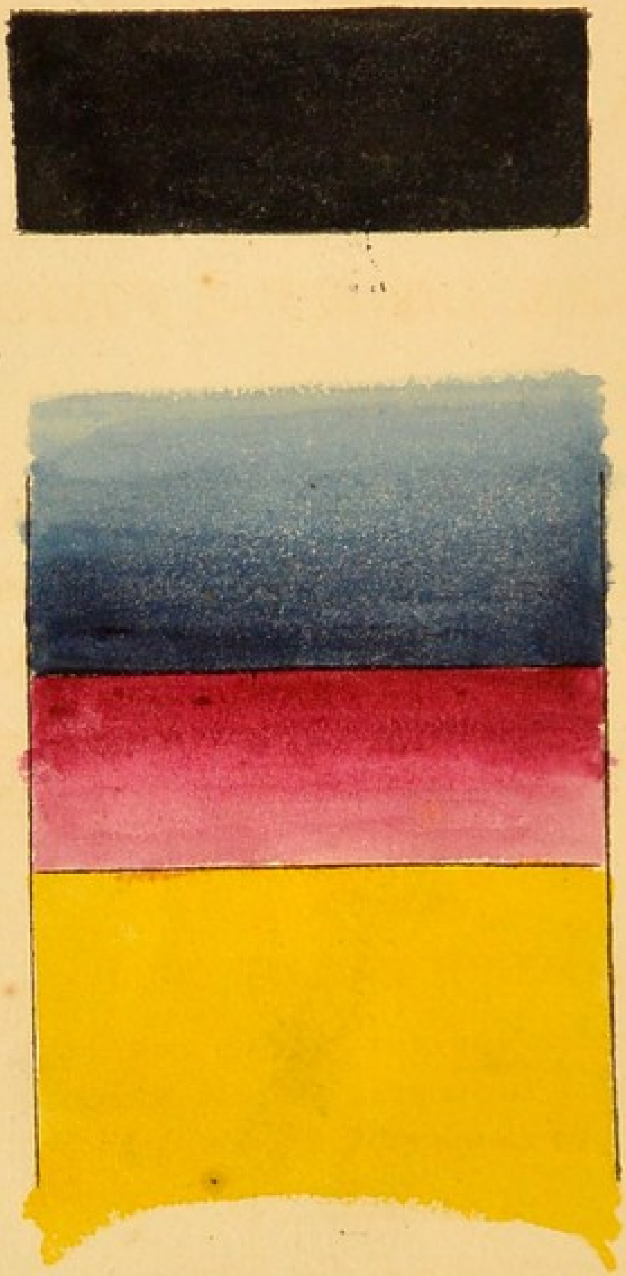
No. 1.



No. 1, A piece of black Cloth, pasted on a pane of glass at the window, and decomposed by a prism into blue, red and yellow rays.

EXPERIMENTAL OUTLINES,

FOR

A NEW THEORY

OF

COLOURS, LIGHT & VISION:

WITH CRITICAL REMARKS,

ON

SIR ISAAC NEWTON'S OPINIONS,

AND SOME NEW

EXPERIMENTS ON RADIANT CALORIC.

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☞ The black colour, No. 1 of the Frontispiece, was painted with the same colours as Nos. 2, 3 and 4, or with blue, red and yellow.

Richard Tivy, Printer, Grand-Parade, Cork.

PREFACE.

If the Author of the following treatise, have accidentally struck into a new, and as yet unbeaten path, of scientific research, it has by no means lessened his respect for the immortal writer of the **PRINCIPIA**. *Had Newton never discovered the different refrangibilities of the coloured rays, in all probability, at the present hour, the science of opticks might be no farther advanced, than in the days of Grimaldi, or Descartes. Indeed every successive age and discovery, add facilities to the natural philo-*

sopher, by accumulating new and interesting facts, stored in the convenient pages of an Encyclopedia, or illustrated in the Lecture Room, where the useless rubbish of antiquity is removed, and the few scattered and remaining gems are polished into lustre by a master's hand.

In this City, where experimental philosophy is in its infancy, and, I am concerned to say, more attention paid to religious and party distinctions than to the culture of the mind, many inconveniencies were to be encountered; many necessary works were not to be found on the shelves of our new born, yet fast improving libraries, and were it not for the politeness of the late Dr. Longfield, whose comprehensive mind *and scientific acquirements reflected credit, not only on himself but on his native City, a stop must have been put to the present investigation. However, it is pleasing to anticipate the advantages, likely to be derived from the efforts of the* Cork Institution, *liberally patronised by an enlightened Government: nor can I allude to this subject, without an expression of regret, (a feeling unanimous with the proprietors,) at the resignation of the Rev. Mr. Hincks, to whose exertions and abilities, we are principally indebted for this establishment: enlisted under the banners of no particular party, religious nor political, he was respected by all.*

Any person, writing on a new

subject, should make himself acquainted with the rise, progress, and present state of the discoveries; otherwise, after much labour, he might find himself anticipated, or be justly accused of plagiarism. The accurate and faithful history of opticks, compiled by Dr. Priestley, *has supplied me with the discoveries down to the year* 1772; *some of the works, written since that period, have come into my hands, others, I regret not being able to procure ; amongst these is a treatise by* Beccaria ; *I therefore have been obliged for the present, to consult the periodical journals, and I may venture to say, that whatever faults appear in this work, (and I am not vain enough to think them few,) it possesses, at all events, the* *merit of novelty. Numerous avocations of a profession, must plead my excuse for frequent inaccuracy of language and want of arrangement. Such an excuse, for a work of imagination, would be an insult on the reader's understanding, but in the present state of science, experiment claims a preference, and in this respect, it is hoped, the reader may be compensated for other disappointments.*

Nearly a year ago, when first I made up my mind to submit those experiments to the press, I endeavoured to sound public opinion, by sending a few detached papers to the journals, expecting to meet from the editors, that liberality, generally, character-

istic of educated and cultivated minds. I was somewhat surprised, to find myself accused by Dr. Thompson, proprietor of the annals of philosophy, of plagiarism, and ignorance of some papers in the philosophical transactions. I immediately wrote to this Gentleman, calling on him to point out any one instance: my letter, with a degree of politeness, peculiar to the learned Doctor, was neither answered nor published in his journal, although accompanied with some new experiments. Here, I have to thank the proprietors of the other journals, for their politeness, and particularly the editor of the Monthly Magazine. Indeed I should have passed over Dr. Thompson's conduct in silence, *were it not, that he has deservedly acquired a name in the scientific world; and I should hope, the Gentleman wrote calamo currenti.* ***Dr. Priestly*** *justly remarks, in the preface to his history. "A man must have very little experience of life, and have acquired very little strength of mind indeed, to be diverted from an undertaking which he believes to be useful, and important to mankind, on account of trifling, unjust, or unreasonable censure."*

At first, I intended interspersing this work with coloured deliniations of the concentric rings, ovals and variegated lines; but on making the attempt, and comparing my best endeavours, with those of nature's more beautiful tints, I threw away my brush in disgust, and determined to leave the *reader to an examination of the originals. Indeed, the trouble and expense are so small, and the apparatus so simple, that no person can want the means.*

Should the present Volume be received with approval, the Author pledges himself, that the second shall contain many new, and he presumes to hope, interesting experiments, tending to prove, that the present theory of vision is founded on error. After which, he intends to publish a work, on each particular disease of the human eye. A treatise on the Cataract, illustrating a new method of operating, and a second edition of his Book, on the Fistula Lachrymalis, are ready for the press.

To be an able Oculist requires, not only manual dexterity, a keen eye, and *a firm nerve, but also, a knowledge of physiology. The very extensive practice which the Author has experienced in this City for some years, and the constant habit of noting every particular case, must tend to make this work the more valuable, by combining practice with theory.*

Here the Author cannot but regret, that this branch of the profession, has been too long, in the hands of advertising quacks, stiling themselves Oculists: as if the diseases of the human eye, were not intimately connected with the general knowledge, necessary for a Physician and Surgeon.

It is no small satisfaction to think, that the theory of black light, advanced in these pages, should agree with the historical evidence of the

Mosaic ***PRINCIPIA.*** *Boyle and Newton were moral and exemplary Christians, yet they ventured to write in direct opposition to divine revelation. The first Book, Genesis, informs us, that darkness was made before light. This production of light, as Mr. Hutchinson justly remarks, was no new creation, but a permission for a substance which already existed, to be modefied into a different state. "And God divided the light from the darkness." Although some of my readers may smile, at an attempt to refute Boyle and Newton from the evidence of the Old Testament alone, without the aid of expement, yet it must be a consolation to the Christian's mind to know, that Religion is upheld by philosophy.*

Cork, August 1st. 1816.

BLACKNESS is compounded of blue, red and yellow rays, and there is as strong a reflection from black as from any other coloured substance.

LIGHT is said to be refracted, when in passing from one medium into another it is bent either from, or towards a perpendicular. On making a dot the size of a garden pea with perfectly black ink or paint on a sheet of white paper, and placing a powerful plano-convex lens immediately over it, little or no refraction takes place, the dot neither appearing to be removed from its place nor increased in size: but on raising the lens some distance from the paper, the black dot appears considerably magnified in all its dimensions; and at a still greater distance, especially if the rays be made to pass near the edge of the glass, the upper part appears blue, the lower red and yellow. Sir Isaac Newton on looking through a telescope at a black object, observed it to be surrounded with a variety of colours, yet was so impressed with his favourite theory, that he seems to have examined the phenomenon with surprising indifference. "If a black object (says this great philosopher) be surrounded with a white one, the colours which appear through the prism are to be derived from the light of the illuminated one, spreading into the regions of the black, and therefore they appear in a contrary order to that in which they are seen, when a white object is surrounded with a black one."* To shew the fallacy of this reasoning I made the following experiments.

EXPERIMENT 1st.

I made a large dot the size of a garden pea, with black paint on a sheet of red paper, on ap-

*Opticks, page 143, 144

plying the prism to my eye, it was analyzed or separated into a beautiful deep blue and orange, the red rays reflected from the illumined red paper added to the brilliancy of the orange. According to Newton's explanation, whence was the blue derived? certainly not from the red illumined paper absorbing 6 parts of the solar light, and reflecting the seventh. Therefore if the black dot absorbed all the rays nothing but the red, which he esteemed a primary colour, could have met the eye.

EXPERIMENT 2nd.

I made a similar dot with black ink on a sheet of yellow paper, and on analyzing it with the prism, perceived a blue, an orange and a lively green; the yellow rays of the paper had mixed with the blue, derived from the black dot, and formed a green. Whence were derived the blue, the red and the green? certainly not from the yellow paper.

EXPERIMENT 3rd.

Having pasted two thin and semitransparent pieces of white paper of equal magnitude on a pane of glass at the window, I applied the prism, and perceived the papers to be changed to a light blue, fringed at the bottom by red and yellow rays. It is evident if Newton's theory were correct, that as I increased the opacity or blackness of the one by successive layers of white paper, the reflected light should become less, for by this means the incident light would be the more powerfully absorbed. But in confirmation of the theory advanced in this treatise, every layer of white paper increased the depth of colour, until the paper appeared to the naked eye a perfect black, and then through the prism it assumed a deep blue, red and yellow, whilst its neighbour was of a pale and sickly hue. From this experiment we might infer that as a white substance becomes black, it reflects the more rays of light, and consequently that a piece of black paper reflects more light than a piece of white paper of the same diameter.

EXPERIMENT 4th.

I made two dots the size of a garden pea, the one with black, the other with white paint on a sheet of white paper. On applying my prism (according to Sir Isaac Newton's theory) I might expect that the white painted dot, which appeared on the paper of a light gray, would have reflected much more decomposed light than the black, for it should reflect not only its own colours, but likewise the borrowed colours of the white illuminated paper; whereas on the other hand the black dot absorbing or suffocating the rays of light, should only bring into view the pallid tints of the illuminated paper, spreading into the regions of the black. On the application of a prism the very reverse was experienced. The black dot reflected a deep blue or indigo, red and yellow, whilst the white reflected only a delicate tinge of the same colours. From these simple experiments and many others tending to similar results, we might conclude, that blackness or darkness arises from the condensation of the blue, red and yellow rays of light. 2dly. that these three colours are primary, as will be hereafter shewn, which blended with others form all the pleasing variety of Nature.

ANALYSIS AND SYNTHESIS OF BLACKNESS.

As a farther confirmation I procured a box of opaque water colour paints,and on mixing blue, red and yellow in certain proportions obtained a perfect black, not white, as represented by Newton; when the red predominated, a reddish black, when the blue predominated, a bluish black resulted. Sir Isaac Newton having produced or supposed he produced, what he calls white light,by concentrating or mixing the seven prismatick rays, by means of a large convex lens, thought he might likewise succeed by mixing up coloured and opaque paints: he says the coloured powders which he made use of, at first produced only a kind of gray, but this was in fact a dull white, or whiteness mixed with shade, for when he contrived to throw a very strong light upon it, it became intensely white, so that a friend of his, who happened to call upon him while he was busy about these experiments, and who knew nothing of what he had been doing, pronounced that the powders he had mixed when thus illuminated, made a better white than some very fine white paper with which he was comparing it. * Here are two experiments as much opposed to each other as black and white. If any person were to say that his black coat was white, because by concentrating the sun beams on the sleeve with a burning glass, a white spot appeared in the focus, we would smile at the conceit, yet Sir Isaac Newton has not only said the same, but likewise gravely told us, that all gray colours are dark white. From Newton's decision I appeal to every painter in the kingdom, I appeal to the sense of sight, and finally I appeal to common sense, and I hope to shew hereafter, that it is impossible to make a white by any mixture of colours whatsoever. As the gray was nothing more or less than a dilute black, Newton's experiment may be brought in confirmation of the theory advanced in this work, for by mixing blue, red and yellow, he formed black. Having thus shewn by a synthetick process that blackness is compounded of blue, red and yellow, it remains to prove the

* Opticks, page 133.

same by analysis, which is done by making a dot with this compounded and black paint on a sheet of white paper: on the application of a prism it can be separated into the three simple and original colours, blue, red and yellow.

As black can be made by mixing up blue, red and yellow, it appears inconsistent to suppose that any of those rays are absorbed or extinguished within the substance. For example, let us take a certain proportion of bise, viride æris and orpiment as directed by Newton, each, if separately spread on a board reflects its own colour to the eye, there is no absorption, no extinction: but when they are blended together they form a black. The board is again painted, and wonderful to relate all the rays that were reflected in a separate state are now absorbed; can any thing be more unphilosophical? But Newton asserted that this black was a dark white, and his name has stamped such a value on the opinion, that even the keen eye of a Northern Critic was deceived, stiling those ignorant and presumptuous, who dared to say that black wasn't white. "In this part of his inquiry, (say the reviewers *) the author presents us with another refutation of the attacks, made on Sir Isaac Newton's doctrines, by *ignorant* persons, and too generally effectual with the multitude of *superficial reasoners* from the boldness of their authors. It has been found by many, that when they tried to mix the simple colours, as prescribed in one of Sir Isaac Newton's methods, their process failed; thus, they obtained black instead of white, by an union of seven primarily coloured substances. Our author, (continues the Edinburgh Reviewer,) shews, that this was the necessary consequence, of placing one substance behind another, instead of mixing them all equally together, in a mosaic work as it were.†" So no person could mix up three simple paints, except Sir Isaac Newton and Professor Venturi,

* In their Analysis of Professor Venturi's work, page 35, for 1805.

† The Author by no means quotes this passage from the Edinburgh Review, with the intent of calling in question the profound Knowledge and keen discernment of those able writers. Neither must the reader suppose that this note was written for the puerile purpose of disarming criticism or of neutralizing its caustic power. On the contrary he would wish to have faults pointed out, that in future they may be corrected.

and the herd of ignorant and presumptuous reasoners, were unable to make a mosaic work of it. Now if three equal particles, of differently coloured paints are placed behind one another, it does not require much logic to prove that two out of three would be invisible. I have quoted this specimen to shew the reader with what severity those authors are treated, who dare to question the Newtonian doctrines.

EXPERIMENT 5th.

ANALYSIS AND SYNTHESIS OF BLACKNESS BY MEANS OF THE PRISMATICK RAYS.

Having pasted a piece of black cloth on the window, on looking at it through the lower refracting angle of a well polished and equilateral prism, when close it appeared black, because the rays were not much separated by refraction; at a greater distance, the upper part appeared blue, the middle black, and the lower red and yellow; at yet a greater distance the black entirely disappeared and the entire piece of black cloth was decomposed into blue, red and yellow; thus, we have a clear and decisive analytick proof, that black is composed of these three colours. It now remains to give a synthetick proof: after which I presume, few will deny to blackness the rank of a colour. If we paste another piece of black cloth of similar dimensions on the window, and at some distance above the one already analyzed: on applying the prism, a fringe of reflected red and yellow rays, is seen at its lower margin. The upper piece of cloth is now to be slowly brought down by an assistant, until the red and yellow, or rather the orange, are spread over the blue of the under cloth, when it appears intensely black. Thus, we can compound or decompound the prismatick rays of black light, with as much precision, as the chymist can demonstrate the component parts of water, atmospheric air, nitric acid, or any other chymical compound. When a piece of black cloth is thus decomposed, the three colours occupy four or five times as much space, as the black light coming to the eye without the intervention of the prism ; therefore we may safely infer that those three rays, are condensed into blackness, and rarefied into decomposition.

I now pasted a piece of black cloth, four inches in length, on a white painted and well illuminated door. On applying the prism, the top of the black appeared blue, and violet underneath arising from the orange, which was brought down, blending with the black light. Black occupied the middle, the cloth being too long for total decomposition. The lower fringe was orange, and the yellow rays spread over the white door. In this experiment a black substance was surrounded by a white one, & the length of the black parallelogram, was four inches when viewed by the naked eye, and five or more when seen thro the prism: a complete refutation of Newton's assertion, " that the colours were produced, by the rays of the white substance spreading into the regions of the black. " If we now reverse the experiment, by pasting a similar sized piece of white paper on a black painted board; on applying the prism, the red and yellow are brought down from the black at the top, and therefore an orange appears over the upper part of the white paper, next white, blue at the bottom, and violet underneath, arising from the orange, blending with the black rays. Here we find as will be more fully shewn hereafter, that the white light reflected from the paper, is not decomposed, but that the black, both above and below, is separated into the three simple, or as others are pleased to call them, primary colours. How can these colours be represented as reversed? And if they were derived from the white light, running into the regions of the black, what was the reason, that the piece of black cloth in experiment the 5th. was changed into a blue? In this last experiment the cloth being too long for total decomposition the black appeared.

If we look through the prism at a crow flying through the air: at a black fly on a pane of glass, or at any other small and black object, they appear blue, red and yellow, and no other colours are apparent. What becomes of the black? From the foregoing experiments, we are authorized to infer that black rays of light exist, as well as those of red, indigo, brown, or any other colour.

ABSORPTION OF LIGHT.

It is rather remarkable that two of the most unphilosophical opinions in science, should have been supported by two of the greatest men perhaps in this or any former age. I mean the theory of latent heat, advanced by Doctor Black, and the theory of luminous absorption, maintained by Newton. Both these philosophers, priding themselves on the advantages of inductive and experimental investigations, seemed to forget, that their opinions on these subjects were hypothetical in the extreme. Irwine and Crawford new modelled the one, while the other remains, a blot on the simple regularity of legitimate induction.

Des cartes was the first, according to Doctor Priestley, to advance the opinion, that black extinguishes or suffocates the rays of light, and that white reflects them. As words are the symbols of ideas, nothing more confuses the mind, and leads to error, than their inappropriate use. Absorption, according to Des cartes, Newton, &c. is the suffocation or extinction of light. Now I must acknowledge I have no appropriate idea, or image in my mind from such words. If it be meant that light is destroyed or annihilated within the substance, the absurdity is gross. If suffocation mean nothing more, than a change of property it is a misnomer.

When solar phosphori are exposed to the light, they are said to absorb it, and to give it out in a dark room, here the term is well understood, there is no strangling, no suffocation, no extinction, no annihilation.

Boyle, and afterwards Newton adopted the same opinion, unsupported by any legitimate arguments. "Many learned men (says Mr. Boyle)supposed that snow effects the eyes, not by a borrowed, but by a native light:" but having placed a quantity of snow in a room from which all foreign light was carefully excluded, neither he nor any other person could perceive it. To try whether white bodies reflect more light than others, he held a sheet of white paper in a sun beam, admitted into a darkened room, and observed that it reflected a far greater light than a paper of any other colour, a considerable part of the room being enlightened by it. To prove that black is the reverse of white with respect to its property, of reflecting the rays of the sun, he procured a large piece of black marble, and having got it ground into the form of a large spherical concave speculum, he found that the image of the sun reflected from it, was far from offending or dazzling his eyes, as it would have done from another speculum, and though this was larger, he could not in a long time, set a piece of wood on fire with it, though a far less speculum of the same form, and of a more reflecting substance, would presently have made it flame.

That light reflected from a white substance, is more dazzling to the eye than from a black one, may be easily granted, without authorising the sweeping conclusion that the one absorbs and the other reflects all the rays. Having directed a stone cutter to give a very high polish to a piece of Italian white marble, and likewise to a black piece from Galway, I held them before the sun and a lighted candle, without seeing that difference which Mr .Boyle mentions as to their dazzling power. I even thought that the image of the candle, reflected from the black marble was better defined. Had Mr. Boyle used a speculum of a dark brown, indigo or violet colour, he would have found that there was as little heat reflected as from black, and consequently he might as well argue, that brown, indigo and violet substances absorb all the rays. The arguments used by this philosopher are the only ones deserving much attention, they rest on the identity of heat and light, and altho' I lean very much to that opinion, still I cannot help thinking they are vague and unsatisfactory. From the analogy of other chymical phenomena, heat should be given out by condensation. When transparent light is attracted by a piece of black marble, it is condensed into blackness, reflected opaque, and deprived in a great measure of its calorific property. But when light is not much condensed, as is the case when reflected from white or semi-transparent substances, its calorific properties are little diminished. Cold and darkness, heat and light being constant associates.

Before Newton's time, we find scarcely any theory of colours of sufficient consequence, to merit notice. In the year 1666 this great philosopher and mathematician, whose very name stamps such a value on his writings and opinions, as to make the task of refutation the more arduous, and perhaps in the opinion of some of his advocates even bordering on presumption, advanced or rather revived the

Cartesian opinion, that blackness arises from absorption, and whiteness from a total reflection of light, while the other colours depend on the capability of this or that substance, to reflect one set of rays and to absorb the remainder; thus, a piece of red cloth, according to the Newtonian theory, reflects all the red rays derived from the incident light, and suffocates the remainder, the orange, the yellow, the green, the blue, the indigo and the violet.

If we make two dots, on a sheet of white paper the size of a garden pea, the one red, the other black, on the application of a magnifying glass to the eye, the image of the black dot appears of an equal size with the red, therefore we might infer, that the black rays diverge as much in their transmission and are equally numerous with those coming from the red dot. If the rays are as numerous, and the image of both equally large, it follows as a necessary sequence that a black substance, reflects as much black light, as a red one of the same magnitude, nor has the one more inherent power of absorbing than the other. If instead of comparing a black dot with a red one, we place two small wafers, the one black, the other white, on a sheet of red paper, the same appearance takes place on viewing them with a convex lens, and therefore we might venture a little farther and infer, that black reflects as much light as white.

A person placed in a room, entirely hung with black, if well illuminated, perceives the length, breadth and angles, in fact he sees every part. According to the Newtonian theory, this would be impossible, as no light could be reflected to the eye, the entire coming from the luminous body, being suffocated or absorbed by the black hangings. To obviate this powerful objection, some double refined theorists, would try to persuade us, that there is no perfect black in nature, but that some white light is always reflected : can any thing be more ridiculous. If so, what gives the sensation of blackness ; is it the white light reflected to the eye ? It is well known that every good black cloth is first dyed a deep blue, in this case the blue must be reflected to the eye, perhaps there is no perfect blue. Bancroft supposes that some light is reflected to the eye, otherwise he says we could have no idea of blackness, but what light it is he does not inform us.

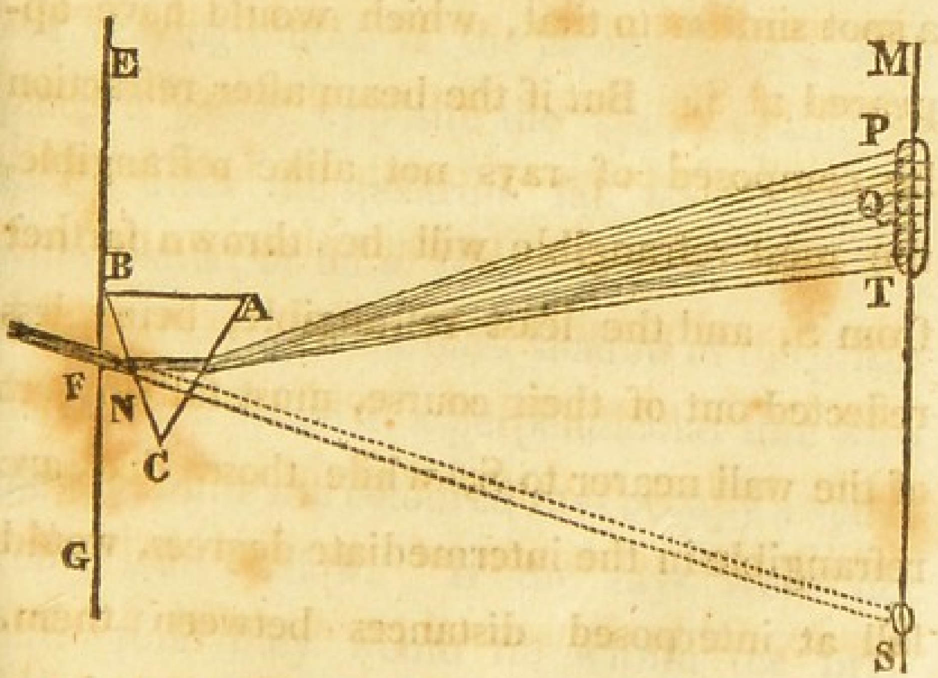
M. Bouguer made many experiments on the absorption of light, but as not one of them proves the fact, I shall speak of them in a concise manner. Looking at an object through one piece of crystal, and at the same time, through four other pieces, all of which put together, were of a thickness equal to that of the one piece, and each of which was placed at an angle of 75 degrees, he not only found that less light was transmitted through the four pieces than through the one, but that even more light was lost, than the rules which he had already demonstrated, concerning the quantity reflected and transmitted, would account for; so that he was obliged to have recourse to another cause for the diminution of light; and upon the whole he concluded that $\frac{1}{16}$ part of the light was absolutely absorbed, at each of the interruptions of the crystal; for whereas, the reflections ought to have reduced the 1000 to 877, it was in fact reduced to 396. One cannot, he says, help attributing this diminution to the second surface, which acts as if it was not perfectly transparent. It extinguished at all moderate incidences (viz. from 0 to 49° 49,) the 3rd. or the 4th. part of the rays. Beyond this inclination it absorbed but a very small part of the rays, though a few were lost, even when they fell perpendicularly.* Here Bouguer thought he had discovered, that transparent substances absorb the rays of light as well as those that are opaque; however he forgot a very essential consideration, that glass is only semitransparent, and that therefore what he has called the absorption of light by transparent substances, is nothing more than reflection, by the opaque atoms which are interspersed, as will be shewn

* Traite'd' Optique P. 160.

hereafter. A perfectly transparent substance transmits all the light; a semitransparent one, both transmits and reflects; an opaque one, reflects the entire. After all that I have read on this subject, I cannot understand what is meant by the absorption of light. One calls it extinction, another suffocation, a third a loss. These terms if they do not imply, at least are very nearly akin to the term annihilation. After the light is absorbed what becomes of it? In fact the theory has been handed down from one writer to another, seemingly without the trouble of investigation.

RAYS OE DIFFERENT COLOURS ARE DIFFERENTLY REFRANGIBLE.

To Sir Isaac Newton we are indebted for the discovery, that the differently coloured rays have different degrees of refrangibility. In the year 1666, when this celebrated philosopher was grinding optick glasses, he procured a triangular glass prism, to satisfy himself concerning the phenomena of colours. Having darkened his chamber, he took two boards and placed one of them close behind the prism, at the window, so that the light might pass through a small hode made in it for the purpose, and fall on the other board which he placed at the distance of about 12 feet, having first made a small hole in it also, for some of that incident light to pass through. He then placed another prism behind the second board, so that the light which was transmitted through both the boards, might pass through that also, and be again refracted before it arrived at the wall. This being done, he took the first prism in his hand, and turned it about its axis, so much as to make the several parts of the image cast on the second board, successively to pass through the hole in it, that he might observe, to what places on the wall, the second prism would reflect them, and he saw by the changing of those places, that the light tending to that end of the image, towards which the refraction of the first prism was made, did in the second prism suffer a refraction considerably greater, than the light which tended to the other end. The true cause therefore of the length of that image was discovered to be no more, than that light is not similar or homogeneal, but that it consists of rays, some of which are more refrangible than others, so that without any difference in their incidence on the same medium, some of them shall be more refracted than others; and therefore, that according to their particular degrees of refrangibility, they will be transmitted through the prism to different parts of the opposite wall. The following figure may serve as an illustration.



Let the space contained between E and G

represent the window shutter: N a beam of light coming from the sun, passing through the hole F, and incident on the plane of the prism A, B, C. If the prism were not interposed, the beam N would proceed in a straight line to S, and would there illuminate a small circular spot on the wall. And if all the colour-making rays, were of the same refrangibility, the whole beam, being equally turned out of its course, would suffer no alteration with respect to the parallelism of its rays, and consequently would after refraction proceed to Q, and there illuminate a spot similar to that, which would have appeared at S. But if the beam after refraction be composed of rays not alike refrangible, the most refrangible will be thrown farther from S, and the least refrangible, being less reflected out of their course, must fall on part of the wall nearer to S, while those that are refrangible in the intermediate degrees, would fall at interposed distances between them. The foregoing experiment says Newton, shews that the sun's light is compounded of rays, whose refrangibilities are not all the same, for after emerging from the prism, instead of illuminating a circular space, they are spread in a variously coloured and oblong spectrum, the lower part or the least refrangible are of a lively red, which higher up, by insensible gradations become an orange, the orange in like manner is succeeded by a yellow, the yellow by a green, the green by a blue, after which follow, a deep blue or indigo, and lastly a faint violet.

An easy method of demonstrating the various refrangibilities of the coloured rays, is to place a prism opposite the sun, turning it round until the spectrum fall on a sheet of white paper, or on a skreen at about the distance of two feet: the dark shadow of the prism strikes on a space in a perpendicular line with the sun, while the coloured rays occupy a space above and below. If the rays were not refrangible they would lie within the prismatick shadow, and if they were of similar refrangibilities they would be equidistant from it. A hollow prism made with plates of thin and transparent glass, may answer to ascertain the refrangibility of various fluids, and the relative distance of the spectrum, from the shadow, may serve as the standard.

