is ſuch a degree of exactneſs as we can never hope to attain from the eclipſes of jupiter's ſatellits.

876 Having thus determined what the aberration of a ſtar in the pole of the ecliptic would be, he calculated, upon that ſuppoſition, what change of declination the ſtars obſerved by him ought to have at ſeveral times of the year; and compared them with the changes which he obſerved them to have: and here he found ſuch an agreement between the hypotheſis and the obſervations, through all the parts of the year, as amounts to a kind of demonſtration that the hypotheſis gives at leaſt the true law of the aberration of different ſtars; and, ſince it does this without allowing any thing at all for annual parallax of the fixt ſtars, he concludes that parallax muſt be much ſmaller than hath been hitherto ſuppoſed by thoſe who have pretended to deduce it from their obſervations: and ſays he is of opinion he ſhould have diſcovered it, if it amounted to ſo much as a ſingle ſecond.

Remarks

Remarks upon § 835.

877 If the annual parallax of the fixt ſtars were diſcoverable by any change of their declination, that change would be greateſt, and conſequently moſt eaſy to be obſerved, in thoſe ſtars that are neareſt the pole of the ecliptic. If a ſtar be in the ſolſtitial colure, any change in declination is juſt ſo much change in latitude; and the converſe is true: but the change of declination and latitude, though it be of the ſame quantity, is not always the ſame
86 way, but in ſome ſtars it is the contrary way, as will eaſily be ſeen by the 86 figure; where E N Q is the ſolſtitial colure, ♋ ♑ the ecliptic, E Q the equator, P the north pole of the ecliptic, N the north pole of the equator: 1, if a ſtar be in the arc P Q between the pole of the ecliptic and the neareſt point of the equator, all increaſe of declination is ſo much increaſe of latitude, and all decreaſe of declination is ſo much decreaſe of latitude; and converſely: thus, ſuppoſe the true place of a ſtar be D, if at any time its apparent diſtance from Q the neareſt point of the equator were to be increaſed any number of ſeconds, as for example if the apparent place of the ſtar were to be at H, its apparent diſtance from ♑ the neareſt point of the ecliptic muſt at the ſame time be increaſed the ſame number of ſeconds, or the ſame arc D H: in like manner, if the ſtar D were ever to appear nearer to Q, it muſt at the ſame time appear nearer to ♑: 2, what I have now ſaid is alſo true of any ſtar that is ſituated in the arc N ♋, between the pole of the equator and the neareſt point of the ecliptic, that all increaſe or diminution of declination is ſo much increaſe or diminution of latitude; and converſely: 3, but if the place of a ſtar be in the arc P N, between the pole of the ecliptic and the pole of the equator, all increaſe of declination is ſo much decreaſe of latitude; and all decreaſe of declination ſo much increaſe of latitude; and converſely: 4, this laſt propoſition is alſo true of ſtars ſituated in the arcs Q♑ and E ♋; but they are too far from the pole of the ecliptic to fall under our preſent conſideration.

878 If any ſtar had a ſenſible annual parallax, its parallactic ellipſis would have the ſame ſhape and poſition, whether it were of the ſame magnitude or not, as its ellipſis of aberration; but there would be the diſtance of three months between the time when the ſtar appears in any given point of its ellipſis of aberration, and the time when it would appear in a ſimilar point of its parallactic ellipſis: thus, whereas a ſtar neither in the pole nor plane of the ecliptic would be in one of the extreme points of the ſhorteſt axis of its ellipſis of aberration, and conſequently have the greateſt or leaſt latitude, when in quadrature with the ſun, § 863; the ſame ſtar would appear in that extreme of the ſhorteſt axis of its parallactic ellipſis which is neareſt the ecliptic

cliptic, and have leaſt latitude, when in conjunction with the ſun: and in the oppoſite extreme, and have greateſt latitude, when in oppoſition to the ſun. Since the ſhorteſt axis of the parallactic ellipſis of a ſtar in the ſolſtitial colure coincides with that colure, the times of the greateſt and leaſt latitude of ſuch ſtar are the two ſolſtices; and theſe are alſo the times of its greateſt and leaſt declination by, § 877. FIG.

879 In fig. 89, let ABCD be the orbit of the earth, A the place of the earth in december, C in june; a ſtar at F that in june is ſeen in the line CF, and paſſes through the zenith of any place ſituated in the parallel DE, will, in december when the earth is at A, be ſeen in the line AF, paſſing ſouthwards from G which is then the zenith, to the diſtance of GF: in like manner, a ſtar at G that paſſes through the zenith of a place in the parallel DE in december, when the earth is at A, will paſs northwards from the zenith in june, being then ſeen in the line CG. 89

Remarks upon § 836, and 837.

880 If the parallax in latitude of a ſtar whoſe diſtance from the pole of the ecliptic is given were found, the parallax that a ſtar at the ſame diſtance from us in the pole of the ecliptic would have might be known: for the parallaxes in latitude of two ſuch ſtars are as the ſines of their latitudes.

881 The parallax of a ſtar in the pole of the ecliptic being given, *the diſtance of* ſuch *a ſtar from the earth* may be thus *found:* in fig. 90, let AB be the orbit of the earth, S the ſun, P a ſtar in the pole of the ecliptic, draw PS and PA, in the triangle PSA, the angle at S is a right one by the conſtruction, and therefore, if the parallactic angle SPA be known, the proportion of AS the ſemidiameter of the orbit of the earth to PS the diſtance of the ſtar P from the ſun may be known by § 143. 90

882 It is eaſy to conceive that any change of latitude or longitude in a ſtar ariſing from its appearing to go round in a parallactic ellipſis would cauſe a change in declination, or right aſcenſion, or in both; and that in a greater or leſs degree, according as the axes of that ellipſis are ſituated in reſpect of the equator: 1, if the ſhorteſt axis, the extream points whereof are the places of greateſt and leaſt latitude, coincides with a ſecondary of the equator, which is the caſe only of ſtars in the ſolſtitial colure; the times of greateſt and leaſt declination are the ſolſtices, as has been ſhewn § 878: 2, if the longeſt axis is nearer than the ſhorteſt axis to coincidence with a ſecondary of the equator, which is the caſe of ſtars near the pole of the equator and nearer to the equinoctial colure than to the ſolſtitial; the times of greateſt and leaſt declination will be nearer to the equinoxes than to the ſolſtices: but the

FIG. times of greateſt and leaſt right aſcenſion would be nearer to the ſolſtices than to the equinoxes. The pole ſtar is very near the equinoctial colure; it was no more than 21′ diſtant from that colure, and about 2° 20′ from the ſolſtitial, when *Flamſteed* obſerved it: he found its declination in december about 40″ greater than its declination in june; ſuch a change agrees as well as could be expected with the obſervations and theory of *Bradley*, but hath by miſtake[a] been thought to proceed from an annual parallax: had that been the cauſe, the greateſt difference of declination would have been found at the two

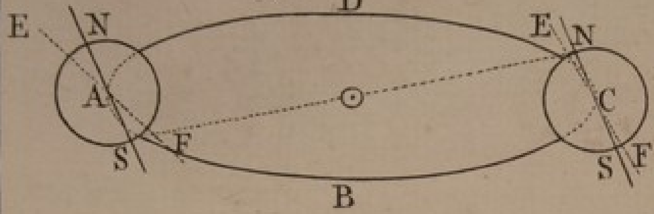
91 equinoxes, as may be ſeen by fig. 91; where let MR be the equinoctial colure, PO the ſolſtitial, P the pole of the ecliptic, N the pole of the equator, EFGH the parallactic ellipſis of the pole ſtar, FH the ſhorteſt axis, coincident with PQ a ſecondary of the ecliptic paſſing through the ſtar; when the ſun is in conjunction with the ſtar, which is a little before the ſummer ſolſtice, the ſtars apparent place is at H, in leaſt latitude; when the ſun is in oppoſition to the ſtar, which is a little before the winter ſolſtice, the ſtars place is at F, in greateſt latitude: but the poſition of the line FH is ſuch, that it is nearly a tangent to the circle ABCD the parallel of the ſtars diurnal revolution; ſo that, whatever be the change of the ſtars latitude meaſured by the line FH, its change of declination meaſured by the diſtance between the two pointed parallels will be much leſs. If any ſenſible change of declination were cauſed in the pole ſtar by annual parallax, it would be moſt eaſily diſcovered about the equinoxes; for near thoſe times that ſtar is in one of the extreme points of the line EG the longeſt axis of its parallactic ellipſis, which axis is nearly coincident with the equinoctial colure: thus the ſtar is near the point G in leaſt declination a little before the vernal equinox; and near the point E, in greateſt declination, a little before the autumnal: if we imagin a parallel GLMO to be drawn tangent to the parallactic ellipſis near the point G, and another parallel to be drawn tangent to the ellipſis near the point E; the diſtance between theſe two parallels is the difference between the ſtars declination at one equinox and its declination at the other: but this difference is too ſmall to be ſenſible. The greateſt parallax of the pole ſtar,

91 at the ſolſtices is in right aſcenſion; this in fig. 91 is meaſured by the angle FNH: the parallax in right aſcenſion of the pole ſtar is to its parallax in latitude, very nearly as the arc of the equator which meaſures the angle FNH is to the arc FH: or, as radius to the ſine of the ſtar's diſtance from the pole: but this parallax has not yet been obſerved to be ſenſible by any aſtronomer.

a This miſtake was taken notice of by *Romer*, in a letter to *Flamſteed: ap.* Horrebovium *in baſi aſtron. c.* 10: and by *Caſſini, mem. d'acad. ann.* 1699.

Book II.

92



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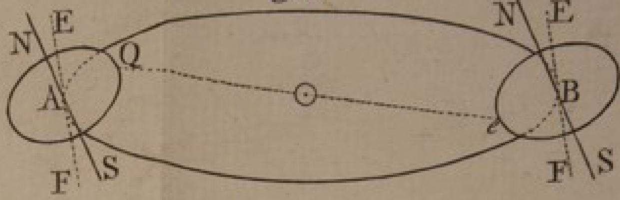

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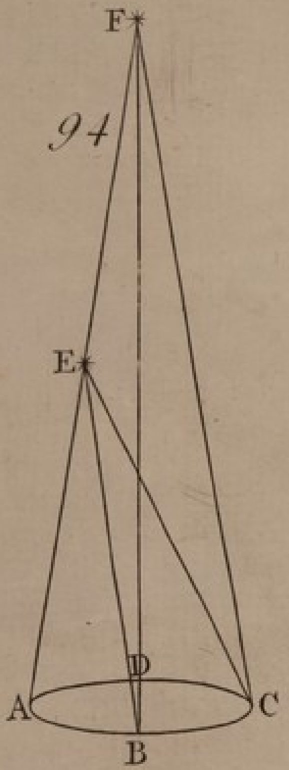

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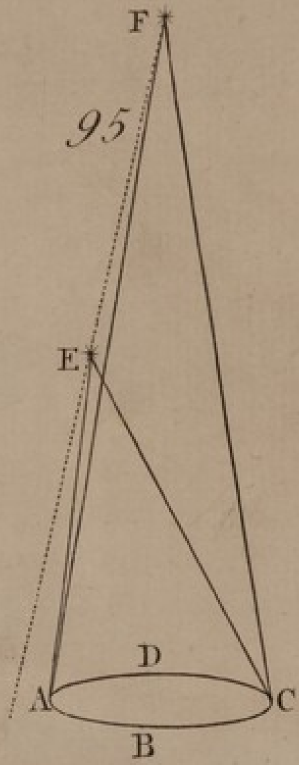

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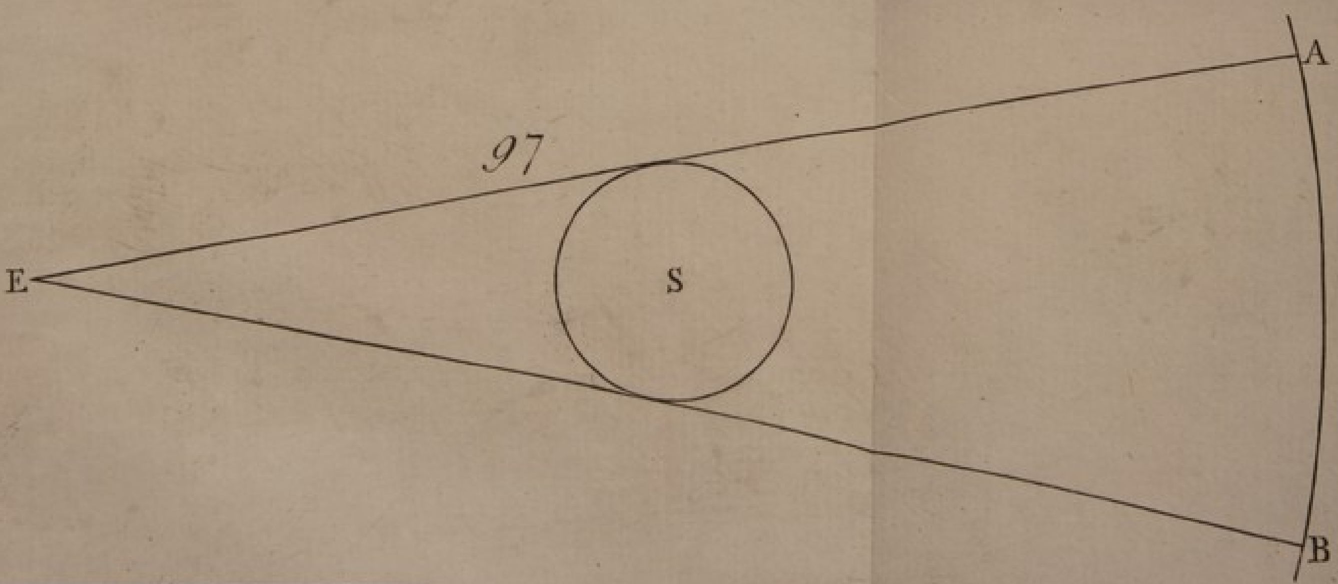