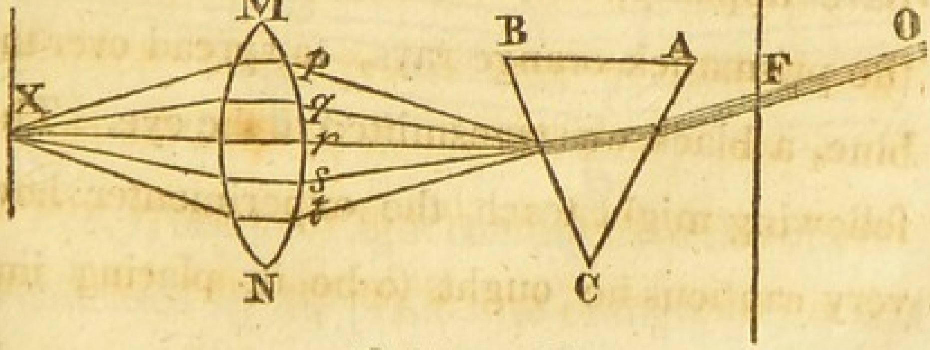
From these experiments Newton inferred, that as seven colours emerge from the prism, so they compose the sun's light. 2dly. He inferred, that the red, nearest the perpendicular was the least, and violet, as being the farthest, was the most refrangible. However plausible these inferences might appear at first sight, I presume the following experiments and reasoning, will point out their fallacy. When we look through the lower refracting angle of a prism at a window, the incident light passes through the transparent panes, and also through the prism, to the eye, undecompounded and colourless, but when we look towards the opaque and dark frames, we perceive a beautiful rainbow-like decomposition, blue, red, and yellow, these three colours, extending six or eight times the breadth of the frames when viewed by the naked eye. Any dark substance pasted on the window, such as a piece of black cloth or paper, will produce the same effect, and the more dense or dark, the deeper the tints. Now it is evident, that if incident or transparent light, were decomposed by merely passing thro' the prism, and separated according to the different refrangibilities of its coloured rays, that light, transmitted through the panes, should be equally decomposed with that reflected from the opaque and dark frames.

Newton's hypothesis, to account for the appearance of white light, after emergence from the prism, will by no means answer this objection. If the rays coming from an object were mixed as he represents, we could have no idea of its figure or situation, when looked at thro' the prism. If the rays crossed, the object would be inverted, besides, we see but three colours, blue, red and yellow: what becomes of the other four? This subject will be more fully investigated when we come to examine Newton's experiments.

To place this objection, if possible in a stronger point of view, I cut two circular holes in my window shutter. One the diameter of $\frac{1}{4}$ inch, mentioned by Newton, the other the diameter of four inches, having darkened the chamber, and applied a prism to my eye, on viewing them, I found that the small aperture admitted rays, tinged with the seven prismatick colours, which when the sun was shining I could receive on a sheet of white paper. The larger aperture was likewise fringed round with the prismatick colours, and transpareut light passed through the middle. Here I would beg leave to ask, if incident and transparent light, were capable of decomposition, by merely passing through the prism, why was not that, coming through the centre, equally decomposed with that at the edges? Had this phenomenon been occasioned by a mixture of the rays, the light coming through the centre of the small hole, should be equally white with that coming through the centre of the large one, on the contrary, in the former, we find it perfectly green. From these and many other experiments I was led to doubt the conclusions drawn by Newton, and am convinced however contrary to received opinion, incident and transparent light is a simple and homogeneous fluid, incapable of decomposition. I have already shewn that Newton was mistaken, in supposing he formed white, by the mixture of primary coloured paints. Let us now examine the experiment from which he inferred, that by mixing up the seven differently coloured prismatick rays, he produced a white, proving, as he conceived both by analysis and synthesis, the truth of his proposition. I shall relate Newton's experiment in his own words.

"By mixing coloured light, to compound a beam of light, of the same colour and nature, with a beam of the sun's direct light, and therein to experience the truth of the foregoing proposition."

Let A, B, C, a, b, c,(in fig. 16.)represent a prism, by which the sun's light, let into a dark chamber through the hole F, may be refracted towards the lens M, N, and paint upon it at P. Q. R. S and T, the usual colours, violet, blue, green, yellow and red, and let the diverging rays, by the refraction of this lens, converge again towards X, and there, by a mixture of all their colours compound a white according to what was shewn above. Then let another prism D, E, G, d, e, g, parallel to the former, be placed at X, to refract that white light, upwards towards G, let the refracting angles of the prisms, and their distances from the lens be equal, so that the rays which converged from the lens towards X, and without refraction, would there have crossed and diverged again, may by the refraction of the second prism be reduced into parallelism and diverge no more, for then those rays will recompose a beam of white light, X, Y. If the refracting angle of either prism be the bigger, that prism must be so much the nearer to the lens. You will know when the prisms and the lens are well set together, by observing if the beam of light X, Y, which comes out of the second prism be perfectly white to the very edges of the light, and at all distances from the prism continue perfectly and totally white, like a beam of the sun's light. For, till this happens, the position of the prism and the lens to one another must be corrected, and then if by the help of a long beam of wood, as is represented in the figure, or by a tube or some other such instrument made for that purpose, they be made fast in that situation, you may try all the same experiments in this decompounded beam of light X, Y, which have been made in the sun's direct light; for this compounded beam of light has the same appearance, and is endowed with all the same properties as a direct beam of the sun's light, so far as my observation reaches: and in trying experiments in this beam, you may by stopping any of the colours *p*, *q*, *r*, *s*, and *t*, at the lens, see how the colours produced in the experiment are no other than those which the rays had at the lens before they entered the composition of this beam; and by consequence, that they arise, not from any new modification of the light by refractions and reflections, but from the various separations and mixtures of the rays originally endowed with their colour making qualities; so, for instance, having with a lens $4\frac{1}{2}$ inches broad, and two prisms on either hand $6\frac{1}{4}$ feet distant from the lens, made such a beam of compound light. To examine the reason of the colours made by prisms, I refracted this compounded beam of light X, Y, with another prism H, I, K. *k*, *h*, and thereby cast the usual prismatick colours P, Q, R, S, T, upon the paper L, V, placed behind, and then by stopping any of the colours *p*, *q*, *r*, *s*, *t*, I found that the same colour would vanish at the paper. So if the purple *p*, upon the paper would vanish, and the rest of the colours would remain unaltered, unless perhaps the blue, so far as some purple latent in it at the lens might be separated from it by the following refractions, and so by intercepting the green upon the the lens, the green *k*, upon the paper would vanish, and so by the rest; which plainly shews that as the white beam of light X, Y, was compounded of several lights variously coloured at the lens, so the colours which afterwards emerge out of it by new refractions, are no other than those of which its whiteness was compounded. The refraction of the prism H, I, K. *k*, *h*, generates the colours P, Q, R, S, T, upon the paper, not by changing the colorific qualities of the rays, but by separating the rays which had the very same colorific qualities before they entered the composition of the refracted beam of white light X, Y. for otherwise, the rays which were of one colour at the lens, might be of another on the paper, contrary to what we find.*

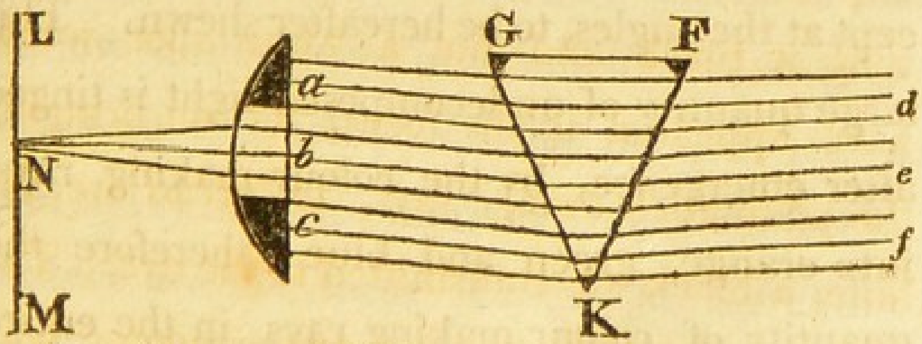


*Opticks, page 166.

The foregoing diagram represents as much of Newton's experiment as is necessary for our purpose. I therefore thought it unnecessary to give the entire, omitting that part which represents the decomposition of the compounded beam at X, the reader may consult the opticks.

Perhaps there never was an experiment more likely to impose on the understanding than this, which to all appearance gives both an analytick and synthetick proof: 1st. that the solar light is separated by the prism into the seven colours, and 2dly. that it is condensed into its original whiteness by means of the convex lens. Had Newton really compounded the seven coloured rays, we might expect from the experiments related in p. 10 of this treatise, that a black and not a white spot would have appeared in the focus, for on bringing the prismatick orange rays, to spread over the blue, a black was transmitted to the eye. The following might teach the experimenter how very cautious he ought to be in placing implicit confidence on even the greatest authority; scepticism in philosophy being both praiseworthy and necessary.

Having placed the prism G, F, K, in the sun beams, I turned it about its axis until the colours were well defined at about 2 feet distance: here I allowed the green rays to pass through a plano-convex lens of about 2 inches focus and intercepted the rest. On receiving this focal light on a sheet of white paper, it was of a dazzling white and not a single shade of green was observable. I now allowed the orange rays to pass thro' the lens, and the same white spot appeared in the focus without a single tinge of red or yellow, I next allowed the entire spectrum to pass through and the same focal light was apparent only more intense.



d, *e*, *f*, beams of light coming from the sun are condensed by the prism into orange, green and blue rays, represented by *a*, *b*, *c*, the orange and blue rays *a*, *c*, are intercepted by pasting paper on the lens, while the green rays *b*, are allowed to pass through, and being converged to the focus N, form a perfectly white spot at the paper L, M.

A more simple, and a better method of performing the experiment is, to receive the green, orange, or blue rays, on a small convex lens, the diameter of the rays to be operated on. The lens I used, was the eye-glass of a small telescope, $\frac{5}{8}$ of an inch diameter, and about one inch focus.

The rationale of this experiment is as follows, when the sun beams fall on the prismatick plane F, K, the incident light passes through undecomposed and colourless, except at the angles, to be hereafter shewn. This large quantity of undecomposed light is tinged after emergence, by the colour-making rays, into orange, green and blue; therefore the quantity of colour making rays in the entire spectrum, is to the quantity of incident and undecompounded light, as the breadth of the opaque angles to the prismatick plane F, K, or in the geometric proportion of two lines to 1½ inch. Therefore when we consider that millions of incidental rays pass through the prism without decomposition, and afterwards thro' the lens, for every one of orange, green or blue, we cannot be surprised that when concentrated into a focus, the incidental light should overcome the condensation, and consequently, the colour of the orange, green or blue rays, in the same manner as when the sun beams are thrown by means of a convex lens, on the spectrum or on differently coloured cloths.

In Newton's experiment, the incident rays passing through a small hole ¼ of an inch in his window shutter, were in a much smaller proportion to the colour-making rays, reflected from the entire circumference, and therefore to produce a white focus it required the entire spectrum to be concentrated, before a sufficient quantity of incidental light could be accumulated to overcome the coloured rays. Taking this view of the subject we may subscribe to the correctness of his statement, without granting the inferences.

We may as well argue that white light is compounded of green, of orange or of both; as to say that it is compounded of the entire rays. Further to convince myself as to the fallacy of the Newtonian experiment, I allowed the spectrum to fall on a sheet of white paper: the sun was very bright and the colours strong and brilliant in the extreme. I then held a plano-convex lens in such an oblique manner as to throw the illuminated focus successively on the prismatick colours. When I found that wherever it fell, the coloured rays were changed into perfect whiteness, the orange appeared as white as the green, and the green as the blue or violet. This proves in the most satisfactory manner, that the condensation of the coloured rays was overcome by the intensity of the concentrated and solar light. Hence when Newton and his friend placed their grey mixture in the sun shine, the condensed grey was overcome, and white was reflected to the eye.

Having shewn that Newton never compounded white light either by means of opaque paints or the prismatick rays; I shall now proceed to shew, that he was mistaken in regard to the different refrangibilities of the coloured rays.

YELLOW RAYS ARE THE MOST, AND BLUE THE LEAST REFRANGIBLE.

Newton has stated as an axiom, "that lights which differ in colour, differ also in degrees of refrangibility." So far, every person in the least acquainted with optical phenomena must agree, and for this discovery, science is much indebted to this great man: but when he proceeds to say, that blue rays are more refrangible than red or yellow, we must entirely differ. "To shew (says Newton *) that blue rays are more refrangible than red, I took a black oblong stiff paper, terminated by parallel sides and with a perpendicular right

* Opticks page 16.

line, drawn across from one side to the other, distinguished it into two equal parts: one of these parts I painted with a red colour, and the other with a blue, the paper was very black and the colours intense and thickly laid on that the phenomena might be more conspicuous, this paper I viewed through a prism of solid glass, whose two sides through which the light passed to the eye were plain and well polished and contained an angle of about 60 degrees, which angle I call the refracting angle of the prism, and whilst I viewed it, I held it and the prism before a window in such a manner that the sides of the paper were parallel to the prism, and both those sides and the prism were parallel to the horizon, and the cross line was also parallel to it, and that light which fell from the window upon the paper, made an angle at the paper equal to that angle which was made with the same paper by the light reflected from it to the eye. Beyond the prism was the wall of the chamber, under the window covered over with black cloth, and the cloth was involved in darkness, that no light might be reflected from thence, which in passing by the edges of the paper to the eye, might mingle itself with the light of the paper, and obscure the phenomena thereof.

These things being thus ordered, I found that if the refracting angle of the prism be turned upwards, so that the paper may seem to be lifted upwards by the refraction, its blue half will be lifted higher by the refraction than its red half. But if the refracting angle of the prism be turned downwards, so that the paper may seem to be carried lower by the refraction, its blue half will be carried something lower thereby than its red half, wherefore in both cases the light which came from the blue half of the paper through the prism to the eye, does in like circumstances suffer a greater refraction than the light which comes from the red half, and by consequence is more refrangible."

On repeating this experiment I never could perceive that the blue half was carried higher or lower than the red. The colours I used were Indigo and Lake; at best it is but a rude and inconclusive experiment, as both Indigo and Lake or dark blue and red, are compound and not simple colours, which is easily proved by looking at them thro' the prism. I shall relate the following experiments and leave the reader to judge for himself.

EXPERIMENT 1st.

Having drawn two parallel lines on a sheet of white paper, about half an inch in breadth, the upper red, the lower blue, I fastened it against a well illuminated wall, immediately opposite a large window; an assistant placed his finger on a line with the blue. On now applying my prism, and looking at these lines through the lower refracting angle, standing at about the distance of 6 or 8 feet, I perceived that all the red rays had fallen below the blue, which appeared on a line with the assistant's finger. Thus, the red rays, instead of being above his finger, and also above the blue as they appeared to the naked eye, were considerably below, or in other words, the lines appeared as if inverted. I now looked at the same lines, through the upper refracting angle and the red rose above the blue. This experiment is so very conclusive, as almost to render others unnecessary; however I shall add the following.

EXPERIMENT 2nd.

Having pasted a strip of black cloth on a pane of glass at the window, I viewed it through the lower refracting angle; when I stood near, it appeared black, and as I gradually withdrew, it separated into its three component colours, blue, red and yellow. On looking at the same piece of cloth through the upper refracting angle, the red and yellow rose above the blue.

EXPERIMENT 3rd.

Having made an orange circle, about the diameter of a six-penny piece, on a sheet of white paper, and having surrounded it with a circumference of Indigo, half an inch in breadth; standing at about 8 feet distance, I viewed it through the lower refracting angle, and found that all the red and yellow rays compounding the orange, had fallen below the blue circumference, which was changed into an oblong shape.

EXPERIMENT 4th.

If we make a hole of any given size in a card, on looking through it at the clouds by means of the lower refracting angle of the prism, the upper edge appears fringed with red and yellow rays, the lower with blue and violet. This appearance does not arise from any real difference in the upper and lower fringes of reflected light, for the dark or black light, reflected from the interior circumference, is compounded of the three simple colours; but in passing through the prism, the red and yellow being more refrangible than the blue, either rise above or fall below it, according as the upper or lower refracting angle is used. This fact is easily demonstrated, for on looking at the same hole through the upper refracting angle, the top is fringed with blue and violet, while the bottom is red and yellow.

I could have brought forward many more experiments tending to similar results, but thought those already stated, fully adequate to prove that the yellow and red rays are more refrangible than the blue. But it may be asked, if the yellow and red rays are more refrangible than the blue, what was the reason that in Newton's experiments, the red rays appeared nearest the perpendicular, and blue and violet, the most remote as represented in fig. 1. page 25.? The following experiments I presume will answer this question, and explain in what manner Newton, by mixing three simple and homogeneal colours produced a spectrum of seven.

INCIDENT LIGHT INCAPABLE OF DECOMPOSITION.

EXPERIMENT 1st.

If a square piece of black cloth, with a small semicircular piece, cut from the lower part in the following manner  be pasted on a pane of glass at the window, on looking at it through the lower refracting angle, we perceive the bottom to be fringed with red and yellow rays. If we now paste another similar piece some distance below it, and in an inverted position as thus represented  we perceive the upper part to be fringed with blue, and violet underneath. Thus we have three simple and one compound colour produced by the black light reflected from the cloth, and decomposed by the prism. The violet arises from the orange blending with the black light of the lower piece of cloth. When those two pieces are about half a foot asunder, we never perceive more than four colours blue, red, yellow and violet. If we now direct an assistant to approximate them, the yellow of the upper piece blends with the blue of the lower one, and a green is formed.

The rationale of this interesting and conclusive experiment is perfectly obvious. The square pieces of black cloth, represent the dark window shutter, the two semicircular apertures when thus united, form a circular hole through which the incident light passed. The black light reflected from the inner edges of this hole was decomposed, and the rays being mixed according to their different order of refrangibility in passing through the prism, gave the spectrum of seven, or rather three distinct colours to the eye.

Here we have a convincing experiment, that incident light passing through the centre is incapable of decomposition, and that the colours are produced entirely by the separation of black light reflected from the upper and lower edges of the inside of the hole; and I would particularly draw the attention of my readers to the fact, that the green proceeds after emergence from a mixture of the blue and yellow, and is by no means a simple colour, as Newton endeavoured to prove.

Although this philosopher has described the spectrick colours as equal to the mystic number seven, if a painter were asked how many there were, he would answer orange, green and violet, but then it would be impossible to set the rain-bow to music, and the sister hand-maids would be deprived of their solar gamut.* Thus did Sir Isaac Newton compound what he calls seven, with the three simple or primary colours, blue, red and yellow.

Whilst he thought he was analysing or decompounding incident light, he was actually and bonâ fide, making all his experiments on the condensed and black light, reflected from the upper and lower edges of the inside of the hole in his dark window shutter, the incident and vision-making light which passed through the centre, only enabled him to see the decomposition of the opaque colours, with which it was blended in various proportions. If it be granted, and I presume few will deny the fact, that the black rays reflected from a piece of black cloth, pasted on the window, can be analyzed

*Des Cartes was the first to compare Green to an Octave, Newton followed up the idea, and set the seven Colours to Music.

by the prism into blue, red and yellow, we can have no difficulty whatsoever in believing, that the black light of a darkened chamber can be equally well decompounded.

In this experiment a doubt might possibly remain on the minds of some, that incident and transparent light may contribute more or less to these phenomena, I therefore instituted the following which may be deemed an experimentum crucis.

EXPERIMENT 2nd.

I removed the two pieces of black cloth already mentioned, and pasted the lower one on a white painted door, fronting a well illuminated window, with the semicircular incision looking upwards, on viewing it through the lower refracting angle of a prism, the upper part was fringed with blue, and violet underneath. I now directed an assistant to hold the upper piece with the semicircular incision looking downward, some distance above it, the lower part was fringed with red and yellow rays: on approximating these, as before done at the window, the hole became variegated with the seven prismatick colours; here no incident light could possibly be suspected, the entire was reflected to the eye from the white door and black cloth, yet the spectrum appeared more beautiful than at the window.

This experiment proves beyond doubt that the spectrum can be produced without incidental light: and yet farther, to prove that the white light reflected from the door was not in the least decomposed, I looked at these two pieces of black cloth, when pasted on a yellow painted board, and in consequence of the encreased verdure of, the median light, the spectrum was more vivid than before. Here the advocates for the Newtonian doctrine would be somewhat puzzled, for only one colour, the yellow, should have been reflected to the eye; the black cloth absorbing all the rays. Therefore it is obvious that neither incidental nor white light were decomposed in these experiments.

From these and many others too numerous to relate, we are authorised to conclude, that incidental light has never yet been decomposed into different colours by Newton, nor any other philosopher, but that he made all his experiments, and drew all his inferences from the decomposition of black or dark light.

I am well aware it might be objected, that our justly celebrated astronomer Dr. Herschel, Sir C. H. Englefield and others, decomposed incident light, by placing their prisms in the open sun beams, where no black reflected light could be supposed present. At first sight this and the phenomena of the rain-bow, may be looked on as serious, if not insurmountable objections; however, so far from invalidating, I hope to prove that they confirm my opinions.

The prism is a semitransparent substance whose angles are perfectly opaque and dark, as might be easily demonstrated, by holding the instrument over a sheet of white paper.

When it is turned about its axis, so as partly to transmit, and partly to reflect the rays those opaque and dark angles condense the light into blackness, in which state it undergoes reflection. These angles likewise, transmit dark rays or shadows thro' the prismatick plane, where they are separated or decompounded into blue, red and yellow, the constituent parts of blackness; these colours intermix after emergence, according to their different degrees of refrangibility, and form the spectrum to be hereafter shewn. As there are three opaque and dark angles in every glass prism, so there are two spectra always formed in the open sunbeams in the same manner as three narrow strips of black cloth or paper pasted at certain given distances and parallel to one another on the window, when viewed through the prism form two spectra.

This circumstance seems to be unknown or disregarded by Newton, who makes no mention of it in the opticks. As I am extremely solicitous that my opinions on light should rest on the secure and firm basis of experimental induction, and to shew that the decomposition takes place at those opaque angles, I made the following experiment.

EXPERIMENT 3rd.

Having placed a prism at the open window, in the sun-beams, and having formed a spectrum on a sheet of white paper, at about $1\frac{1}{2}$ foot distance, I slowly turned the instrument round its axis until I separated the red and yellow rays coming from the upper angle, from the blue coming from the middle one, and instead of green which occupied the centre of the spectrum, white and transparent light passed through the prismatick plane. This proved beyond the possibility of doubt, that the green is compounded, after the blue and yellow emerge from the prism, and that it is not a primary or homogeneal colour as Newton inferred. Indeed there is something extremely inconsistent in supposing that green is at one time heterogeneal when paints are blended, and homogeneal at another when passing through the prism; neither is Newton's reasoning on this subject very correct, when he draws the distinction between the two greens, by saying the one is capable, and the other incapable of decomposition by the prism; for if the prismatick blue and yellow rays form a green, they must have the same refrangibility, and therefore be incapable of further separation. No green formed by the hand of man can be at all equal in delicacy to the prismatick rays, and therefore we might well suppose that such a green when passed through the prism might be capable of separation.

Thus, when the spectrum is received on a sheet of white paper, at about four inches distance from the prism; merely by turning the instrument on its axis, and so altering the angle of incidence, we can either form a spectrum composed of red, yellow, blue and violet, or we can form one of red, yellow, blue, green and violet. Indeed this simple experiment is nearly sufficient to overturn the entire Newtonian Doctrine.

I now ascertained that the red and yellow rays came from the upper angle, by intercepting them with my finger or any other opaque substance. By running my finger along the middle angle, I intercepted the blue rays, and by pasting narrow and parallel strips of paper on the prismatick plane, I made different spectra in the same manner as when pasted on the window, and viewed through the prism.

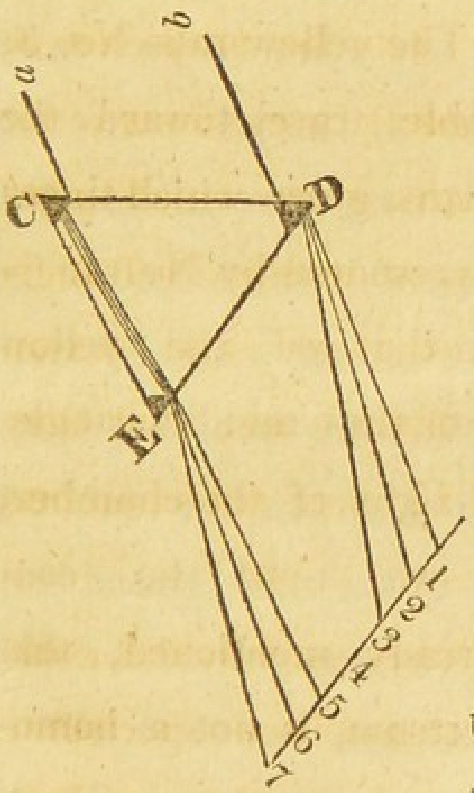
However, to place this interesting fact beyond the limits of a doubt, I looked by means of one prism, at the light passing through an other, and perceived those fringes at the angles. I then looked through the lower refracting angle at the clouds, and when the prism was held at a short distance, and in a certain position, I plainly perceived the fringes with my naked eye.

Such are the arguments from which I would infer, that the solar light is simple and homogeneal, and that the prismatick colours, take their origin from the separation of the black light, reflected from the opaque angles.

Newton says, (page 53. prop. iii.) "the sun's light consists of rays differing in reflexibility, and these rays are more reflexible than others which are more refrangible." That the colour-making rays are differently reflexible, I am ready to admit: but Newton did not seem to be aware, that the light reflected from the plane of a prism, is perfectly transparent and colourless, except at the edges or angles, at whatever angle of incidence it may strike, making a reflected spectrum somewhat similar to the transmitted one. This fact adds encreasing strength to the foregoing arguments; for if a beam of incident light, were compounded of seven different rays, of unequal refrangibilities and reflexibilities, there is no reason whatsoever, at least as far as I see, that they should not be separated by mere reflection into their various colours.

Here the flimsy hypothesis, used by this great man, in regard to the transmitted spectrum, "that the rays are mixed into whiteness," is too preposterous to hold for one moment; for if this were the case, the angles of incidence could never be equal to the angles of reflection; and consequently reflecting mirrors would be useless to society. The supporters of the Newtonian theory, are therefore bound to shew why these different rays, composing white light are all reflected at equal angles and without decomposition.

The following diagram represents the manner in which those opaque angles produce the descending spectrum.



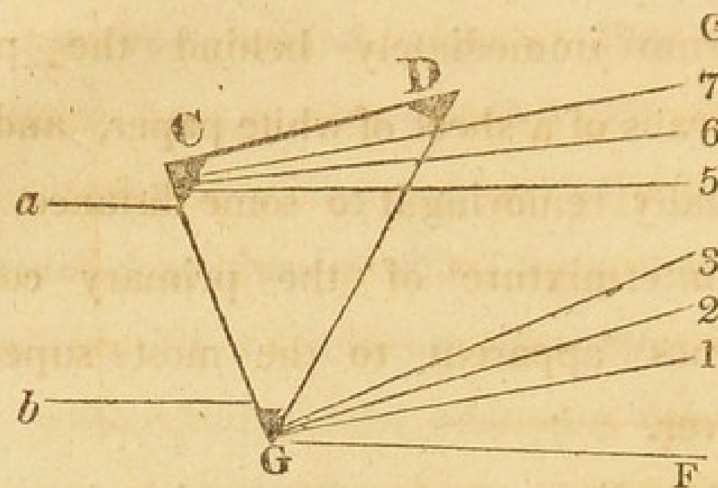
a b, two beams of incident and transparent light coming from the sun, strike on the prismatick plane C D, and pass through without decomposition, in company with all the intermediate ones. Again the opaque angles, C D, reflect two dark shadowed lines, which passing through the prism, are decompounded or separated into blue, red and yellow rays. The blue rays No. 1, are the least refrangible, and therefore remain invisible in the dull light of the chamber; however those rays can be rendered visible, by turning the prism in a certain position, and thus changing the obliquity of the incidental rays.

The red rays No. 2, blended with some yellow, form orange, a mixed colour partaking of the refrangibility of its constituent rays, and so intimately blended as to be inseparable by the prism. The yellow rays No. 3, being the most refrangible, travel towards the blue rays No. 5, and form a green which tinges the transparent light represented by No. 4.

No. 6, and 7, or the red and yellow rays proceeding from the middle angle, mixed with the dark light of the chamber, form violet. Here we must be convinced as I have already mentioned, that the green of the spectrum is not a homogeneal but a mixed or secondary colour; easily demonstrated, by intercepting the spectrum immediately behind the prism, by means of a sheet of white paper, and then gradually removing it to some distance, when the intermixture of the primary colours, becomes apparent to the most superficial observer.

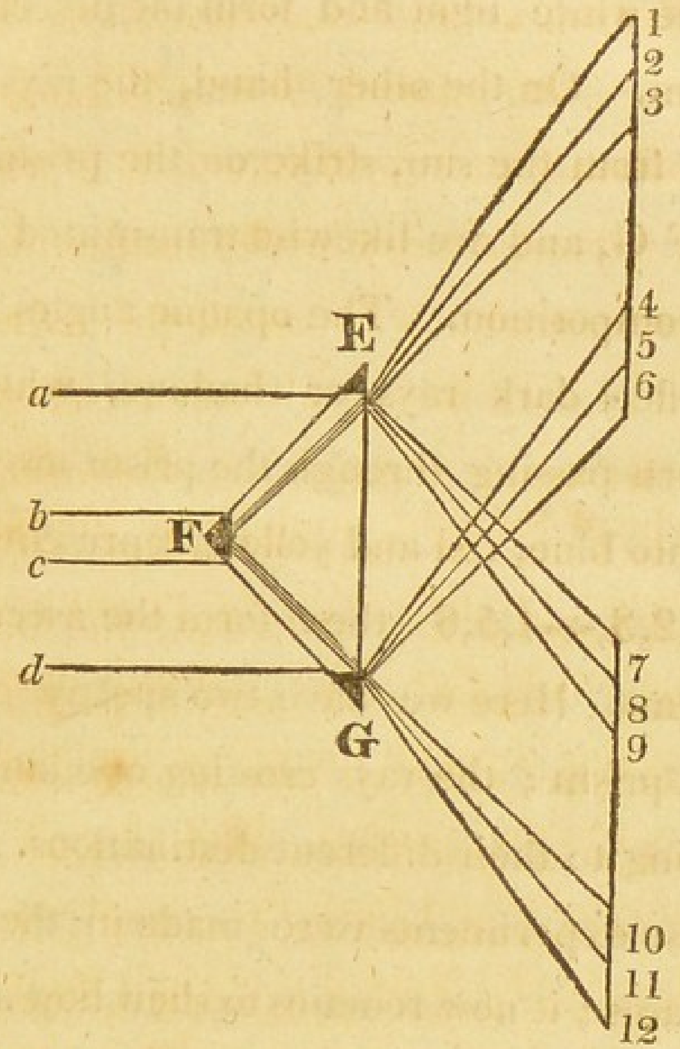
This diagram represents the descending spectrum and shews the source of Newton's mistake; he supposed that the colour-making rays diverged from one another, from their very emergence, and therefore formed a spectrum longer than the hole, in the window shutter. The fact is, that the entire incident rays passing through the prism, are first refracted to both a calorofic and luminous focus, at a short distance behind the prism, and then in consequence of the different refrangibilities of the blue, red and yellow rays, the spectrum is lengthened, encreasing with the distance at which it is intercepted.