J. Mynde sc.

883 The learned *Gregory* remarks[a], that *Flamſteed*'s method of determining the annual parallax of the pole ſtar, by its diſtance from the pole being greater near the ſummer than it was near the winter ſolſtice, ſuppoſes the axis of the earth to be parallel to it ſelf at both thoſe times; which it would not be, if the ſouthern hemiſphere of the earth ſhould happen to be more denſe than the northern: for in that caſe, the ſouth pole, being nearer to the ſun in december than in june, would be more attracted by him; and this attraction of the ſun would cauſe ſuch an alteration in the poſition of the earth's axis, at the two ſolſtices, as would make ſtars in north declination and north latitude appear at thoſe times to change their declination the ſame way as they ought to do from annual parallax: thus, fig. 92, let ABCD be the orbit of the earth, A and C the earth; if the ſouth pole S be heavier than the north pole N, it is nearer to the ſun, and conſequently more attracted towards him in the direction S ☉, in december, when the earth is at A; than in june, when the earth is at C: and conſequently, at the winter ſolſtice, the axis of the earth will incline from the ſituation NS towards the ſituation EF, more than it does at the ſummer ſolſtice. Now to this, beſides what has been ſaid by *Whiſton*[b], it may be anſwered, that ſuch a nutation or dipping of the north pole as is here ſuppoſed would cauſe a like change in all the ſtars that are in or near the ſolſtitial colure; which is contrary to *Bradley*'s obſervations. FIG. 92

884 There is indeed another nutation of the earth's axis, demonſtrated *a priori*, from the earth being an oblate ſpheroid, as was mentioned § 805; but this nutation is the ſame way at both ſolſtices: thus fig. 93, in december when the earth is at A, the protuberant parts about the equator, which may be conſidered as a ring round the earth, are moſt attracted where they are neareſt to the ſun, as at Q, and that in the direction Q☉; in june, when the earth is at B, they are neareſt the ſun at *e*, and moſt attracted in the direction *e*☉; but both theſe attractions tend to change the ſituation of the axis the ſame way, from NS to EF: this nutation *Whiſton* has calculated to be not above 42‴, and conſequently too little to fall under the niceſt obſervation[c]. 93

885 There are ſeveral ſtars, as the firſt in the head of the ram, the head of Caſtor, the middle one in the ſword of Orion, the ſtar in the breaſt of Virgo marked by *Bayer* with the letter γ, &c. which, appear ſingle to the bare eye, but are by the teleſcope diſcovered to be double; and ſome authors[d]

a aſtronom. book 3, prop. 55. b *aſtronom. lect.* 4. *prælect. mathemat. lect.* 21. c *aſtron. lect.* 4.

d *Gregory* in his aſtronomy book 3 prop. 54, ſays *Caſſini* diſcovered that the firſt of aries and ſome other ſtars appear ſometimes divided into two ſtars; this expreſſion implies that at other times they appear ſingle, but *Caſſini* ſays no ſuch thing: the truth is, theſe ſtars appear ſingle and perhaps a little oblong, through a ſhort teleſcope, bnt a long one ſhews them double.

FIG. tell us that the ſame ſtar appears ſingle at one time and double at another: if this laſt aſſertion be true of any ſtar ſeen through the ſame teleſcope, it muſt be owing to one of theſe three cauſes, either 1, one or both the ſtars ſo viewed change their ſituations, which is not very probable[a]: or 2, one of them has one ſide much darker than the other, ſo as to be viſible or inviſible to us at different times, according as the rotation of that ſtar round its axis turns its bright or dark ſide towards us[b]: or 3, the diameter of the earth's orbit is not quite inſenſible, in compariſon of the diſtance of thoſe ſtars from us; but cauſes an annual parallax in them: if this laſt were the caſe, there would be ſtated times of ſuch ſtars appearing ſingle or double, according as the earth is in ſuch or ſuch part of her orbit; but I do not find this aſſerted by any aſtronomer; had ſuch an obſervation ever been made, it would decide in favour of the annual parallax; upon this conſideration, I was my ſelf induced to obſerve all the double ſtars here mentioned, at different times of the year, through two very good teleſcopes, one of 14 and another of 17 feet: I have not yet repeated my obſervations often enough to determine poſitively in the affair, but from thoſe I have made I am perſuaded they will be found to appear always the ſame, without any ſenſible change of diſtance or ſituation: this will not ſeem ſtrange, after what has been ſaid about the ſmallneſs of the annual parallax, § 876.

886 How the annual parallax would be diſcovered by a ſtar appearing
94 ſingle at one time of the year and double at another, may be ſeen by fig. 94; where let ABCD be the orbit of the earth, E and F two ſtars at conſiderably different diſtances from the ſolar ſyſtem; if a line EF drawn through them and continued touch the orbit of the earth in any point as A, when the earth is in that point they will appear as one ſtar: when the earth is in any other point as B, they muſt be ſeen by two viſual lines BE and BF; and their apparent diſtance is meaſured by the angle EBF: when the earth is in the point C oppoſite to A, their apparent diſtance meaſured by the angle ECF is the greateſt poſible; and then, if ever, they will appear as two ſtars: if the diſtance of the neareſt of theſe ſtars E from the ſolar ſyſtem be ſo great in compariſon of the diameter of the orbit of the earth that the angle ECF becomes inſenſible, there will be the appearance but of one ſingle ſtar throughout the
95 year. By the ſame way of reaſoning, fig. 95, when a line continued through

[a] See § 796.

[b] The ſtars ſeem to be of the ſame nature with the ſun: the ſun, as we ſhall ſee hereafter, has ſometimes a conſiderable number of dark ſpots upon his ſurface; the ſtars may ſome of them have the like ſpots: and ſome ſtars may be ſo cruſted over with ſpots as to be rendered wholly or in part dark and inviſible to us: the ſolar ſpots diſcover the ſun to have a rotation round his axis; the ſtars may, ſome of them at leaſt, have a like rotation.

two

two ſuch ſtars E and F as are at a great diſtance from each other as well as from the ſolar ſyſtem does not touch the orbit of the earth, but comes near ſome point thereof A, if the diſtance of the neareſt ſtar E from the ſolar ſyſtem be ſo great in compariſon of the diameter of the earth's orbit that the difference between the angles FAE and FCE, even magnified by the teleſcope, is inſenſible, though they appear through it as two ſtars very near together, there will be no ſenſible variation in the apparent diſtance between them, throughout the year; and to the eye unaſſiſted they may always have the appearance of a ſingle ſtar. FIG. 95

887 The middle ſtar in the ſword of Orion is found to be a cluſter of three ſtars, which form a triangle having two of its ſides nearly equal, and the angle between thoſe ſides a little obtuſe; the ſtar at the obtuſe angle is much larger than either of the other two, which are nearly equal; theſe three ſtars, together with four others adjacent, are ſurrounded by a faint hazy light like that of a bright whitiſh cloud; this light is brighteſt near the ſtars, and grows gradually more faint and diluted at a diſtance from them, till it becomes inſenſible. *Hugens* who firſt diſcovered this wonderful appearance, as he juſtly calls it, has given us a draught of it, but the ſtars are all drawn nearly of equal magnitude, and the luminous ſpace is more defined than it ought to be; which faults were in all likelyhood owing to the miſtakes of the engraver: I have therefore, in fig. 96, given another ſcheme of it, ſuch as I have 96
often ſeen it through a teleſcope of 17 feet, and have expreſt therein the apparent magnitudes of the ſeveral ſtars.

I ſhall conclude this chapter, when I have told the reader that a general account of Mr. *Bradley*'s inſtrument with a figure of it may be ſeen in *Smith*'s optics vol. 2 p. 454; and that a more particular deſcription of a like inſtrument, made portable for the uſe of the members of the R. Academy at Paris who went in the year 1736 to meaſure a degree upon the meridian within the N. polar circle, may be found in a book intituled *degre du meridien entre Paris et Amiens determine &c.* 8vo Paris 1740.

CHAP. 19. OF THE DISTANCE AND MAGNITUDE OF THE FIXT STARS.

888 The diſtances of the ſtars from us and their magnitudes are very proper to be conſidered together, becauſe the knowledge of either of theſe will help us to determine the other: for, ſuppoſing the apparent magnitude of an object, or the angle under which it appears to be known, geometry teaches us, if the diſtance of the object be alſo known, how to find its real magnitude;

FIG. or, if its real magnitude be known, how to find its diſtance from us. How the diſtance of a ſtar would be found, if its annual parallax could be aſcertained, has been ſhewn in the chapter immediately preceding[a]: we have there ſeen that the diſtance of the ſtars comes out from *Bradley*'s obſervations to be at leaſt 400000 times as great as the diſtance of the ſun from us[b]; an amazing diſtance this, and beyond the power of the imagination to reach: perhaps we may have a better idea of its vaſtneſs, if we meaſure it by the velocity of ſome moving body, as *Heſiod* does the height of heaven, when he tells us that an iron anvil would be nine days in falling from heaven to earth, and would not reach the earth till the tenth day[c]. A cannon ball has been found to go about 100 french toiſes in a ſecond, which is a little more than 7 engliſh miles and $\frac{1}{4}$ in a minute[d]: ſound, according to many accurate experiments of Mr. *Derham*, goes at the rate of an engliſh mile in 9 half ſeconds and $\frac{1}{4}$, or 13 miles in a minute[e]: the diſtance of the ſun from the earth, ſuppoſing his parallax $10''$ as before ſettled, is 10300 diameters of the earth, or 82 millions of engliſh miles; ſo that a cannon ball going with the velocity above mentioned would be above 21 years in paſſing from our earth to the ſun: ſound would go this length in 12 years: light is found to run from the ſun to our earth in a little more than 8 minutes. If the diſtance of a ſtar from the earth be 400000 times as great as the diſtance of the ſun, its light muſt take up above ſix years in coming to us: ſound would be 4800000 years, and a cannon ball 8600000 in going through that ſpace.

889 This diſtance of the ſtars is concluded from a ſuppoſition that the parallax is ſuch, that the whole annual parallax of a ſtar in the pole of the ecliptic and at the ſame diſtance from us with thoſe obſerved by *Bradley*
90 would be one ſecond; in which caſe the angle SPA, fig. 90, would be half a ſecond: that accurate aſtronomer does not ſay that he found the parallax of any of thoſe ſtars ſo much as one ſecond, but that he thinks it cannot be more than that: from whence we may reaſonably conclude, that the diſtance of the ſtars from us is at leaſt as great as was juſt now mentioned: we are not ſure that it is not much greater, ſince, for aught appears to the contrary, the parallax of the ſtars may be much leſs than a ſecond. The ſtars obſerved by *Bradley* were ſome of them of the 2d and 3d magnitude; how

a § 880 and 881. b § 837. c *in Theogonia v.* 722. *Heſiod* here gives us a much more grand idea of the height of heaven than *Homer*, who makes *Vulcan* fall from thence to earth in a day; *Iliad* A. *v.* 592: but perhaps thoſe poets had different views; *Heſiod* had a mind to repreſent the great height of heaven; *Homer* to ſhew the ſwiftneſs of *Vulcan*'s fall, when thrown down from thence by *Jupiter*. *Milton* copies after *Heſiod*, in deſcribing the fall of the rebellious angels;

Nine days they fell——— Paradiſe loſt book 6. v. 871.

d Hugenii *coſmotheor. l.* 2. e *Jones* Phil. tranſ. abr. vol. 4. pag. 396.

much greater then, in all probability, is the diſtance of thoſe of the 5th and 6th magnitude? and how much greater ſtill is that of thoſe teleſcopic ſtars which cannot be ſeen without very long teleſcopes, and of numberleſs others which we may very reaſonably believe to be ſo far off as to be out of the reach of any teleſcopes that can ever be made? We cannot indeed conclude that the ſtars are all of equal dimenſions, and that all the difference in their apparent magnitudes is owing to their being at different diſtances from us; nor have we any reaſon to believe they are all at the ſame diſtance from us, and that thoſe which appear largeſt are all proportionably of greater real magnitude: it ſeems moſt probable, that, though they are of various ſizes, and ſcattered through the vaſt expanſe of ſpace at various diſtances from us and from one another; yet many of them are nearly of the ſame ſize, ſo that, in general, and as to a great number of them, the reaſon why ſome appear leſs than others is becauſe they are placed at a greater diſtance from us. From the brightneſs of the ſtars, the exceeding ſmallneſs of their diameters when diveſted of ſpurious rays by the teleſcope, and their vaſtly great diſtance from the ſun and from the earth, we may certainly conclude, that their light is not received from the ſun and reflected to us, as that of the planets is; but they are ſelf-ſhining bodies like our ſun: they are placed ſo far from one another, that if every ſtar be, like the ſun, ſurrounded with a number of planets and comets, there is no reaſon to believe that one of theſe ſyſtems does diſturb or otherwiſe affect any of the reſt; and particularly their immenſe diſtance from the ſolar ſyſtem makes it utterly improbable that they ſhould have any kind of influence upon our earth, or any of the planets.

890 Some aſtronomers, deſpairing to diſcover the annual parallax, have thought of other methods of finding out the diſtance of the ſtars; which, though they may be looked upon as conjectural, deſerve to be mentioned, for the ingenioufneſs of their contrivance. The apparent diameters of the ſun and planets are eaſily meaſured with ſufficient exactneſs, the diſtance of the ſun and of any of the planets from our earth may at any time be computed, near enough to the truth for the purpoſe now before us; from theſe *data* the diſtance of a ſtar may be found, ſuppoſing it equal to the ſun in its real dimenſions, and that its apparent diameter is equal, or in a known ratio to one of the planets: thus *James Gregory*, by ſuppoſing ſirius to be of the ſame bigneſs with the ſun, and to have the ſame apparent diameter with jupiter in oppoſition, inveſtigated the diſtance of that ſtar; as may be ſeen at large in *Gregory*'s aſtronomy, book 3, prop. 57 &c. The learned *Hugens* tells us that he found it ſo difficult to meaſure the apparent diameters of the fixt ſtars, by reaſon of their ſmallneſs, in as much as they appear even through the

the teleſcope but as lucid points without any ſenſible magnitude, when the glare of the ſpurious rays that ſurround them is taken away; that he was induced to try ſome way of diminiſhing the ſun's apparent diameter, till it was reduced to the ſmallneſs of a ſtar: in order to this, he covered one end of a twelve foot empty tube with a very thin plate of braſs, wherein he had pierced a very ſmall hole not above the 140th part of an inch in diameter, and, with his eye at the other end of the tube, looked at the ſun, which by being thus viewed was diminiſhed to an 182d part of his whole diameter, but ſtill appeared much brighter than ſirius does by night: in order therefore to diminiſh ſtill farther the ſun's apparent diameter, he took from a microſcope a ſmall globule of glaſs of about the ſame bigneſs with the hole, and placed it therein; this, according to calculation, reduced the ſun's diameter to an 152d part of that 182d part which was ſeen before through the bare hole, or to a 27664th part of his whole apparent diameter; and yet this particle of the ſun was equal in brightneſs to ſirius: from whence he concludes that, if the ſun were at 27664 times his preſent diſtance from us, he would appear equal to ſirius; and conſequently, if ſirius be of the ſame magnitude with the ſun, the diſtance of that ſtar muſt be 27664 times as great as the ſun's diſtance from us[a]: the force of this reaſoning will be better underſtood, if we conſider the following *lemma*.