We shall now examine the ascending spectrum, when formed in the open sun-beams, as represented in the following page.



a b, two beams of light, impinge on the plane C G, passing through without decomposition. The opaque angles C G, transmit dark rays which passing through the prism, are separated into blue, red and yellow. 1, 2, 3,---5, 6, 7. these intermix and form the spectrum as already described. Now it is evident from these diagrams, that yellow rays are the most refrangible, and blue the least; for if we produce a straight line from G to F, the blue rays No. 1, and 5, are nearest the perpendicular, and consequently the least refrangible, and the yellow rays No. 3, and 7, are the farthest from the perpendicular, and therefore the most refrangible.

The following diagram represents a prism in the open sun-beams, forming both a descending and ascending spectrum.



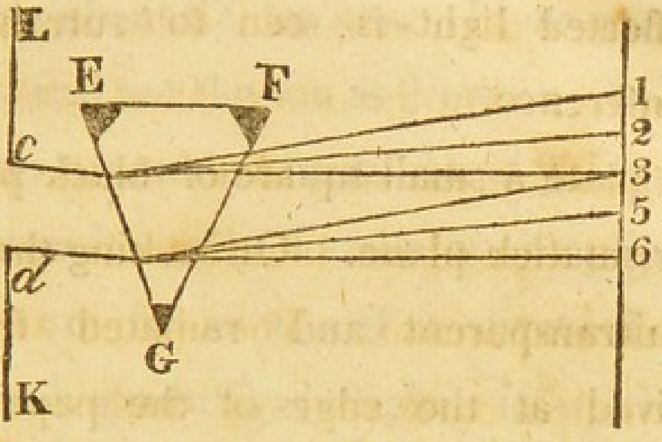
a b, two beams of light, strike on the prismatick plane E F, are then refracted and transmitted without decomposition.* The opaque angles E and F, reflect dark light or shadows, which passing through the prism, are separated into blue, red and yellow rays, 7,8,9,---10,11,12, these

* The rays *a b c d*, are not represented in their passage through the prism, lest confusion may result. Perhaps some of my readers might think that this transparent light in passing near the opaque angles is inflected. However as reflection, inflection and deflection are produced by the same power, we may subscribe to the opinion without altering the theory.

tinge the white light and form the descending spectrum. On the other hand, the rays *c d*, coming from the sun, strike on the prismatick plane F G, and are likewise transmitted without decomposition. The opaque angles F G, also reflect dark rays or shadows, which in their turn passing through the prism are separated into blue, red and yellow, represented by Nos. 1,2,3,—4,5,6. these form the ascending spectrum. Here we have two spectra formed by one prism ; the rays crossing one another, in passing to their different destinations.

These experiments were made in the open sun-beams ; it now remains to shew how a spectrum was formed, through a dark hole in the window shutter. I would refer the reader to page 25, wherein he will see a figure, illustrating Newton's ideas on this subject; he conceived not only that the incident light was decomposed by the prism, but likewise, that the rays diverged after emergence.

The following figure, represents what I conceive to be the real explanation.



c d, two beams of black light, reflected or inflected into blackness by the inside edges of the hole in the window-shutter, strike on the prismatick plane E G, and in passing through, are decompounded into blue, red and yellow rays, represented by Nos. 1, 2, 3, 5, 6. The incident rays coming from the sun and passing through the hole, likewise pass through the prism E F G without decomposition, and blending in different proportions with the colour-making rays, serve to illuminate the spectrum. If the foregoing theory required further confirmation, the following experiments might be made.

Make a circular hole in a card; on looking through it by means of the lower refracting angle of the prism, when close, a dark fringe of reflected light is seen to surround the circumference.

Or paste a small square of black paper on the prismatick plane. On looking through it, a semitransparent and radiated fringe is perceived at the edges of the paper. The superciliary ridge should be in contact with the angle of the prism.

Having thus shewn that the decomposition of black light is the cause of the prismatick colours, I shall proceed to the investigation of some more of the Newtonian opinions.

THE SPECTRUM NOT AN IMAGE OF THE SUN, BUT A FORAMINAL OR PRISMATICK IMAGE.

EXPERIMENT 1st.

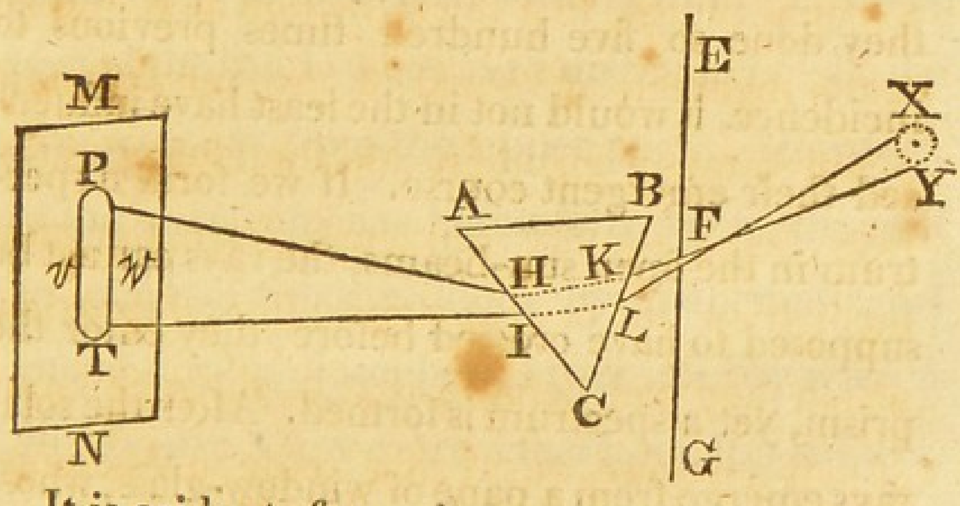
Having darkened the room, and admitted a sun-beam through a hole in the window-shutter, one inch in diameter; I placed a prism immediately behind, in such a position as to pass the rays through the lower refracting angle, which was about 62 degrees. I now perceived the hole, and not the sun as Newton conceived, to be represented in beautiful and vivid colours on the opposite wall; for on intercepting the the spectrum by means of a sheet of white paper, and gradually bringing it up behind the prism, I perceived the hole in the window-shutter, represented in the same manner it would have been, had I looked at it through the prism; the lower edge of the circumference was fringed with red and yellow rays, the upper with blue and violet, while transparent and incident light passed through the middle. If I passed the rays through a triangular aperture, the image immediately behind the prism was likewise triangular. Indeeed Sir Isaac Newton, with a surprizing degree of inconsistency admitted that the shape of the spectrum depended on the figure of the aperture; and yet he set about mathematically demonstrating, that the diameter of what he calls the solar image, answered to that of the sun; proving that he mistook the rationale of a prism, for that of a convex-lens: a convex-lens would undoubtedly form an image of the sun in the focus, although the rays were passed through a triangular or any other shaped aperture; a prism never could. Newton says (page 23,) "For the image was eighteen feet and an half distant from the prism, and at this distance, that breadth if diminished by the diameter of the hole in the window-shutter, that is by quarter of an inch, subtended an angle at the prism of about half a degree, which is the sun's apparent diameter," and again page 60, he says "Instead of this parallelogram hole, may be substituted a triangular one of equal sides, whose base for instance, is about the tenth part of an inch, and its height an inch or more, for by this means, if the axis of the prism be parallel to the perpendicular of the triangle, the image P T, in page 25, will now be found of equicrural triangles *a g b k c i d k e l f m* &c, and innumerable other intermediate ones, answering to the triangular hole in shape and bigness, and lying one after another in a continual series between two parallel lines *a f* and *g m*."

It signified nothing to this great mathematician whether the spectra were triangular, circular or oblong, they were all images of the sun. An Elephant with as much propriety might be called an image of the sun, as either a triangular or oblong party coloured spectrum. The english word image, is immediately derived from the latin imago, or more properly from imitatio, implying a likeness or representation.

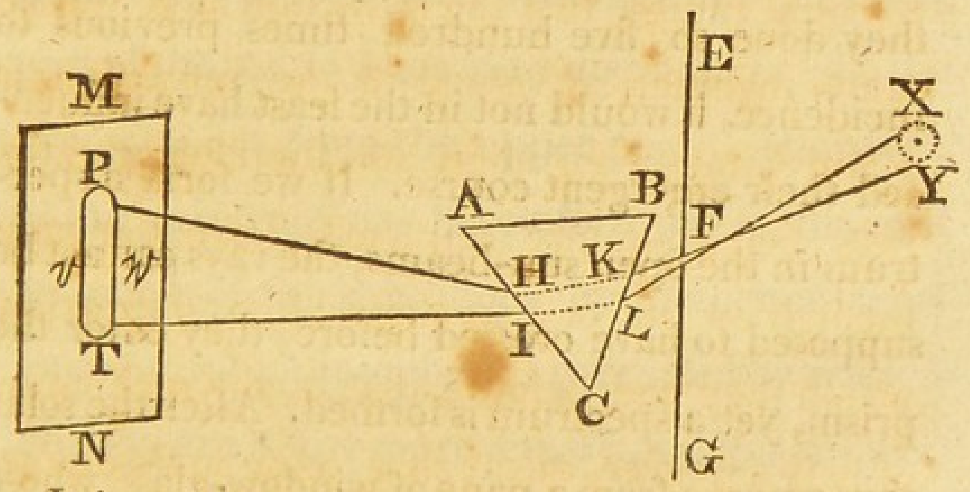
Therefore as the prism (contrary to what Newton supposed, when he accounted for the median white light, by a mixture of the rays) refracts all the rays in one direction, either upwards or downwards, it is impossible that any exact likeness of an object could be formed: a circle when viewed through it appears oblong; a straight stick appears curved, and separated into three colours; a black crow appears elongated, blue, red and yellow. It would be absurd to say, that by looking through the prism, we could form any correct idea of these objects. A triangular convex-lens placed opposite the sun, forms a luminous triangle before the rays cross one another, but after they cross a round solar image is delineated. The focus of a prism is entirely different, as will be seen hereafter, when we come to speak of Dr. Herchel's opinions concerning radiant caloric. However, as I could find no more appropriate name, I have retained the word spectrum ; perhaps luminous object would have answered.

I need scarcely say, the visible image should be in every instance an exact representation of the tangible object, otherwise the sense of feeling instead of being an advantage, would be a real injury to the sense of sight.

This mistake of Newton's (as is generally the case in false reasoning,) gave rise to many others. He supposed that the decomposed rays, moved from the round hole in his window-shutter, in regular circles, one above the other, according to their degrees of refrangibility, so as to produce an oblong figure on the wall; whereas the real reason, that a circular hole gives an oblong spectrum, is that the rays after emergence from the prism, move in curved lines: a parallelogram hole would equally well produce an oblong spectrum. Newton proceeds page 25 "For let E G, fig. 13, represent the window-shutter: F, the hole made therein, through which a beam of the sun's light was transmitted into the darkened chamber, and A B C, a triangular imaginary plane, whereby the prism is feigned to be cut transversely through the middle of the light. Or if you please, let A B C, represent the prism itself, looking directly towards the spectator's eye with its nearer end; and let A Y, be the sun; M N, the paper upon which the solar image or spectrum is cast, and P T, the image itself whose sides towards N and W, are recte-linear and parallel and ends towards P and T semicircular. G K H P and X L J T, are two rays, the first of which comes from the lower disk of the sun to the higher part of the image, and is refracted in the prism at K and H, and the latter comes from the higher part of the sun, to the lower part of the image, and is refracted at L and J. Since the refraction on both sides of the prism are equal to one another, that is, the refraction at K equal to the refraction at J, and the refraction at L equal to the refraction at H, so that the refractions of the incident rays at K and L taken together, are equal to the refractions of the emergent rays at H and J, taken together, it follows by adding equal things to equal things, that the refraction at K and H, taken together, are equal to the refractions at J and L taken together, and therefore the two rays being equally refracted, have the same inclination to one another after refraction, which they had before; that is, the inclination of half a degree, answering to the sun's diameter, for so great was the inclination of the rays to one another before refraction. So then the length of the image P T, would by vulgar opticks, subtend an angle of half a degree at the prism, and by consequence be equal to the breadth V W, and therefore the image would be round. Thus it would be, were the two rays X L I T and Y K H P, and all the rest which form the image P W T V, alike refrangible, and therefore seeing by experience it is found that the image is not round, but about five times longer than broad, the rays which going to the upper end P of the image, suffer the greatest refraction, must be more refrangible than those which go to the lower end T, unless the inequality of refraction be casual."



It is evident from the entire of this passage and from an examination of the figure, that Newton supposed the rays of light coming from the upper and lower parts of the sun's disk, X Y, crossed one another at F, the hole in his window-shutter, and then passing through the and is refracted in the prism at K and H, and the latter comes from the higher part of the sun, to the lower part of the image, and is refracted at L and J. Since the refraction on both sides of the prism are equal to one another, that is, the refraction at K equal to the refraction at J, and the refraction at L equal to the refraction at H, so that the refractions of the incident rays at K and L taken together, are equal to the refractions of the emergent rays at H and J, taken together, it follows by adding equal things to equal things, that the refraction at K and H, taken together, are equal to the refractions at J and L taken together, and therefore the two rays being equally refracted, have the same inclination to one another after refraction, which they had before; that is, the inclination of half a degree, answering to the sun's diameter, for so great was the inclination of the rays to one another before refraction. So then the length of the image P T, would by vulgar opticks, subtend an angle of half a degree at the prism, and by consequence be equal to the breadth V W, and therefore the image would be round. Thus it would be, were the two rays X L I T and Y K H P, and all the rest which form the image P W T V, alike refrangible, and therefore seeing by experience it is found that the image is not round, but about five times longer than broad, the rays which going to the upper end P of the image, suffer the greatest refraction, must be more refrangible than those which go to the lower end T, unless the inequality of refraction be casual."



It is evident from the entire of this passage and from an examination of the figure, that Newton supposed the rays of light coming from the upper and lower parts of the sun's disk, X Y, crossed one another at F, the hole in his window-shutter, and then passing through the prism, emerged at diverging angles, and continuing to diverge, formed an inverted image of the sun on the opposite wall.*

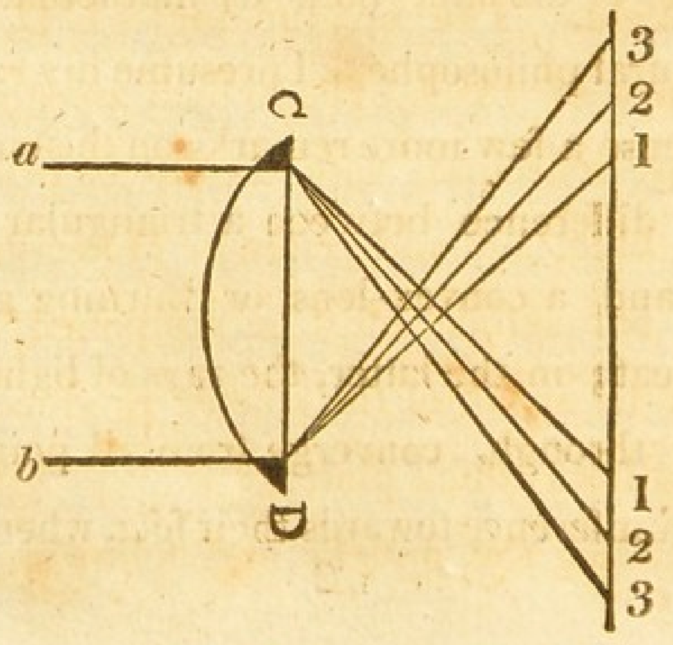
Can we suppose that this great philosopher and mathematician was unacquainted with the fact, that rays of light sent from any luminous body, and passing through a refracting medium, such as the prism, can never form an inverted image without coming to a focus after emergence. Indeed it signified nothing, that the rays crossed before they entered the prism, for had they done so five hundred times previous to incidence, it would not in the least have influenced their emergent course. If we form a spectrum in the open sun-beams, the rays cannot be supposed to have crossed before they enter the prism, yet a spectrum is formed. After the solar rays emerge from a pane of window-glass, whose posterior, and anterior surfaces are parallel, is an image of the sun ever formed? Never,

* Why those rays should have crossed before entering the hole, I am at a loss even to conjecture. Had Newton applied his Eye to this orifice, he would neither have seen the Sun nor any other object inverted. Therefore this part of his diagram is mathematically correct, but experimentally false.

because the rays are not converged to a focus: but if a circular, oblong or triangular hole be cut in a window-shutter of a sufficient size; the rays pass through and form an image or representation of the hole, not the sun, on the opposite wall. When a spectrum is formed by the light of a candle, an image of the candle is never seen. Indeed I cannot help expressing my opinion, that Newton was entirely unacquainted with the properties of the prism, we find him according to this figure and many others refracting the rays H K, coming from the lower part of the sun in a contrary direction to I L, the rays coming from the upper part. However, as the spectrum has heretofore been thought an image of the sun, both by mathematicians and natural philosophers, I presume my readers will excuse a few more remarks on this subject.

The difference between a triangular glass prism and a convex-lens or burning glass is very great; in the latter, the rays of light after passing through, converge from all points of the circumference towards their foci, where they cross and then diverge at different angles, as represented in the following figure.

Here it is necessary to remark, that as every triangular glass prism, has three opaque angles, so every lens has its angular edge or circumference perfectly opaque; this is so evident to the eye as to require no illustration. On holding the lens opposite the sun or a lighted candle, and allowing the transmitted light to fall on a sheet of white paper, before the rays are brought to a focus, a ring or circle of red and yellow rays is seen to margin the circumference: this ring continues until the rays cross one another, when they vanish and a blue circle takes their place, as thus represented.



a b two beams of incident light, impinge on the opaque circumference C D, are there reflected. The opaque circumference C D, likewise transmits a shadowed ring of black light which in its passage through the lens, is decomposed into the three primary colours, blue, red and yellow. Before those rays arrive at their focus, the blue rays No. 1, are in shade, and consequently invisible, but after crossing the red and yellow Nos. 2, and 3, are in their turn thrown into shade, and the blue rays become visible. These colours heretofore were little noticed, and attributed by Newton and his followers, to what they unphilosophically named, the aberration or dispersion of the rays of light. The opaque angles C D, also reflect rays of black light, which are decomposed by reflection, into the three primary colours, blue, red and yellow. However this part of our subject must be postponed, until we come to speak of the colours produced by reflection from thick plates.

On reading the opticks and following the figures it is obvious that Newton as already stated, had a very confused and imperfect idea of the action of a prism. At one time he supposed it to act like a convex-lens, at another the rays were made to diverge. Professor Leslie of Edinburgh, an able mathematician and accurate experimenter, has been led into the same mistake, when he says " what is the eye itself but a compound prism,"*

In dioptrics, a prism is always triangular, and has little or no similitude to a convex-lens. The transparent cornea, the aqueous humour and the crystaline are so many convex-lenses: if they acted on the principle of a prism, the rays of light coming from an object, could never be brought to a regular focus at the retina.

Newton has the following passage, page 141, " what is said of colours made by prisms may be easily applied to glasses of telescopes and microscopes; or by the humours of the eye. For if the object glass of a telescope be thicker on one side than on the other, or if one half of

* Nicholson's Journal, 4to. page 130.

the glass, or one half of the pupil of the eye be covered with any opaque substance, the object glass, or that part of it, or of the eye which is not covered,may be considered as a wedge with crooked sides, and every wedge of glass or pelluced substance, has the effect of a prism, in refracting the light which passes through it."

Here we have a direct assertion, that half a convex-lens refracts the light like a prism. In a prism the rays of light, although the more refrangible overlap the least refrangible, still they are all refracted in one and the same direction, going to either the upper or lower part of the wall. On the other hand, in consequence of the convexity of the spherical surface there is no arc of a convex-lens, however small that does not refract the light in contrary directions. If we look at an object through a prism, it is elongated and changed as to colour, but never inverted, which must be a necessary sequence, if the prism acted as a lens, and the spectrum were an inverted image of the sun. Every convex-lens should be the arc of a perfect and solid sphere, the refracting power depending on the breadth of the axis, in proportion to the diameter, or length of the chord; therefore any attempt to make a magnifying glass without a regular spherical convexity must be for ever futile.

Indeed according to this philosopher, nature must be very fond of mixtures and complicated in her operations. The incident rays are first separated in the body of the glass, they are then mixed into whiteness and again mixed at some distance into their primary colours. From a parity of reasoning, if it deserve that name; the rays of incident light must be separated and mixed into whiteness in the body of a convex or a concave-lens. It would be an insult to the reader's understanding, to attempt a serious refutation; I therefore shall only remind him, that on holding a convex-lens close to the eye, objects appear as they would through a glass with parallel surfaces, shewing that there is no separation nor mixture.

Sir Isaac Newton remarked,* "that on looking at any object through a prism, the edges only appear tinged with certain colours, and as he conceived in a certain order." He has accounted for this phenomenon in the following curious manner.

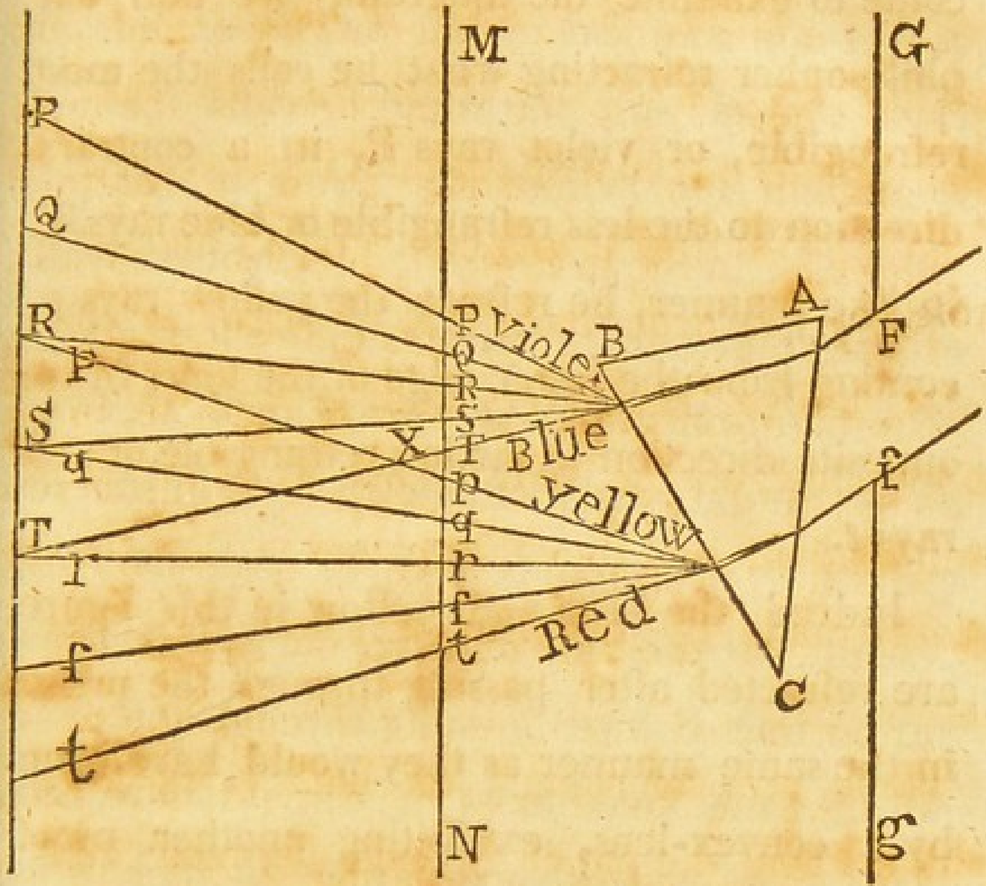
"Let A B C, (in figure 12 of the opticks,) represent a prism refracting the light of the sun, which comes into a dark chamber through a hole F *f*, almost as broad as the prism; and let M N, represent a white paper on which the refracted light is cast, and suppose the most refrangible or deepest violet-making rays fall on the space P *p*, the least refrangible or deepest red-making rays upon the space T *t*, the middle sort between the indigo-making and blue-making rays upon the space Q *q*, the middle sort of the green-making rays upon the space R *r*, the middle sort between the yellow-making and orange-making rays upon the space S *s*, and other intermediate sorts upon intermediate spaces. For so the spaces upon

* Opticks, page 141.

which the several sorts adequately fall, will by reason of the different refrangibility of those sorts be one lower than another. Now if the paper M N, be so near the prism, that the spaces P T, and *p t*, do not interfere with one another, the distance between them T *p*, will be illuminated by all the sorts of rays in that proportion to one another, which they have at their first coming out of the prism, and consequently be white. But the space P T, and *p t*, on either hand, will not be illuminated by them all, and therefore will appear coloured. And particularly at P, where the outmost violet-making rays fall alone, the colour must be the deepest violet; at Q, where the violet-making and indigo-making rays are mixed, it must be a violet inclining much to indigo; at P, where the violet-making, indigo-making, blue-making, and one half of the green-making rays are mixed, their colours must (by the construction of the second problem) compound a middle colour between indigo and blue. At S, where all the rays are mixed, except the red-making and orange-making, their colours ought by the same rule to compound a faint blue, verging more to green than indigo. And in the progress from S to T, this blue will grow more and more faint and dilute, till at T, where all the colours begin to be mixed, it ends in whiteness. So again, on the other side of the white at *t*, where the least refrangible or utmost red-making rays are alone, the colour must be the deepest red. At *s*, the mixture of red and orange will compound a red inclining to orange. At *r*, the mixture of red, orange, yellow, and one half of the green must compound a middle colour, between orange and yellow. At *q*, the mixture of all colours but violet and indigo, will compound a faint yellow, verging more to green than to orange. And this yellow will grow more faint and dilute continually in its progress, from *q* to *p*, where by a mixture of all sort of rays it will become white.

These colours ought to appear, were the sun's light perfectly white: but because it inclines to yellow, the excess of the yellow-making rays, whereby 'tis tinged with that colour, being mixed with the faint blue between S and T, will draw it to a faint green, and so the colours in order from P to *t*, ought to be violet, indigo, blue, very faint green, white, faint yellow, orange, red. Thus it is by the computation, and they that please to view the colours made by a prism, will find it so in nature.

These are the colours on both sides the white, when the paper is held between the prism and the point X, where the colours meet, and the interjacent white vanishes. For if the paper be held still farther off from the prism, the most refrangible and least refrangible rays will be wanting in the middle of the light, and the rest of the rays which are found there, will by mixture produce a fuller green than before. Also the yellow and blue will now become less compounded, and by consequence more intense than before. And this also agrees with experience."



Newton then goes on to say, " that if a person look through a prism upon a white object encompassed with blackness or darkness, the reason of the colours arising on the edges, is much the same, as will appear to one that shall a little consider it." As we have already noticed this assertion, and I hope refuted it to the reader's satisfaction in page 2, of this treatise, I shall now make a few observations on the remaining part of this very subtle and refined hypothesis. In the first place, when we come to examine the diagram,* we find our philosopher refracting what he calls the most refrangible, or violet rays P, in a contrary direction to the less refrangible or blue rays T. In like manner, he refracts the yellow rays *p*, coming from the lower edge of the hole, in an opposite direction to the less refrangible or red rays *t*.

Indeed the blue and yellow in this figure are refracted after passing through the prism in the same manner as they would have been by a convex-lens, exhibiting another proof (if another were wanting) of Newton's mistake in regard to these two instruments. This objection is sufficiently strong to invalidate the entire reasoning, and if we were in want of an argument to prove that the yellow rays are the most refrangible as already shewn, we might refer to this very diagram itself. For if we produce the yellow rays *p p*, they not only

* I have taken the liberty to alter the letters in this diagram, from Greek to small Roman—the letters chi to express Q, was highly inappropriate, tending to make confusion more confused if possible. I have also placed colorific names to the upper and lower margins of the spectrum.

ascend above the blue, but also above the violet;* however to prevent this, he cut short his rays at a very convenient and mathematical distance.

2ndly we might expect a priori that the two spaces P T and *p t*, should be illuminated by similar rays of coloured light. However, we have the sense of sight to inform us that they are not, and the ipse dixit of Newton to say, that they are illuminated by only five of the component rays of incident light. It cannot be looked on as very unreasonable, to ask the Newtonian advocates, why the red and yellow rays are wanting in the upper space, the blue and violet in the lower, and none others. Newton says "but the spaces P T, and *p t*, on either hand will not be illuminated by all the rays, and therefore will appear coloured." Now I must acknowledge such sceptiscism in philosophy, as not to place much faith in the mere assertion of even a Newton. What became of

* I must here refer to Newton's diagram in the opticks, as the wood-cutter has not given an exact representation of the diverging angles, their sinçs being encreased.

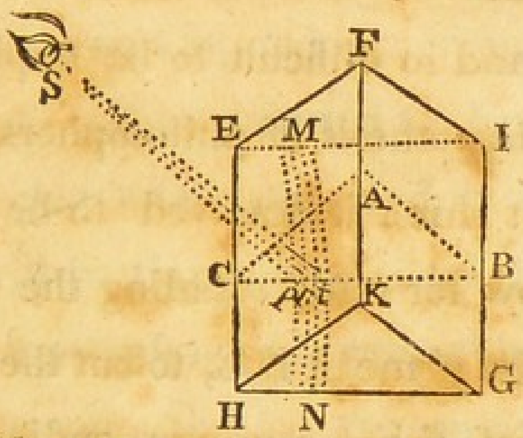
these banished rays? Were they suffocated in their birth as they came out of the womb of white light? Or did they only hide their blushing heads in the bosom of the white paper M N.

3dly. Newton says, "the seven rays constituting white light, are separated into coloured rays* in the body of the prism, yet they come out white." I should be glad to know the precise degree of separation constituting coloration, and also the precise approximation or mixture constituting whiteness.

Indeed nothing can appear more inconsistent than to say, that the mixture of seven opaque colours, (for hereafter I shall shew that they are opaque,) could under any circumstances compound a transparent fluid such as incident light; neither can any thing appear more unphilosophical, than to say that two such opposite causes, as separation and approximation, could produce similar effects. The prism separates the seven component rays

* I use the words coloured rays, although some may think that Newton draws a line of distinction between coloured and colour making rays.

of light, yet they remain white. The convex-lens approximates them, yet they are white. "There is another phenomenon (says Sir Isaac Newton*) that occurs in the use of the prism, which is so odd a one, and so difficult to explain by the vulgar hypothesis, that it deserves to be taken notice of; it is as follows.



Let H F G, (in figure 13,) represent a prism in the open air, and S the eye of the spectator, viewing the clouds by their light, coming into the prism at the plane side F I G K, and reflected in it by its base H E I G, and thence going out through its plane side H E F K, to the eye. And when the prism and eye are conveniently placed, so that the angles of incidence and reflection at the base, may be about 40 degrees, the spectator will see a bow M N,

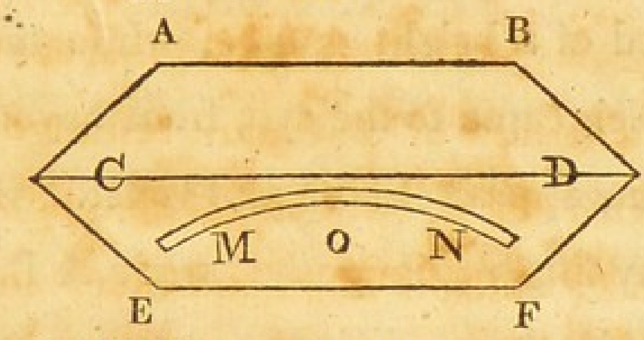
* Opticks page, 145.

of a blue colour, running from one end of the base to the other, with the concave side towards him, and the part of the base I M N G, beyond this bow will be brighter than the other part E M N H, on the other side of it. This blue colour M N, being made by nothing else than by a specular superficies, seems so odd a phenomenon, and so difficult to be explained by the vulgar hypothesis of philosophers, that I could not but think it deserved to be taken notice of. Now for understanding the reason of it, suppose the plane A B C, to cut the plane sides and base of the prism perpendicularly. From the eye to the line B C, wherein that plane cuts the base, draw the lines *s p* and *s t*, in the angles *s p c*, $50\frac{1}{9}$ degrees, and *s t c*, $49\frac{1}{28}$ degress, and the point *p*, will be the limit beyond which none of the most refrangible rays can pass through the base of the prism, and be refracted, whose incidence is such, that they may be reflected to the eye; and the point *t*, will be the like limit for the least refrangible rays, that is, beyond which none of the rays can pass through the base, whose incidence is such, that by reflexion they may come to the eye. And the point *r*, taken in the middle way between *p* and *t*, will be the like limit for the meanly refrangible rays. And therefore all the least refrangible rays which fall upon the base beyond *t*, that is, between *t* and B, and can come from thence to the eye, will be reflected thither. But on this side *t*, that is between *t* and *c*, many of those rays will be transmitted through the base, and all the most refrangible rays which fall upon the base beyond *p*, that is, between *p* and B, and can by reflexion come from thence to the eye, will be reflected thither, but every where between *p* and *c*, many of those rays will get through the base and be refracted, and the same is to be understood by the meanly refrangible rays on either side of the point *r*, whence it follows, that the base of the prism must every where between *t* and B, by a total reflexion of all sorts of rays to the eye, look white and bright. And every where between *p* and C, by reason of the transmission of many rays of every sort, look more pale, obscure and dark. But at *r*, and in other places between *p* and *t*, where all the more refrangible rays are reflected to the eye, and many of the less refrangible are transmitted, the excess of the most refrangible in the reflected light, will tinge that light with their colour, which is violet and blue, and this happens by taking the line C *p r t* B, any where between the ends of the prism H G, and E T."

The reader will not be little surprised, after all this laboured investigation, to be informed by actual experiment, that our philosopher was all the while looking intently at the opaque angle of his prism, within a short distance of his eye.

EXPERIMENT 1st.

Let a prism be held at a short distance from the eye, the spectator standing in an open field, and looking through the lower refracting angle at the clouds; on turning the instrument on its axis, so as somewhat to lower the middle angle, an orange bow is seen to extend along the entire plane. The following figure will explain the appearance.



Let A B E F represent a prism, whose plane A B C D, is nearly parallel to the horizon. The spectator looking through the lower refracting angle at O, will perceive an orange bow at M N. That this bow proceeds from the decomposition of the black shadowed light of the angle A B, is rendered evident by running the finger along that angle. By holding a kniting needle immediately below the angle A B, so as to produce a second shadowed line, another bow is seen with its curviture in the same direction, blue at top, and orange at the bottom. On examining this orange bow, I noticed a circumstance not a little surprizing. I found that on looking through the lower refracting angle at the clouds, my eye being placed at O, part of my forehead was reflected in the plane A B C D, and that part of the bow which seemed to extend over my forehead appeared of a bright orange, while the other part which came to the eye, from beyond this reflection, appeared blue and violet. By running my finger along the angle A B, I was convinced these different colours belonged to the same bow, and arose from the decomposition of the black shadow. To prevent the reflection of my forehead in the plane A B C D, I pasted a strip of black cloth on it, and then the entire bow was a bright orange. By changing the angles of incidence, I could make this bow appear blue and violet. These colours are modefied by the light in which they are viewed. Thus, if a piece of white paper be viewed through the lower refracting angle of a prism, holding it between the spectator's eye and the window, the upper margin appears blue and violet, the lower red and yellow; if the spectator now turn his back to the window, viewing the same paper, the upper margin changes to red and yellow, the lower to blue and violet.

EXPERIMENT 2nd.

Let the observer rest the lower refracting angle of his prism on the nasel bridge, looking through the upper refracting angle, when by throwing back the head, the plane A B C D is brought parallel to the horizon, he will see a beautiful orange bow, with the curviture upwards: this like the preceding one, can be shewn to proceed from the Angle A B, by running the finger along it: and by holding a knitting needle immediately above it, a second bow is perceived with its curviture in the same direction.

After these conclusive and direct experiments, it would be a waste of time to enter more particularly into a refutation of the opinion, that this blue bow, proceeds from a specular superficies; indeed no doubt can remain with respect to the cause of the phenomenon.

* Opticks page 145.

Newton relates the following experiment.* "The sun shining through a large prism A B C, (in figure 9,) upon a comb X Y, placed immediately behind the prism, his light which passed through the interstices of the teeth, fell upon a white paper D E; the breadths of the teeth were equal to their interstices, and seven teeth together with their interstices took up an inch in breadth. Now when the paper was about two or three inches distant from the comb, the light which passed through its several interstices, painted so many ranges of colour, *k l*, *m n*, *o p*, *q r*, *&c.* which were parallel to one another, and contiguous, and without any mixture of white. And these ranges of colours, if the comb was removed continually up and down, with a reciprocal motion, ascended and descended in the paper; and when the motion of the comb was so quick, that the colours could not be distinguished from one another, the whole paper by their confusion and mixture in the sensorium appeared white.

* Opticks page 125.

Let the comb now rest, and let the paper be removed farther from the prism, and the several ranges of colours will be dilated and expanded into one another more and more; and by mixing, their colours will dilute one another, and at length when the distance of the paper from the comb is about a foot, or a little more, (suppose in the place 2 D 2 E) they will so far dilute one another as to become white.*

With any obstacle let all the light be now stopp'd which passes through any one interval of the teeth, so that the range of colours which comes from thence may be taken away, and you will see the light of the rest of the ranges to be expanded into the place of the range taken away, and there to be coloured. Let the intercepted range pass on as before, and its colours falling upon the colours of the other ranges, and mixing with them, will restore the whiteness.

Let the paper 2 D 2 E be now very much

* Newton attributes similar effects to opposite causes. In this Experiment the colours are dilated or expanded into whiteness, in others they are condensed by a convex-lens into whiteness.

inclined to the rays, so that the most refrangible rays may be more copiously reflected than the rest, and the white colour of the paper through the excess of those rays will be changed into blue and violet. Let the paper be as much inclined the contrary way, that the least refrangible rays may now be more copiously reflected than the rest, and by their excess the whiteness will be changed into yellow and red. The several rays therefore in that white light do retain their colorific qualities, by which those of any sort, whenever they become more copious than the rest, do by their excess and predominance cause their proper colour to appear.

And by the same way of arguing, applied to the third experiment of this book, it may be concluded, that the white colour of all refracted light at its very first emergence, where it appears as white as before its incidence, is compounded of various colours.

In the foregoing experiment the several intervals of the teeth of the comb do the office of so many prisms, every interval producing the phenomenon of one prism."

On what principle the open interval of a comb could act like a prism or semi-transparent piece of glass, so as to separate these coloured rays of light, I am at a loss to conjecture.

There are two prominent features in this experiment. 1st. That the teeth of the comb must not be placed at right angles with the axis of the prism, and 2ndly, that each tooth produces a shadow. What became of these black shadows? In the first part of this treatise I have shewn, both by analysis and synthesis, that a black shadow can be rarefied into blue, red and yellow rays: hence we have an easy and satisfactory solution of the phenomenon. The black shadow is rarefied by the refracted light into decomposition.* The following ex-

* A question may arise, whether blue, red, and yellow rays, actually exist as such in black light, or whether these colours are brought into view by prismatick condensation and rarefaction. In sulphate of soda, neither the acid nor the alkalescent properties remain, yet both can be separated by decomposition. Let us suppose that in consequence of the laws of attraction and repulsion, the black light in passing through the prism is modefied and condensed according to the thickness or thinness of the prism, it may be sufficient to account for the change of colour. However as I am anxious to avoid hypothetical reasoning as much as possible, I shall refer to some experiments in the second part of this work.

periments may serve to elucidate the subject.

EXPERIMENT 1st.

Let a large prism be placed in the sun-beams, receiving the descending spectrum on a sheet of white paper at about six inches distance: let a knitting needle or any other slender and opaque body be held near the paper, a black shadow is seen to be reflected: on slowly raising the needle towards the prism, this black shadow is perceived to dilate, and as it dilates, to be separated into blue, red and yellow rays; at a short distance from the paper the middle appears black, especially if the needle be large. That refracted light after emergence should have the same effect in producing the decomposition of black rays of light, as in the body of the prism, is a singular fact, and may tend to the explanation of the law of refraction, which seems to arise from condensation and rarefaction. When the needle is held at right angles with the axis of the prism, no decomposition is produced except at the top and bottom. Is the black shadow a mere privation of light, or is it a positive substance? That it is not a mere privation is demonstrated by the changes of colour, and dilatation. Indeed to doubt these facts would be to doubt our senses. If the black shadow be not changed in colour what becomes of it?

EXPERIMENT 2nd.

Make a line with perfectly black ink, about $\frac{1}{10}$ of an inch in breadth, on a piece of white paper; on looking at it through the upper or lower refracting angle of a prism, when the line is perpendicular to the prismatick axis, no lateral decomposition takes place, but on turning the paper so as to make an acute angle, the black line is perceived gradually to dilate, and as it dilates, to change into a beautiful blue, red and yellow colour. This is a simple, yet highly interesting experiment, tending to prove that a black substance is separable into different colours. If instead of this black line a knitting needle be held in such a position over the white paper as to reflect a shadow, this black shadow in passing thro' the prism to the eye, undergoes a similar change with the line, and by turning the paper can be equally decomposed. From this experiment we may infer that a black shadow is a positive substance and not a negative property.

I shall now conclude the examination of the experiments and inferences drawn from the first part of the Optics, without entering on Newton's musical division of the spectrum, or those experiments founded on a basis of confusion, so well imitated and illustrated in lecture rooms, by whirligigs and the spinning of painted tops. Indeed we might as well argue, that a cannon ball driven from the mouth of a four and twenty pounder and passing through the air, is transparent and colourless, as that coloured rays reflected from a whirligig are white, neither are the rays sent from a spinning top, or any other instrument revolving round an axis mixed, either in the eye or the sensorium. The impressions are so transitory and quick, that the mind cannot discern any particular rays, but it would be inconsistent to suppose that they approached or receded, for they are all equally acted on by the rotary motion.

I cannot finish this part of my subject, without mentioning a phenomenon, to be explained hereafter when we come to treat of vision, with which it is intimately connected. When a knitting needle is viewed through the lower refracting angle, it appears curved downwards, blue at top, red and yellow at the bottom; but when the same knitting needle is placed on the prismatick plane and the shadow received on the ascending spectrum, it is curved upwards, blue at bottom, red and yellow at the top. In like manner the colours are reversed when the spectrum is received on the wall and on the eye: the hole when viewed through a prism appearing red and yellow at the top, blue and violet at the bottom; when received on the wall, red and yellow at the bottom, blue and violet at the top.

I have attributed the spectrick colours, to the opaque angles of the prism. However, the reader must not infer, that if the angles were rounded into convexity, the spectrum would cease. Any glass which produces a shadow, provided that shadow passes through the refracting medium, will generate colours: a rounded prism would produce this effect.

END OF THE FIRST BOOK.

BOOK II.

VARIEGATED LINES AND CONCENTRIC RINGS.

No subject in natural philosophy, has more engaged the attention of the learned than that on which we are at present engaged. Mr. Boyle, Dr. Hooke and Sir Isaac Newton were among the first, Dr. Herschel among the last experimenters; after such characters it might seem unnecessary to enter the field of enquiry, unaided by novelty of experiment. I therefore rest my claim principally on that ground, and hope in the following pages the reader may find this difficult yet interesting subject somewhat simplefied and elucidated.*

* For the following epitome the Author has been indebted to Dr. Priestley's work on vision, light and colours.

The first account of the colours produced by thin plates, is to be found in Mr. Boyle's works. To shew the chemists that colours may be made to appear or vanish, where there is no accession or change either of the sulphureous, the saline or the mercurial principles of bodies; he says that all chymical essential oils, as also good spirits of wine by shaking till they rise in bubbles, appear of various colours which immediately vanish when the bubbles burst, so that a colourless liquor may be immediately made to exhibit a variety of colours, and loose them in a moment, without any change in its essential principles. He then mentions the colours that appear in soap bubbles and also in turpentine. He sometimes got glass blown so thin as to exhibit similar colours, and observes that a feather of a proper shape and size, and also a black ribbon, held at a proper distance between his eye and the sun, shewed a variety of little rain-bows with very vivid colours, none of which were constantly to be seen in the same objects. Here we must remark, that although Mr. Boyle did not advance any theory from these experiments, yet he connected the production of different colours with the thinness of the substance is apparent, from his endeavours to blow glass sufficiently thin. This afterwards gave the idea to Sir Isaac Newton.

Dr. Hooke was the next to investigate this interesting subject. At a meeting of the royal society 7th March 1672, he promised to exhibit at their next meeting, something which had neither reflection nor refraction, and yet was diaphanous; he then produced a bubble of soap and water. It was no wonder that so curious an appearance should excite the attention of one of the most learned, liberal and scientific societies in Europe; they requested him to bring an account of it in writing at their next meeting. By means of a glass pipe, he blew several small bubbles out of a mixture of soap and water, when, it was observable that at first they appeared white and clear, but that after some time the film of water growing thinner, there appeared upon it all the colours of the rain-bow, first a pale yellow, then orange, red, purple, blue, green, &c. with the same series of colours repeated, in which it was farther observable, that the first and last series were very faint, and that the middlemost order or series was very bright: after these colours had passed over the changes above mentioned, the film of the bubble began to appear white again, and presently in several parts of this second white film there appeared several holes, which by degrees grew very big, several of them running into one another. Dr. Hooke made other observations, little worth relating. The great objection to these experiments rests on the fact that the bubble bursts before any accurate opinion can be formed, not remaining more than a few seconds for examination.

We now come to Sir Isaac Newton's experiments: this philosopher having demonstrated the different refrangibility of the rays of light, applied them to thin plates, on which he built his entire hypothesis of colours. I shall therefore pay particular attention to his investigations.

On compressing two prisms* hard together, in order to make their sides (which appeared to be a little convex,) to touch one another, he observed that in the place of contact they were perfectly transparent, as if they both had been one continued piece of glass. For when the light fell so obliquely on the air, which in other places was between them, as to be all reflected, it seemed in that place of contact to be wholly transmitted, in so much, that it looked like a black and dark spot, and when it was looked through, it appeared like a hole in that air, which was formed into a thin plate, by being compressed between the glasses; through this hole objects might be seen very distinctly, though they were not visible through other parts of the glasses, where the air intervened: though these glasses were a little convex, yet

* Opticks, page 169.

this transparent spot was of a considerable breadth, which seemed to be owing to the parts of the glass giving way when they were pressed, for by pressing them very hard together, it would become much broader than before. When this plate of air, by turning the prisms about their common axis, became so little inclined to the incident rays, that some of them began to be transmitted, there arose among it many slender arcs of colours, which at first were shaped like a conchoid as they are delineated in figure 87, and by continuing the motions of the prisms, these arcs encreased and bended more and more about the transparent spot, till they were completed into circles or rings surrounding it, and afterwards they grew continually more and more contracted.

To observe more nicely the order of the colours produced, as he supposed by this thin plate of air, he took two object glasses, one of them a plano-convex belonging to a 14 foot refracting telescope, the other a large double convex one for a telescope of about 50 feet, and laying the former of them upon the latter, with its plane side downwards, he pressed them closely together, in order to make the colours emerge successively in the middle of the circle. By this means he says he was able to observe distintly the order and quality of the colours, from the central spot to a very considerable distance. Next to the pellucid central spot made by the contact of the glasses, succeeded blue, white, yellow and red. The blue was so little in quantity that he could not discern it in the circles made by the prisms: neither could he distinguish any violet in it. But the yellow and red were pretty copious and seemed about as much in extent as the white, and four or five times as much as the blue. The next circuit immediately surrounding these consisted of violet, blue, green, yellow and red; and these were all of them copious and vivid, except the green which was very little in quantity and seemed much more faint and dilute than the other colours. Of the other four, the violet was the least in extent, and the blue less than the yellow or red. In this the purple seemed more reddish than the violet in the former circuit, and the green was much more conspicuous being as brisk and copious as any of the other colours except the yellow; but the red began to be a little faded, inclining very much to purple. The fourth circle consisted of green and red, and of these the green was very copious and lively, inclining on the one side to blue and on the other side to yellow; but in the fourth circle there was neither violet, blue or yellow, and the red was very imperfect and dirty. All the surrounding colours grew more and more imperfect and dilute, till after three or four revolutions, they ended in perfect whiteness. The appearance of these circles, when the glasses were more compressed, so as to make the black spot appear in the centre, is delineated in fig. 88, in which *a b c d e f g h i k l m n o p q r s t v y z*, denote the colours reckoned in order from the centre viz. black, blue, white, yellow, red, green, red, greenish blue, red, greenish blue, pale red, greenish blue, reddish white.

To determine the interval of the glasses, or thickness of the interjacent air, by which each colour was produced, he measured the diameter of the first six rings at the most lucid part of their orbits, and squaring them, he found their squares to be in the arithmetical progression of the odd numbers, 1, 3, 5, 7, 9, 11. And since one of these glasses was plane, and the other spherical, their intervals at those rings must be in the same progression. He measured also the diameters of the dark or faint rings between the more lucid colours, and found their squares to be in the arithmetical progression of the even numbers, 2, 4, 6, 8, 10, 12. And it being very nice and difficult to take these measures exactly; he repeated them divers times at divers parts of the glasses, that by their agreement he might be confirmed in them. And the same method he used in determinining some others of the following observations."

Here Newton goes on to give the exact thickness necessary for the production of the different colours with tables, as far as the one millionth part of an inch!!! Although this theory has been received by philosophers, as sufficient to explain the phenomena, I cannot help thinking it both wanting in fact and ingenuity. To suppose for one moment, that a thin and transparent plate of air, under any circumstances whatsoever, could form and reflect opaque colours, is a curious stretch of the imagination; opacity produced by transparency. In the first place we might expect that if a plate of air were the cause of these concentric rings, when one lens was merely placed on the plane surface of the other, colours should have been produced without pressure. However this is not the case, for unless the superior glass be sufficiently heavy, or manual exertion be used, no rings are formed.

2ndly. the centre changes colour according to the angle of reflection, at which it is viewed. That centre which appears blue, when the eye is nearly vertical, at an obliquity of 45° will appear perfectly white. In this case the intercent air could not be acted on or rendered thicker or thinner, by any obliquity of the eye.

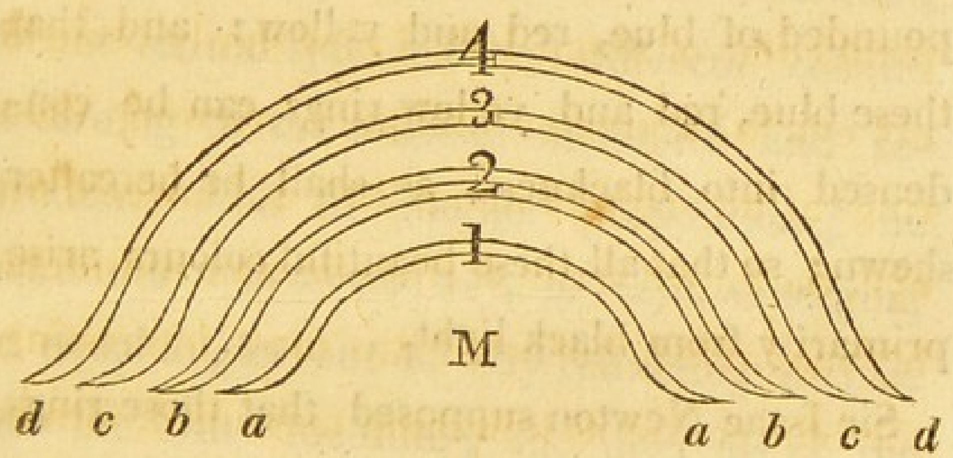
This change of colour in the centre, according to the angle of reflection, was with many other essential circumstances, disregarded by Newton, who always pressed his lenses so closely together, as to produce a transparent centre. Indeed, as far as I know, I have been the first to notice this interesting phenomenon, particularly described in the following experiment.

EXPERIMENT 1st.

With a diamond having cut from a mirror, a well polished slip of glass, four inches square, and having scraped off the amalgam, I laid it on the window-stool, very close to the pane, so as to throw a full light and reflection of the window on the rings. I now placed a large and very convex-lens belonging to a magic lantern, about half an inch focus, with its plane surface upon this slip. The pressure occasioned by the lens, was equal to $1\frac{1}{4}$*lb.* producing eight series of concentric rings, surrounding a blue centre, in the following order. Centre blue. 1st. series, yellow, red, and dark blue. 2nd. series, yellowish, green, and red. 3rd. series, green and red. The five other series were green and red, each ring growing paler and narrower, according to its distance from the centre.

This was the appearance of these concentric rings, when my eye was nearly vertical to the lenticular axis, or at an obliquity from the perpendicular of about 10°. I now slowly brought my eye to a greater obliquity, viewing those rings at an angle of about 20°; as I lower'd my eye, the entire series of rings became considerably magnified, but what was most interesting, the blue centre as it became magnified, formed into a concentric ring, giving place to a brown centre. The order was then as follows. A brown centre, surrounded by a blue ring, proceeding from the blue which had formed the former centre. 1st. series, yellow, red and blue.

2nd. series, green and red, and so on. At yet a greater angle, when the eye was placed at about 70°, from the perpendicular. The brown centre in its turn became magnified and forming into a concentric ring, gave place to a white centre; when the order was as follows. White centre. 1st. series, brown and dark blue. 2nd. series, yellow, red and blue. 3rd. series, green and red, &c. At yet a greater angle, these concentric rings became more and more magnified, and at last opening in front, formed a figure as thus represented.



M, a white centre. No. 1, or first series, brown and blue. No. 2, or second series, yellow, red and blue. No. 3, or third series, green and red. No. 4, or fourth series, green and red. The limbs or ends of these curvilinear series, *a*, *b*, *c*, *d*, when thus magnified, were blue, red, and yellow, demonstrating that each series was compounded of these colours and none others in different states of condensation. Thus the first series was brown and blue. The brown when separated, gave red and yellow at the limb *a*. The second series was yellow, red and blue. The third series was green and red. The green when decomposed at the limb *c*, gave yellow and blue. So we must infer from this experiment, that each series, whatever colours may have appeared to the eye, was in reality compounded of blue, red and yellow: and that these blue, red and yellow rings can be condensed into blackness, as shall be hereafter shewn; so that all these beautiful colours arise primarily from black light.

Sir Isaac Newton supposed that those rings of opaque colours were produced from the rays of heterogeneous light, being separated by a thin plate of air. As one absurd opinion is generally upheld by others yet more absurd; so our philosopher was obliged to resort to the curious hypothesis (more ridiculous if possible, than any advanced in the Aristotelian School) that rays of light, are subject to fits of easy and difficult transmission, and reflection. Newton has the following proposition.* "The reason why the surfaces of all thick transparent bodies, reflect part of the light, incident on them, and refract the rest, is, that some rays at their incidence are in fits of easy reflection, and others in fits of easy transmission." I need not again remind the reader, that the experiment just related, refutes this assertion; for the central spot reflected different colours according to the angle of incidence and reflection. And in another proposition,‡ he continues "in several sorts of rays, emerging in equal angles out of any refracting surface into the same medium; the intervals of the following fits of easy reflection and easy transmission are either accurately or very nearly, as the cube roots of the squares of the lengths of a chord, which sound the notes of an eight,

* Opticks, page 256. ‡ Opticks, page, 259.

fol, la, fa, fol, la, mi, fa, fol, with all their intermediate degress, answering to the colours of those rays, according to the analogy described in the seventh experiment of the second part of the first book." If any other person had written such musical nonsense, it might provoke a smile, but the commanding genius of a Newton forbids such levity and elicits a sigh, that so much precious time and mathematical calculation should be thrown away to such little purpose; for I cannot agree with a late scientific writer, Dr. Brewster, that the theory of alternate fits of reflection and transmission is either beautiful or conclusive. The thin plate of air could have undergone no change by any obliquity of the eye, to induce the rays at the centre, to throw themselves alternately into blue, red, yellow, or white fits, unless like Darwin's flowers, they were endowed with volition. Setting the rain-bow to music. Playing on a luminous piano forte.* Making

* A friar whose name I now forget, had the folly to expect, that by throwing the prismatick colours on the keys of a piano forte, luminous music would result; as we might expect, the poor friar was disappointed.

one flower whisper tender tales of love into the ear of another, may be very fine and extremely poetic, but the rigid analysis of experimental philosophy rejects such dreams with something like contempt.

Perhaps it might be objected, that the foregoing experiment was not similar to Newton's, as two plane surfaces were brought into contact. However, on repeating the experiment mentioned in the opticks, with two object glasses, the one a plano-convex for a fourteen foot telescope, the other a large double convex for one of fifty feet, I found the colours nearly similar, with this difference, that they were more condensed in the Newtonian experiment. I therefore preferred the one already described for the following reasons. 1st. the place of contact was considerably larger than could possibly arise from the application of any convex-lenses whatsoever, (even the Huygenian object glasses, belonging to the Royal Society, and used by Dr. Herschel; one of 122, the other 170 feet focal length.)

The colours and diameters of the rings depend on the radius of curviture. Dr. Herschel derived little advantage from the use of these glasses. 2ndly. In my experiment the necessity of an eye-glass of high magnifying powers was done away, for the coloured rays, in passing through the superior lens were powerfully refracted and enlarged. Indeed the use of either an eye-glass or a prism is liable to many objections, the principal of which is, that coloured rings are brought into existence from the decomposition of black light.

To convince the experimenter that this is the case, let him look at the central transparent and black spot, surrounded by a white field, through the lower rafracting angle of a well polished prism, and he will perceive the black centre to have undergone decomposition, the upper margin appearing blue, the lower red and yellow; therefore we cannot be surprized that Newton saw many more coloured rings through the prism than with the naked eye. Each dark interval formed three rings; for if we delineate three black concentric rings or lines with ink, on a sheet of white paper, and look at them through a prism, they are decomposed into nine.*

EXPERIMENT 2nd.

Newton says,† "The motions of the prisms about their axis being continued, these colours contracted more and more, shrinking towards the whiteness on either side of it, until they totally vanished into it. And then the circles in those parts appeared black and white, without any other colours intermixed. But by farther moving the prisms about, the colours again emerged out of the whiteness, the violet and blue at its inward limb, and at its outward limb, the red and yellow. When the rings, or some parts of them, appeared only black and white, they were very distinct and well defined."

* Mr. Brougham has written a paper in the philosophical transactions, to prove that a pin placed in the spectric light produces three shadows: as already mentioned, this arose from the decomposition of the black light. How blue, red and yellow shadows could proceed from the privation of light, I am at a loss to imagine.

† Opticks, page, 171.

According to this description Newton supposed, that he actually pressed all the colours of the rain-bow out of whiteness.

He indeed must be blinded by a favourite theory, who does not perceive that it is the black and not the white rings are changed into colours. The fact is plain, it is incontrovertible; to deny it, is to deny our senses, for we have no stronger evidence of our very existence than we have that these black rings are dilated into colours, and condensed into blackness.

Newton neither satisfactorily accounts for these black circles, nor tells us on what principle the thin and transparent plate of air acted on the light, so as suddenly to change it from fits of easy reflection to fits of easy transmission: he also compares these black circles to the black centre, not aware that the one was black from the condensation of blue, red and yellow, the other only appearing black from transparency; let the reader make the following experiment.

Place a convex-lens, about two or three inches diameter, and of a long radius, on the plane surface of the plano-convex-lens mentioned in the last experiment; on pressing them very closely together, the centre becomes transparent and black, while a number of very narrow black and white rings surround it: no pressure we can use will evolve colours, as the convexity of the lens prevents these black rings from being dilated by pressure.

By sliding a small watch glass into the greater curviture of another, I have often been enabled with well regulated pressure, to make one half of the concentric circumference of these rings blue, red and yellow, the other half perfectly black.

EXPERIMENT 3rd.

EFFECTS OF PRESSURE ON VARIEGATED LINES.

Some time after Newton's investigation, the Abbé Mazias, endeavouring to give a high polish to the flat surface of an object glass, happened to rub it against another piece of flat and smooth glass, when he was surprised to find that after this friction, they adhered very firmly together, till at last he could not move the one upon the other; but he was much more surprised to observe the same colours between those plane glasses, that Newton observed between the convex object glass of a telescope, and another that was plane.

The Abbé goes on to make a number of experiments and observations, tending to shew, that these colours could not be produced by a thin plate of air. However as none of his experiments are conclusive nor lead to any new theory I shall refer the reader to his paper. Indeed these colours are so intimately connected with the discovery of black light, that it is no wonder experimenters heretofore should have been extremely puzzled at the phenomena.

Having cut two pieces about four inches square from a well polished looking glass, I scraped off the amalgam and applied them together near a well illuminated window, in such a manner as to make an acute angle. On decreasing the angle with a firm degree of pressure and some friction against the edge, I perceived a number of perfectly black lines, no broader than the finest human hair, to be pressed from the angle. As the pressure was encreased each of these lines separated and dilated itself into a series of variegated coloured lines. The 1st. series nearest the angle was brown and blue inclining to purple, the 2nd. series, yellow, red and blue, the 3rd. series, green and red, the rest were green and red. The 1st. series was the best defined; and according to their distance from this, they became somewhat narrower and fainter. Beyond the brown and nearer the angle, were fields of white and black transparency. On gently separating the glasses by making the angle larger, these variegated lines contracted themselves, and each became condensed into perfect blackness, retreating to the angle with an appearance like black hairs and there vanishing.

From this experiment we must infer, that these concentric rings and variegated lines are dilated into colours. Indeed after the direct experiments related in the 1st. Book of these outlines, I think it unnecessary further to notice the assertion, that these rings proceeded from the white light.

EXPERIMENT 4th.

EFFECTS OF PRESSURE ON CONCENTRIC RINGS.