891 If two globes of equal dimenſions be at different diſtances from us, their apparent diameters will be reciprocally as their diſtances, ſee § 242 and 243: thus, if the diſtance of a ſtar which is of the ſame bigneſs as the ſun be 30000 times the diſtance of the ſun from us, the apparent diameter of that ſtar will be but a 30000th part of the apparent diameter of the ſun: from whence the converſe follows, that if the apparent diameter of a ſtar which is of the ſame bigneſs as the ſun be a 30000th part of the ſun's apparent diameter, the diſtance of that ſtar from us is 30000 times as great as the diſtance of the ſun.

892 *Caſſini* endeavoured to find out the diſtance of ſirius by the following method[b]: to abate the ſparkling of that ſtar, he viewed it through a teleſcope of thirty four feet, covering the object glaſs with a thin paſtboard which had in the middle a round hole of an inch and an half diameter; through the teleſcope thus prepared, the diſk of ſirius was ſeen very well defined, and free from thoſe glaring rays which appear to the bare eye: jupiter was above the horizon at the ſame time, and, being viewed through the ſame teleſcope, and by ſeveral methods compared with ſirius, the diameter of that planet was judged to be ten times as great as the diameter of ſirius;

a Hugenii *coſmotheor. l.* 2. b *memoires d'acad. ann.* 1717.

the

the apparent diameter of jupiter was at that time 50 ſeconds, from whence it follows that the diameter of ſirius was about 5 ſeconds: if we ſuppoſe then, ſays that author, ſirius to be equal to the ſun in bigneſs, the diſtance of the ſun from us being about 10000 diameters of the earth, and the apparent diameter of ſirius being to that of the ſun as 1 to 384, the diſtance of ſirius from the earth comes out 3840000 diameters of the earth. Thus *Caſſini* makes the diſtance of ſirius but 384 times as great as the ſun's diſtance, which is much leſs than *Hugens* brings it out, who yet makes it but a fifteenth part of what the diſtance of the ſtars obſerved by *Bradley* is concluded to be, from their parallax: it is very probable ſirius is much nearer to us than thoſe ſtars, ſince he appears ſo much bigger. The methods made uſe of by *Gregory*, *Hugens* and *Caſſini* may well be called conjectural, becauſe they depend upon two uncertain ſuppoſitions; one, that the ſun and ſirius are equal in magnitude; the other, that the apparent diameter of ſirius is determined with ſufficient exactneſs: I need not ſay any thing of the uncertainty of the firſt of theſe ſuppoſitions, and as to the ſecond, *Caſſini* himſelf has given us an obſervation of his in another place[a], which makes it evident that we may eaſily be deceived in meaſuring the apparent diameter of a fixt ſtar, ſo as to determine it to be much greater than it is; as I am apt to think that learned aſtronomer has done in the preſent caſe.

893 The account he gives of his obſervation is as follows; there is a ſtar in the breaſt of Virgo called γ by *Bayer*, which, though ſingle and round to the bare eye, through a teleſcope of 11 feet, ſeems oblong; and through one of 16 feet, appears divided into two ſtars, ſo near together that the diſtance between them is no more than equal to the apparent diameter of one of them: it was known that the 21ſt day of april, 1720, new ſtyle, about midnight, the moon was to paſs over theſe ſtars, and eclipſe them; ſo curious a ſight deſerved to be attended to; the moon was then near the full, and ſhone ſo bright as to cauſe many of the ſtars then above the horizon to diſappear; this muſt alſo diminiſh the apparent magnitude of theſe ſtars, which through a teleſcope of 16 feet were ſeen ſtript of their ſpurious rays, with their diameters very well defined: as the dark edge of the moon drew near to them, it cauſed no change in their colour or ſituation; at $0^h\ 25'\ 14''$ after midnight, the occultation of the moſt weſterly of the two ſtars, by the appulſe of the dark edge of the moon, was obſerved through the 16 feet teleſcope; and at $0^h\ 25'\ 44''$, the moon covered alſo the moſt eaſterly ſtar; each of them diſappeared in an inſtant, or half a ſecond, without any preceding diminution of magnitude or brightneſs: at $0^h\ 51'\ 16''$, they both came together into

a *memoires d' acad. ann.* 1720.

view

view again, from behind the bright edge of the moon, to which they were then parallel: the reaſon of there being ſuch an interval between the times of their occultations was, their being then in an oblique poſition to the dark edge of the moon's diſk.

894 There were two circumſtances attending this obſervation that deſerve to be taken notice of: the firſt is, that each ſtar diſappeared in an inſtant, or in about half a ſecond; whereas there was an interval of 30 ſeconds in time between the two occultations: from the difference between the time the moon took up in hiding each ſtar and the time ſhe was going through the ſpace between the two ſtars, it is evident, that the diſtance between the centers of theſe ſtars is to the diameter of one of them as 30 to $\frac{1}{2}$, or as 60 to 1; from whence it follows, that the apparent diameter of one of the ſtars (being equal to half the diſtance between their centers) is to its true diameter as 30 to 1: thus we ſee that, notwithſtanding the diminution of the glare of thoſe ſtars by the teleſcope, their apparent diameters were ſtill 30 times greater than they ought to be; and conſequently their apparent diſks were magnified to 900 times their true dimenſions: we may judge from hence, how extreamly ſmall the fixt ſtars would appear, if we could ſee them perfectly freed from that falſe light which ſo greatly increaſes their apparent magnitude: and from this ſmallneſs of their apparent diameters, if they be nearly equal in magnitude to the ſun, it will follow that their diſtance is exceedingly great, ſee § 891.

895 The other remarkable was, that this obſervation makes it probable that there is not any atmoſphere round the moon; ſince, if there had been any, one of theſe ſtars, falling obliquely into it before the other, ought, by refraction, to have ſuffered ſome change in its colour, or in its diſtance from the other ſtar which was not yet entered into the atmoſphere: but no ſuch alteration could be perceived, though the obſervation was performed with the utmoſt attention to that particular, and was very proper to have made ſuch a diſcovery; becauſe, thoſe two ſtars being of the ſame magnitude and brightneſs, if any change had happened to either of them, it would have been eaſy to have taken notice of it: but this we ſhall have occaſion to conſider again, when we come to treat of the moon.

896 *Caſſini*, in order to determine the real magnitude of Sirius, having firſt mentioned the great difficulty of finding the diſtance of the ſtars from annual parallax, ſuppoſes Sirius to be at no greater diſtance from the earth than ſaturn, which ſays he is about 100000 diameters of the earth, and is the leaſt that can be aſſigned by whatever hypotheſis we explain the motions of the heavenly bodies; ſince all aſtronomers agree that the ſtars are farther off

off than the planets: from this diſtance of Sirius, and its apparent magnitude $5''$, he calculates the true diameter of that ſtar to be more than two diameters of the earth[a]. But this diſtance of Sirius is certainly much too ſmall, and conſequently his real magnitude deduced from thence muſt be too ſmall likewiſe, if we allow his apparent diameter to be ſo much as $5''$. The comet that appeared in 1680 is computed, when in aphelion, to be at a diſtance from the ſun 14 times as great as the diſtance of ſaturn[b]: we cannot but ſuppoſe the neareſt ſtars to be at a greater diſtance from the ſun than any comet of the ſolar ſyſtem ever goes to: if we ſuppoſe ſirius to be but 20 times the diſtance of ſaturn from the ſun, and his apparent diameter to be $5''$, his real diameter will be 48 diameters of the earth.

897 The apparent diameter of $5''$ here aſſigned to ſirius, though leſs than it has been eſtimated by many aſtronomers[c], is certainly too great; perhaps the error is cauſed by *Caſſini* uſing, as he tells us he did, a teleſcope with a ſmall aperture at the object glaſs; for this will make any of the larger ſtars ſeem to have a ſenſible diameter[d]; whereas, if, inſtead of contracting the aperture, the eye-glaſs be thinly ſmoked, they appear like lucid points, without any ſenſible magnitude[e]: to this purpoſe Dr. *Halley* ſays as follows, 'The diameters of 'ſpica virginis and aldebaran are ſo ſmall, that when they happen to im'merge behind the dark edge of the moon, they are ſo far from loſing their 'light gradually, as they muſt do if they were of any ſenſible magnitude, that 'they vaniſh at once with all their luſtre; and emerge likewiſe in a moment, 'not ſmall at firſt, but at once appear with their full light, even though the 'emerſion happen very near the cuſp, where, if they were four ſeconds in di'ameter, they would be many ſeconds of time in getting entirely ſeparated 'from the limb: but the contrary appears to all thoſe who have obſerved the 'occultations of theſe bright ſtars. Now though ſirius be bigger than either 'of them, yet he is by far leſs than two of them, and conſequently his dia'meter to one of theirs is leſs than the ſquare root of 2 to 1, or than 14 to '10; ſo that, in *Caſſini*'s teleſcope which ſhewed the diameter of ſirius $5''$, 'one of theſe ſtars ought to appear about 4 ſeconds in diameter: whereas we 'are otherwiſe certain that they are leſs than one ſingle ſecond in diameter; 'the great ſtrength of their native light forming the reſemblance of a body, 'when it is nothing elſe but the ſpiſſitude of their rays[f].

a *Elements d'aſtronomie par Mr.* Caſſini *in 4to* Paris 1740. *liv.* 1. *chap.* 5. b According to *Halley*, the aphelion diſtance of this comet from the ſun is a little more than 138 times the mean diſtance of the earth from the ſun, *v.* Newton. *princip. l.* 3. *prop.* 41. c *Tycho* makes the apparent diameter of a ſtar of the firſt magnitude two minutes, *v.* Ricciol. *almag. l.* 6. *c.* 9. d *Flamſteed*, committing the ſame fault of leſſening the aperture, makes the diameter of ſirius $15''$, *Hiſt. cæleſt vol.* 1. *p.* 17. e *Hugens* makes this remark, *ſyſtem. ſaturn.* f Phil. tranſact. abridg. vol 6. p. 166.

FIG. 898 Since the apparent diameters of the ſtars, even thoſe of the firſt magnitude, are thus ſmall, not amounting to a ſingle ſecond; we cannot hope to determin the meaſure of them with any certainty: we may aſſign them a meaſure which we certainly know they do not exceed; but we cannot be ſure that meaſure is not too great for them: all luminous objects appear larger than opake ones of the ſame dimenſions; thus, mercury appears larger when in all his brightneſs than when he is ſeen like a dark ſpot upon the ſun[a]; though he be neareſt us in the ſituation laſt mentioned. The apparent diameters of the fixt ſtars are much ſmaller than they have been generally determined by thoſe who have conſidered them, and yet ſmall as they are, the real magnitudes of them are probably very great; otherwiſe they would not be viſible to us at all, by reaſon of their immenſe diſtance from us: if we ſuppoſe the apparent diameter of any of the ſtars obſerved by *Bradley* to be equal to a 400000th part of the ſun's apparent diameter, or a 200th part of a ſecond, and this does not ſeem too much to aſſign for the apparent diameter of one of them, which is a ſtar of the ſecond magnitude[b]; it will follow from that ſuppoſition and from what has been ſaid of the diſtance of that ſtar, that it equals the ſun in bigneſs. In ſhort, we have no proofs that any of the ſtars are leſs than the ſun; it is very probable many of them equal and many ſurpaſs that luminary in their real dimenſions: and this may be true, not only of thoſe which are of the greateſt luſtre, but even of thoſe which are ſcarcely viſible to us. How great ſoever be the real magnitude of any body, we may aſſign it a diſtance from us large enough to make it appear under an angle of any given ſmallneſs: thus, if the ſun were 10000 times as big as he is, we might ſuppoſe him to be removed to ſuch a diſtance from us, as to appear no bigger than the ſmalleſt teleſcopic ſtar; or even to be out of the reach of any glaſſes that can ever be made.

CHAP. 20. THE APPARENT DIAMETERS OF THE SUN AND PRIMARY PLANETS.

899 The apparent diameter of the ſun, or of any planet is the angle under which the ſun or the planet appears to an inhabitant of the earth: thus, fig.
97 97, let S be the ſun, E the eye of an obſerver upon the earth, EA and EB lines drawn from the eye of the obſerver tangents to the globe of the ſun and terminated in the ſphere of the heaven at A and B; the angle AEB is the apparent diameter of the ſun, the meaſure of that angle is AB, an arc of a

a *Flamſteed* meaſured his diameter in the former ſituation 16″, *Hiſt. cœleſt. vol.* 1. *p.* 17. *Bradley* in the latter but 10″ 45‴, Phil. tranſ. abr. vol. 6. p. 238. b The ſtar η in the great bear.

great

great circle in the ſphere of the heaven, and the apparent diameter of the ſun is ſaid to be ſo many minutes and ſeconds as that arc contains: ſee § 235 to 244, ſee alſo § 292.

900 The apparent diameter of the ſun was pretty well known to the ancients; we ſhall ſee by the table that ſome of them were not out much above a minute, in determining it: when they ſet down what it was at the ſun's greateſt diſtance, and what at his leaſt diſtance from us; I do not think they had any method of finding out the difference by immediate obſervation; but they firſt ſuppoſed the ſun to move equably in a circle, and, finding the ſpace of time from the vernal equinox to the autumnal was ſeveral days longer than from the autumnal to the vernal, they conſidered how much the earth muſt be placed out of the center of the ſun's circle[a] to cauſe ſuch an apparent inequality in his motion; and how much nearer he muſt be to us in winter than in ſummer: and from thence inferred how much greater his apparent diameter muſt be in winter than in ſummer. The moderns have been able to obſerve directly what difference there is in the ſun's apparent diameter, at different times of the year; and from thence have concluded what change there is in his diſtance from us: and this is done, either by looking at the ſun, where the teleſcope and micrometer are of great uſe; or by projecting the ſun's picture upon a white plane in a dark room.

901 The ſun's vertical or perpendicular diameter is found by taking the height of the upper and lower edge of his diſk, as mentioned § 292: this is moſt conveniently done when the ſun is in or near the meridian; becauſe there is then no ſenſible change in his altitude, during the ſpace of two or three minutes: the height of each edge muſt be corrected by proper allowance for parallax and refraction, and we ſhall have the true diameter, which is the difference between the true height of the upper and lower edge. This method is very ſimple, and gives us the ſun's apparent diameter with as much exactneſs as can be expected from the diviſions of the inſtrument, which ſhould be a large quadrant, furniſhed with a teleſcope with two croſs-hairs[b], one perpendicular, the other horizontal.