To examine the effects of pressure more particularly, I placed a piece of plate glass, on the plane surface of a lens belonging to a magic lantern, on pressing them together with the slightest possible exertion, I perceived a very pale and dilute red spot, with a green centre; a second degree of pressure occasioned the green centre to dilate itself into a concentric ring and a red spot to arise in the middle somewhat darker than the first; a third degree of pressure dilated this red spot into a concentric ring, and caused a darker green to arise in the middle; a fourth degree of pressure caused the green to dilate itself into a concentric ring and a darker red to form in the middle; the fifth degree of pressure caused the red to dilate itself into a concentric ring, and a yellow spot to form in the centre; the sixth degree of pressure caused the yellow to dilate itself into a concentric ring, and a blue bordering on purple to arise in the centre; the seventh degree of pressure caused the blue to dilate itself into a concentric ring, and a red inclining to brown to arise in the centre; the eighth degree of pressure caused the red to dilate itself into a concentric ring, and a dark blue to form in the centre; the ninth degree of pressure caused the blue to dilate itself into a concentric ring, and a brown to form in the centre; the tenth degree of pressure caused the brown to dilate itself into a concentric ring, and a white to form in the centre; the eleventh degree of pressure caused the white to dilate itself into a broad concentric ring and a transparent spot to appear in the centre. By farther pressure, this transparent spot encreased in size, but never changed colour, and all the rings were propelled to a greater distance.*

This experiment establishes some very interesting facts. By pressure we can form any desired colour. 2dly. We remark that every ring is pressed from the centre, like waves when a stone is thrown into water. 3dly. No two colours are alike in the different rings; thus, a brown in the first series, a dark red inclining to orange in the second series, vermillion in the third series, a pale red in the fourth and yet a paler in the fifth; until at last the red becomes so dilute and pale, as not to be visible to the naked eye.

The same difference is remarked in regard to the blue and other colours; in the first series, the blue inclines to purple, in the second series it is a dark blue, in the third it blends with the yellow forming green. This difference of colour removes a seemingly strong objection to the theory,

* There were no intervals between those rings, therefore they could not be accounted for by alternate fits of reflexion and transmission, as described in the 4th figure of the opticks. Book 2, Tab. 1.

just now to be advanced, that all the colours are produced by different states of condensation and rarefaction; for if two series in different degrees of condensation, gave the same colour, the theory would be deficient in a most essential point. However this subject will be resumed hereafter.

Newton in his experiments lays it down as a law, that the squares of the diameters of these coloured rings are in arithmetical proportion. I need scarcely say, (what every experimenter must know,) that it would be utterly impossible to square the diameters of rings, varying with every change of the angle of incidence and reflexion; even the rolling of the eye, while in the act of mensuration, would alter the calculations carried to such a length as the one millionth part of an inch.

Such mathematical precision is extremely imposing, especially with those who are either unable or unwilling to repeat them. But on the other hand, when impossibilities are paraded, and insisted on by rule and compass, we are apt to grow sceptical in regard to the entire doctrine. I have sometimes thrown away an hour or two in squaring these rings, but could never make the same calculation twice over. Euler involved nothing to an infinite series. Newton measured a transparent and unknown something* to the one millionth part of an inch. !!!

There are many other strong objections to Newton's calculations. Did any workman ever make a convex-lens with a perfect curvitüre, that is to the millionth part of an inch? Could any convex-lens be so placed on another, as not to incline to either side the one millionth part of an inch? Indeed there is such a yielding of the glasses, when either pressed closely together by the hands or by a great

* The following observation (Opticks, page 183,) shews that Newton was not very certain, as to the cause of these colours, he says "its appearance was such as interjacent air would have caused, and it exhibited the same colours. But it was not air, for where any bubbles of air were in the water, they would not vanish. *The reflection must have rather been caused by a subtiler medium, which could recede through the glasses at the creeping in of the water.*" Mathematicians of the present day would be somewhat puzzled, to ascertain the ordinates of a convex plate of an unknown something, and that unknown somethimg escaped from the water, by running through the glasses. Does this deserve the name of philosophy?

weight, that their surfaces even as far as the exterior ring in the Newtonian experiment, are nearly equally in contact. For when we consider that with the large Huygenian lenses, Dr. Herschel found it necessary to use a powerful eye glass, what must be the diameters of Newton's rings, the largest scarcely the $\frac{1}{8}$ of an inch? Yet what wonderful precision in taking the diameters of these fairy rings.

The reader's surprise will be somewhat encreased when informed, that Newton mistook almost all the colours, yet he could measure their exact diameters: the order of the colours he says, were black, blue, white, yellow and red. The next circuit violet, blue, green, yellow and red. The third circuit purple, blue, green, yellow and red. The fourth circuit green and red.* Now the experiment is so easily made, that any person can in a moment convince himself, that the rings are black, white, brown, blue, yellow, red, blue, green, red, green, red, green, &c. Without

* Opticks, page, 174.

knowing the colours, he could inform us by an exact table, what thickness of a plate of air, water, or glass, gave any required tint.

If I have used strong language in regard to this part of Newton's theory, let it by no means be thought that the learning and genius of this great man have not impressed my mind with an admiration bordering on enthusiasm. I revere his talents and may safely say, that with so many opposing facts, perhaps no man on earth but himself could have made the world believe, that transparent light was compounded of opaque rays,* that a transparent plate of air could produce opaque colours; and lastly, that the rays of light had fits of easy transmission and reflexion.

EXPERIMENT 6th.

Having poured some water, previously boiled to expel the air, into a large wash-hand

* Some Authors have been accused of ignorance, for saying that Newton held this opinion. However were it worth while, I could retort on those gentlemen in Newton's own words; If we admit that black light be opaque, and I believe few can see in the dark, we must admit that its component parts blue, red and yellow are also opaque: by mixing wtth transparent light these colours become visible.

basin, I immersed a piece of plate glass, on which I placed the large convex-lens already mentioned, with its plane side downwards: at first no rings appeared, however by a gentle degree of friction, similar concentric rings made their appearance as already described in the open air. I now removed these glasses from the basin, without disturbing the colours, or the interjacent plate of water, and perceived them well defined, but not so brilliant as when the glasses were dry. Having pressed them very strongly together, between my thumbs and fore fingers, I produced a large oval, one inch in length, and half an inch in breadth; I now relaxed the pressure on one side, by removing the left hand fingers, and perceived the rings to contract towards the right; as they contracted they left an atmosphere of vapour, which followed like the tail of a comet. That these rings were not occasioned by a plate of water was evident from the circumstance, that by certain degrees of pressure, they could be separated from the water: sometimes I have formed the one half of these concentric rings in the water, and the other half in the interjacent air.

EXPERIMENT 7th.

CONCENTRIC RINGS ARE PRODUCED BY AN ATMOSPHERE OF VAPOUR.

Having selected two pieces of very well polished looking glass, from which the amalgam had been scraped; I put on a pair of gloves to prevent any soil from my hands, and pressed them well together; a large oval formed in the middle, $1\frac{1}{2}$ inch in length, with a black centre fully half an inch in diameter. Having warmed the glasses, by holding them for some time before the fire, I again pressed them together by placing my thumb and fore finger on each side of the central black spot; on suddenly separating them I perceived a large soil, exactly answering by measurement with a compass, the diameter of the largest central ring; the middle was clear and unstained: in some few instances the breadth of the different rings could be traced. This appearance could only proceed from attenuate dust, remaining after the aqueous particles had been evaporated. With a handkerchief I could wipe off this stain or any part. However, as it requires great nicety, with very clear and well polished glasses, to trace these rings, I would recommend the experiment to be made by pressing one piece of plate glass against the edge of another, until the variegated lines are well formed, and the angle perfectly transparent to some extent; on separating the glasses, this stain is very perceptible.

When one clear watch-glass is inserted into the larger curviture of a second, by well regulated and alternate pressure, these rings are made to pass from one place to another, and as they proceed leave behind them a soil such as a snail would make: this soil remains after separating the glasses.

From these experiments and many others, no doubt can remain, that when a plate of air is condensed between two glasses, whether plane or convex, an atmosphere of vapour holding in suspension a number of pulverized atoms is brought into existence.

Before entering on my own theory of concentric rings and variegated lines, I think it necessary to relate a few more experiments; in all of which the experimenter is to hold the glasses in such a manner before the window as to reflect the panes and bring the colours within their area, otherwise these rings or soils cannot be examined with any degree of accuracy.

EXPERIMENT 8th.

AN IRREGULARITY OF CONDENSATION IS NECESSARY FOR THE PRODUCTION OF COLOURS IN THIN PLATES.

Further, to demonstrate that vapours produce colours, I well wiped the plane surface of the large plano-convex-lens already mentioned, with a dry silk handkerchief, and then holding it in such a position before the window as to reflect the panes, I breathed several times on it, until covered with a thin stratum of vapour. No colours appeared, except where the evaporation seemed to proceed irregularly ; here the vaporific spherules were condensed together in groups, and appeared either black, or reflected various colours. I could destroy this coloration by again breathing on the glass, and thus causing an uniformity of condensation. Breathing again on the surface, I ran my finger over it in such a manner as to make a number of concentric furrows, which immediately reflected all the colours in nature. How far this phenomenon is connected with refraction, I shall not here stop to consider.

When the surface of the lens is uniformly covered with aqueous vapour, the light impinges on each vaporific atom with an equality of condensation ; the attraction and repulsion are equal ; an uniformity of thickness is preserved. But when the finger, like a plough passing over a field, turns these vapours into ridges and furrows, that uniformity is detroyed, black and condensed lines are formed, which reflecting the light in different states of condensation and rarefaction, produce coloration. That this phenomenon is not caused by any given thinness or thickness of the plate of vapour is obvious from the fact, that if we breathe ever so often on the plane surface, and thus produce a plate of any desired thickness, in a short time it becomes thinner and thinner by successive evaporation, without any tint of colour; but as soon as an inequality of condensation is produced by the finger at any thickness whatsoever, the colours are formed. We also observe that when these furrows are formed, the colours are changed from blue to green, red yellow, &c. merely by breathing on them, and thus changing the condensation.

EXPERIMENT 9th.

A PLATE OF AIR IS NOT THE CAUSE OF THE COLOURS BETWEEN GLASSES.

Having dipped two pieces of plane and well polished plate glass, about three inches square, into a basin of water; I withdrew them, and while wet, applied their surfaces together; a great number of air bubbles were scattered up and down in the water, some $\frac{1}{4}$ of an inch in diameter, perfectly transparent and colourless. On rubbing the glasses together, so as to produce a slight degree of friction, these transparent air bubbles assumed a great variety of colours. On again allowing the glasses to remain at rest, they lost these colours and became perfectly transparent. The rationale of this experiment seems to be, that by the friction, a quantity of vapour causing the colours is produced in those plates of air. When left at rest, the vaporific atmosphere either becomes condensed, and again blends with the water, or is equally diffused thro' the air. Indeed when the condensation is going on, these vapours are perfectly evident to the eye; at first the circumference of the air bubble becomes transparent, while the centre remains opaque, and at length the centre itself is condensed or equally diffused.

This experiment is conclusive, that a plate of transparent air is incapable of coloration, which depends on some matter evolved by friction. The more we examine the Newtonian theory, the more untenable it appears. When two lenses are placed together, a plate compounded of two permanently elastic gasses, oxygene and nitrogene, incapable of condensation, and therefore incapable of becoming opaque by any degree of pressure, is said to reflect and transmit alternately those very rays of light, which had just passed through a plate of glass without any fits.

Further, to shew that a vaporific atmosphere is the exciting cause of these variegated lines and concentric rings, I raised the upper glass so as to make an acute angle with the undermost one, as thus represented: 
the interjacent water immediately passed towards the angle, and I was thus enabled by regulating the distance of the glasses, to make a plate of water of any required and encreasing thickness. No colours were produ-

ced, but when the plate was pressed forward, and then by enlarging the angle, suddenly made to recede, the water evaporated, and a number of beautiful and variegated lines made their appearance. The yellow was the outermost, the blue the innermost; the yellow being produced by the thinner, the blue by the thicker vapours.

From this experiment we may infer, that no encreasing thickness of a plate of water or of air, interjacent between two glasses, could possibly produce colours; for the production of which an irregularity of condensation is absolutely necessary. A bubble of soap and water, glass, or any other semi-transparent substance may be blown so thin as to induce irregular condensation; perfectly transparent air never could.

When a sun-beam is admitted into a dark room thro' a small hole in the window-shutter, if the eye be placed perpendicular to the rays, the opaque particles of dust are seen to reflect all the colours of the rain-bow;

here it is not the transparent air, but the opaque dust that condenses the light. We also know that potash has a great attraction for the moisture of the atmosphere, so much so as to deliquate in a short time. Might not this property remain in the glass? Hence the difficulty of exciting an electric cylinder or plate, when the air is charged with moisture.

EXPERIMENT 10th.

I now procured a piece of well polished and perfectly dry mahogany: on pressing it against the plane surface of a lens, an atmosphere of vapour was formed, which could be moved from one place to another. That this was vapour evidently appeared from the following considerations. 1st. We know that no other substance capable of becoming opaque by condensation, exists in the atmosphere. It could neither arise from the pressure of nitrogene, oxygene, nor carbonic acid gas. 2ndly. After breathing on the lens, and again applying it to the mahogony, the quantity of this matter was encreased, and the wood in both circumstances appeared as if wet. Looking on these experiments as fully sufficient to establish the fact, that the colours proceed from attenuate and partly opaque vapour ; I shall proceed with some others.

EXPERIMENT 11th.

EFFECTS OF HEAT ON CONCENTRIC RINGS.

I believe the Abbé Mazias was the first to observe the effects of heat on concentric rings. He says, that as the glasses grew warm the colours retired to the edges, and there became narrower and narrower, until they were reduced to imperceptible lines : withdrawing the flame they returned to their place. At first the Abbé had no doubt that these colours were owing to a thin plate of air between the glasses, to which Newton ascribed them, but he says, the remarkable circumstances attending those produced by flat plates, and those produced by the object glasses, convinced him that the air was not the cause of this appearance, for he continues, the colours of the flat plates vanished at the approach of flame, but those of the object glasses did not. Had we no other objection than this, it might be easily overruled, by saying that heat could not act in a similar manner on a plate of air between plane and convex surfaces.

Having well wiped and warmed the pieces of plate glass already described; I rubbed their surfaces together until a large oval was formed, one inch and a half in length, and about one inch in breadth, with a large transparent centre. On holding this coloured oval over the heater of a smoothing-iron made hot, I perceived all the rings to contract towards the centre, and then to vanish. I merely mention this experiment, as it is directly contrary to one described by the Abbé Mazias in the memoires presentés.* When heat was communicated, it rarefied the interjacent vapour and thus separated the glasses; and as the volume of vapour between the convex-glasses was extremely small, this effect could not be produced to a sufficient extent. Hence the

* Vol. 3, page 144.

difference observed by the Abbé. When the plane glasses are well rubbed together, they begin to cohere, and at last are so firmly united as to require great force in the separation.

Chymists are in the habit of shewing this phenomenon in their class rooms, to illustrate the attraction of cohesion or aggregation between the vitreous particles, not aware that the surfaces are as it were glued together by the vapour. Pounded glass has no such attraction. Indeed I am strongly led to believe that the ancient maxim, "corpora non agunt nisi fluida sint" has few if any exceptions. It would be difficult to shew an instance, where condensed vapour can be entirely excluded, the atmosphere holding such a quantity in suspension. I shall now proceed to relate a few new, and may I presume to hope, interesting experiments on thin plates.

EXPERIMENT 12th.

COLOURS ARE PRODUCED BY SOAP BUBBLES.

If a bubble (says Sir Isaac Newton) be blown with water, made tenacious by dissolving a little soap in it, 'tis a common observation, that after a while it will appear tinged with a great variety of colours. To defend these bubbles from being agitated by the external air, (whereby their colours are irregularly moved one among another, so that no accurate observation can be made of them,) so soon as I had blown any of them, I covered it with a clear glass, and by that means its colours emerged in a regular order, like so many concentric rings encompassing the top of the bubble. And as the bubble grew thinner by the continual subsiding of the water, those rings dilated slowly and overspread the whole bubble, descending in order to the bottom of it, where they vanished successively. In the mean while, after all the colours were emerged at the top, there grew in the centre a small black spot, like that in the first observation, which continually dilated itself, uutil it became sometimes one half or $\frac{3}{4}$ of an inch in breadth before the bubble broke. At first I thought (continues Newton) there had been no light reflected from the water in that place, but observing it more cautiously, I saw within it several smaller round spots, which appeared much blacker and darker than the rest, whereby I knew that there was some reflexion at the other places, which were not so dark as those spots. And by further trial I found that I could see the images of some things, (as of a candle or the sun) very faintly reflected, not only from the great black spot, but also from the little darker spots which were in it. Besides the aforesaid coloured rings, there would often appear small spots of colours, ascending and descending up and down the sides of the bubble, by reason of some inequalities in the subsiding of the water. And sometimes small black spots, generated at the sides, would ascend up to the larger black spot at the top of the bubble, and unite with it."* Here Newton gives a particular description of the order in which those rings appeared. I have repeated the experiment with much attention, but could never perceive sufficient

* Opticks, page 188.

regularity in the rings, to authorize any legitimate inference. The ascending and descending spots of colours might convince any unbiased experimenter that the theory is fallacious. To explain them by any inequality in the subsidence of the water, being contrary to the first principles of Hydrostatics.

Having made a very thick lather with soap and water, in a wash-hand basin; I dipped the mouth of a tobacco pipe into it. The length of the pipe was six inches. A film now occupied the orifice, which I blew into a bubble, the size of an orange. On holding the pipe in my mouth opposite a well illuminated window, two reflected images of that window were seen, while the rest of the bubble was enlightened by the dull light of the room. The anterior image was reflected from the convex surface, and erect. The posterior image was reflected from the concave surface and inverted.

When this bubble became sufficiently thin, a great number of very small coloured particles like dust, seemed to float over the sphere, particularly brilliant when they came within the bright light of the imaginal area. These coloured atoms floated together without any regularity. I could perceive a green atom, seemingly in contact with blue, red, yellow or brown, which convinced me that the colours could not arise from any particular thinness or thickness of the saponaceous film. Not satisfied with this experiment, I determined if possible to make a plane and permanent film.* The following experiments realised my most sanguine expectations.

EXPERIMENT 13th.

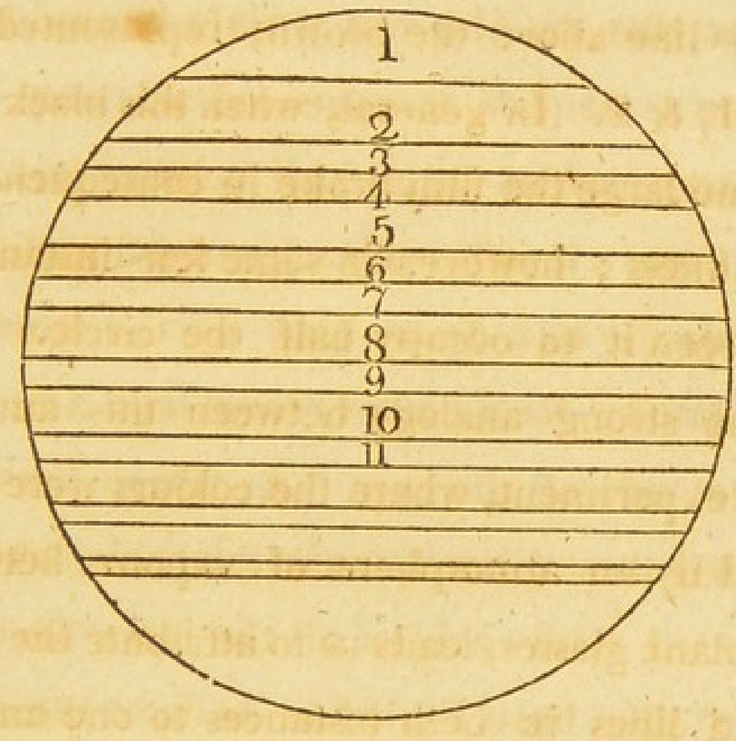
VARIEGATED LINES PRODUCED BY A PLANE SOAP-FILM.

Having made a solution of common brown soap and water in a small basin, I dipped the open mouth of an egg-cup into it, until a semi-transparent film occoupied the orifice. I now covered the cup with a very clear watch-glass,

* Mr. Melville of Edenburgh, (a young man of great promise, who unfortunately for science, died at the age of 24,) attempted to make soap bubbles permanent by freezing, and suggested the idea of drawing out a saponaceous plate upon a wooden or metalline frame. Both were impossible.

for the purpose of preventing any agitation from the air, and likewise to diminish that evaporation which caused the bubble to break sooner than it otherwise would.

On holding the egg-cup covered with the glass, before the window, and in such a position as that the film was at right angles to the horizon: at first it appeared all over of a semi-transparent or greyish colour, but in a short time, a number of variegated lines formed towards the top, descending as the atoms accumulated; for numbers were seen ascending by the side of the cup. As these lines descended they dilated, until the entire film was carpetted with stripes of the most luxuriant tints: often have I tried to imitate them with my pencil, but on comparison gave over the attempt. I therefore shall refer the reader to the experiment itself, the more especially as the apparatus are cheap and easily procured. The order of these lines was the same as that described between the two plane glasses in experiment 3rd. 1st. Series a rich brown, or snuff colour, with a dark blue inclining to purple, as represented in the following figure by Nos. 3, and 4. 2nd. Series, Nos. 5, 6, and 7, yellow, red and blue. 3rd. Series, Nos. 8, and 9, green and red. 4th. Series, Nos. 10, and 11, green and red &c. &c.



Each series became narrower and narrower, paler and paler, until the film was too thick and tenacious to separate into lines; it then appeared towards the bottom, of a greyish semi-transparency.

No. 3, the first or brown line, like a chord, divided the top of the film into a segment or arch, all over of a silvery white; this arch dilated as the lines descended, and at length changed to a semi-transparent darkness: the dark or black light within the cup being partly transmitted through the film to the eye. The top now appeared black, with a white and broad line above the brown, represented by Nos. 1, & 2. In general, when this black spot became large the film broke in consequence of its thinness; however in some few instances I have seen it to occupy half the circle.

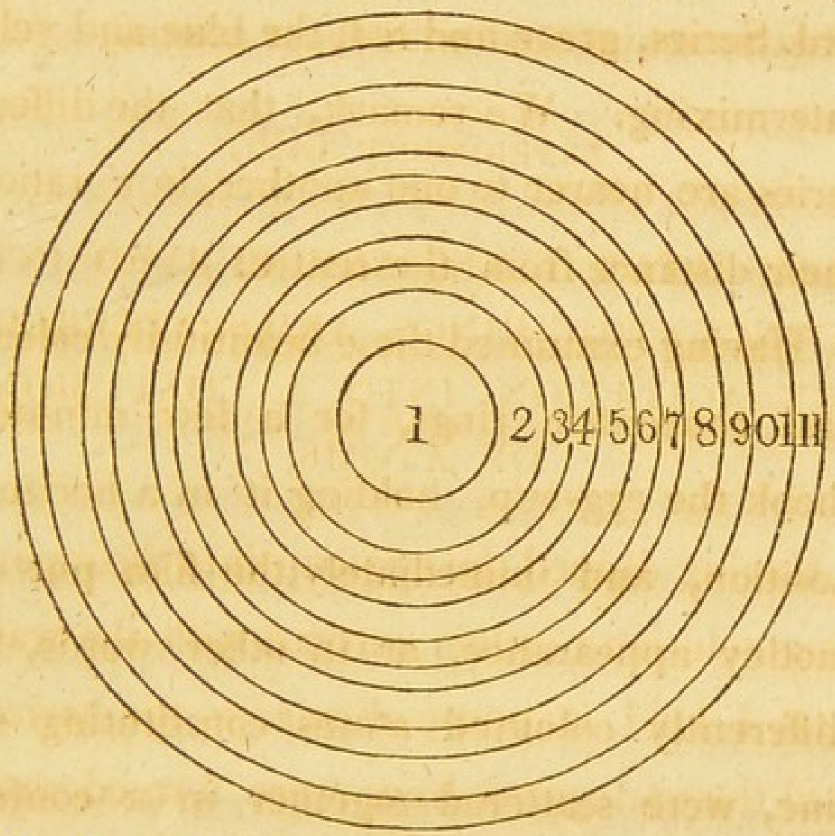
The strong analogy between this and the third experiment, where the colours were produced by an atmosphere of vapour between two plane glasses, leads us to attribute the variegated lines in both instances to one and the same cause; the partial condensation of atoms. In the third experiment, when the glasses were pressed together, a number of black lines no broader than a human hair came from the angle, and then dilated into differently coloured lines, exactly similar to those represented in this experiment. Here we have a decisive proof, that a black line can be formed, either by brown and purple, by blue, red and yellow, or by green and red. The following experiment makes the analogy still stronger.

Having made a very weak solution of soap and water, and having immersed the egg-cup, I held the film at right angles to the horizon, and perceived a number of perfectly black lines to form at the top; as they descended they dilated, and as they dilated they became differently coloured as already described. Here the analogy between the two experiments becomes nearly perfect, with this slight difference, that each coloured series could not be again condensed into a black line, as in the third experiment. Thus we might infer, that a soap film is compounded of aqueous and saponaceous atoms, which when placed at regular distances, according to the laws of repulsion and attraction, appear all over of a gray and semi-transparent colour. On the other hand, when in consequence of the subsidence of the fluid parts or from any other cause, the uniformity of condensation is destroyed, these atoms are condensed into different lines: thus, a line of atoms in a state of white condensation, reflects a white colour: a line of atoms in a state of blue condensation, a blue colour, and so of the rest. The next experiment brings us better acquainted with those atoms.

EXPERIMENT 14th.

VARIEGATED LINES ARE CURVED INTO CONCENTRIC RINGS, AND SCATTERED BY AGITATION INTO A CONFUSION OF ATOMS.

Having dipped the egg-cup into the saponaceous solution; when covered with the watch glass, I held it perpendicular to the horizon, until the variegated lines were formed, and a silvery arch occupied the top. I gently turned the cup, so as to bring the film to a horizontal position, and placed it on the window-stool, resting on the leg. As the film was gently turned, the lines became curved and at last formed into concentric rings around the vertex.* When first the egg-cup was placed on the window stool, the vertex or polar axis appeared perfectly white; however in some time this white spot dilated, and a black transparent one formed in the centre, as represented in the following figure.



No. 1, A black transparent spot, like a hole in the film, thro' which the inside of

* When the soap film is brought to a horizontal position, it is supposed to become somewhat convex, otherwise we could not account on hydrostatick principles, for the regular distances of those descending rings, occasioned by the upward pressure, counteracting the accumulation and consequent specific gravity of the atoms. On the other hand, the rectilinear appearance of the perpendicular film in experiment 13th. demonstrates the superficies to be nearly plane.

the egg-cup could be very distinctly seen: sometimes a number of white spots were interspersed. No. 2, A perfectly white band. Nos. 3, and 4, or the 1st. Series, brown and purple. Nos. 5, 6, and 7, or the 2nd. Series, yellow, red and blue. Nos. 8, and 9, or the 3rd. Series, green and red, the blue and yellow intermixing. We remark, that the different series are nearer to one another, in a ratio to their distance from the centre.

Having examined these beautifully coloured and concentric rings, for a few minutes, I shook the egg-cup, holding it in a horizontal position, and immediately the film put on a motley appearance, or in other words, the differently coloured atoms constituting each line, were scattered together in a confused manner, the appearance being somewhat like a piece of oxydized lead. The green was very conspicuous. Having again placed the egg-cup on the window stool; in a short time all these scattered atoms formed into broad concentric rings; the centre was white, with a few transparent spots like holes. On shaking it a second time, the atoms became scattered in a thousand directions, and on again placing the cup on the window stool, the rings were less perfect and defined. On a third time shaking the film it appeared semi-transparent with a very few small and coloured atoms. On placing it again on the window stool, no rings appeared, the centre appearing perfectly semi-transparent and colourless. After this no colours could be formed either by rest or agitation, the film becoming too thin from evaporation; and at last, perhaps in the space of an hour, the entire became of a dark transparency like the centre. At any time when the coloured lines are most brilliant, by a certain degree of agitation the motley appearance can be converted into semi-transparency, or the partial condensation be overcome, and the atoms removed to regular distances.

Having again dipped the egg-cup in the saponaceous solution; I placed it, while the film was in a state of semi-transparency on the window stool: in a short time it separated into broad concentric rings, with a white centre as already described. These atoms could be scattered by the slightest agitation; and if the experiments were made without a watch-glass, the atoms by slightly breathing on them, may be scattered either in the perpendicular or horizontal direction. Newton supposed that he prevented the bursting of the bubble, by stilling the agitation of the air, with a glass cover: on the contrary, agitation preserves the film, and keeps it alive, when on the eve of bursting. Evaporation thins it and causes it to break; the covering diminishing the process by confining a stratum of moist, heavy and stagnant air between the glass and the film.

EXPERIMENT 15th.

THE COLOURS OF SOAP FILMS DO NOT ARISE FROM ANY PARTICULAR THICKNESS OR THINNESS OF THE PLATE.

Having made a strong solution of soap and water I immersed the egg-cup and procured a very thick and semi-transparent film, of a gray colour; I immediately covered it with the watch-glass, and placed it resting on the window stool. In some time the film grew thin and semi-transparent from evaporation, without any appearance of colours whatsoever, and perhaps in an hour or two it became as thin, semi-transparent and black as the central space described by Newton. Had I no stronger experiment than this to oppose the Newtonian doctrine, it might be deemed sufficient: indeed it is an experimentum crucis. For on all hands it must be allowed that this horizontal film passed through the successive thicknesses described in the Newtonian tables, yet no colours appeared. The reason is obvious. The film was too thick and tenacious to allow the atoms to subside, and thus form into lines of various condensations. What became of the alternate fits of reflexion and transmission, depending on relative thicknesses?

When we examine all the experiments with plane glasses, soap films, &c. we are not a little surprised to find, that there are no intervals whatsoever between the different series; the entire is one continued sheet of reflected colours, from the central and dark spot, to the most distant rings of red and green. Yes, I pledge myself to the assertion that this part of the Opticks is a misrepresentation. The confines of the brown join or run into the purple, the confines of the purple into the yellow, the confines of the yellow into the red, the confines of the red into the blue, the confines of the blue into the green &c. &c.

The learned yet acrimonious Mr. Hutchinson, cotemporary with Newton when criticising the Opticks, and Principia says "It is to no purpose to stun us with mathematical principles of natural philosophy, till the principles themselves are simply proved: for mathematicks are applicable to any data, real or imaginary, true or false: they have nothing to do with the dispute and ought to take the last place in science; nor would any wise man chuse to waste his time in proportioning falsehoods." That Sir Isaac Newton on looking at the rings of colours between his convex glasses, thought he saw what he described, I am ready to believe and to admit, and that his numerous mistakes arose from the imperfection and limited nature of his experiments. In consequence of the convexity of the one surface of his glasses, the plate of vapour produced by pressure must have been extremely small, and the black rings very little dilated, consequently the colours appeared only at the edges, while a blackish ring occupied the middle. This reflected blackness he mistook for transparency, assimilating it to the central spot.

Thus the hypothesis that blackness is the privation of light, prolifick in absurdities, engendered many others, it was the support, the very corner stone of the entire fabrick, resting on as fanciful a foundation as the tortoise supporting the ancient world. When first the black lines are formed at the angle of the plane glasses as described in experiment 13th. intervening spaces seem to alternate; however these black lines are soon dilated or rarefied by pressure into various colours. This was the source of error, as will readily appear to any person repeating the experiments, and I hope none others may ever criticise these pages. I presume the last experiment will be deemed conclusive, however I made the following in corroboration.

Having dipped the egg-cup into a saponaceous solution, sufficiently fluid to produce colours, as mentioned in the 14th. experiment, I shook it in the horizontal position, until the motley and coloured appearance was converted into perfect semi-transparency: by continuing this agitation, the semi-transparency was preserved, until the film in perhaps about a quarter of an hour, became too thin to allow a partial condensation, when it appeared very semi-transparent and colourless; placed at rest no colours were formed. In this experiment as well as the former, the film must have passed through all the thicknesses described by Newton.

EXPERIMENT 16th.

ATOMS CHANGE COLOUR WITH EVERY CHANGE OF CONDENSATION.

Having dipped the egg-cup as represented in experiment 13th. and having formed a film which was placed in a horizontal position on the window stool, in a short time the rings appeared, and a number of blue atoms were seen to pass from the circumference towards the vertex ; as these ascended they sometimes changed colour, and like well disciplined soldiers, fell into that rank or line to which their exact tints of colour belonged. Thus have I seen a blue atom, passing successively to different shades of red, yellow &c. and at last to take a place amongst its companions of the same complexion. I have often seen them change to a white, which occupied a greater space than the original blue atom, from which it must be inferred that they were rarefied into whiteness. By slow degrees this film, which might be preserved under the watch-glass for hours, underwent successive changes of colour, according to the power of evaporation, for a bubble or film made with warm water became semi-transparent, and the changes were more rapid than with another of a less temperature; at length a number of holes seemed to form towards the vertex, and the bubble burst. This change of colour can be well demonstrated between two plane glasses, when a blue or brown spot remains as it were insulated in a white field, for by pressing with the thumbs and fore-fingers, the blue can be changed or rarefied into brown, the brown into white, and the white into transparency.

These experiments throw considerable light on the theory of dying, heretofore so little understood. When a few drops of sulphuric acid, are added to an infusion of blue cabbage, it is instantly changed to a red colour ; when a few drops of an alkalescent solution are added to the same infusion, a green colour results. This can be accounted for, on a simple change in the rarefaction or condensation of the atoms composing the blue infusion, without resorting to any absorption of oxygen. Indeed it appears evident from these experiments, [that colour should not be regarded as a fixed or distinct principle, different from the coloured substance but merely as a property dependant on the condensation of the constituent atoms, liable to continual change from evaporation, heat or chemical changes. However we may with propriety speak of the colouring matter of any substance, or that portion of colour reflecting atoms, which tinges or paints the remainder. Thus, if we dissolve a small bit of gamboge in water, we may call the gamboge the colouring principle. It often happens that two substances, each of which has a deep colour, are rendered entirely colourless, when united together, and frequently two colourless bodies, exerting a chemical action on each other and thus changing the condensation of the atoms, form a coloured compound. A piece of linen or cotton dipped into the blue infusion of cabbage, appears blue, into the red, red, and into the green, green; those three colours are mere adjective properties of the same atoms in different states of condensation.

Dr. Bancroft who has lately written a valuable treatise on dying, suggested the division of colouring matters into substantive and adjective; the first standing alone without the help of a mordant, the other requiring to be fixed by some earthly or metalic bases. Such a division answers perfectly well in a practical point of view, without any reference to theory.

It is obvious from what has been already said that any substance, acting on colour-making atoms, so as to change their degree of condensation, must change their colour. Evaporation, heat, light, and chemical decomposition are the principal agents.

When a piece of gray linen is exposed for some time to light, heat and moisture, the grey atoms are by degrees rarefied into whiteness in exactly the same manner as when the soap film becomes white. When a similar piece of linen is exposed to the influence of muriate of lime, or of oxy-mur-acid, similar effects are produced by dissimilar causes; the acid acting on the gray or black rarefies them into white reflecting atoms. The effect of light on the colouring matter of the oxides of the metals of gold and silver, as they are improperly called, is likewise attributable to the same process. I have at present in my possession, the metallick and concave speculum of a reflecting telescope, which from exposure in a dark drawer, to the moisture of the atmosphere became beautifully oxydated, exhibiting blue, red, yellow and green tints. The surface of this speculum, from analogy with the experiments already mentioned, must be in different states of condensation, according to their combination with different doses of oxygen. These different tints of colour are only perceptible, when the reflection of the window is made to fall on the speculum, for in the dull light of the room, it appears all over of a brownish gray, illustrating the striking effect produced by different intensities of light.

The process of bleaching has been explained in the following manner. The oxygen arising from the decomposition of water, is supposed to combine with the colouring matter of the thread, and thus to produce what chemists are pleased to call a slow combustion, by which the colour is gradually destroyed and the substance to be bleached, at last rendered white. It has been so much the fashion of the day, to account for almost every phenomenon on chemical principles, that I am apprehensive a solution by mere mechanical means, will appear too simple for hypothetical ingenuity.

When first the saponaceous film is placed under the watch-glass, it is of a gray colour, not unlike a piece of gray linen; here the similitude ends, for in consequence of fluidity, the one becomes variegated in a beautiful manner; on the other hand the piece of gray linen being of a solid texture undergoes a slow and invisible process; yet we can have no hesitation in saying, that the gray colour in both instances, arises from the reflexion to the eye of very minute blue, red, and yellow atoms, arranged at regular distances. The process of evaporation goes on; the condensation of these atoms is by degrees changed, the blue are rarefied into red, the red into yellow, and finally the yellow into white, and if the piece of linen were left much longer, the white would become semi-transparent and sufficiently light in consequence of the rarefaction, to be elevated and taken into the upper regions. For we can have little doubt, that an ultimate and invisible atom of gray linen, soap, or any other, even the hardest substance, is neither larger nor heavier than an ultimate atom of oxygen or nitrogen. A given bulk of ultimate atoms may be heavier than another, in consequence of a greater degree of condensation, but I must confess that the theory of relatively sized ultimate atoms appears to my mind, neither mathematical nor metaphysical.

When a soap film is placed under the glass, it exemplifies both the theory of bleaching and evaporation. To suppose that the colouring atoms of the film, undergo any chemical change, or that the water is decomposed, would be absurd to the last degree.

Indeed I have found that the soap film assumes these colours in the dark as well as in the light; for on immediately covering it, and then suddenly letting in the light, the variegated lines seemed as brilliant as if they had been formed in the open day, proving in a convincing manner, that this agent, although it might promote the change or formation of colour, is not absolutely necessary.

Fourcroy has made some experiments; chiefly with watery solutions of colouring matter, exposed to the atmosphere or subjected to a boiling heat. He observed that in consequence of the action of the air, vegetable decoctions formed pellicles, which lost their solubility, and underwent successive changes of colour. He marked the gradations thus produced, and concluded from his observations, that oxygen entered into the composition of the colouring particles; that when it was combined with them, their tints were changed, and that the more they received the more fixed their colour became. He therefore observed, that the best method of obtaining permanent colours for painting, was to chuse such as had been exposed to the action of the oxy-mur-acid. I have repeated some of these experiments, and found, that when the vegetable infusions were exposed to an atmosphere of nitrogen, similar appearances took place. I therefore would attribute the change of colour in some measure to the process of fermentation, changing the condensation. That light exerts a chemical power on some substances and changes their colour by either the evolution or absorption of oxygen, such as the changes produced on the oxydes of silver, gold, &c. or on the nitric acid, I am ready to admit, without subscribing to the sweeping conclusion, that oxygen is the sole and immediate cause of colour.

If we subscribe to the opinion, that change of colour arises from change of condensation, we must allow that various and different causes may produce the same effect. Whether light independant of the heat it converts has any effect in altering the condensation is indeed a very undecided point. For on exposing the plate of coloured vapour between the two plane glasses, to the light of the room, for six months together, I could perceive no visible change. I likewise scraped some nitrate of silver, and confined one half between two dry and plane glasses, the other half being placed on a sheet of white paper; both were equally exposed for some days to the solar rays: that on the paper changed in a short time, first to a brown and then to a black, whilst that between the glasses remained white. In this experiment both were exposed to the same degree of light. I also remarked, that the nitrate of silver was dissolved on the paper. Therefore we must attribute more to the moisture imbibed from the atmosphere, than to the light.

It has been shewn by the celebrated Franklin, and also by the experiments of the no less celebrated Sir H. Davy, that differently coloured substances are unequally heated by the solar rays. Franklin on placing pieces of differently coloured cloths on snow, while the sun was shining, found that the darker colours were most heated, as shewn by their sinking deepest. When we connect those experiments with the theory of condensation and rarefaction of variously coloured atoms, constituting a semi-transparent or grey colour, it is not unreasonable to suppose that these atoms condense the light into heat in a similar manner, yet in a lesser degree. Let us for example take a basin of semi-transparent water, compounded of ultimate atoms in different degrees of condensation, the blue condense the light, and convert it into heat, which heat causes them to be rarefied into red, the red into yellow, the yellow into white, and the white into perfect transparent and invisible atoms; these last from their great degree of rarefaction, become specifically lighter than the super-incumbent stratum of air, through which they pass, and are again condensed, forming clouds, fogs, snow&c. and finally descend again on the earth; thus in consequence of condensation and rarefaction decay and renovation are produced. The most solid rocks combining with moisture becoming rarefied, by the agency of heat and moisture, are thus reduced to invisible atoms, sufficiently light to ascend into the upper regions. If it be objected that evaporation and the process of bleaching go on in the dark, we must recollect that there is no black light incapable of further condensation. If vision-making and transparent light be capable of calorific conversion, why should not blackness, which is nothing more or less than a modefication.*

Berthollet has advanced the theory, that changes may be produced in the colours of bodies, either by the separation of oxygen, or by the union of that principle with one of the

* The theory of spontaneous Evaporation, although investigated by Men of the first abilities, such as De' Luc, Seussure, Halley, and Dalton, seems yet to remain a Mystery. Some attribute the process to the solvent power of the air; yet it goes on in vacuo. Others attribute it entirely to the agency of caloric, without informing us how the caloric is produced; evaporation goes on from the surface of Ice. If it be granted that all the bodies in nature are compounded of equiponderable and ultimate atoms rendered visible by condensation, and that specific gravity entirely depends on different degrees of condensation and rarefaction, the difficulty is in a great measure removed.

elements of the colouring matter. In the latter case which applies to vegetable substances, the oxygen is supposed to combine with the hydrogen; the attraction of the colouring particles for their basis is thus weakened, and they are easily carried off by water. This (according to Berthollet) takes place more or less rapidly, according to the nature of the colouring particles, or rather according to the properties which they possess in the state of combination into which they have entered. Colouring substances therefore must resist the action of the air, the less they are disposed to unite with oxygen, and thereby to suffer more or less quickly a smaller or greater degree of combustion. Light is said to promote this effect, which in many cases is not produced without its assistance, but the colouring matter in its separate state, is more liable to suffer this combustion, than when united to a mordant, such as alumine, which may either defend it by its own power of resisting combustion, or by attracting it strongly, weaken its action on other substances. This Berthollet thinks to be the chief effect of mordants, and finally, this last compound acquires still greater durability when it is capable of combining intimately with the stuff.

The simple objection we have to bring against this combustible theory, is, that oxygen is not essentially necessary either to bleaching or mutation of colour, as is exemplefied by the changes visibly produced on the surface of the saponaceous film by condensation and rarefaction, and also by the effects of pressure and heat on the plate of coloured vapour between the two plane glasses in experiment 14th. For it would be absurd to suppose that oxygen was either evolved or absorbed in these processes. Indeed to compare the process of dying or bleaching to the burning of a candle, is a far fetched, if not an inconsistent hypothesis. When phosphorus is burned in oxygen gas, the product or phosphoric acid is equal in weight to the two component parts; on the contrary, in bleaching the stuff is found to have lost weight. I would therefore define a mordant to be any substance, which combined with colour reflecting atoms, resists their rarefaction or further condensation.

The theories of dying, bleaching and evaporation are so extremely interesting, that it is with some regret I think it necessary to confine myself to these few remarks, however at a future period I hope to lay more extensive experiments before the public, and shall now proceed to the further investigation of our experimental enquiry. Almost all the inferences heretofore drawn, were from the fugitive colours produced by soap films. It therefore occurred that it would be very desirable if possible, to make these films permanent by the addition of a mordant. For which purpose the following beautiful and interesting experiment was instituted.

EXPERIMENT 17th.

COLOURS PRODUCED BY A GELATINOUS SOAP BUBBLE.

Having pounded and minutely divided $\frac{1}{4}$ of an ounce of isinglass, I steeped it for one night in a tea cup, containing about two or three ounces of water, to which the size of a small pea of common brown soap was added : next morning this tea cup was placed in a bason of boiling water, and when the mixture was dissolved into a jelly, it was well rubbed down with a tea spoon, until it put on a whitish appearance like salt. It was again placed over boiling water, until the entire was dissolved and appeared of a gelatinous brown colour with a white scum. I now plunged the mouth of a tobacco-pipe into it, and when a film occupied the orifice, blew it into a bubble or perfect sphere, the size of a large orange, with the mouth of the pipe inverted. Having held a card underneath, I made it touch the bottom of the bubble, to which it adhered, when raising the pipe, this bubble separated from the orifice, and closing, formed a perfect sphere. At first the gelatinous and saponacious bubble appeared all over of a semi-transparent and gray colour like ice, but in a short time when the card was placed on the window-stool, the fluid parts subsided and partly evaporated; when in consequence of the unequal condensation of the remaining atoms, the bubble put on a variegated clothing, more beautiful than imagination can conceive, or pen describe, exceeding if possible the plumes of the tropicks. The semi-transparent appearance generally remained for three or four minutes, and when the film became dry and coloured, if the solution had been very fluid, a few concentric rings, yellow, red, blue and green, made their appearance: but in general the colours appeared in no particular order.

Whilst writing this description, I have collected ten cards with these saponaceous and gelatinous bubbles before me, having blown them all of different diameters, from the size of a hazel nut to that of a pine apple; two, display rings of colours, surrounding the vertex, and one appears all over of a silvery white. I remarked when this last was blown, the mixture was very hot, and changed on a sudden from the gray semi-transparency to its present clothing. The base, or that part which rests on the card, is either of a gray semi-transparency, or of a blue and purple hue, with different colours interspersed.

The discovery of a substance capable of being blown sufficiently thin to display colour reflecting atoms, and sufficiently tenacious to remain permanent for examination, has long been a desideratum in philosophy. This experiment has also the advantage of being shewn to each individual in a class room. I have preserved one of these bubbles the size of a large orange, for months together. We hall now proceed to examine the colours of thin plates by transmitted light.

EXPERIMENT 18th.

EXAMINATION OF THESE COLOURS BY TRANSMITTED LIGHT.

Sir Isaac Newton says* "By looking through the two contiguous object glasses, I found

* Opticks, page 181.

that the interjacent air exhibited rings of colours, as well by transmitting light, as by reflecting it. The central spot was now white, and from it the order of the colours were, yellowish red, black, violet, blue, white, yellow, red, violet, blue, green, yellow, red, &c. But these colours were very faint and dilute, unless when the light was trajected very obliquely through the glasses: for by that means they became pretty vivid, only the first yellowish red, like the blue in the fourth observation, was so little and faint as scarcely to be discerned. Comparing the coloured rings made by reflection, with those made by transmission of the light; I found (continues Newton) that white was opposite to black, red to blue, yellow to violet, and green to a compound of red and violet: that is, these parts of the glass were black when looked through; which when looked upon appeared white, and on the contrary. And so those which in one case exhibited blue, did in the other case exhibit red: and the like of the other colours."

Here he gives a figure which I shall not copy, as I look on the entire representation as fallacious, partly arising from his confounding blackness with transparency. The great objection against viewing these rings through glasses is that the opake and vitrious atoms condense the light and obscure the examination: to avoid which I procured an egg-cup open at both ends, and having dipped it into the saponatious and gelatinous solution, formed a film, which was laid in a position perpendicular to the horizon; in a few minutes it became dry, from evaporation, exhibiting six well defined and variegated lines at the top, each about $\frac{1}{8}$ of an inch in breadth. The order was white, brown, blue, yellow, red, blue; the lower part of this film was thicker than the upper and appeared semi-transparent, except here and there where it was a little coloured. I now placed my eye at the end, looking through the film as through a telescope. The colours appeared much fainter than by reflexion, however I could easily discern that they were similar, the red appearing most brilliant. When the sky was charged with white and heavy clouds, through the film it appeared beautifully variegated with warm tints. Here the colours were not obscured by any intervening substance, and therefore had a decided advantage over the Newtonian experiment. As we might a priori expect, the tints in a great measure depended on the distance of the film from the eye, and also on the intensity of light. When held very close the colours were scarcely perceptible. I now varied the experiment in the following manner. When the sun was shining through the window, I held the egg-cup open at both ends in such a position, as to allow some of the beams to pass through, and to fall on a sheet of white paper placed a few inches behind: from this paper the colours were reflected to the eye, in the same order as from the film itself, with this difference, that the white was invisible from a white field, and the other colours were somewhat more faint and dilute. Nor could I perceive that otherwise there was the least difference between the tints reflected and transmitted. To bring the examination as near as possible to that of the Newtonian, I made the following experiment.

EXPERIMENT 19th.

Having ascertained from the former experiments, that the coloured lines were the same both by reflexion and transmission ; I pressed two plane glasses together, as already described in the third experiment, until a large oval appeared.

On looking through the central and semi-transparent spot at the sky or at any other objects, they appeared as they would to the naked eye ; on looking through the white ring, objects appeared as if seen through a thick fog ; not black as represented by Newton. The next or brown ring, appeared much fainter than by reflexion, yet sufficiently well marked ; the dark blue was somewhat muddy ; the yellow red and green extremely bright. I now allowed the sun shine to pass through these coloured glasses as in the former experiments, and found, when the colours were received and reflected from a sheet of white paper at about half a foot distance, the transmitted rays appeared in exactly the same order as those reflected to the eye, except the white and transparent spot. I now held the glasses perpendicular to the sun and in such a manner as by reflexion, to throw the coloured rays on a sheet of white paper, held nearly opposite and at the distance of about half a foot; here I perceived a beautiful and reflected picture, which was one sheet of colours without any intervening and alternate series. This with the former experiments must convince the reader, that the alternate fits of reflexion and transmission are merely imaginary.

From these experiments we infer, that each atom reflects and transmits to the eye its own colour and none other. The method of ascertaining the transmitted colours, by looking through the glasses or the film, is by no means so exact or conclusive, as allowing them to be carried through by the solar rays, and then reflected from white paper; those which appear by transmission alone being often too faint and dilute to be discerned. That this is the case might be easily shewn, for on looking through a pair of green spectacles, objects do not appear green, but if the sun-shine be transmitted through the same glasses, when reflected from a sheet of white paper, the green rays are very conspicuous.

EXPERIMENT 20th.

COLOURS PRODUCED BY A SAPO-GELATINOUS AND HORIZONTAL FILM.

Having dipped the egg-cup into the saponaceous and gelatinous solution, as already described; I placed the film in a vertical position, to allow the atoms to fall from the top: in a few minutes, eight well defined and variegated lines were formed, the bottom of the film to the extent of somewhat more than half the superficies, being of a gray semi-transparency. The order was the same as in the other experiments. As the colours were forming, I accurately examined the progress of evaporation, and perceived that as a spot became dry, it became coloured, the margin being surrounded with lines of red and green much in the same manner as when the water left coloured lines behind it, as described in a former experiment; no colours appeared when the film was wet.

With the intent of making a horizontal film sufficiently thin to become entirely coloured, I blew a bubble from a sapo-gelatinous solution and placed it in the mouth of a wine glass, continuing by blowing, to enlarge its diameter, until it adhered to the sides; then separating the pipe, a film occupied the orifice, of an equal degree of thickness; after a few minutes this film became dry and exhibited a brilliant display of coloured tints. To try the effect of heat and moisture, I breathed softly on this film, and saw the colours change, the yellow became a dark green, the red changed to blue, &c. &c. By continuing to breathe, the entire film at last became colourless or of a gray semi-transparency. Having blown a number of these sapo-gelatinous bubbles on a black board, nothing could exceed their beauty: when placed over the chimney-piece, of a dry day they appeared stiff and coloured, of a moist day they acted as hygrometers, becoming flaccid and dull; hence we may conclude that heat and moisture are the principal agents in bleaching.

The limits I have prescribed myself, will not admit a more minute description of these experiments, I therefore shall proceed to give a theory of colours, deduced from the preceding examination. Should any other writer see them in a different light, it will at all events give me pleasure to think that I have contributed to the further investigation of this delightful science, and shall be ever ready to adopt new and more approved suggestions.

ATOMIC THEORY OF COLOURS.

Having established the fact by numerous experiments, that a plate of opake vapour, and not transparent air, is the cause of the colours between glasses, it is necessary to account for the concentric rings.

The atmosphere holding in suspension a great quantity of vapour, when two pieces of glass are pressed closely together a certain quantity becomes condensed, forming a thin stratum. This condensed and vaporific atmosphere is thrown into undulations by every encreasing degree of pressure, evolving black waves which emerge from the centre, and are rarefied into colours. The second degree of pressure evolves a second undulation and so on, each wave being stronger in proportion to the pressure. When a stone is thrown into still water, a number of black waves are seen in concentric rings exactly resembling these coming from the angle of the glasses, and regulated by the same laws; at first they are black and condensed. If similar waves of water could possibly be produced between two pieces of plate glass I have no doubt they would become coloured by pressure, according to their rarefaction and condensation. In the experiment with soap films, it was demonstrated, that a semi-transparent and gray film, could be condensed into white, yellow, red and blue reflecting atoms, and that other colours were produced by their intermixture, each atom reflecting its own light wherever it was moved, unless it underwent a change of condensation; it then changed from one colour to another. We also remarked that on repeating the 2nd experiment, when these atoms changed colour, they occupied a larger or a smaller space. These are facts demonstrable to the sense of sight. When we proceed a step farther and speculate on the ultimate and invisible state of these atoms, we are obliged to resort to hypothesis and to square our reasoning according to the rules of analogy. The following appears to my mind the most plausible; however I only give it as conjecture. If we suppose all bodies in nature, to be composed of a series of ultimate and spherical atoms, connected together by the force of attraction, and each atom surrounded by an atmosphere of caloric or convertible light, the cause of repulsion. These atoms in their ultimate and most rarefied state are perfectly transparent and invisible, as when vapour is blended in the atmosphere, or gold dissolved in aqua regia. The next degree of condensation approximates and makes them semi-transparent, forming clouds &c. The third degree of condensation represents them to the Eye, as perfectly opake and coloured. These different stages of condensation are well illustrated by the plate of vapour pressed between two plane glasses in experiment the 4th. These ultimate and spherical atoms are likewise supposed to be of one and the same size, and form; their transparency or colour depending on relative distances. Here I may remark that the atomic theory of colours advanced in these pages is essentially different from that of the ancient or modern atomists, as it neither supposes that ultimate atoms are of relative sizes, nor figures. The antients on the contrary supposed them to be conical, cylindrical &c. Mr. Boyle in treating on the nature of whiteness and blackness attributes colours to the asperity of the reflecting or suffocating surface. "I come now (says this celebrated philosopher,) to enquire into the nature of whiteness and blackness. Whiteness considered as a quality in the object, seems in the general chiefly to depend upon the roughness of the surface of the body, called white; which gives it innumerable small superficies, that acting like so many little specula in various positions, reflect the rays of light that fall on them, not towards one another, but externally towards the spectator's eye."* And in another passage he says "what we have said of whiteness may assist us to form a notion of blackness; these two qualities being sufficiently opposite to illustrate each other. And as that which makes a body white, is chiefly such a disposition of its parts, as disposes it to reflect more of the light that falls on it, than bodies of different colours; so that which renders a body

* Boyle's Works Abridged by Shaw, page 27.

black, is principally a peculiar kind of texture of its superficial particles; whereby it damps the light that falls on it, so that very little is reflected to the eye. This texture is explicable two several ways; and first by supposing in the superficies of the black body, a particular kind of asperity whence the superficial particles reflect few of the incident rays outwards, and the rest inwards, upon the body itself: as if for instance, the surface of a black body should rise up in numberless little cylinders, pyramids, cones &c. which, by being thick set and erect throw the rays of light from one to another inwards, so often, that at length, they are lost before they can come out again to the Eye.*

This shuttlecock theory of blackness, wherein the rays of light are tossed from pyramid to cone, and from cone to cylinder, was taken up by Sir Isaac Newton, who however instead of supposing with Mr. Boyle that white was a simple colour made it a compound of all the pris-

* Boyle's Works Abridged by Shaw, page 32

matic rays. "When the several sorts of rays are mixed (says Sir Isaac Newton,) and in crossing pass through the same space, they act not one upon another, so as to change their colour-making qualities; but by mixing their actions in the sensorium, beget a sensation, differing from what either would do apart, that is, a sensation of mean colour between their proper colours, and particularly, when by the concourse of mixtures of all sorts of rays, a white colour is produced; the white is a mixture of the colour which the rays would have apart: the rays in that mixture do not alter their several colour-making qualities; but by all their various kinds of actions, mixed in the sensorium, beget a sensation of a middling colour, between all their colours which is whiteness."

As we have already shewn, that the experiment on which this opinion rests is fallacious, and that all the prismatic colours actually proceed from the decomposition or different condensation of the black light reflected from the opake angles of the prism; we shall now endeavour to shew that these very seven colours which Newton would compound so as to produce a transparent fluid,* are perfectly opake.

Light is either rarefied and modefied into visibility and transparency by the sun, or some other luminary, or it is at rest, perfectly dark and opake; the one constituting day, the other night. Darkness or shadow has already been shewn to be compounded of blue, red and yellow rays, or more properly

* All through the Opticks Newton confounds transparency with whiteness, and whiteness with blackness, making use of the terms white light and dark white, the latter term being as strange as if we were to say a sheet of paper was a black white. The rays reflected from a white painted door, are opake, and only rendered visible by the associated and transparent light. If two perfectly transparent gasses, such as the muriatic and ammoniacal gasses are mixed together, a quantity of white light is immediately reflected from the muriate of ammonia and the glass globe becomes opake. Indeed there is no reflecting substance entirely composed of one and the sameseries of atoms, many being interspersed and overpowered by the predominating colour; hence we see different colours in some silks, according to the angle of incidence. A sheet of white paper is compounded of white reflecting atoms, often tinged with blue, yellow and semi-transparent ones, which last transmit the light. When the paper is held between the spectator's eye and the window, the white, blue or yellow are opake. Newton supposed that transparency depended on the thinness of the plate or particles, and attributed the transparency of a thin leaf of gold to mechanical division: if this were the case, gold dust and vermillion should become transparent from trituration. By dissolving gold, we change the condensation and thus remove the colour. Mechanical division is not sufficient for that purpose.

speaking, blackness when illuminated by vision-making and transparent light, can be rarefied into these colours, therefore we must allow them to be equally opake with blackness. We see them not by any illuminating power of their own, but by the associated day light; thus they illuminate objects according to their degree of condensation and the intensity of the commixed and transparent rays: green is not more or less illuminating than blue, blue than red, they are perfectly opake. If a green glass be slightly stained, and the transmitted light allowed to fall on a sheet of white paper, a small object, such as a pin's head is seen, not by means of the green rays, but in consequence of the quantity of transparent light which passes through the semi-transparent and vitrious atoms: if the glass be farther stained the pin becomes more invisible, until at last the entire atoms become green and opake, when there is a total reflection.

Dr. Herschel in 1800, published two papers in the philosophical transactions, wherein he enumerates many experiments on the illuminating power of coloured rays. This able philosopher thought that, the microscope offered itself as the most convenient instrument for this investigation, with which he viewed different objects in the coloured rays; these were magnified by a power of 42, and a nail is mentioned as peculiarly suited for remarks of this kind. It was chosen on account of its solidity and blackness, as most likely to give an impartial result of the modefications arising from an illumination by differently coloured rays; but on viewing it, Dr. Herschel was struck with a bright constellation of thousands of luminous points, scattered over its whole extent, as far as the field of the microscope could take it in. Their light was that of the illuminating colour, but differed considerably in brightness, some of the points being dim and faint, while others were luminous and brilliant. The brightest of them also admitted of a little variation in their colour, or rather in the intensity of the same colour; for in the centre of some of the most brilliant of these lucid appearances, their light had more vivacity, and seemed to deviate from the illuminating tint towards whiteness, while on and near the circumference it seemed to take a deeper hue.

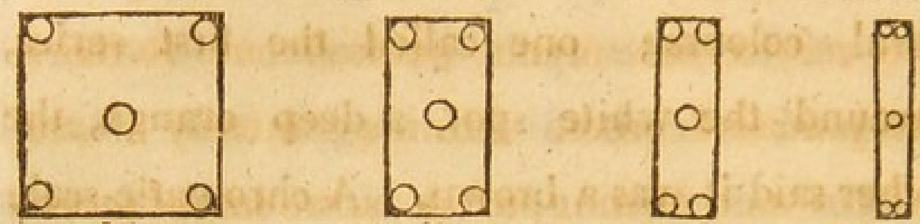
When the reader considers the experiments already related in this work, I make little doubt he will agree, that a microscope of such a high magnifying power, and a black object were badly adapted for this investigation. The black nail, indented and variously polished, reflected the light in different shades; these in their turn were separated into colours by the glass. Most nails are pentagonal, every side reflecting a different shade. If we look at the head of a black nail, through the prism it reflects all the prismatic colours: a microscope must produce nearly a similar effect. Therefore the naked eye would answer much better for the investigation.

Dr. Herschel drew the following conclusions from his experiments. "That the red-making rays were far from possessing an eminent degree of illumination; that the orange possess more of it than the red; the yellow still more. The maximum of illumination lies in the brightest yellow, or the palest green; the green itself is nearly as bright as the yellow; but from the full deep green, the illuminating power decreases very sensibly. That of the blue is nearly upon a par with the red; the indigo much less than the blue, and the violet is very deficient. With regard to the principle of distinctness, none of the colours appeared to be deficient; that is to say, that though for want of illumination in the less powerful colours in this respect, fewer bright spots could be discerned, yet those which were visible were perfectly distinct."

When the sun was shining, I allowed the beams to pass through two pieces of plate glass, with an interjacent and large chromatic oval, and to fall on a well printed book; the letters were much more distinctly seen in the yellow and green, than in the brown or blue, but they were very differently illuminated by the respective greens ; for as already remarked, no two in the concentric rings were alike. I next held a large prism in such a manner over the same book, as to immerse the letters in the green rays. When it was so turned on its axis as to condense the green, the letters became much more indistinct ; when the green was again rarefied, much more distinct, than in the orange. This experiment demonstrates, that as great a difference exists in the illuminating power of two prismatic greens, as between any two other colours. Although I entirely attribute the illuminating power of the coloured rays, to the associated and transparent light, yet I admit that cæteris paribus, the same quantity of vision-making light, will not give the same degree of distinctness to the green and blue, or to the orange and brown. Indeed a regular and well defined nomenclature would be a desiderable improvement in the science of opticks, perhaps no two painters expressing the same colours by the same names. Some time ago I was anxious to take the opinion of two painters as to the oval colours; one called the first series, around the white spot, a deep orange, the other said it was a brown. A chromatic scale might in a great measure obviate this inconvenience, to which the artist could resort with as much accuracy as the carpenter does to his rule; even the different degrees of intensity might be expressed: no two colours are more mistaken than red and orange, purple and violet.