902 The ſecond method of determining the ſun's apparent diameter is to obſerve by a good clock the time the ſun's diſk takes in paſſing through the plane of the meridian, or ſome other hour circle. At or very near either of the equinoxes, when the ſun's apparent diurnal motion is in the equator, or

a I ſpeak here of thoſe among the ancients who ſuppoſed the earth to be placed in the center of the univerſe, and the ſun and planets to move round the earth in excentric circles, in a manner that will be explained hereafter.

b They are now generally very fine ſilver wires; though called hairs, perhaps becauſe hairs were firſt in uſe.

 in

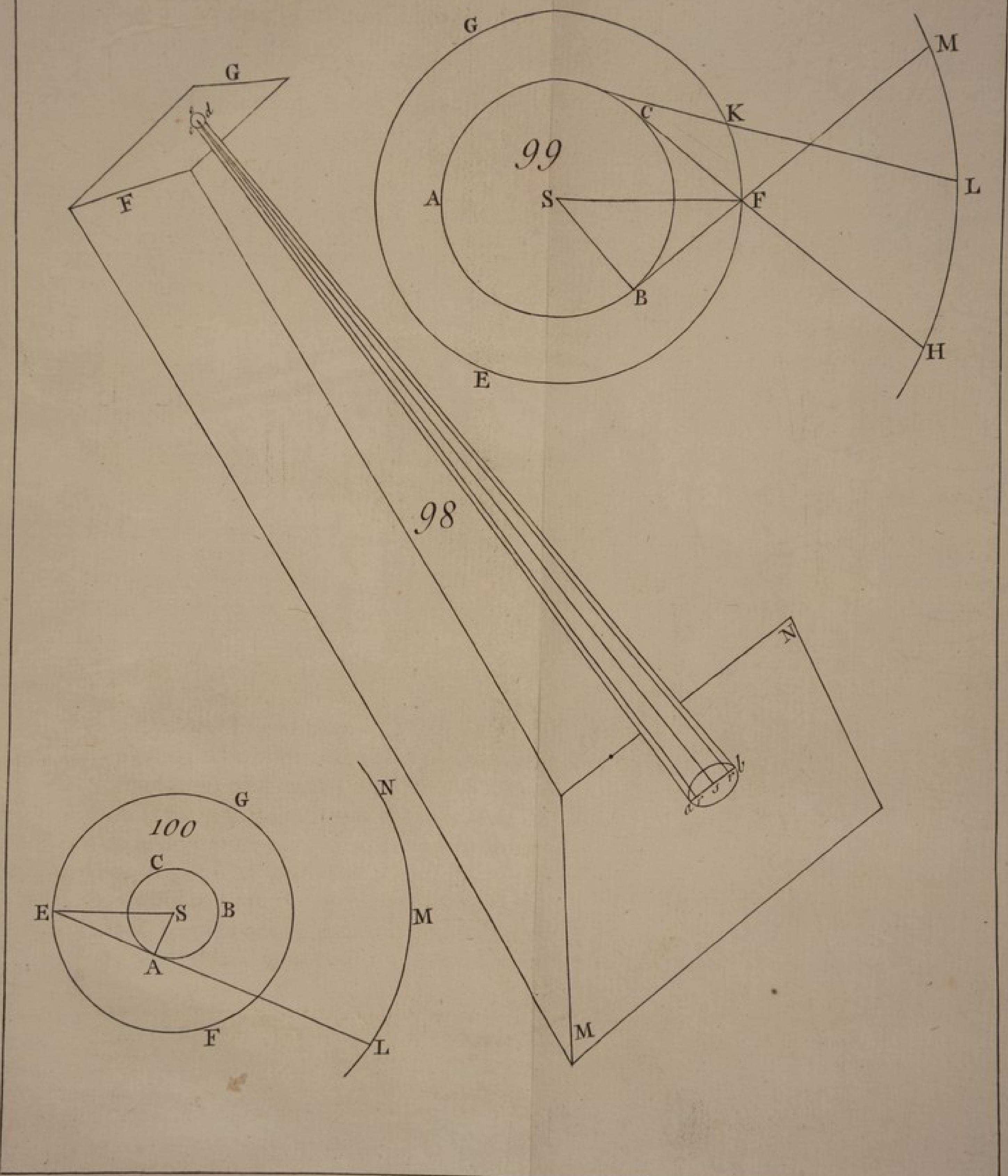
in a parallel very near that circle, ſay, as the time between the ſun's leaving the meridian or any other hour circle and returning to it again, is to 360 degrees; ſo is the time of the ſun's tranſit, to the number of minutes and ſeconds of a degree contained in his apparent diameter. The time of the ſun's tranſit may alſo be turned into parts of a great circle, by the table page 79. At any other time of the year, when the ſun is in a parallel at ſome diſtance from the equator, his diameter meaſures a greater number of minutes and ſeconds in that parallel than it would do in a great circle, and takes up proportionally more time in paſſing over the meridian; we may then uſe this analogy; as the whole ſine, is to the coſine of the ſun's declination; ſo is the time the ſun is paſſing through the meridian reduced to minutes and ſeconds of a degree, to the arc of a great circle which meaſures the ſun's apparent horizontal diameter. This method is eaſily put in practice by two perſons, one of which is to look through a teleſcope with croſs hairs, and give a ſignal by pronouncing quick the word *now*, or ſome other monoſyllable, at the moment the ſun's weſtern edge, as alſo when his eaſtern edge appears to touch the perpendicular hair; the other is to meaſure the interval of time between thoſe two moments, by the ſwings of a pendulum, or the hand of a clock that ſhews ſeconds: the whole may alſo be performed by one obſerver, if he makes uſe of a ſtop-watch; or has a clock placed near enough for him to hear the beats, whilſt he is viewing the tranſit.

903 In the year 1732 on the 23, 24 and 30 of december, new ſtyle, which is the time of year when the ſun is neareſt us, *Caſſini*[a] meaſured, with a micrometer carefully adjuſted, the vertical diameter of the ſun; and after proper allowances for parallax and refraction, found his greateſt apparent diameter to be $32' \, 37'' \, 24'''$, or $32' \, 37''\frac{1}{2}$. In the year 1735 on the 30 of june, new ſtyle, when the ſun is at the greateſt diſtance from us, the ſame *Caſſini* found his true apparent diameter $31' \, 32'' \, 24'''$, or $31' \, 32''\frac{1}{2}$: *Caſſini* here takes notice that his obſervations agree ſo exactly with thoſe made ſome years before by *Louville*, that there is not the difference of a ſingle ſecond between them. *Louville* appears to have taken the apparent diameter of the ſun with the utmoſt care; he meaſured the horizontal diameter by the time of the ſun's paſſage by the vertical hair of his teleſcope, he made uſe of a clock which beat ſeconds, and a ſtop-watch which made five beats in a ſecond: he took the vertical diameter of the ſun with a micrometer; and found it juſt ſo much leſs than the horizontal, as it ought to be by the different refraction of the upper and lower edge: upon the whole, he makes the ſun's greateſt apparent diameter $32' \, 37'' \, 7'''$, and from thence computes his leaſt to be $31' \, 32'' \, 50'''$[b].

a *Elements d'aſtronomie liv.* 2. *chap.* 5.   b *memoires d'Acad. R. ann.* 1724.

The

page 333.



J. Mynde sc.

The greateſt and leaſt apparent diameters of the ſun, according to *Caſſini* the father and *Flamſteed*, are ſomething different from thoſe here ſet down: ſee § 775, and the following table. FIG.

A table of the ſun's apparent diameter at his greateſt, mean and leaſt diſtance; according to ſeveral authors[a].

Authors names.	greateſt diſtance of ☉	mean diſtance of ☉	leaſt diſtance of ☉
	′ ″ ‴	′ ″ ‴	′ ″ ‴
Ariſtarchus, Archimedes	30 0	30 0	30 0
Ptolemy	31 20	32 18	33 20
Albatennius	31 20	32 28	33 40
Regiomontanus	31 0	32 27	34 0
Copernicus	31 40	32 44	33 54
Tycho	30 0	31 0	32 0
Ricciolus	31 0	31 40	32 8
Joh. Domin. Caſſini[b]	31 40	32 13	32 46
Gaſcoigne[c]	31 40		32 50
Flamſteed[d]	31 30		32 48
De la Hire[e]	31 38	32 11	32 44
Louville[f]	31 32 50	32 4 36	32 37 7
M. Caſſini F.[g]	31 32 30	32 5 0	32 37 30

904 In order to take the ſun's apparent diameter by the projection of his picture, let the ſun ſhine into a dark room though a hole in a thin plate of metal FG, fig. 98, the diameter of the hole *cd*, which ſhould not exceed 98 two inches, muſt be known in equal parts of as ſmall a ſcale as is poſſible; for inſtance let it be found how many hundredth parts of an inch it contains: let the plate FG, be ſo placed at the time of the obſervation, that a ray from the center of the ſun may fall perpendicularly upon it: receive the circular image of the ſun upon a plate MN, which ſhould be white, and placed parallel to the plate FG; the diſtance between the two plates *es*, muſt be known, in equal parts of the ſame ſcale, by which the diameter of the hole *cd*, was meaſured: let the diameter of the ſun's image *ab*, be taken with a pair of

a *v.* Ricciol. *almageſt. nov. l.* 3. *c.* 10. & *aſtronom. reformat. l.* 1. *c.* 12. b *obſervations aſtronomiques, p.* 22. c Flamſteed. *hiſt. cœleſt. vol.* 1. *p.* 4. d *Hiſt. cœleſt. vol.* 1. *p.* 23. e *Tabb. aſtronom. edit.* 2. *p.* 17. f *memoires d'Acad. R. ann.* 1724. g *Elements d'aſtronomie, liv.* 2. *chap.* 5.

compaſſes,

FIG. 98 compaſſes, and meaſured upon the ſame ſcale; if the diameter of the hole *cd* be ſubſtracted from it, there will remain the true apparent diameter of the ſun, *viz. rr*, in hundredth parts of an inch; and conſequently the ſemidiameter *rs*, is known: imagin the line *es* drawn, and you have the right angled triangle *esr*, two ſides of which *viz. es*, and *sr*, and the right angle *rse*, are known, and conſequently the remaining angles may be known by trigonometry; and therefore it may be known what the angle *ser* is, by which the ſun's ſemidiameter *sr*, is meaſured.

905 One method of finding *the apparent diameter of a planet* is, to compare it with, and eſtimate what proportion it bears to, the diameter of the moon, or of a ſpot in the moon, or the interval between two ſtars near to one another, and not far diſtant from the planet. 2, another way is to place between the planet and the eye a thin plate of metal with a ſmall hole in it, at ſuch a diſtance from the eye, that the entire diſk of the planet may appear exactly to fill the hole; and then, by meaſuring the diameter of the hole and the diſtance of the plate from the eye, to determine by trigonometry the viſual angle ſubtended by the diameter of the hole, which in this obſervation is the ſame as the apparent diameter of the planet. 3, a third method ſimilar to the ſecond is, to ſuſpend a thread or wire between the eye and the planet, at ſuch a diſtance from the eye that it may juſt cover the diſk of the planet, and to determine trigonometrically the viſual angle then ſubtended by the thickneſs of the thread, which is done by meaſuring its diſtance from the eye, and finding its real thickneſs, by winding it cloſe round a rule and obſerving how many threads cover an inch in length: by this method *Galileo* attempted to meaſure the apparent diameter of lyra, and computed it to be 5 ſeconds[a]. 4, a fourth way is to meaſure the picture of the planet caſt through a teleſcope upon white paper in a dark room, and compare it with the diameter of the ſun or moon caſt in the ſame manner. 5, to mention no more ſuch uncertain methods[b], the diameters of the planets are beſt taken by the micrometer: venus and mercury have been ſeen in the ſun, ſo that their diameters have been compared with the diameter of the ſun: the apparent diameter of jupiter may be found by reducing into ſeconds of a degree the time a ſatellit, or, which is better, the time the ſhadow of a ſatellit takes in paſſing over his diſk. 6, the diſk of a planet may alſo be meaſured, when there is an occultation of it by the moon, by counting the number of ſeconds that paſs between the appulſe of the edge of the moon's diſk to the edge of the diſk of the planet and the time of the planet being totally hid by the moon: but then the horary motion of the moon and of the planet at the time

a *Syſtem. coſmic. dial.* 3. b *v.* Ricciol. *almag. nov. l.* 7. § 6. *c.* 9.

of

of obſervation muſt be known, as alſo whether the edge of the moon's diſk comes upon the planet directly or obliquely; and, if obliquely, with what degree of obliquity.

906 The ſmalleſt object, as the fineſt hair or wire, placed in *the focus of a teleſcope*[a] appears greatly magnified and very diſtinct: if a thin plate of metal be placed therein having a round hole of a diameter a little leſs than the diameter of the eye-glaſs, it will diſtinctly circumſcribe ſo much ſpace in the heaven as is viſible through the teleſcope at one view: this ſpace may be meaſured, either by finding two ſtars whoſe diſtance from each other is exactly equal to its apparent diameter, and is otherwiſe known; or by obſerving the time a ſtar in or very near the equator takes in paſſing over it, ſee § 902. Some aſtronomers have determined the apparent diameters of the planets by eſtimating how many times they were contained in the apparent diameter of the ſpace thus circumſcribed by the teleſcope[b]. *Hugens* adviſes to prepare two or three long narrow braſs plates, with ſides very ſtrait, but a little converging, and, having two ſlits ſo made in the oppoſite ſides of the teleſcope, that the plane of a long plate ſliding therein may touch the plane of the plate with the round hole, to thruſt it in till the planet be juſt hid; and, obſerving in what part of the long plate the breadth of it is juſt ſufficient to cover the whole planet, to take that breadth with a fine pair of compaſſes, and compare it with the diameter of the hole: from whence the apparent diameter of the planet is eaſily found[c]. The diameters of planets meaſured by *Hugens*'s method are ſomething bigger than they ought to be, becauſe the rays of light are inflected as they paſs by the edges of ſolid bodies, as was mentioned § 220.

907 *The micrometer* is an inſtrument now very well known, it is ſo contrived that two parallel fine wires being placed in the focus of a teleſcope, one fixed the other moveable, or both of them moveable, they may be made to approach or recede one from the other till they appear exactly to touch two oppoſite points in the diſk of the planet; and then the index ſhews the apparent diameter of the planet in minutes and ſeconds: ſee the deſcription of this inſtrument in *Smith*'s optics book 3 chap. 8, ſee alſo Phil. tranſact. abr. vol. 1 p. 218. *Flamſteed* made uſe of a micrometer with two plates, one of which was made to approach to or recede from the other, till the planet appeared to be claſped between the edges of the two plates: this method gave the apparent diameters of the planets as much too ſmall as *Hugens*' gave them too great; and that by reaſon of the rays being inflected the contrary way, ſee

a The focus of the teleſcope is a place within the tube where the focus of the object-glaſs and the focus of the eye-glaſs coincide. b *v.* Ricciol. *alm. l.* 7. § 6. *c.* 9. c Hugenii *ſyſtem. ſaturn.*

§ 220.

§ 220: upon this account, *Whiſton* very adviſedly choſe the mean between the meaſures of *Hugens* and thoſe of *Flamſteed*.

908 I ſhall now give a table of the apparent diameters of the primary planets, as they are ſtated by different authors[a]: nothing exact can here be expected from the ancients; among the moderns, thoſe marked with an aſteriſk are ſuch as may beſt be depended upon.

Authors names.	Diam.	♄			♃			♂			♀			☿		
		′	″	‴	′	″	‴	′	″	‴	′	″	‴	′	″	‴
Albatennius[b]	mean	1	44	28	2	36	40	1	34	0	3	8	0	2	5	20
Alfraganus	mean	1	44	28	2	36	40	1	34	0	1	34	0	1	15	12
Tycho	mean	1	50		2	45		1	40		3	15		2	10	
Hortenſius	leaſt	0	31	0	0	38	30	0	9	0	0	15	20	0	10	0
	mean	0	37	0	0	50	0	0	36	0	0	53	0	0	19	0
	greateſt	0	42	40	1	1	40	1	4	0	1	40	0	0	28	0
Kepler	greateſt	0	30		0	50		6	30		7	6				
Ricciolus	leaſt	0	22	0	0	38	18	0	10	6	0	33	30	0	9	20
	mean	0	26	40	0	49	46	0	22	0	1	4	12	0	13	48
	greateſt	0	36	0	1	8	46	1	32	0	4	8	0	0	25	12
* *Hugens*[c]	greateſt	0	30		1	4		0	30		1	25				
* *Flamſteed*[d]	greateſt	0	25		0	54		0	33		1	12				
* *Horrox*[e]	greateſt										1	18	30			
* *Crabtree*[f]	greateſt										1	9				
* *Pound*[g]	mean	0	18		0	37	15									
* *Bradley*[h]	greateſt													0	10	45

Remarks upon the ſun's apparent diameter.

909 The continual ſtreaming of the particles of light from the body of the ſun make it reaſonable to believe he muſt waſte in bulk: Sir *Iſaac Newton* remarks, that comets which in their revolution round the ſun come ſo near him as to go through his atmoſphere, may by the reſiſtance thereof, have their motions ſo retarded, that, approaching nearer and nearer to him every revolution, they may at laſt fall into the ſun: ſuch a ſupply, though very

a v. Ricciol. *almag. nov. l.* 7. § 6. *c.* 9. & *aſtronom. reformat. l.* 10. *c.* 7. b *Albatennius* and *Alfraganus* determine the apparent diameter of each planet by eſtimating to how great a part of the ſun's apparent diameter it is equal: thus they ſay the apparent diameter of jupiter is equal to a 12th part of the ſun's apparent diameter, &c; *Ricciolus* collects their meaſures as here ſet down from the ſun's apparent diameter as ſettled by them. c *Syſtem. ſaturn.* d *Hiſt. cœleſt. vol.* 1. *p.* 8, & *ſeqq.* e *Venus in ſole viſa.* f *ibid.* g Newton's *princip.* book 3 phenom. 1, 2. h Phil. tranſact. abr. vol. 6. p. 238.

ſmall

ſmall and happening but rarely, if we conſider the inconceivable minuteneſs FIG.
of the particles of light, may be thought ſufficient to keep up the bulk of the ſun for many ages, ſo that no diminution thereof ſhould be perceiveable by the inhabitants of the ſyſtem: but however that be, the moſt ancient and modern obſervations of the ſun's apparent diameter are quite inſufficient for determining whether it be diminiſhed or not. See *Smith*'s optics p. 415.

CHAP. 21. THE DISTANCES OF THE PLANETS FROM THE SUN: THE REAL MAGNITUDES OF THE SUN AND PLANETS.

910 The parallaxes of the ſun and planets and their apparent diameters are ſo well determined, that the diſtances of the planets from the ſun and the real magnitude of the ſun and planets are known to a tolerable degree of certainty: the horizontal parallax of the ſun is now generally agreed to be about 10″, ſee § 820; from hence the diſtance of the ſun from the earth may be found by § 143.

911 In the *Copernican* ſyſtem, the proportion between the ſemidiameters of the planetary orbits, or between the diſtances of the ſeveral planets from the ſun is found by trigonometry; ſo that if the diſtance of any one of them, as for inſtance if the diſtance of the earth from the ſun be given, the diſtances of all the reſt of the planets from the ſun may be found: in any of the ſuperior planets, the ratio its diſtance from the ſun bears to the diſtance of the earth from the ſun is known, by meaſuring the angle of the planets retrogradation: thus, fig. 99, let S be the ſun, ABC the orbit of the earth, EFG 99
the orbit of mars, HLM part of a great circle in the ſphere of the heaven wherein mars appears to go retrograde, let the place of mars be at F; by the earth paſſing in her orbit from B to C, mars will appear to move retrograde from M to H: the angle then of the retrogradation of mars namely MFH is known by obſervation, to this the vertical angle BFC is equal: draw SF and SB, and you have the triangle SBF, wherein the angle SBF is a right one, by § 28; the angle SFB is equal to half the angle of retrogradation, and conſequently known; ſo that in this triangle two angles are known, and therefore the remaining angle FSB may be found, § 55 cor. 3: and, all the angles being known, the ratio of any one ſide to any other, as the ratio of SB the diſtance of the earth from the ſun to SF the diſtance of mars from the ſun may be found, § 141.

Scholium. The angle of the retrogradation of mars is here expreſſed as if mars ſtood ſtill at F, whilſt the earth went from B to C; whereas mars in the

 mean

FIG. mean time moves forward in his orbit, from F to K, ſo that his real retrogradation will be only ML leſs than MH: but ſince the quantity of mars's motion in his orbit may be found, during the time of his retrogradation, it may be known how much the angle of his retrogradation is thereby diminiſhed, and conſequently what his retrogradation would have been, if he had ſtood ſtill all the while at F.

912 *In* either of *the inferior planets*, the ratio of the ſemidiameter of its orbit to the ſemidiameter of the orbit of the earth is eaſily found, by the an-
100 gle of the planet's greateſt elongation: thus, fig. 100, let S be the ſun, ABC the orbit of mercury, EFG the orbit of the earth, LMN an arc of a great circle in the ſphere of the fixt ſtars; A the place of mercury when ſeen at L in his greateſt elongation from the ſun; draw SE, and SA, and you have a triangle, whereof the angle SAE is a right one, SEA is the angle of mercury's elongation, known by obſervation, and therefore the remaining angle ASE may be found: and conſequently the ratio of ES the diſtance of the earth from the ſun to AS the diſtance of mercury from the ſun may be known.

913 The two ſections immediately preceding ſhew how to find the comparative diſtances of the planets from the ſun, but only in a general and leſs accurate way; becauſe neither the excentricities of the planetary orbits nor the inclinations of their planes are there taken into the account: more exact methods may be ſeen in *Gregory*'s aſtronomy book 3 prop. 19, 21 and 22; and *Caſſini elements d'aſtronomie liv.* 4. *chap.* 6.

914 The diſtances of the planets from the ſun are found to be in a certain ratio to the periodical times of their revolutions round the ſun; the ſquares of their periodical times are as the cubes of their diſtances: this analogy, diſcovered by *Kepler*[a], furniſhes us with a method of finding the ratio between the diſtances of the planets from the ſun, to greater exactneſs than can be done by any other method; becauſe the periodical times of the planets are known to great exactneſs.

915 *The periodical times of the planets* were given before in round numbers; in the following table they are ſet down more accurately[b].

		days	hours	min.
mercury	revolves round the ſun in	87.	23.	16
venus		224.	16.	49
the earth		365.	6.	9
mars		686.	23.	27
jupiter		4332.	12.	20
ſaturn		10759.	6.	36

a *epit. aſtron. l.* 4. *Gregory* aſtron. book 1 prop. 40. & 67. Streete *aſtron. Carolin.* b Streete *ibid.*

916

916 *The comparative mean diſtances of the planets from the ſun* were before ſet down only in round numbers, § 619; the following table has them with greater exactneſs[a].

	♄	♃	♂	⊕	♀	☿
According to *Kepler*	951000.	519650.	152350.	100000.	72400.	38806.
According to *Bullialdus*	954198.	522520.	152350.	100000.	72398.	38585.
From the periodical times	953806.	520116.	152369.	100000.	72333.	38710.

917 From hence, *the abſolute diſtances of the planets from the ſun*, ſuppoſing the ſun's parallax 10″, are as follows;

The diſtance of		from the ſun is		ſemidiameters of the earth, or		engliſh miles.
	mercury		8000		32,000000	
	venus		14900		59,000000	
	the earth		20600		82,000000	
	mars		31400		125,000000	
	jupiter		107300		426,000000	
	ſaturn		196700		780,000000	

918 From their apparent diameters and theſe real diſtances, we have *the real diameters of the ſun and primary planets*, as follows[b];

The diameter of		is equal to		diameters of the earth, or		engliſh miles.
	the ſun		100		793,000	
	mercury		$\frac{1}{3}$		2,600	
	venus		1		7,900	
	the earth				7,935	
	mars		$\frac{3}{5}$		4,800	
	jupiter		9 [illegible]		77,000	
	ſaturn		8 [illegible]		67,000	

919 *The ſuperficial contents of the ſun and primary planets* are as follows, § 86;

The ſuperficial content of		is equal to		ſurfaces of the earth.
	the ſun		10000	
	mercury		$\frac{1}{9}$	
	venus		1	
	mars		$\frac{1}{3}$	
	jupiter		93	
	ſaturn		72	

a *Newton*'s *princip.* book 3. phenom. 4. The near agreement of the comparative diſtances computed from the periodical times with thoſe determined from obſervations by *Kepler* and *Bullialdus* is a good proof of the analogy mentioned § 914.

b In the apparent diameters, I follow *Bradley* for mercury; the mean between *Horrox* and *Crabtree* for venus; *Flamſteed* for mars; and *Pound* for jupiter and ſaturn.

920 *The solidities of the sun and primary planets* are as follows, § 87;

The solidity of		is equal to		
	the sun		1000000	times the solidity of the earth.
	mercury		$\frac{1}{27}$	
	venus		1	
	mars		$\frac{1}{5}$	
	jupiter		899	
	saturn		612	

921 The mean distances of the planets from the sun, or the semidiameters of their orbits being given; it is easy to compute the circumferences of those orbits; by § 68. The circumference of the orbit of a planet, and the periodical time in which it goes round therein being given; we may easily compute the mean velocity with which the planet goes round the sun in its orbit. *The mean horary velocities of the primary planets* are as follows;

	goes round the sun at the rate of		
mercury		94000	miles in an hour.
venus		69000	
the earth		59000	
mars		48000	
jupiter		26000	
saturn		19000	

Scholium. The horary motion of every planet when in perihelion is swifter than is here set down, and slower when in aphelion: as was said § 672.

922 The distances of the planets from the sun above set down suppose the parallax of the sun to be precisely 10″, as it was determined by the parallax of mars, § 820 and 822: but since it is impossible to be certain there is not an error of 2 or 3 seconds in the parallax of mars, arising from the imperceptible errors in the observations upon which the calculation of the parallax of that planet is founded; and since the difference of 3″ in the parallax of mars would occasion a difference of 1000 semidiameters of the earth in his distance; it is impossible to determine the distance of mars from the earth with certainty, so near as to 1000 semidiameters of the earth: and consequently the distance of the sun from the earth cannot be determined nearer than within about 2000 or 3000 semidiameters of the earth. If the parallax of mars were greater, it would be more easy to determine his distance with certainty; the difficulty of determining the distances of phenomena increases in a duplicate proportion of their distances, so that a distance 20 times as great as another is 400 times as difficult to be determined with equal certainty. When astronomers give us the distances of the planets in leagues and miles, as they may do

do, ſince the ſemidiameters of the earth may be reduced to leagues and miles with accuracy enough, as when they tell us the diſtance of the earth from the ſun is about 30 millions of leagues; we can have no greater certainty the number is exact within 2 or 3 millions of leagues, than we have that in a diſtance by common eſtimation of 30 leagues upon the earth there is not a miſtake of 2 or 3 leagues. *Caſſini obſervations aſtronomiques*, § 37.

923 Thoſe among the ancients who placed the earth in the center of the univerſe determined the moon's diſtance by her parallax, which they could diſcover; as for the diſtances of mars, jupiter and ſaturn, they conjectured them to be proportional to their periods: and ſince the moon, which they found to be neareſt to the earth, performed her circuit in the ſhorteſt time; they concluded ſaturn, whoſe period was longeſt, to be proportionally the moſt diſtant planet from the earth: this rule could not be applied to venus or mercury; becauſe they are always near the ſun. Some of them placed mercury farther from the earth, others nearer to the earth than venus: others, obſerving that mercury and venus were never very far diſtant from the ſun, imagined the orbits of thoſe two planets to have the ſun for their center, and that they accompanied the ſun in his annual revolution round the earth.

924 The ancients determined the diſtance of the ſun from the earth by eclipſes of the moon; or by obſervations of the moon when ſhe appears half illuminated by the ſun: and, from the diſtance of the ſun thus found, computed his parallax; which they made much greater than the obſervations of the moderns have ſhewn it to be, as was ſaid § 815.

Pythagoras conjectured the diſtances of the ſeveral planets from the earth to be in certain harmonical proportions[a], and was herein followed by ſome of the Platonic philoſophers[b] and others.

CHAP. 22. CHANGES IN THE FIXT STARS: CLOUDY STARS.