All Dr. Herschel's experiments on the illuminating power of the coloured rays, depend on the angle which the prismatic plane makes with the incidental light: as he has omitted to inform us of this circumstance, a repetition of the experiments would be impracticable. If it were possible to fill a room with any particular colour, such as red or green rays, I am confident they would be perfectly invisible. As diagramatic illustrations tend to give geometric precision to our ideas, the following figures may represent the atomic theory of colours.

No. 1, No. 2, No. 3, No. 4,



white, yellow, red, blue,

These four parallelograms, represent the four simple or primary colours, white, yellow, red and blue, from which all the other tints in nature may be formed by the artist. No. 1, or the white reflecting atoms are the most rarefied, or the spheres are repelled to a greater distance. No. 2, or the yellow reflecting atoms are somewhat more condensed. No. 3, or the red reflecting atoms yet more so, and No. 4, or the blue reflecting atoms, are the most condensed of all.

The 13th experiment illustrates this theory. To lay down any particular geometric or arithmetic rule for the exact degrees of condensation would be impossible, as the phenomenon is far removed from ocular demonstration; yet no doubt can remain that colours are produced by substances according to their rarefaction; indeed it would be falling into the very error already pointed out, to mark the precise degrees. However merely for the sake of methodizing our ideas, we might represent the rarefaction of the white atoms No. 1, or the spherical root, by the quantity a. The yellow, by a^2. The red by a^3. The blue by a^4. The compound colours may be expressed by simple equations. Thus, 1 atom a^2 + 1 atom a^4 = 1 atom green. Again 1 atom a^2 + 1 atom a_3 = 1 atom orange. These two last are binary compounds, a ternary one may be thus expressed, 1 atom a^2 + 1 atom a^3 + 1 atom a^4 = 1 atom black.

However it must be recollected that every colour has different degrees of intensity, from a dilute to a deep tinge, and therefore the compound colours formed from the mixture, of what in vulgar language are called red and yellow, may be very dissimilar; for example, red and yellow in one state of condensation form orange; red and yellow, in another form brown; hence the great difficulty of bringing the mixture of paints to any fixed and determinate standard. The eye alone can judge, and a painted scale is the least exceptionable test.

The word atom derived from a priv. and temno, seco, implying indivisibility, is one of these absurd derivations, more apt to mislead than to inform the mind. I indiscriminately use the term to express a visible congeries of small particles, or an invisible quantity of matter, referring the reader to the ancients for speculations on the prima principia and semina rerum. Thus we may say, that a number of black or carbonacious atoms, may be rarefied to the same degree of transparency and specific gravity, as those composing oxygen, and if both were inflamed in a closed vessel, this might be supposed to take place. Carbonic acid gas is heavier than oxygen or nitrogen, yet it remains in a mixed state in the atmosphere. Now the question is, whether carbonic acid gas be in the same degree of condensation when in a separate state, and when mixed with other gasses. If it can be supposed that the ultimate atoms of carbon or of water, are of no greater specific gravity than those of carbonic acid gas, or of oxygen or hydrogen, we can have no difficulty in accounting for their remaining when rarefied in a mixed state in the atmosphere. In a theatre, the carbonic acid gas, evolved from the lungs, ascends to the top, and is there sustained by the upward pressure, but as soon as its condensation is sufficient to counterbalance that resistance, it falls by its gravity. In the grotto del cano, the carbonic acid descends. In the atmosphere, a small quantity is intimately blended with other gasses. Are the ultimate atoms of both in the same degree of condensation ?

SIMPLE OR PRIMARY COLOURS.

Sir Isaac Newton supposed that the transparent and solar ray, which he termed white light, was compounded of seven primary rays. Not aware that the light is never separated into these colours by the prism, but that all the coloured rays proceed from the various condensations, and mixtures of the rarefied black light reflected from the opake angles, he was obliged to adopt the curious opinion, that green, orange and violet are simple and primary colours, when made by the prism; secondary or compound when made by the hand of the artist. "For a mixture (says this great man) of homogeneal red and yellow, compounds an orange, like in appearance to that orange which in the series of unmixed prismatic colours lies between them; but the light of one orange is homogeneal as to refrangibility, that of the other is heterogeneal, and the colour of the one if viewed through a prism, remains unchanged, that of the other is changed and resolved into its component colours, red and yellow. And after the same manner other neighbouring homogeneal colours may compound new colours, like the intermediate homogeneal ones, as yellow and green the colour between them both, and afterwards, if blue be added, there will be made a green the middle colour of the three which enter the composition, for the yellow and blue on either hand, if they are equal in quantity they draw the intermediate green equally towards themselves in composition, and so keep it as it were in æquilibrio, that it verge not more to the yellow on the one hand, than to the blue on the other, but by their mixed actions remain still a middle colour.*"

The following simple experiment contradicts the assertion, "that the prismatic orange cannot be separated into red and yellow." Let a large piece of black cloth, suppose six inches square, be fixed on a pane of glass at the window, and let the experimenter, standing at a very short distance, view this cloth through the lower refracting angle of the prism; a fringe of bright orange and yellow occupies the lower part. As the spectator moves backwards, still keeping his eye intently fixed upon these colours, he shortly perceives the orange to dilate, and as it dilates, to separate into a

* Optics, page 116.

bright crimson and yellow colour. On again approaching the cloth, the red and yellow are condensed into an orange. This experiment likewise proves, that the distance of the object from the refracting medium considerably alters the magnifying power. However we shall speak more at large on this part of the subject in our second volume, when treating of refraction.

A gentleman lately repeating some of these experiments, expected that by pasting a piece of orange cloth or paper, on a pane of glass at the window, the colours would be separated by the prism; he forgot that the orange appeared dark in that position. I mention this to guard my readers against a similar mistake. In the experiment just now related, the orange fringe was blended and associated with the transparent light.

Before Newton's experiments, red, yellow and blue were supposed to be the primary colours, and the rest to be compounds arising from their mixture. Thus, red with yellow, produce orange; yellow with blue, green; and blue with red, indigo. At first when I discovered the composition of blackness, and that the spectrum was formed by these three colours, I was led to adopt the same opinion, and published a short paper on the subject in the journals, but more mature consideration has induced me to think otherwise.

Mr. Boyle says* "there are but few simple and primary colours, from the various compositions whereof, all the rest result: for though painters imitate the hues of those numerous and different colours, to be met with in the works of nature, and of art, yet I have not found, (continues Mr. Boyle,) that to exhibit this strange variety, they need employ any more than white, black, red, blue and yellow; these five variously compounded, and re-compounded, being sufficient to exhibit such a variety, as those, who are altogether strangers to the painter's pallet, can hardly imagine. Thus black and white differently mixed, make a vast number of lighter and darker greys: blue and yellow

* Boyle's Works, page 65.

make a great variety of greens; red and yellow make an orange; red with a little white, make a carnation; red, with an eye of blue, make a purple: and by these simple compositions again compounded, the skilful painter can produce what kind of colour he pleases; and a great many more than we have names for."

The objection to this theory, is, that black is a compound, not a simple colour; why Mr. Boyle should rank it amongst the primary ones after degrading it into a non-entity, appears somewhat strange and inconsistent: indeed I think it unnecessary to enter into the crude opinions of the ancients, relative to those colours produced by the prism, and supposed to be apparent and not real. What Newton calls the solar spectrum, Mr. Boyle calls a prismatic iris. The Greeks and Latins confined the word iris to the rain-bow, which Horace stiles pluvius arcus, or to some other variegated substance.*

* When we look at a straight and dark window-frame through a prism, it appears curved, like a tri-coloured arc, or rain-bow. When the black rays coming from the opake prismatic angle, are received on a sheet of

Another hypothesis has lately been advanced by Prieur, and supported with some ingenuity; according to him the red, green and violet are the primary colours; the red and green giving rise by their intermixture to orange or yellow, according as the former or the latter predominates; the green and violet forming blue, and the violet and red purple; thus by various modifications of these three original colours (according to Prieur,) all the others are obtained. He likewise asserts, that he produced white light, by combining red, green and violet rays. Newton to prove his theory, made what he called white light by the union of seven; and I have shewn in page 37, Book 1. that green can be made transparent or colourless, (that is to say, the condensation can be overcome,) by merely passing it through a convex lens. The fallacy of these experiments has been rendered too obvious to need further comment.

paper; immediately behind the instrument they appear in a similar manner. It is no wonder that the ancient and modern writers unacquainted with the real cause of these colours, should have formed strange notions and encumbered the simplex munditiies *naturæ* with unnatural ornaments.

Prieur might also have made fully as good a white, or more properly speaking black, as ever Newton did, by the mixture of red, green and violet coloured and opake paints, for these three are compounds of blue, red and yellow. Indeed we necessarily find these colours to be the basis of every theory.

Du. Fay and Father Castelli with many others, maintained, that there were but three primary colours, resting their arguments on the supposed fact, that a painter with blue, red and yellow on his pallet, could form all the variety in landscape. If indeed this were the fact, it would be a powerful argument. But it has been generally overlooked, that the painter operates on a white ground or canvas, or is obliged to use a certain quantity of white paint; not indeed such as Sir Isaac Newton compounded. Neither could he possibly form, with all his ingenuity, a carnation or a gray without a mixture of white. I therefore have adopted white as a primary colour. Perhaps some of my readers may be inclined to think, that semi-transparent atoms should likewise be esteemed primary, however in consequence of their condensing and changing the light in a very slight degree, I thought it better to omit them.*

Fourcroy says " light in refracting, is decomposed into seven rays, red, orange yellow, green, blue, indigo and violet. It has been supposed (continues that celebrated chemist)" that three of these colours, the red, yellow and blue were simple, and that the other four were formed, each of its two neighbours, that is, the orange from the red and yellow, the green from the yellow and blue, the indigo from the blue and violet, and the violet from the red and indigo. But this supposition (continues Fourcroy) has never been proved.

Dr. Young, in remarking on this opinion in a paper written for Nicholson's journal says " Besides that this is a mere hypothesis,

* The experiments with soap films, and thin plates of vapour, confirm white as a primary colour.

unsupported by any fact, as Fourcroy observes, we remark, that it is in itself inadequate; 1st. because in the solar spectrum, the red and indigo are not neighbouring colours, but are almost at the greatest possible distances from each other." This would be a strong objection to the opinion I have advanced, that the colours of the spectrum are produced from three, but we must recollect, that indigo can be made with blue and red, in certain proportions, violet from red and black, which are neighbouring colours. 2dly continues Dr. Young, "according to this hypothesis, indigo is composed of blue and violet; but violet is compounded of red and indigo; indigo therefore is a compound of red, blue and indigo, that is, indigo itself is one of its own essential ingredients, which is absurd."

I shall refer the reader to my former experiments with the prism, as related in the 1st Book, wherein it is fully shewn, that prismatic orange is a mixture of red and yellow, green of blue and yellow, indigo of red and blue, and violet of red and black. The following observations, made by Dr. Young, are so consonant to my own that I shall beg leave to quote them. "On this doctrine of the two-fold generation of green, we may in the first instance remark, that, the ancient and received axiom "Deus nil agit frustra" ought not to be too hastily abandoned, as it must appear to be, if this doctrine were maintained: for if green may be produced by blue and yellow, then blue and yellow being alone existent, green is a consequence; and therefore peculiar rays formed for the production of green, are superfluous. This waste of power or multiplicity of means is not adopted by the supreme artist."

Having thus in a cursory manner noticed the different theories of primary colours, and shewn that none of them are sufficient to account for the phenomena, and having likewise shewn that all the colours compounded by the painter, or formed by the prism, can be made with white, yellow, red and blue, I shall not enter into the opinion, whether prismatic colours are immaterial or artificial; for we have already shewn that they are produced by the black angles of the prism. Thus we find that not only the spectric colours, but also the colours produced by thin plates can be traced to the rarefaction of black light; nor is it surprizing that these rings should have been a mystery to philosophers unacquainted with that circumstance.

Du. Tour conceived the rings to result from a simple prismatic refraction. He supposed that the first lens acted like a prism, and separated the incident heterogeneous rays, so as to form a coloured spectrum on the second, from whence it was reflected to the eye, placed above both. I need scarcely say (if this doctrine were maintained) that the number of rings, and the circumstance, that these rings can be equally well formed between two pieces of plane glass, are sufficient objections. Indeed no two figures are more dissimilar, than the spectrum when thrown on the wall, and those concentric or oval colours between glasses.

Dr. Herschel attributes these rings to a certain modification of the rays of light, denying the theory of alternate fits of transmission and reflection, yet, endeavouring to accommodate his opinions to those of Newton, who says "every ray of light acquires, in passing through a refracting surface, a certain transient constitution or disposition, which returns at equal intervals during its progress, and makes it at each return of that disposition, be easily transmitted through the refracting medium, and in the intervals disposes it to be easily reflected" prop. xii. Book ii. Part iii.

I shall take leave of this part of my subject, with a few remarks on Dr. Young's* theory. "If the solar light consisted of seven primitive homogeneal coloured rays (says Dr. Young) and that these homogeneal rays were equally refrangible, the spectrum would consist of

* Dr. Mathew Young was fellow of Trinity College Dublin, and I have been informed left some valuable manuscripts, calling in question the Newtonian Doctrines. Dr. Thomas Young has also written largely and scientifically on light and colours in his system of phylosophy. As his opinions are connected with much mathematical reasoning, I have reserved them for the second Volume of these outlines.

seven circles of different colours, since the homogeneal rays of each colour would paint a circular image of the sun; but it is manifest, that seven circles would not compose an oblong spectrum, with recteliness sides. Therefore the rays of the same denomination of colour, must be differently refrangible, which is also made still farther evident by observation of the spectrum, since in it we perceive, that the prismatic colours are diffused over spaces, which are, on the sides, terminated by right lines; and therefore the centres of the circles of the same denomination of colour, are diffused over lines equal to these segments of the rectilineal sides of the spectrum."

On this I have to observe, that the spectrum is not an image of the sun, but a foraminal or prismatic image. After some remarks on Newton's opinion, he goes on to say, "now since the rays which are of the same denomination of colour are differently refrangible, they will either form oblong spectrums, detached from each other, or they will in part lap over, and fall on each other. The former position is manifestly false: therefore the original prismatic colours will partly lap over and fall on each other, and therefore necessarily generate the intermediate colours. And so Sir Isaac Newton observes, where he says, that the original prismatic colours will not be disturbed by the intermixture of the conterminous rays, which are intermixed together. This over-lapping however, which Newton speaks of, arises only from the sun's having a sensible diameter, and does not necessarily imply an equal refrangibility in any differently coloured rays. If there be but three original prismatic colours, red, yellow and blue, and that the red and yellow lap over, so as that there shall be a certain space in the sides of the spectrum equally occupied by yellow and red circles, then will these circles by their intermixture compound an orange colour; and this colour as to refrangibility will be homogeneous, because the coincident rays of different colours are equally refrangible. In like manner green may be compounded by the mixture of blue and yellow circles equally refrangible. Now this is simple, and conformable to the other phenomena of the spectrum; for if rays of the same denomination of colour be differently refrangible, it is not unreasonable to suppose, that rays of a different denomination of colour may be equally refrangible; and therefore since the red rays are unequally refrangible, and likewise the yellow, there is nothing incongruous (continues Dr. Young) in supposing that some of the less refrangible of the yellow may be equally refrangible with some of the more refrangible of the red; and if so, they will consequently be intermixed with them: and the same may be said of the green. This hypothesis likewise receives considerable strength from this consideration, that the orange, green, indigo and violet, occupy those places which they ought to do, in case there were but three primitive colours, red, yellow and blue: thus the orange lies between the red and yellow, because it is formed by some of the extreme rays of red and yellow, which are equally refrangible; in like manner the green lies between the blue and yellow, because it is formed by the mixture of blue and yellow. The indigo and violet must also occupy the extreme part of the spectrum, where the most refrangible red and blue rays are united, and gradually becoming more and more dilute, fade away, and at length entirely vanish. But if the orange, green, indigo and violet be primitive colours, there is no apparent reason why they should have had such degrees of refrangibility assigned them, as that they should occupy the places they do, rather than any other.

Moreover, if these three colours, red, yellow and blue be the primitive colours, they cannot themselves be generated; and accordingly we find, that yellow cannot be generated by the mixture of the adjacent prismatic colours, orange and green; and the reason of this is evident, because orange is compounded of red and yellow, and green is compounded of yellow and blue; but red and blue compose purple;

which added to the yellow will generate a new compound colour, viz. A sickly green, differing manifestly from yellow, the colour which ought to result according to the analogy of the other prismatic colours, in which the extremes, by their mixture, generate that which is intermediate. In the same manner blue cannot be generated by the mixture of green and indigo, because green is a compound of yellow and blue, and indigo of blue and violet: therefore the resulting colour is composed of blue, yellow and violet: but yellow and violet do not compose blue, therefore neither will blue, yellow and violet compose a blue colour. Now if orange and green be primitive colours, in the same manner as red, yellow and blue, we can assign no reason why blue should not be generated by the mixture of the adjacent colours, as well as green and orange. But it is a received principle, that an hypothesis should solve all the phenomina. Of the two hypothesis therefore namely, that there are seven primitive colours, differently refrangible; the latter alone solves all the phenomena of the solar spectrum, and therefore is to be preferred."

According to this hypothesis, Dr. Young deprives the coloured rays of their characteristic property, making some of the red equally refrangible with those of the blue. The following experiment is so easily made and so conclusive on this subject, that I cannot but express a degree of surprise that it should not have occurred to some former experimenter. On holding a quire of white paper immediately behind the prism, and removing it to different distances, we are enabled to trace the mixtures with much accuracy.

EXPERIMENT 21st.

When the paper was placed at about two inches behind the prism, in such a manner as to allow the descending spectrum, partly to fall on the ground, and partly to be received on the paper, by which contrivance the colours could be compared at different distances at one and the same time: that half which fell on the paper was bounded at top and bottom by orange, yellow and blue rays, whilst the middle was occupied with transparent light. But as no prism can possibly be manufactured without the presence of many veins and bubbles, this mediate and transparent light was marked with extremely narrow lines of blue, red and yellow, proceeding from the decomposition of the black light, reflected from these opake veins. The other half of the prismatic spectrum lying on the ground, exhibited the seven colours. On now withdrawing the quire of paper to about a foot distance, the orange and yellow became dilated, and also the blue which was margined with a line of violet.

At this distance, the middle of the spectrum was occupied by two broad streaks of red and blue, yet other veins could be traced. The order of the colours was now as follows, orange, yellow, a dirty blue, red, orange, blue and violet. These colours could be much altered, by turning the prism on its axis; for by diminishing the angle which the prismatic plane made with the perpendicular rays, the mediate red and blue were made to vanish, and green to supply their place: this evidently arose from the overlapping of the rays. On again removing the quire of paper to about the distance of two feet or less, the colours at the margins became dilated; the yellow was seen to spread over the red streaks in the middle, and to form orange: at this distance the yellow from the upper margin, and also from the mediate streaks, intermixed with the blue, forming a green. At somewhat a greater distance, the colours became smooth and well blended, exhibiting the spectrum in all its loveliness. We remark, that although the orange and blue margins approach each other, with every retrocession of the paper, yet the spectrum is lengthened in consequence of the dilatation of the violet and indigo.

Newton says, the red is the least refrangible. Now the fact is, no red exists at the bottom of the ascending, nor at the top of the descending spectrum, it is orange; pure red is only to be seen where the veins occupy the middle. To make this experiment the more conspicuous and conclusive, narrow strips of paper or of black cloth may be pasted on the prismatic plane, to represent veins, and a number of little bits of paper to represent bubbles. The inferences are obvious: the yellow rays being the most refrangible, pass over the red and blue of the middle, making the one green, the other orange. At yet a greater distance the yellow and red of the lower prismatic angle, pass over the blue, forming indigo, and the violet is made with the red and black, or dark light of the apartment.

END OF THE SECOND BOOK.

BOOK III.

Rays of Black light are decomposed, or rarefied into blue, red and yellow colours, by reflexion from semi-transparent and thick plates, provided the surfaces are not parallel.

We now come to the fourth part of the second Book of the opticks, wherein Newton speaks of the refractions and colours of thick and transparent polished plates. "There is no glass or speculum (says this philosopher) how well soever polished, but, besides the light which it refracts or reflects regularly, scatters every way irregularly a faint light, by means of which the polished surface, when illuminated in a dark room by a beam of the sun's light, may be easily seen in all positions of the eye. There are certain phenomena of this scatter'd light, which when I first observed them seem'd very strange and surprising to me. My observations were as follows.

The sun shining into my darkened chamber through a hole one third of an inch wide, I let the intromitted beam of light fall perpendicularly upon a glass speculum ground concave on one side and convex on the other, to a sphere of five feet and eleven inches radius, and quick-silvered over on the convex side. And holding a white opaque chart, or a quire of paper at the centre of the spheres to which the speculum was ground, that is, at the distance of about five feet and eleven inches from the speculum, in such manner, that the beam of light might pass through a little hole made in the middle of the chart to the speculum, and thence be reflected back to the same hole: I observed upon the chart four or five concentric irises or rings of colours, like rainbows, encompassing the hole much after the manner that those, which in the fourth and following observations of the first part of this third book appeared between the object glasses, encompassed the black spot, but yet larger and fainter than those. These rings as they grew larger and larger became diluter and fainter, so that the fifth was scarce visible. Yet sometimes, when the sun shone very clear, there appeared faint lineaments of a sixth and seventh. If the distance of the chart from the speculum was much greater or much less than that of six feet, the rings became dilute and vanished. And if the distance of the speculum from the window was much greater than that of six feet, the reflected beam of light would be so broad at the distance of six feet from the speculum where the rings appeared, as to obscure one or two of the innermost rings. And therefore I usually placed the speculum at about six feet from the window; so that its focus might there fall in with the centre of its concavity at the rings upon the chart. And this posture is always to be understood in the following observations where no other is expressed.

The colours of these rainbows succeeded one another from the centre outwards, in the same form and order with those which were made in the ninth observation of the first part of this book by light not reflected, but transmitted through the two object-glasses. For, first, there was in their common centre a white round spot of faint light, something broader than the reflected beam of light, which beam sometimes fell upon the middle of the spot, and sometimes by a little inclination of the speculum receded from the middle, and left the spot white to the centre.

This white spot was immediately encompassed with a dark grey or russet, and that dark grey with the colours of the first iris; which colours on the inside next the dark grey were a little violet and indigo, and next to that a blue, which on the outside grew pale, and then succeeded a little greenish yellow, and after that a brighter yellow, and then on the outward edge of the iris, a red which on the outside inclined to purple.

This Iris was immediately encompassed with a second, whose Colours were in order from the inside outwards, purple, blue, green, yellow, light red, a red mix'd with purple.

Then immediately followed the colours of the third iris, which were in order outwards, a green inclining to purple, a good green, and a red more bright than that of the former iris.

The fourth and fifth iris seemed of a bluish green within, and red without, but so faintly that it was difficult to discern the colours.

Measuring the diameters of these rings upon the chart as accurately as I could, I found them also in the same proportion to one another with the rings made by light transmitted through the two object glasses. For the diameters of the four first of the bright rings measured between the brightest parts of their orbits, at the distance of six feet from the speculum were $1\frac{11}{16}$, $2\frac{3}{8}$, $2\frac{11}{22}$, $3\frac{3}{8}$ Inches, whose squares are in arithmetical progression of the numbers 1, 2, 3, 4. If the white circular spot in the middle be reckoned amongst the rings, and its central light, where it seems to be most luminous, be put equipollent to an infinitely little ring; the squares of the diameters of the rings will be in the progression 0, 1, 2, 3, 4, *&c.* I measured also the diameters of the dark circles between these luminous ones, and found their squares in the progression of the numbers $\frac{1}{2}$ $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, &c. the diameters of the first four at the distance of six feet from the speculum, being $1\frac{3}{16}$, $2\frac{1}{16}$, $3\frac{2}{3}$, $4\frac{3}{20}$, inches. If the distance of the chart from the speculum was increased or diminished, the diameters of the circles were increased or diminished proportionally.

By the analogy between these rings and those described in the observations of the first part of this Book, I suspected that there were many more of them which spread into one another, and by interfering mixed their colours, and diluted one another so that they could not be seen apart. I viewed them therefore through a prism, as I did those in the 24th observation of the first part of this book. And when the prism was so placed as by refracting the light of their mixed colours to separate them, and distinguish the rings from one another, as it did those in that observation, I could then see them distincter than before, and easily number eight or nine of them, and sometimes twelve or thirteen. And had not their light been so very faint, I question not but that I might have seen many more." The remainder of this Book, is taken up with mathematical calculations, and musical analogies.

These experiments were resumed by the Duke De Chanlnes, who ascribed the colours to an inflection of light. He observed, that when the nearer surface of the glass mirror was clouded, by breathing upon it, so as lightly to tarnish it, a white, diffused, and vivid light was seen upon the pasteboard, and all the colours of the rings became much stronger and more distinct. This appearance he made constant by moistning the surface of the mirror, with a little milk and water, and suffering it to dry upon it.

In all his experiments upon this subject, (he says,) he found that when the rays fell converging on the surface of the mirror, the rings were hardly visible; when they fell parallel upon it, as they must have done in all the experiments of Newton, they appeared sufficiently distinct; but when by means of a convex-lens placed in the hole of the window, they were made to diverge from the centre of the sphere to which the mirror was ground, so that they fell perpendicularly upon the surface of the mirror, the colours were as vivid as he could make them. In this case he could remove the reflected image to a great distance from the hole, without making the rings disappear, and he could plainly perceive them to arise from their central spots, which changed their colours several times.

The effect of tarnishing the mirror made the Duke De Chanlnes think that these coloured rings depended upon the first surface of the mirror, and that the second surface, or that which reflected them, after they had passed the first, only served to collect them, and throw them upon the pasteboard in a quantity sufficient to make them visible, and (he says) he was confirmed in his supposition by the following experiments.

He took a plano-convex glass, of six feet focus, and placed it six feet from the pasteboard, with its convex side towards it. By this means the rays which fell upon that surface, after being refracted there, were transmitted through the thickness of the glass parallel to one another, and fell perpendicularly upon the plane surface that reflected them, and in their turn would be collected upon the pasteboard. In these circumstances the rings appeared very distinct, after he had tarnished the convex surface, which in this position, was next to the light.

Turning the same glass the contrary way, so that the plane surface was towards the pasteboard, he could perceive none of the rings at the same distance of six feet; but they were visible at the distance of three feet, because at that distance, the second surface reflected the rays, by its concavity, directly towards the pastebo ard.

These two experiments (says the Duke,) demonstrate the use of the second surface of the mirror, and shew the manner of placing it to the most advantage. These that follow, shew the use of the first surface with respect to these rings: and he was led to make them by the casual observation above mentioned.

Newton, he observes, had remarked that, when he made use of a mirror of the same focus with the first that he had used, but of twice the thickness, he found the diameter of the rings much smaller than before. This observation the Duke thought to be favourable to his own conclusions; for if these rings depend upon the first surface, the nearer it is to the second, which only reflects the rays transmitted from it, the larger they ought to appear on the pasteboard.

To ascertain the fact, he thought of making use of two moveable surfaces, and a mocrometer, to measure the distance between them with exactness. For this purpose he took a metallic mirror, belonging to a reflecting telescope, being part of a sphere of ten feet radius, and he fixed it upon a foot in which was a groove, that carried a light frame, to which was fastened a thin piece of talc, tarnished with milk and water.* The frame that supported the piece of talc, could either be brought into contact with the mirror, or be removed to the distance of eight or nine inches from it, and the micrometer shewed, to the utmost exactness, the least motion of the frame.

Having placed this mirror ten feet from the pasteboard, that is, at the distance of the radius of its own sphere, he observed the rings to appear very distinct, the form of his mirror being very true; but the diameter of the rings upon the pasteboard varied with the distance of the talc from the mirror, so that they were very large when the talc was near the mirrror, and very small when it was placed at the distance of seven or eight inches.

* A view of this apparatus, and diagrams of his experiments may be seen in Priestley's work, on vision, light and colours, fig. 111.

The Duke De Chanlnes, thought these experiments proved that the rings were formed by the first surface, and reflected by the second; but it still remained to be determined in what manner they were to be formed. He immagined that the small pencils of rays that were transmitted through the pores of the glass, or any other transparent substance, might suffer a kind of inflection, which might change the cylinder which they formed, into a truncated cone, either by their different degrees of inflexibility, or by the different distances at which they pass by the edges of the small hole. Pursuing these ideas, he thought of making use of some body, the pores of which were of a known and determinate shape. Instead therefore, of the piece of talc, he placed a piece of fine muslin in the above mentioned square, streching it as even as possible, to make the pores formed by the threads more exact and more permeable to the light: and he soon found with great pleasure, that his conjecture was verified; for instead of the circular rings which he had before, they were now manifestly square, though their angles were a little rounded, and they were coloured as the others, though the light was not very vivid, on acount of the quantity that was stopped by the muslin.

When instead of the muslin, he stretched across his frame fine silver wires, exactly parallel, at the distance of about three quarters of a line, or a whole line from one another, without any other wires across them; instead of the rings, which he had seen before, there was nothing upon the pasteboard but a gleam of white light, divided by many small streaks, coloured in a very vivid manner, and in the same order as in the rings.

Lastly, in order to simplify the experiment, and to bring it into a nearer comparison with those of Newton on the inflection of light, instead of the frame above mentioned, he fixed nothing but the edge of a knife, and he had the same appearance as with the silver wires, except that the light was much less intense, though sufficient to prove the identity of the effect."

Nothing more clearly shews the fallacy of the present theory of opticks, than the instability of these experiments and all others connected with the subject. As it has been already seen that the colours of the prism and those of thin plates, chiefly depend on the rarefaction of black light, so in the following pages I hope to shew, that the rings by reflection proceed from the same cause. But previous to any critical remarks on the opinions of Newton and the Duke De Chaulnes, I think it necessary to relate a few simple experiments; convinced, that one well regulated experiment is preferable to a volume of speculations.

EXPERIMENT 22nd.

A PLANO-CONVEX, OR A CONVEXO-CONVEX SPECULUM, HAS BOTH A REFRACTED AND A REFLECTED FOCUS, REGULATED BY SIMILAR LAWS.

Having held a small plano-convex lens or burning glass, about two inches diameter and two and a half focus, opposite a candle, I received the refracted light on a sheet of white paper, held at about one inch behind. A circle of black light, margined at the inside with bright orange rays, was seen to surround this refracted and emergent light, appearing much brighter than that reflected from other parts of the same paper. I need scarcely remind the reader, that these orange rays proceeded from the partial decomposition of the black light passing through the lens, and reflected from the opake circumference. The light received at this distance, I would call the refracted antifocal light. Having examined it for some time, I removed the sheet of paper to about two inches and a half from the lens, and perceived the mediate light to become more condensed, and finally converging and crossing to a focus, an exact image or representation of the candle was formed. This has been already called the focus of refracted light by optical writers. I now gently removed the sheet of paper to yet a greater distance and perceived the image of the candle to encrease in size, to become dilute and finally to vanish. This light margined with blue instead of orange rays, I would term the refracted postfocal light. So far these phenomena have been already noticed and attributed to the aberration of light, an unmeaning and absurd term.