925 There are ſeveral ſtars now to be ſeen in the heaven, which are not mentioned in the ancient catalogues; and others are now not to be found, though the places in which they formerly appeared have been ſet down by aſtronomers who obſerved them: there are alſo ſome ſtars whoſe apparent

a Pythagoras *prodidit hunc totum mundum muſica factum ratione; ſeptemque ſtellas inter cœlum & terram vagas, quæ mortalium geneſes moderantur, motum habere* ἔνρυθμον, & *intervalla muſicis diaſtematis habere congrua, ſonituſque varios reddere pro ſua quæque altitudine ita concordes, ut dulciſſimam quidem concinant melodiam, ſed nobis inaudibilem propter vocis magnitudinem, quam non capiant aurium noſtrarum anguſtiæ.* Cenſorin. *de die natalis c.* 11. *Vide* Ciceronis *ſomnium* Scipionis.

b Macrob. *in ſomn.* Scip. *l.* 2. *c.* 3. *V.* Ricciol. *alm. l.* 9. § 5. *c.* 7.

magnitude

magnitude is periodically increaſed and diminiſhed: as to thoſe ſtars which are omitted in the ancient catalogues but inſerted in thoſe of later date, it is probable many were overlooked at firſt by reaſon of their ſmallneſs: ſome of the ancients mention the pleiades as conſiſting of ſix ſtars only, others as of ſeven: this has induced ſome authors to count the ſeventh of the pleiades among the new ſtars; but this difference in reckoning may perhaps be owing to the difference in the eyes of the obſervers; or to the different conſtitution of the air: it may not be improper upon this occaſion to mention, that ſeveral aſtronomers have given us figures of the pleiades, as they appear through the teleſcope: thus *Galileo* gave us one containing 36 ſtars[a]; *Hook* has one of 78[b]: *De la Hire* has a ſcheme of 64[c]: and *Maraldi* one of 56 ſtars[d]: as to ſome little difference between their ſeveral draughts, it may eaſily be accounted for, by the great difficulty there is in placing thoſe ſtars in their true ſituation. *v. Ricciol. l.* 8. § 2. *c.* 1. Phil. tranſ. abr. vol. 1. p. 246.

926 The moſt ancient obſervation of a new ſtar is that by *Hipparchus*, about 120 years before Chriſt; which occaſioned his ſetting about a catalogue of the ſtars, as was ſaid, § 606: it is pity we have not ſome account in what part of the heaven this ſtar was ſeen: another new ſtar is ſaid to have appeared about A. D. 130: a third about A. D. 389: a fourth in the ninth century in the 15° of ſcorpio, which is ſaid to have caſt as much light as a quarter of the moon does: a fifth A. D. 945 between the conſtellations of Caſſiepea and Cepheus: a ſixth in the year 1264 near the conſtellation of Caſſiepea: but as to all theſe ſtars, the accounts we have of them are ſo imperfect, that nothing can be built upon them[e].

927 The firſt new ſtar of which we have any good account is that which in the beginning of november 1572 appeared in Caſſiepea, making nearly a rhombus with the three ſtars α β γ of that conſtellation, where it was ſeen 16 months ſucceſſively, without any change of place among the fixt ſtars: this ſtar had no hair round it or tail as comets have; but ſhone with the ſame luſtre as the other fixt ſtars do; ſurpaſſing ſirius or lyra in brightneſs and magnitude: it appeared even bigger than jupiter, which at that time was near his perigee; and by ſome was thought equal to venus when ſhe is in her greateſt luſtre: it ſhone forth at once in all its brightneſs; and continued to do ſo all november, ſo as to be ſeen, by thoſe who had very good eyes, even at noon-day; which none of the ſtars or primary planets can be, except venus: and in the night it might be perceived through thin clouds by which other ſtars were hid: it did not continue long of the ſame

a *in nuncio ſydereo.* b *micrographia pag.* 241. c *memoires d'acad. ann.* 1693.
d *memoires d'acad. ann.* 1708. e *v.* Tychon. *progymnaſmat. cap.* 3. & Ricciol. *l.* 8. § 2. *c.* 1.

apparent

apparent magnitude, for in december it ſeemed to be but equal to jupiter: in january 1573 it was leſs than that planet, but a little bigger than ſtars of the firſt magnitude: to which it was equal in february and march: thus gradually diminiſhing, in april and may it was but of the ſecond magnitude; in june july and auguſt it was only equal to the biggeſt ſtars in Caſſiepea, which are counted of the third: in ſeptember october and november, it was no bigger than a ſtar of the 4th order; and in december it equalled the ſtar called κ by *Bayer* to which it was near: towards the end of the year 1573, and in the month january of the year following, it was but little ſuperior to ſtars of the fifth; in february it was no bigger than a ſtar of the ſixth magnitude: and in march became quite inviſible. It was alſo ſubject to divers changes in brightneſs and colour, as it diminiſhed in bigneſs: for when it appeared biggeſt, its light was white and brilliant: from that time it grew a little yellowiſh: and in the beginning of the ſpring 1573 was ſomething of the colour of mars, being reddiſh like the bull's-eye, and a little leſs bright than the right ſhoulder of Orion: in may it was of a pale lividiſh white, like ſaturn: which colour continued to the laſt, as did its ſparkling alſo; only growing more dim and faint, as it was nearer to its diſappearing. This ſtar was obſerved by ſeveral aſtronomers, but eſpecially by *Tycho Brahe*, who wrote a treatiſe upon it, wherein he determines its longitude and latitude, and concludes it to be in the region of the fixt ſtars, at a greater diſtance from the earth than the moon, or even any of the planets; by reaſon of its having no ſenſible parallax: he gives us alſo the obſervations of it and opinions about it of the *Prince* of *Heſſe*, *Hainzelius*, *Mæſtlinus*, and others, with his own remarks upon them. Some have thought this ſtar to be the ſame which is ſaid, § 926, to have appeared in A. D. 945, and 1264; its place in the heaven ſeems to favour this opinion.

928 Auguſt 13 1596, *David Fabricius* obſerved a ſtar in the neck of the whale, in 25° 45′ of aries, with a ſouth latitude of 15° 54′: it diſappeared after the month october of the ſame year: *Bayer*, in his maps of the heaven printed in 1603, marks it with the letter o, as a ſtar of the 4th magnitude: *Phocyllides Holwarda* obſerving it in the year 1637, and, not knowing what had been done before, thought that the firſt time of its being taken notice of; he ſaw it come into view again, after having diſappeared nine months: it has been ſince found to be every year pretty regular in its period; except that from october 1672 to december 1676 *Hevelius* could not ſee any thing of it. *Bullialdus*, in a treatiſe printed at Paris in 1667, having compared together the obſervations which had been made of it from the year 1638 to 1666, determined the periodical time between this ſtars appearing in its greateſt brightneſs

neſs and returning to it again to be 333 days: he found alſo that about 120 days paſs between the time when it is firſt ſeen of the 6th magnitude and its diſappearing: that it continues in its greateſt luſtre for about 15 days: that after its firſt appearance of the 6th magnitude it increaſes in bigneſs much faſter till it comes to be of the 4th, than it does from that time to its being of the third: and that from its being of the third its increaſe to the ſecond magnitude is by ſtill ſlower degrees. He accounts for theſe appearances, by ſuppoſing this ſtar to be a globe having the greateſt part of its ſurface dark, the reſt being luminous; and that, having a rotation round its axis, it turns ſometimes its dark ſometimes its luminous part towards the earth [a].

929 A ſimple rotation will not explain the variations that appear in this ſtar: for 1, it does not every year arrive at the ſame apparent magnitude; but ſome years it ſurpaſſes ſtars of the ſecond order and other years does not equal thoſe of the third: 2, the time of its appearance is not always the ſame; but ſome years it is viſible four months, and in other years no longer than three months: 3, the time between its firſt appearance and its coming to its greateſt brightneſs is not always equal to the time between its arriving at its greateſt brightneſs and its diſappearing; but ſometimes its apparent magnitude increaſes faſter than it decreaſes, and ſometimes it decreaſes faſter than it increaſes: 4, according to *Hevelius*, it was not to be ſeen at all for four whole years, from october 1672 to december 1676. *Caſſini* makes the mean period of this ſtar 334 days, allowing it to be ſometimes 3 or 4 days more or leſs than that: he accounts for the variations obſerved in it, by ſuppoſing a change in the poſition of the axis of the ſtars rotation [b]: I think it is more probable, that the ſurface of the ſtar is ſubject to change, being ſometimes covered over with more ſpots than at other times.

930 Three changeable ſtars have been diſcovered in the conſtellation of the ſwan; the firſt was ſeen by *Gulielmus Janſonius* in 1600, at the ſetting on of the neck, near that in the breaſt called γ by *Bayer*, who mentions it as a new ſtar: it is not in the catalogue of *Tycho*, though he ſets down ſeveral other ſtars near it which are leſs: in 1606 *Kepler* publiſhed a ſmall treatiſe of this ſtar annexed to a larger piece about the new ſtar that appeared in Serpentarius: he therein evidently proves it to be a new ſtar, againſt ſome who at that time were of another opinion: he tells us that it had for ſix years at leaſt continued conſtantly immoveable as to its place among the fixt ſtars, and unchangeable as to its magnitude; being reckoned by all who obſerved it of the third order, ſomething leſs than the ſtar in the breaſt, and a little bigger than that in the bill of the ſwan; he determined its place to be in 16° 18′ ♒

a Caſſini *elements d'aſtronomie l.* 1. *c.* 6. b *idem ibidem.*

with

with 55° 30′ or 32′ north latitude: from the year 1606 I find no account of it for 10 years; but in 1616, 1621, 1624 and 1629, *Ricciolus* ſays it was ſeen by himſelf and others: that author, who ſeems to think it appeared all the intermediate time from the year 1606 to 1629, could not find any writer who had taken notice of the time of its diſappearing: but is very poſitive that it was inviſible in the laſt years between 1640 and 1650: in 1655 *Domenicho Caſſini* ſaw it again; when it grew bigger, ſo as in 1657, 1658 and 1659 to be of the 3d magnitude, according to *Hevelius*; who from the beginning of the year 1660, with ſurprize, found it gradually leſs, and at the end of 1661 to be quite inviſible: in november 1665 it began to appear again, and in ſeptember 1666 *Hevelius* ſaw it exactly in the ſame place as before, with his naked eye, but exceedingly ſmall: in 1670, 1671, 1672, 1675 and 1677 it appeared of about the 6th magnitude: in 1681 it could not be ſeen without a teleſcope: in 1715 it appeared of about the 6th magnitude, as it does this preſent year 1741.

931 The ſecond changeable ſtar in the ſwan was diſcovered june 20 1670, near the head on the ſide towards the arrow; it was of the 3d magnitude, and kept its bigneſs to the 3d of july; but its light was then ſenſibly fainter: the 11 of that month it was ſcarce of the 4th magnitude: on the 10 of auguſt it did not exceed the 5th; in ſeptember it diminiſhed very faſt; and oct. 14 *Hevelius* could not ſee it, though he looked for it very diligently: this ſtar, after having diſappeared near ſix months, was ſeen again march the 17th 1671, being then of the 4th magnitude: the 3d of april it was judged to be bigger than either of the ſtars which are at the bottom of the harp, and are of the third magnitude; but was a little leſs than that in the bill of the ſwan: on the 4th of april it was looked upon to be almoſt equal in bigneſs to, and much brighter than the ſtar in the bill: on the 9th it ſeemed a little leſs, and nearly equal to the biggeſt of the two ſtars on the bottom of the harp: on the 12th it was equal to the leaſt of thoſe two ſtars; but on the 15th it was grown bigger, and was again equal to the biggeſt of thoſe two ſtars: between the 16 and 27 of april it appeared of various magnitudes; ſometimes equal to the biggeſt of thoſe two ſtars, ſometimes to the leaſt, and ſometimes of a middle ſize between them both: the 27 and 28 of the ſame month it was become as big as the ſtar in the bill of the ſwan, and grew bigger than that, and nearly equal to the ſtar in the breaſt, but its light was a little dimmer and redder, from the 30 of april to the 6 of may: on the 15 it was leſs than the ſwan's bill; and the 16 it was of a middle ſize between the two ſtars in the bottom of the harp: from that time it continued to grow leſs and leſs, ſo that on the 2d of auguſt it was judged by *Hevelius* to

be ſcarcely of the 6th magnitude, and on the 11th of ſeptember it could not be perceived by him at all: this ſtar appeared twice in its greateſt ſplendor in the ſpace of one month; the firſt time on the 4th of april, the ſecond in the beginning of may 1671, which is not known to happen to any other ſtar. By comparing the obſervations of theſe two years, it ſeemed at firſt to return periodically to the ſame phaſe in about 10 months, ſo that it ought to have appeared again in february 1672, whereas it was hardly viſible to the bare eye on the 6th of march in that year, and on the 29 it was ſcarce of the 6th magnitude, and it has never appeared ſince. This ſtar is not to be found in any ancient catalogue, though ſeveral much ſmaller ſtars near it are ſet down in them. Its longitude was 1° 52′ 26″ of ♒, and its latitude 47° 25′ 22″ north. *The days in this § are all new ſtyle.*

932 The third changeable ſtar in the ſwan is the ſtar χ of that conſtellation, which in the year 1686 was diſcovered by *Kirchius* to change its apparent magnitude: by 20 years obſervations of its periods, this ſtar was found to return to the ſame phaſe in about 13 months and $\frac{1}{3}$, or 405 days; though ſubject to great phyſical alterations, for in ſome years it arrived at a greater magnitude than in others; but rarely exceeded ſtars of the 5th: and in the years 1699, 1700 and 1701 it could not be ſeen at all, even at thoſe ſeaſons when, according to the obſervations of other years, it might be expected to appear in its greateſt luſtre. Its longitude from the firſt ſtar in ♈ is about $9^s\ 6°\ 30'$, with 52° 40′ north latitude.

933 In the year 1604, in the latter end of ſeptember old ſtyle, a new ſtar appeared near the heel of the right foot of Serpentarius: there were in that part of the heaven at that time the three ſuperior planets, very near one another; a ſight which ſo engaged the attention of aſtronomers, that no appearance thereabouts could long have eſcaped them: on ſept. 17, *Kepler*, who wrote a treatiſe about this ſtar, from which this account is taken, carefully obſerved the three ſuperior planets: on the 23 he again viewed mars and jupiter, then drawing near to conjunction; as a ſcholar of his did alſo on the 27: on the 28 thoſe planets were obſerved by ſeveral perſons: on the 29, which was the day when mars and jupiter were in conjunction, they were obſerved by *Mæſtlinus*; but none of theſe perſons as yet ſaw any thing of the new ſtar: on the 30 the ſudden breaking of the clouds gave one of *Kepler*'s friends an opportunity of having a very ſhort view of it; for, in looking for mars and jupiter, beſides thoſe two planets he ſaw a bright ſtar near them, but ſoon loſt ſight of it again, by the clouds intervening: on the 2, 3, 4, and 6, of october, it was ſeen by ſeveral perſons in different places; but, by reaſon of the cloudy weather at Prague, *Kepler* could not have a view of it till the 7 of

of that month. He tells us that all who obſerved it agreed in this, that it was exactly round, without any beard or tail, with one of which comets are always attended; and that it was exactly like one of the fixt ſtars, except that in the vividneſs of its luſtre and quickneſs of its ſparkling it exceeded any thing they had ever ſeen before: as to its colour, both *Kepler* and *Mæſtlinus* took notice that it was every moment changing into ſome of the colours of the rainbow, as yellow, orange, purple, and red; but was generally white, when it was at a little height above the vapours near the horizon. As to the magnitude of this ſtar at its firſt appearance, every body who ſaw it was of opinion that it was not only bigger than any of the fixt ſtars, but ſurpaſſed ſaturn and mars, and even jupiter; which laſt planet was near it all the month of october; and was, by his ſteady light, eaſily diſtinguiſhed from this vehemently ſparkling ſtar: *Tycho* pronounced the ſtar in Caſſiepea to be ſomething bigger than jupiter, who was at that time in perigee; the ſtar in Serpentarius was much bigger than jupiter, but jupiter was then in apogee, and conſequently in his leaſt apparent magnitude. It continued for the whole month of october nearly of the ſame bigneſs; except that, as the ſun began to grow nearer to the ſtar than to jupiter, it did not ſeem to exceed that planet in magnitude ſo much as before: and yet oct. 30 it was ſo much brighter than jupiter, that *Kepler* could ſee the ſtar, when he could not ſee jupiter; though that planet was at the ſame time farther off from the ſun's beams than the ſtar was: novemb. 6 *Kepler* ſaw it for the laſt time before it was got too far into the evening twilight; for cloudy weather followed: another perſon ſaw it on the 8: on the 12, though its place might be marked by the moon, which was then near it, yet no new ſtar was to be ſeen: it was not however covered by the moon, becauſe her latitude was then above 3 degrees, whereas the ſtar had not ſo much as 2 degrees latitude: at Prague therefore the ſtar was inviſible, by the ſun being too near it, ſome time between the 6 and the 12 of november; but at Turin, where the height of the pole is leſs than at Prague, it was ſeen the 13 of november, by thoſe who had very good eyes: decemb. 24, the ſky being clear after a good deal of cloudy weather, *Kepler* had the firſt certain view of it again, after its being hid by the twilight; it ſparkled exceedingly, but was much diminiſhed in magnitude; however it ſtill ſeemed bigger than ſcorpion's heart, though deeper in the twilight than ſcorpion's heart: but it appeared leſs than arcturus; perhaps becauſe arcturus was out of the ſun's beams: for on the 3d of january, being quite out of the twilight, it ſeemed bigger than either arcturus, or ſaturn, which planet had then been three days out of the twilight. From this time the ſtar grew leſs and leſs; for on the 10 of march, being carefully viewed, it appeared much leſs than ſa-

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turn; and but little bigger than the ſtars of the 3d magnitude in the knees of Serpentarius. April 11 it ſeemed equal to the bright ſtar in the right knee of Serpentarius; and continued nearly of that magnitude, may and june: auguſt the 2 and 4, being carefully compared with ſome adjacent ſtars, it was judged to be equal to the neareſt ſtar in the leg of Serpentarius, which is counted of the 3d magnitude, but is leſs than that in the knee: the new ſtar continued ſtill to ſparkle more ſtrongly than any other fixt ſtar: aug. 19, by reaſon of the lightſomeneſs of the night at that time of the year, it could hardly be determined whether the new ſtar appeared bigger than that in the leg or not; but it was more eaſily diſcerned than that, by reaſon of its greater ſparkling: ſept. 3 it was leſs than that in the leg: ſept. 28, which was a year after its firſt coming into view, it was more eaſy to be ſeen than the ſtar in the leg, and yet it was not very eaſily ſeen, becauſe it was now got a little within the evening twilight again, and was this year hid by the nearneſs of the ſun's light 40 days ſooner than in the preceeding year; from which circumſtance, it may be conjectured how much greater its magnitude was at its firſt appearance than now. In january 1606 the ſky was ſeldom clear in the morning, however, on the 25 in the morning *Kepler* could ſee the place of it, but could not ſee the ſtar. Jan. 27 he was uncertain whether he did not ſee ſome glimmering of the new ſtar or not; ſo that, if it was not quite extinct, it was grown too ſmall to be perceived in the morning twilight. In march its place was ſo far out of the ſun's beams, that it roſe high enough above the horizon before the appearance of the morning twilight, but there was not the leaſt glympſe of the ſtar to be ſeen. Upon the whole, *Kepler* concludes that it diſappeared ſometime between october 1605 and the february following; but on what day is uncertain. He ſays it had no parallax nor motion; and remarks, that all the planets were ſucceſſively in conjunction with this ſtar, during the time of its appearance.

934 Beſides theſe, ſeveral other changes have been obſerved in the ſtars: *Montanari* found two ſtars of the 2d magnitude in the conſtellation of the ſhip, marked β and γ by *Bayer*, to be wanting: he ſays, they were ſeen by himſelf and others in 1664, on occaſion of the comet which appeared that year; when they firſt diſappeared he does not know, only he is ſure that on the 10th of april 1668 there was not the leaſt glympſe of them to be ſeen; and yet the reſt about them, even of the 4th and 5th magnitudes, remained unchanged: he ſays, he has obſerved above an hundred other changes among the fixt ſtars, though none of them ſo great as thoſe. *Domenicho Caſſini* diſcovered a new ſtar of the 4th and two of the 5th magnitude in Caſſiepea: five new ſtars in the ſame conſtellation, whereof 3 have ſince diſappeared

peared: two in the beginning of the conſtellation Eridanus; one of the 4th, the other of the 5th magnitude: four of the 5th or 6th order, near the north pole: that great aſtronomer has alſo remarked that the ſtar placed by *Bayer* near the ſtar ε of the little bear is no longer viſible: that the ſtar A in Andromeda which had diſappeared came again into view in 1695: that in the ſame conſtellation inſtead of one in the knee marked υ there are two others come more northerly; and that the ſtar ξ is grown much leſs: that the ſtar placed by *Tycho* at the end of the chain of Andromeda as of the fourth magnitude was grown ſo ſmall that it could ſcarcely be ſeen: that the ſtar which in *Tycho*'s catalogue is the 20th of the fiſhes is no longer viſible, except it can be imagined to have changed its place and gone above 4 degrees lower, to the place marked ο by *Bayer*: thus *Caſſini*, in his *elements d'aſtronomie*, *pag.* 73, but the truth is, there is a falſe print in *Tycho*'s catalogue, where this laſt mentioned ſtar is ſet down in north latitude inſtead of ſouth: *Flamſteed* has ſet it right in his edition: it is very probable, ſome other ſuppoſed changes in the ſtars are, like this, only miſtakes of the tranſcriber or printer.

935 In 1672, *Dom. Caſſini* ſaw a ſtar in the neck of the bull which he thought was not viſible in *Tycho*'s time, nor when *Bayer* made his figures. *Halley*, in his catalogue of the ſouthern ſtars, ſays, that two ſtars one in the paſtern the other in the knee of the left fore-leg of Sagittary, reckoned of the 2d magnitude by *Ptolemy* and *Bayer*, were by him found ſcarcely of the 4th: that a ſtar ſet down by *Ptolemy* in the left thigh, and another in the bending of the right hind-leg are now inviſible: and that four of the unformed ſtars near the ſouthern fiſh, ſet down by *Ptolemy* of the 3d magnitude, appeared to him of the 6th, or at moſt not above the 5th. In the year 1679 *Flamſteed* could not with the naked eye ſee the ſtar (f) in aquarius, ſet down by *Ptolemy* of the 5th magnitude, and by *Tycho* and *Bayer* of the 6th: and in the year 1680 the ſtar (n) in virgo was in vain ſought for by him.

936 Many other changes in the ſtars have been taken notice of by *Maraldi*; as that the ſtar κ in the left leg of Sagittarius, marked by *Bayer* as of the third magnitude, appeared but of the 6th in 1671: in 1676 it was found again to be of the 3d by *Halley*; in 1692 it could hardly be perceived: but in 1693 and 1694 it was of the 4th magnitude. In the ſame conſtellation the ſtar in the right arm reckoned by *Halley* of the 3d magnitude has been obſerved to be grown much leſs. That in the thigh called θ had diſappeared; *Maraldi* ſaw it, from 1699 to 1709, of the 6th magnitude; he found it to be compoſed of two ſtars, diſtant from each other 35′ in latitude[a]. The ſtar θ in the tail of the ſerpent, counted by *Tycho* of the 3d, was found by *Montanari*

a Thus the *memoires*, and *Caſſini* from them, but it muſt be a miſtake; I ſuppoſe it ſhould be 35 ſeconds.

of

of the 5th; but grew bigger in the following years. The ſtar ρ in Serpentarius did not appear from the time of its being obſerved by *Montanari* to 1695. The ſtar ψ in the lyon, after diſappearing, was ſeen by *Montanari* in 1667; *Maraldi* ſaw it in 1691, but very ſmall. The ſtar ξ of the ſame conſtellation, marked by *Tycho* and *Bayer* of the 3d magnitude, was hardly viſible in 1693. The ſtar (i) in the breaſt of the lyon of the 6th order was not viſible in 1709; but there might be ſeen thereabouts 8 ſtars not ſet down in the catalogues. The ſtar β in Meduſa's head was found to be of different magnitudes in different years by *Montanari*; *Maraldi* could perceive no change in it in 1693, but in 1694 it varied conſiderably, ſo as to be ſometimes of the 2d magnitude, at other times of the 3d or 4th. The ſtar γ in the ear of the great dog is ſet down by *Tycho* and *Bayer* of the 3d magnitude: it was inviſible in the year 1670; but in 1692 and 1693 appeared of the 4th magnitude. *Maraldi* diſcovered 4 new ſtars in the great dog which are not in *Bayer*'s catalogue.

937 In 1704, *Maraldi* diſcovered a ſtar in the Hydra to be periodical; its poſition is in a right line with thoſe two in the tail marked π and γ, at the ſame diſtance from π eaſterly as π is from ψ: this ſtar had been deſcribed by *Montanari* in 1670, but was not viſible in april 1702: *Maraldi* ſaw it for the firſt time in the beginning of march 1704, in the ſame place where *Montanari* had found it 34 years before: it appeared of the 4th magnitude, and brighter than the ſtar ψ, and continued nearly in the ſame ſtate till the beginning of april: it then gradually diminiſhed till the end of may, when it could no longer be ſeen by the naked eye, but was viſible through the teleſcope for a month longer: it could not be ſeen again till towards the end of november 1705, when that part of the heaven began to get out of the ſun's rays; it was very faint, and grew leſs and leſs till the end of february 1706, and could then be ſcarce perceived even with a teleſcope: it did not appear again till the 18 of april N.S. 1708; when it was bigger than ſtars of the 6th order: it was then increaſing, ſo as on the 11 of may to be equal to the laſt ſtar but one of the Hydra: on the 16 and 20 it was ſtill bigger; but the 5 of june, after being hid ſeveral days by cloudy weather and moon-ſhine, it was found to be grown leſs, and continued decreaſing the following days; by reaſon of the evening twilight, it could not be ſeen without a teleſcope, which ſhewed it equal in magnitude to the brighteſt of the two ſtars which compoſe the laſt but one of the Hydra; this makes it probable, that it might have been ſeen ſome time longer, if it had not been among the vapours which are near the horizon: november the 23 1709 it appeared again of the ſame magnitude with the laſt ſtar but one of the Hydra: in december it was equal to a ſtar which is near to that laſt mentioned and cannot be ſeen without

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a teleſcope: february the 7 1710 it could hardly be ſeen with the teleſcope: may the 24 1712 this ſtar appeared again for the 5th time; it was a little ſmaller than the laſt but one of the Hydra: june the 9 it was equal to an unformed ſtar near it, and could be ſeen in moon-ſhine: june 16 it was leſs, and afterwards diſappeared. This ſtar was ſeen by *Hevelius* in 1662 of the 5th magnitude: it ſeems to be *a periodical ſtar*, like thoſe in the whale and the ſwan: *Maraldi*, after comparing the ſeveral obſervations which had been made of it, judged the time between its appearing with its greateſt luſtre, or equal to a ſtar of the 4th magnitude, and its return to the ſame phaſe again to be about 2 years; though with conſiderable variations: as is likewiſe the caſe of the periodical ſtars of the ſwan and the whale, which are liable to variations in their periods.

938 Beſides theſe, in the *memoires* for the year 1709, *Maraldi* ſays he has obſerved other changes in the ſtars; of which theſe four are the moſt conſiderable: 1, of two ſtars ſet down by *Bayer* under the ſouthern hand of virgo one of the 6th magnitude the other of the 5th, the laſt is ſtill to be ſeen of the ſame magnitude; but that of the 6th, which was a degree more ſouth, could not be ſeen with the teleſcope. 2, *Ricciolus* ſets down a ſtar of the 6th magnitude in the northern thigh of virgo which *Bayer* has omitted, and is not now to be ſeen. 3, A ſtar of the 6th magnitude ſet down by *Bayer* in the weſtern ſcale, in 12° 20′ of ♏ with 3° north latitude, is inviſible. 4, In 1666, *Hevelius* ſays he could not find a ſtar of the 4th magnitude in the eaſtern ſcale of libra, taken notice of by *Tycho* and *Bayer*, but *Maraldi* in 1709 ſays he had ſeen it for near 15 years laſt paſt, ſmaller than *Tycho* and *Bayer* had found it, but brighter than ſome other ſtars near it ſet down by *Hevelius*. A ſtar of the 4th magnitude firſt diſcovered by *Dom. Caſſini* near the conſtellation of the hare appeared in the ſame ſtate in 1709.

939 *Gregory*, in his aſtronomy, book 2 prop. 30, ſays that ‘Some ſtars ‘of the 6th, 5th and 4th magnitude ſet down in the ancient catalogues and ‘obſerved by *Tycho*, are now quite vaniſhed; we have ſeveral inſtances of ‘this in the catalogue of *Hevelius:* he mentions four in his *prodromus aſtro-* ‘*nomicus*; as one in the left thigh of Aquarius, the firſt of the two adjoyn- ‘ing ſtars in the tail of Capricorn, the ſecond of the belly of the whale, and ‘the firſt of the unformed ſtars behind the ſcales of libra. The French aſtro- ‘nomers have made farther obſervations of theſe ſtars. There have been alſo ‘remarkable changes in the brightneſs of ſome ſtars of the firſt 2d and 3d or- ‘der, as appears by the difference amongſt authors in aſſigning their magni- ‘tude.’ To name no more, a notable change has happened to a ſtar in the great bear marked δ by *Bayer*, within theſe few years; it is now ſcarce

of

of the 3d magnitude, whereas it is ſet down by *Tycho* and *Bayer* as of the ſecond.

940 *Cloudy ſtars* are ſmall luminous ſpots in the heaven, ſome of which appear to the naked eye like dim ſtars ſurrounded by an hazy light; others like little whitiſh clouds, pretty much reſembling the milky way in brightneſs and colour. *Ptolemy* ſets down five cloudy ſtars: 1, one at the extremity of the right hand of Perſeus: 2, one in the middle of the crab, called *præſepe* or the manger: 3, one unformed, near the ſting of the ſcorpion: 4, the eye of Sagittary, which he calls cloudy and double: 5, one in the head of Orion. The firſt of theſe, that in the hand of Perſeus, appears through the teleſcope ſo thick ſet with ſtars, that I believe the like is hardly to be found in any other part of the heaven: *Galileo*[a] counted 21 ſtars in that in the head of Orion; and above 40 in the *præſepe:* in the eye of Sagittary two ſtars may be ſeen in a clear ſky by the naked eye, the teleſcope ſhews ſeveral more. *Flamſteed* takes notice of a cloudy ſtar before the bow of Sagittary, which conſiſts of a great number of ſmall ſtars: and that the ſtar (d) above the right ſhoulder of Sagittary is encompaſſed with ſmall ſtars after the manner of a cloudy ſtar. *Dom. Caſſini* diſcovered a little patch between the great and little dog, which he ſays is very full of ſtars; the ſame was obſerved alſo by *Flamſteed.* The two whitiſh ſpots near the ſouth pole called *the Magellanic clouds*, which ſeen by the bare eye exactly reſemble the milky-way, viewed by *Halley* through a teleſcope appeared to be a mixture of ſmall clouds and ſmall ſtars.

941 There are alſo in the heaven little whitiſh *ſpots*, which through our beſt glaſſes appear magnified and more luminous, but without any ſtars: of this ſort is a ſpot near the moſt northern ſtar in the girdle of Andromeda, firſt taken notice of in 1612 by *Simon Marius*; it appeared to his naked eye like a little cloud, but through the teleſcope he ſaw white rays which were brighteſt near the center of the ſpot: its diameter was about a quarter of a degree. *Bullialdus* obſerved it in 1664, and judged it liable to ſuch changes as to be ſometimes inviſible: it is remarked in confirmation of this opinion, that it was repreſented in ſome figures of the conſtellations drawn about the year 1500, but is not ſet down either by *Tycho* or *Bayer*; that it was ſeen in 1612, but from that time till 1664 it was not taken notice of by any aſtronomer; and that in the year 1667 it was leſs bright than the year before: ever ſince the year laſt mentioned it has been conſtantly viſible, and is ſo this preſent year 1741 to the naked eye; but is now not near ſo much as a quarter a of degree in diameter.—Another cloudy ſpot is near the ecliptic, between the head and bow of Sagittary, not far from the point of the

a *in nuncio ſydereo.*

winter

winter ſolſtice: it is ſmall but very luminous.—A third is upon the back of the centaur, marked ω by *Bayer*: but cannot be ſeen in England.—A fourth is a ſmall obſcure ſpot, but there is a ſtar ſhines through it, which makes it more bright: it precedes the right foot of Antinous, it was diſcovered by *Kirchius*, who could not ſee it with the bare eye, but ſaw it with a teleſcope of 4 feet.—A fifth is in the conſtellation of Hercules, nearly in a right line between the ſtars ζ and η, ſomewhat nearer ζ than η: it is but a little ſpot, but viſible to the bare eye when the ſky is clear and the moon abſent.

942 But of all the cloudy ſtars hitherto taken notice of none is ſo remarkable as that deſcribed by *Hugens* in words to this effect[a]; 'Looking accidentally 'in the year 1656 through a teleſcope at the middle ſtar in Orion's ſword, I 'ſaw twelve ſtars inſtead of one, which was no new thing; their poſition was 'ſuch as is ſhewn in the figure annexed: ſeven of theſe ſtars, of which three 'are very cloſe together, ſeemed to ſhine through a cloud, ſo that a ſpace 'round them of the ſhape repreſented in the figure appeared much brighter 'than any other part of the heaven; which, being very ſerene and very black, 'looked here as if there were an opening through which one had a proſpect 'into a brighter region: I have ſince often viewed this wonderful appearance, 'which continues the ſame without any change of place or ſhape to this time, '(1659) This phenomenon, which was obſerved by *Hugens* with an excellent teleſcope of 23 feet, I have often viewed with one of 17 feet, through which I could ſee very well all the 12 ſtars mentioned by him: ſee what is ſaid § 887; to which I ſhall only add, that the luminous ſpace has ſometimes appeared to me nearly of the ſame ſhape with the figure which is formed by the ſeven ſtars within it.

There are undoubtedly more of theſe ſpots, which have not yet been taken notice of: *Caſſini* is of opinion, that the brightneſs of them proceeds from ſtars ſo minute as not to be diſtinguiſhed by the beſt glaſſes[b]; others more probably think they are great ſpaces in the *ether* through which a lucid medium is diffuſed: they appear indeed ſmall to us, moſt of them but of few minutes in diameter; yet ſince they are among the fixt ſtars, that is, ſince they have no annual parallax, they cannot fail to occupy ſpaces immenſely great, and perhaps not leſs than our whole ſolar ſyſtem: in all theſe ſo vaſt ſpaces it ſhould ſeem, that there is a perpetual uninterrupted day, which may furniſh matter of ſpeculation, as well to the curious naturaliſt, as to the aſtronomer[c].

943 I have here given as full an account as I could of changeable and cloudy ſtars, from ſeveral writers; by comparing of all which together, I

a *Syſtem. ſaturn. p.* 8. b *elements d'aſtronomie l.* 1. *c.* 7. c Phil. tranſ. abr. vol 4 p. 225.

 have

have corrected the miſtakes that ſome of them had fallen into: I have ſometimes quoted my author, but have not done it in every inſtance, to avoid being tedious: for the reſt, theſe that follow may be conſulted; Tychonis *progymnaſmata:* Keplerus *de nova ſtella in pede Serpentarii:* Ricciol. *almag. l.* 8. § 2. *c.* 1. Hevelii *hiſtoria miræ ſtellæ: ejuſdem cometographia, pag.* 374 *et ſequ.* & 400: Caſſini *elements d'aſtronomie l.* 1. *c.* 6 & 7: Phil. tranſ. abr. vol. 1: *Acta eruditor. Lipſiæ ann.* 1688: Flamſteedii *hiſtoria cæleſtis vol* 1: Halleii *catalogus ſtellarum auſtralium: Memoires de l'Acad. R. des ſciences ann.* 1706 & 1709.

944 When the new ſtars were firſt obſerved, the *Ariſtotelians*, who held that the heavens and heavenly bodies were not ſubject to any change, would have it that they were only meteors generated in our atmoſphere, and raiſed up to a great height therein[a]: but their having no ſenſible parallax was an evident demonſtration to the contrary, and ſhewed that they were far above the moon: and their agreeing with the ſtars in ſome other particulars as well as in their great diſtance from the earth, has induced the generality of philoſophers to think they are of a ſimilar nature.

945 How the changes in thoſe ſtars that are periodical may be effected, has been in ſome meaſure ſhewn, § 928 and 929. *Maupertuis*[b] has another ſolution of theſe appearances, which is to this effect: 1, he ſuppoſes many of the ſtars, like the ſun, to have a rotation round their own axes: 2, that this rotation cauſes them to deviate from an exact globular ſhape into that of an oblate ſpheroid, or globe flatted: 3, that there may be infinite variety in the degrees of this flatneſs, ſo that ſome may be quite thin and flat like a round trencher: 4, that a ſtar of this ſhape may have a large planet going round it, in a plane different from that of the ſtars equator: in this caſe, the planet would be twice in every revolution round the ſtar in the plane of the ſtar's equator continued, at which times it would cauſe no change in the ſituation of that plane; but at all other times it would, by its attraction, change more or leſs the ſituation of the plane of the ſtar's equator, and moſt of all at the two ſeaſons when it is fartheſt out of the plane continued: by this change, he ſuppoſes that ſuch a flat ſtar as at ſome times cannot be ſeen by us, when only its thin edge is turned towards our earth, may at other times, by turning a good deal of its flat ſide towards us, become viſible. *He-*

a *Bullialdus* gives us a pleaſant inſtance of the philoſophical bigotry of a Florentine Phyſician, who would not be prevailed upon to look at any of the heavenly bodies through a teleſcope himſelf, for fear of ſeeing ſomething which ſhould oblige him to deſert ſome of *Ariſtotle*'s opinions: and as for any diſcoveries made by glaſſes, which others told him of, he would have no regard at all to to them. *apud* Hevelium *in cometograph. p.* 329.

b *Diſcours ſur les differentes figures des aſtres. v. hiſtoire de l'Acad. R. des ſciences ann.* 1732. & *acta eruditor. menſis julii* 1733.

velius

velius is of opinion, 1, that the ſun and ſtars are ſurrounded with atmoſpheres: 2, that, whirling round their axes with great rapidity, they throw off great quantities of matter into thoſe atmoſpheres, and thereby cauſe great changes therein: 3, and that thus it may come to paſs, that a ſtar, which when its atmoſphere is clear ſhines out with great luſtre, may at another time, when it is full of clouds and thick vapours, appear greatly diminiſhed in brightneſs and magnitude, or even become quite inviſible [a].

946 As for ſuch ſtars as, after having been for many years inviſible, break out ſuddenly into ſhining all at once, like thoſe in Caſſiepea and Serpentarius, it has been thought that, as the ſun may have now and then a comet fall into it, in the manner deſcribed § 909; the ſame may alſo happen to any of the ſtars which like the ſun have planets and comets revolving round them: and then a ſtar which had for a long time been ſo covered over with ſpots as not to be viſible to us may, when a comet falls into it, be made to blaze out ſuddenly, by the acceſs of that new fuel; and may for a while continue to ſhine with great luſtre; till, by the ſpots returning and covering its ſurface, it appears gradually to diminiſh in brightneſs and magnitude, and at laſt becomes again quite inviſible. *Fontinelle*, upon mentioning changeable ſtars, has this reflection [b]; 'The fixt ſtars being ſo many ſuns, it is very poſſible that 'among the infinite number of them there may be ſome *half-ſuns* [c]; our ſun 'has often ſpots upon his ſurface, which, if they were permanent and more 'extenſive, would reduce him to an half-ſun: if all the ſuns are ſurrounded 'with planets inhabited, it is eaſy to imagine what a fright the inhabitants 'muſt be in, when they looſe ſight of their ſun for a conſiderable time; or ra'ther with what calmneſs they behold a ſight which is familiar to them but 'would be dreadful to us. The ſtars which appear and diſappear without any 'regular periods may be ſuns that are ſometimes covered with very large 'ſpots, from which at other times they are perfectly free: the changes in the 'ſpots upon the ſun give us room to think there may be great variety of ca'ſes in this affair:' but whatever be the caſe of periodical ſtars, which may have planets inhabited by creatures fitted for ſuch viſſitudes of light and darkneſs as are allotted to them, I do not think it probable that a ſtar which for a whole century does not caſt light enough to be ſeen by us ſhould be appointed to do the office of a ſun, or have any planetary worlds to be enlightned and cheriſhed by it: what other ends it may be made for, it may be in vain for us to conjecture: in the works of creation, as well as in the ways of providence, the deſigns of infinite wiſdom, and the methods by which infinite power brings about thoſe deſigns are often to man unſearchable.

a Hevelii *cometograph. p.* 380. b *hiſtoire de l'acad. ann.* 1706. c *demi-ſoleils.*

ADDENDA.

ADDENDA.

Since the ſixteenth chapter of the ſecond book was printed off, wherein is ſhewn, that there is great probability of the obliquity of the ecliptic continually decreaſing, two books have come to hand which have confirmed me in that opinion; one of them is *de Bononienſi ſcientiarum et artium inſtituto atque Academia commentarii, Bononiæ* 1731: together with *Academicorum quorundam opuſcula varia*, in 4to: in page 258, there is an account of a review of the meridian line at Bologna mentioned § 423, by *Euſtachio Manfredi:* that line, which is drawn upon braſs plates inlaid into the pavement, was found by him to have continued exactly in the plane of the meridian, but, as to its horizontal ſituation, it was riſen up too high in ſome places, and worn down too low in others, by peoples walking over it: in order to make allowances for this change, *Manfredi* made a table, by which he corrected his obſervations: after theſe corrections, the height of the pole there came out 44° 29′ and 20″ or 25″, the ſame as *Ricciolus* and *Caſſini* had formerly ſettled it; but he found the angle between the equator and ecliptic about 30″ leſs than *Caſſini* had obſerved it, at the time of his firſt drawing that line, which was between 60 and 70 years before: he recommends drawing a meridian line upon an upright wall, in order to avoid the alterations one made upon a pavement is ſubject to, by its being trodden upon. The treatiſe of *Manfredi* upon this ſubject, read at the Academy in the year 1722, is among the *opuſcula*, page 596. The other book is *Elements d'aſtronomie, par Mr. Caſſini, Paris* 1740, wherein *l.* 2. *chap.* 3. that author ſays, that, comparing together a great number of obſervations made in the R. Obſervatory for 66 years paſt, the obliquity of the ecliptic is found to have decreaſed about 30″ in that ſpace of time. He mentions the obſervations of the ancients, and gives a table of the obliquity according to ſeveral authors, both as they obſerved it, and as it would have come out according to a regular annual decreaſe: I have occaſion to add nothing from him to my table given pag. 281, except that the obliquity was obſerved by *Richer* in the year 1672 to be 23° 28′ 54″, and at the R. Obſervatory 1738, 23° 28′ 20″. He does not ſay by whom this laſt obſervation was made; the numbers are the ſame as thoſe of *Godin* in 1730.

The End of the firſt Volume.

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