However the following part of this experiment is new and I hope may prove acceptable to men of science. Having desired an artist to quicksilver the plane surface of this lens, for the purpose of the better examining the reflections, I was surprised yet pleased to discover that both the reflected and refracted lights were regulated by similar laws, with this difference that the reflected focus was nearer. As these appearances are of the first consequence in our investigations on the colours of thick plates, I shall be somewhat particular.

Having held this plano-convex lens, with its convex surface towards the candle, and a sheet of paper about half an inch before it, in such a position as to receive the reflected light, a luminous and converging circle margined with orange rays was perceived. This we may call the reflected antifocal light. On now withdrawing the paper to about one inch, these rays were seen gradually to converge, and finally to form an inverted image of the candle, this may be called the reflected focus. Beyond this point the rays diverged, the outline of the image being destroyed. This we may call the reflected postfocal light. Here there was no concave surface to reflect and make the rays decussate. Indeed neither Newton nor the Duke De Chaulnes seem in the least to have attended to the course of these reflected rays.

EXPERIMENT 23rd.

BLACK LIGHT IS DECOMPOUNDED OR RAREFIED INTO COLOURS BY REFLECTION, FROM BOTH SURFACES OF A REFRACTING SPECULUM.

Being convinced from numerous experiments, that the decomposition of black light by reflection, was in a ratio to the curviture or refracting power of the lens, and to make the phenomena as conspicuous to the spectator as possible, I procured a large plano-convex lens belonging to a magic lantern, quick-silvered on the plane surface, and to avoid any extraneous reflections which may tend to confuse the results, I laid it on a writing table, resting on the plane or quick-silvered side, by which means nothing but the white ceiling was reflected. I now held a black knitting needle, so as to bisect the hemisphere, or as a tangent to the vertex, when I perceived two reflected images; one at the anterior surface, putting on a curved form, the other reflected from the posterior or plane surface, much magnified: both appeared black, for at the vertex there was scarcely any degree of curviture. I now moved the needle, still making it touch the lens, towards the lower refracting angle, and perceived the posterior reflected image to become curved at top and bottom. In proportion as the needle descended, the shadow was dilated and put on a clothing of blue at top, black in the middle, and orange at the bottom. When it arrived nearly at the lower refracting angle, it was curved into an oval, or nearly into the form of a capital D. When the same needle was moved from the vertex towards the upper refracting angle, similar appearances took place, with this difference, that the curviture was upwards, and the colours reversed, the orange being above, the blue below. On again bringing the shadow to the vertex, so as to bisect the hemisphere, and raising the knitting needle about one inch, I perceived that there were three posterior images; the two at top and bottom were perfectly curved, and a straight one in the middle. The two curved ones were beautifully coloured and seemed to surround the circumference, whilst the third bisected them or rather the lens. That these were distinct and separate images of the same object was evident, for by gently moving the needle either upwards or downwards, the middle image was seen to leave the one and join the other, but never could be made to exist separate from both. On raising the needle a little higher from the lens, the two curved images regulated by the curviture of the lens began to close, in the same manner as if two meridian circles of an armillary sphere were brought together, whilst the middle and erect image became dilated, and at last vanished. I omitted to mention that these curved images which joined, were from their first formation inverted; so that it is an error in opticks to think that the erect image by reflection becomes an inverted one.

With every encreasing distance of the needle from the speculum, this inverted image which now remained alone in the field, diminished in size, and could be made to change the colours at top and bottom and also its curvi-ture, by bringing it over either the superior or inferior refracting angle. When the coloured oval was formed by the union of the erect and one of the inverted images, it immediately re-minded me of the change of colour, which the centre underwent from pressure, in the experiments with thin plates. Regulating the distance of the needle, I could make the centre of the oval formed from these two images, of any desired colour. In this experiment my eye acted in the place of a screen. I next varied the experiment in the following manner.

Having placed the convex surface of the speculum opposite the sun, shining powerfully into my apartment; I threw the reflected light on a quire of white paper, at about one foot distance. In this light, between the speculum and screen, and touching the former, I held a black pin: on bringing it from the vertex towards the lower or upper refracting angle of the lens, the same appearances as just now described took place. At a given distance the two images of the pin were seen to join at top and bottom on the screen, and to form a coloured oval: the centre of the oval, by regulating the distance of the pin, could be made of any desired colour. At somewhat a greater distance, this oval vanished, and one inverted image of the pin remained, displaying the most brilliant tints of blue and orange. It would be difficult according to the Newtonian theory to account, why the shadows of a straight needle became a coloured oval. As a complete refutation of the opinion, that the colours by reflection depend on any particular thickness of the plate, we have only to remark, that this oval can be made to pass from the vertex to the angle and back again, without any change of colour, that is, through every alternate thickness. This experiment will be more particularly resumed in the second volume of these outlines.

EXPERIMENT 24th.

Having procured a small mourning ring, I held it immediately over the vertex of the same lens, placed on a writing table in the shade, my eye at about a foot distance; and perceived a magnified image reflected from the posterior surface; the inside of the circumference was blue, black in the middle, and orange outside, or towards the refracting angle. This posterior image was erect, for the shadow of my finger holding the ring, was at the same side with the real one. On gently raising the ring, still keeping the shadowed image around the vertex, I perceived a second ring or image to come from the circumference of the lens and to contract in diameter, according as the ring was raised from the vertex. This image was considerably larger, appearing nearer to the eye, and the colours were reversed in regard to the first, the orange being at the inner margin, the blue at the outer. On raising the ring a little higher, a third and much larger ring came from the circumference, with the colours in the same order as in the second ring. This last image decreased with every encreasing distance of the object from the lens. When the ring was withdrawn to a certain distance, perhaps about one inch and half, the two inner images became confused, the colours spreading, and at last they vanished and left the lenticular field entirely to the inverted one. These were the appearances in the shade, my eye like a screen receiving the reflected rays. We remark in this experiment, that the posterior reflected image is black in the middle when the ring touches the vertex or convex surface, but when removed to a greater distance, the rays of black light are magnified and rarefied entirely into colours. In fact every succeeding experiment adds encreasing stength to the discovery, that all these colours proceed from the decomposition of shadowed and black light.

In reading with a deep magnifying glass, the same appearance may be seen by transmission, for when the black letters are immediately under the vertex, they appear black, but when brought near to the refracting angle, the eye being at the same distance, they are seen to become magnified and changed into blue, red and yellow. When reading very small print with a powerful plano-convex speculum, I am in the habit of decomposing the letters, for the purpose of magnifying and distinguishing them the better. Having as in the preceding experiment thrown the shadows of this mourning ring on a screen in the sun shine, I perceived similar appearances as in the shade. When the lens was about a foot from the screen, and the ring close to the vertex, two inverted and coloured images were reflected: as the ring was gently removed towards the screen, these images encreased in size, became confused, and at a certain distance gave place to one inverted and coloured image.

EXPERIMENT 25th.

THE COLOURS ARE PRODUCED BY BOTH SURFACES OF THE SPECULUM.

The Duke De Chaulnes thought his experiments proved, that the rings were formed by the first surface and reflected by the second, and that the appearances were to be attributed to the inflection of light. The following experiment shows, that they are formed and reflected by both surfaces, and are to be attributed to the decomposition of black light.

Having painted six black dots about the size of a large pin's head, in a circular manner, around and near the refracting angle of the quick-silvered speculum, and also having made a dot on the vertex; on looking at the anterior and posterior surfaces, I saw, that the six anterior black dots, threw their shadows on the plane and posterior reflecting surface, from whence they come to the spectator's eye beautifully decomposed into blue and orange, without a single tinge of black. These six dots on the anterior and convex surface appeared to the eye perfectly black. Here we must be convinced, that the black rays, in passing from the anterior to the posterior reflecting surface, were completely decomposed by refraction; for on looking at the reflected images of the dot, at or near the vertex it appeared black in the middle, with a narrow margin of colours around it, nor was it above half the size of those near the angle. To bring this experiment as near as possible to that of the Duke's, I held the lens perpendicular to the solar rays, and reflected the black dots to a screen at about a foot distance: here I saw two sets of coloured dots, six large and six small, both sets blue and orange, and both inverted.

Let us now stop, to make a few remarks. The first difficulty is to account, why the anterior dots, black to the eye, should appear coloured on the screen. Analogy informs us, that in a former experiment, when a pin or any opake body was held in the refracted light of the prism, its shadow was decompounded in the same manner as it would have been, had the black rays passed through the refracting medium. The same thing happens here. When the solar light passes through the lens, it is refracted in consequence of meeting many opake atoms in the glass. When reflected, it mixes with and decomposes the black light, passing from the anterior dots to the screen. The nebulous light is not sufficiently powerful to produce this effect in the shade; hence the differenee. A question also arises in the mind, whether reflection alone without refraction, be under any circumstances capable of decomposing light; I am led to think not. I am aware, that Dr. Herschel produced colours, by reflecting the shadows of hair powder, from a polished metalic speculum,* but when we consider that the effect of polishing the speculum, is to render some of the opake atoms at the surface semi-transparent, and thus to produce two reflecting surfaces, we are not to esteem this experiment an exception, for we know, that the opake atoms of glass, after leaving the furnace, are quickly polished into semi-transparency by the wheel. However I only give this opinion as probable, not having as yet made sufficient experiments.

For the purpose of repeating the Duke De Chaulnes' experiments, I tarnished the convex surface of my reflecting speculum with milk and water: on allowing it to dry, I perceived that the stain was not regular, but here and there opake and round spots, thicker than the

* Vide. Experiments on coloured rings in one of the late Numbers of the philosophical transactions.

rest, sent their shadows to the posterior surface, whence they were reflected to the eye in a decompounded state, forming appearances like rings of different colours. When these stains were uniform and thin, the posterior reflections were white, and surrounded by a circumference of different colours,

The Duke De Chaulnes was mistaken in supposing the rays were transmitted from the anterior to the posterior surface of his speculum parallel to one another; for if that were the fact, the reflections from both surfaces should appear of the same size, whereas they diverge, forming a magnified image at the posterior one.

The reason the rings did not appear on his screen when the plane surface was turned, at six feet or the focal distance of his lens, is easily accounted for on the principle, that the foci of the two surfaces were different, and that the colours were not conspicuous until after the decussation of the rays. I presume the following experiment will appear interesting, and throw light on this hitherto obscure subject.

EXPERIMENT 26th.

THE COLOURS IN NEWTON'S EXPERIMENT WERE OCCASIONED BY THE BLACK LIGHT, REFLECTED FROM THE INNER MARGIN OF THE HOLE IN THE QUIRE OF PAPER.

May, 20th. 1816, at 12 o'Clock, the sun shining into my apartment, I removed a pane of glass from the window, and in its stead substituted a piece of white pasteboard, perforated in the middle by a triangular hole. On holding the plano-convex lens with its convex surface towards the pasteboard, at about one inch behind the hole; I perceived two species of light coming through, the one reflected from the clouds, which formed, when sent back to the screen, a lucid circle of weak light, margined with orange rays. In the centre of this circle, appeared an erect image of the hole, margined round with coloured light, blue at top, orange at the sides.

There was likewise another reflection from the anterior surface, which it is unnecessary to notice, as our attention must principally be directed to the colours of the Newtonian experiment. That the two lights just mentioned, were separate and distinct, appeared from the circumstance, that they could be thrown to different parts of the pasteboard, by raising the lens out of the perpendicular line. I also observed that both species of reflected light could be converged to a focus. For the sake of distinction, we might call the one, the nebulous, the other the solar light. At about two inches and a half, the solar light when reflected converged to a focus, and instead of the triangular hole, represented the meridian sun, bright and colourless. The nebulous light also converged, but as the focus was more distant, it appeared as a circle, margined with orange, having an image of the sun in the centre. If the lens were removed somewhat farther from the screen, the nebulous light also converged to a focus, and at yet a greater distance, the two species formed two inverted images of the triangular hole, encreasing in size, in a ratio to the distance of the lens from the screen, until at last the light became so faint and dilute as not to be distinguished from the light of the room. At about five or six inches distance, these two inverted representations of the hole were, the one within the area of the other, and both were margined with different colours. If this experiment were made with the rays passing through a circular hole, such as represented by Newton, instead of being triangular, the colours would form concentric rings, depending on the shape of the hole. This must convince every unbiased reasoner, that the coloured rings do not depend on the thickness of the plate, for no triangular hole could possibly be cut in a convex lens, whose thicknesses would be equal.

EXPERIMENT 27th.

Perhaps it might be objected with some

force, that this last experiment is entirely different from Newton's, the one being made with a concavo-convex lens, the other with a plano-convex one; I therefore requested an artist to quicksilver a concavo-concave lens, as I could not in this city procure one similar to Newton's. Indeed the concavo-concave is much preferable to a lens with parallel curves, the brilliancy and intensity of the colours always depending on the size of the refracting angle.

Having fixed the piece of pasteboard in the frame of a dressing glass, moveable on two pins, I placed a lighted candle behind. I now held the concavo-concave lens, of two and a half inch reflected focus, at about one inch distance, and perceived two erect images of the hole to be represented by reflection on the screen, both margined with coloured rays, especially when the images were reflected from either side of the lens. On withdrawing the speculum to about two inches and a half, the rays belonging to the small and inner image, converged to a regular focus, or inverted representation of the candle, whilst the larger image remained foraminous, and encreased in size with every retrocession of the glass. At yet a greater distance, the small image likewise became foraminous. On viewing the surface of the lens, it was easy to ascertain, that the large image came from the anterior, never being inverted, and that the small image came from the posterior surface, that is, the rays crossed before they arrived at the eye. I preferred making this experiment with a candle, to demonstrate the inversion and focus. I now varied it in the following manner.

Having placed the frame carrying the pasteboard on a table in the sun-shine, I held the concave-concave lens at about one inch behind it, when I perceived two erect images, the one within the area of the other. On regulating the lens in such a manner, as to make the rays fall near the vertex, there were scarcely any colours at the edges, because the surfaces were nearly parallel, and therefore little refraction, but on causing them to be reflected from either side, the colours, blue and orange were beautifully marked. In the Newtonian experiments, a glass of such a long focus was highly unfit, and in all probability was the reason that this philosopher seems to have examined the phenomena in such a superficial manner. Removing the lens to about two inches and a half, the small image came to a focus, whilst on the contrary, the other diverged, becoming larger and larger. The two images now appeared, the one inverted, the other erect, and with every encreasing distance of the lens from the screen, they both encreased in size. I now held a pin close to the lens, and within the area of the images, when two erect shadows were reflected in the antifocal light of both images, but in the postfocal reflected light, the images were erect in the larger reflection, in the smaller one inverted. These shadows of the pin were entirely decomposed or rarefied into blue and orange, when sent from the refracting angle:

near the vertex they were black in the middle.

In this experiment like the former, the shadow of the pin reflected from the anterior surface to the screen, was rarefied into colours, by mixing with the refracted light sent from the posterior one.

To ascertain the calorific power of the reflected foci, I placed a thermometer, standing at 60° at the screen, so that the bulb received the focal image. In one minute, from the plano-convex lens, it rose to 100°, or gained 40°. The heat of the image of the sun, reflected from the concave lens, was eight degrees, when the beams were very powerful.

From these experiments and many others, unnecessary to relate at present, I am led to infer, that the coloured rings in the Newtonian experiment, arose from the rarefaction of black rays of light, reflected from the inside of the hole in his chart. I suspect he was mistaken as to the focal distance, as the rings are better marked in the postfocal than in the antifocal light. The focal light is perfectly achromatic, or the coloration is overcome by the intensity of the radiation. We are also led to infer, that the colours produced in the Duke De Chaulnes' experiments, are not to be attributed to the inflection, but to the reflection, refraction and rarefaction of the black shadows sent from the silver wires, &c.

Before we proceed to consider what has been termed the inflection or diffraction of light, I would beg leave to state an experiment, which more properly belongs to the first Book of these outlines. I have already mentioned, that Newton drew a far fetched distinction between coloured and colour-making rays. The following experiment must for ever set aside such a curious opinion.

The sun shining into a darkened room thro' a circular hole in my window-shutter, about half an inch in diameter; I placed a prism so as to make the beam pass through the lower refracting angle to the wall; on looking closely at the emergent rays, I perceived them exactly like a skein of silk, differently coloured. The blue and red were very conspicuous. The other colours could not be perceived.

INFLECTION OF LIGHT.

Sir Isaac Newton supposed, "that a beam of light compounded of seven rays, was separable into colours or decomposable, by passing within a certain distance of an opake body. To illustrate this opinion, he made a small hole with a pin in a piece of lead, the breadth of which was the 42nd. part of an inch. Through this hole he let into his darkened chamber a beam of the sun's light, and found that the shadows of hairs, and other slender substances placed in it, were considerably broader than they would have been, if the rays of light had passed by these bodies in right lines.

He therefore concluded that they must have passed as they are represented in a plate of the opticks. Since, when the paper which receives the rays is at a great distance from the hair, the shadow is broad, it must follow, he observes, that the hair acts upon the rays of light at some considerable distance from it, the action being strongest on those rays which are at the least distance, and growing weaker and weaker on those that are farthest off. And hence it happens, that the shadow of the hair is much broader in proportion to the distance of the paper from the hair when it is nearer, than when it is at a great distance

He says he found, that it was not material whether the hair was surrounded with air, or with any other pellucid substance; for he wetted a polished piece of glass, and laid the hair in the water upon the glass, and then laying another polished plate of glass upon it, so that the water might fill up the space between the glasses, and holding them in the beam of light, he found the shadow, at the same distance was as big as before. Also the shadows of scratches made in polished plates of glass, and the veins in the glass, cast the like broad shadows, so that this breadth of shadow must proceed (continues Newton) from some other cause than the refraction of the air.

The shadows of all bodies, metals, stones, glass, wood, horn, ice &c. in this light, were bordered with three parallel fringes, or bands of coloured light, of which, that which was contiguous to the shadow was the broadest and most luminous, while that which was the most remote was the narrowest, and so faint, as not easily to be visible. He says, it was difficult to distinguish these colours, unless when the light fell very obliquely upon a smooth paper, or some other smooth white body, so as to make them appear much broader than they would otherwise have done; but in these circumstances the colours were plainly visible, and in the following order. The first or innermost fringe was violet, and deep blue next the shadow, light blue, green, and yellow in the middle, and red without. The second fringe was almost contiguous to the first, and the third to the second, and both were blue within, and yellow and red without; but their colours were very faint, especially those of the third. The colours therefore, proceed in the following order, from the shadow; violet, indigo, pale blue, green, yellow, red, blue, yellow, red, pale blue, pale yellow, and red. The shadows made by scratches and bubbles in polished plates of glass, were bordered with the like fringes of coloured light.*

He also observes that, by looking on the sun through a feather or black ribbon, held close to the eye, several rainbows will appear, the shadows, which the fibres or threads cast on the retina being bordered with the like fringes of colours.

Measuring these fringes and their intervals with the greatest accuracy, he found the former to be in the progression of the numbers 1. $\sqrt{\frac{1}{3}}$ $\sqrt{\frac{1}{5}}$, and their intervals to be in the same progression with them, that is, the fringes and their intervals together to be in the continual progression of the numbers 1. $\sqrt{\frac{1}{2}}$, $\sqrt{\frac{1}{3}}$, $\sqrt{\frac{1}{4}}$, $\sqrt{\frac{1}{5}}$ or thereabouts. And these proportions

* Opticks, page 293.

held the same very nearly at all distances from the hair, the dark intervals of the fringes being as broad in proportion to the breadth of the fringes at their first appearance, as afterwards at great distances from the hair, though not so dark and distinct."

I have repeated this experiment with great care, and can assure the reader, that so far from being able to measure their breadths to a mathematical certainty, I could scarcely perceive the colours. Newton, and all other opticians, impressed with the idea, that shadow was a mere privation of light, were necessarily obliged to attribute these colours to the decomposition of the solar rays.

When the black shadow of the hair was broad, these colours were apparent, but when the hair was brought very near the paper, the black rays or shadows were condensed, and no colours whatsoever were perceived; demonstrating in a satisfactory manner that they proceeded from the rarefaction of black light, and not from any decomposition of the solar ray, which is simple and homogeneous. Further to illustrate the theory of inflection, Newton made the following experiment.

The sun shining into his darkened chamber, through a hole $\frac{1}{4}$ of an inch broad, he placed, at the distance of two or three feet from the hole, a sheet of pasteboard, black on both sides, and in the middle of it he made a hole about $\frac{3}{4}$ of an inch square, for the light to pass through, and behind the hole he fastened to the pasteboard the blade of a sharp knife, to intercept some part of the light which passed through the hole. The planes of the pasteboard and blade of the knife were parallel to one another, and perpendicular to the rays; and when they were so placed that none of the light fell on the pasteboard, but all of it passed through the hole to the knife, and there, part of it fell upon the blade of the knife, and part of it passed by its edge: he let that part of the light which passed by, fall on a white paper, 2 or 3 feet beyond the knife, and there saw two streams of faint light shoot out both ways from the beam of light into the shadow, like the tails of comets. But because the sun's direct light, by its brightness upon the paper, obscured these faint streams, so that he could scarce see them, he made a little hole in the middle of the paper for that light to pass through and fall on the black cloth behind it; and then he saw the two streams plainly. They were like one another, and pretty nearly equal in length, breath, and quantity of light. Their light at that end which was next to the sun's direct light, was pretty strong for the space of about $\frac{1}{4}$ of an inch, or $\frac{1}{2}$ an inch, and decreased gradually, 'till it became insensible.

The whole length of either of these streams, measured upon the paper, at the distance of three feet from the knife, was about 6 or 8 inches, so that it subtended an angle, at the edge of the knife, of about 10 or 12, or at most 14 degrees. Yet sometimes he thought he saw it shoot 3 or 4 degrees farther, but with a light so very faint, that he could hardly perceive it. This light he suspected might, in part at least, arise from some other cause than the two streams. For, placing his eye in that light, beyond the end of that stream which was behind the knife, and looking towards the knife, he could see a line of light upon its edge, and that not only when his eye was in the line of the streams, but also when it was out of that line, either towards the point of the knife, or towards the handle. This line of light appeared contiguous to the edge of the knife, and was narrower than the light of the innermost fringe, and narrowest when his eye was farthest from the direct light; and therefore seemed to pass between the light of that fringe and the edge of the knife; and that which passed nearest the edge seemed to be most bent, though not all of it.

He then placed another knife by the former, so that their edges might be parallel and look towards one another, and that the beam of light might fall upon both the knives, and some part of it pass between their edges. In this situation he observed that, when the distance of their edges was about the 400th. part of an inch, the stream divided in the middle and left a shadow between the two parts. This shadow was so black and dark, that all the light which passed between the knives seemed to be bent and turned aside to the one hand or to the other; and as the knives still approached one another, the shadow grew broader, and the streams shorter, next to it, 'till, upon the contact of the knives, all the light vanished.

From this experiment, Sir Isaac Newton concludes, that the light which is least bent, and which goes to the inward ends of the streams, passes by the edges of the knives at the greatest distance; and this distance, when the shadow began to appear between the streams, was about the 800th. part of an inch; and the light which passed by the edges of the knives, at distances still less and less, was more and more faint, and went to those parts of the streams, which were farther from the direct light; because when the knives approached one another 'till they touched, those parts of the streams vanished last, which were farthest from the direct light.

In the experiment with one knife only, the coloured fringes did not appear; but, on account of the breadth of the hole in the window, became so broad as to run into one another, and, by joining, to make one continual light in the beginning of the streams; but in the last experiment, as the knives approached one another, a little before the shadow appeared between the two streams, the fringes began to appear on the inner ends of the streams, on either side of the direct light, three on one side, made by the edge of one knife, and three on the other side, made by the edge of the other knife. They were the most distinct when the knives were placed at the greatest distance from the hole in the window, and became still more distinct by making the hole less; so that he could sometimes see a faint trace of a fourth fringe, beyond the three above mentioned; and as the knives approached one another, the fringes grew more distinct and larger, 'till they vanished; the outermost vanishing first, and the innermost last. After they were all vanished, and the line of light which was in the middle between them, was grown very broad, extending itself on both sides into the streams of light described before, the above mentioned shadow began to appear in the middle of this line, and to divide it along the middle into two lines of light, and increased 'till all the light vanished. This enlargement of the fringes was so great, that the rays which went to the innermost fringe seemed to be bent about 20 times more when the fringe was ready to vanish, than when one of the knives was taken away.

From both these experiments compared together, Newton concluded, that the light of the first fringe passed by the edge of the knife at a distance greater than the 800th. part of an inch; that the light of the second fringe, passed by the edge of the knife, at a greater distance than the light of the first fringe, and that of the third at a greater distance than that of the second; and that the light of which the streams above mentioned consisted, passed by the edges of the knives at less distances than that of any of the fringes."

I think it perfectly unnecessary to pursue these experiments any farther, referring the reader to the opticks.

EXPERIMENT 28th.

Having made a circular hole in my window shutter $\frac{1}{4}$ of an inch in diameter, I received the sun shine on a quire of white paper, and at a foot distance perceived the circumference of the image of the hole to be margined with rays of dirty orange. At the lower part, the hole in the window shutter was a little ragged, and here I could discern some blue. This margin of colours increased with every increasing distance of the quire of paper, and the image became larger and larger until, at about six feet, the image of the hole measured one inch in diameter; and here the coloured margin seemed to be the most conspicuous. On receiving the light somewhat obliquely, a blue tinge inside the dirty orange, was very perceptible; but these colours were so ill defined that it would be perfectly absurd to attempt any measurement.

I now fixed a black pin diametrically across the hole in my window shutter, and receiving the image immediately behind, perceived the shadow of this pin perfectly black. On gently removing the paper to a greater distance, I first perceived the shadow to become dilute, broad, and then coloured of a dirty orange and blue. At about three feet from the window the shadow vanished, spreading into the solar light.

From this experiment we must infer that, the solar light and also the black rays of light diverge, in passing through the hole, and that the colours are not to be attributed to any inflection of the solar rays, but to the rarefaction of the black light reflected from the edges of the inside of the circular hole in the window shutter, and also from the shadow of the black pin bisecting the circumference.

As far as I know, no person has hitherto noticed the colours at the edges of the foraminous image. A penknife or any other polished substance was perfectly unfit for these experiments; for on looking either at the plane surface or at the edge of a penknife in the solar light, transmitted through the hole, a number of colours are reflected from the coloured and opaque atoms, which are intermixed with the semi-transparent and polished ones. These are particularly evident within the area of the refracted image of the sun. The edge of the knife looks exactly like a spider's rope when sparkling in the sun beams with different colours. A human or horse's hair has the same appearance, as may be seen by allowing the solar light, coming through a hole in the window shutter, to fall on the seat of a black horse hair chair, when it immediately becomes veriagated with the most exquisite colours. I shall take leave of this part of the subject by relating one more experiment from the opticks.

The sun shining into his darkened room, through the small hole mentioned above, he placed at the hole, a prism to refract the light, and to form on the opposite wall, what he erroniously conceived to be an image of the sun; and he says he found, that the shadows of all bodies held in the coloured light between the prism and the wall, were bordered with fringes of the colour of that light in which they were held; and comparing the fringes made in the coloured lights, he found that, those made in the red light were the largest, those made in the violet were the least, and those made in the green were of a middle bigness. For the fringes with which a man's hair was bordered, being measured across the shadow, at the distance of six inches from the hair, the distance between the middle and most luminous part of the first or innermost fringe on one side of the shadow, and that of the like fringe on the other side of the shadow, was, in the full red light $\frac{1}{37\frac{1}{2}}$ of an inch, and in the full violet $\frac{1}{46}$

The like distance between the middle and most luminous parts of the second fringes, on either side of the shadow, was in the full red light $\frac{1}{22}$nd and in the violet $\frac{1}{27}$th of an inch; and these distances of the fringes held the same proportion at all distances from the hair, without any sensible variation.

From these observations, it was evident,(continues Newton,) that the rays which made the fringes in the red light, passed by the hair at a greater distance than those which made the like fringes in the violet; so that the hair, in causing these fringes, acted alike upon the red light or least refrangible rays, at a greater distance, and upon the violet or most refrangible rays at a less distance; and therefore occasioned fringes of different sizes, without any change in the colour of any sort of light.

It may, therefore, be concluded, that when the hair in the first observation was held in the white beam of the sun's light, and cast a shadow which was bordered with three fringes of coloured light, those colours arose not from any new modifications impressed upon the rays of light by the hair, but only from the various inflections whereby the several sorts of rays were separated from one another, which before separation, by the mixture of all their colours, composed the white beam of the sun's light; but when separated, composed lights of the several colours which they are originally disposed to exhibit."*

So far from admitting those conclusions, experiment informs us, that it is the black shadow or rays of black light which are rarefied by means of the refracted and solar light into colours. When a pin, a hair, or any other black and slender substance is placed in the transparent light emerging from the prism, at a given distance from the spectrum the shadow is bordered by blue on one side, and by orange at the other; no more colours appear. At yet a greater distance the entire of the black shadow is changed into blue and orange. What became of the other component colours? What

* Opticks page 311.

became of the black shadow? Indeed, next to the inconsistency of supposing transparent light to be a compound of different colours, is that of supposing the affinities so weak, as to be affected by passing within a certain distance of an opake body; and moreover that decomposition was occasioned by two opposite causes repulsion and attraction. If the rays composing white light were all acted on according to their different degrees of refrangibility at the same time, no decomposition or separation would result. For according to the Newtonian hypothesis, there is no reason that all the least refrangible or red rays passing by at different distances, should be brought together so as to form a red fringe, unless the force of attraction be associated with a power of assortment, which is absurd.

When the pin above mentioned, is held near the spectrum or paper, perhaps at the distance of $\frac{1}{4}$ of an inch, the blue and orange rays are condensed, and form a perfect black shadow. This fact is sufficient in itself to overturn the entire conclusions drawn by Newton. For farther information on this interesting subject, I must refer to the experiment itself; these outlines being only intended as preliminary to a more extensive work, and to stimulate investigation.

For the readers amusement I shall give the following queries, taken from the opticks; Newton never pursuing the subject of inflection any farther. This is the more surprising as the caustic Dr. Hooke was dead. (So Dr. Thompson, in his history of the Royal Society, stiles this celebrated philosopher, because he dared to think and write against Newton.)*

Quere I. Do not bodies act upon light at a distance, and by this action bend its

* Sir Isaac Newton, in an Advertisement prefixed to the opticks says, "To avoid being engaged in disputes about these matters, I have hitherto delayed the Printing, and should still have delayed it, had not the importunity of friends prevailed on me." This reason for delay has been eulogised by some of this great man's indiscriminate admirers; however, I cannot help thinking, that the withholding a benefit from the public, for the sake of personal ease, or dread of such an able adversary as Hooke, was unworthy the Name and abilities of Newton.

rays; and is not this action the strongest at the least distance?

II. Do not the rays which differ in refrangibility differ also in inflexibility, and are not they by their different inflections, separated from one another, so as to make the coloured fringes above mentioned; and after what manner are they inflected to make those fringes?

III. Are not the rays of light, in passing by the edges and sides of the bodies, bent several times backward and forward, with a motion like that of an eel; and do not the three fringes of coloured light above mentioned, arise from three such bendings?

IV. Do not the rays of light which fall upon bodies, and which are reflected and refracted, begin to bend before they arrive at the bodies; and are they not reflected, refracted and inflected by one and the same principle, acting differently in different circumstances?

The answer to these queries is, that

the solar light is simple and homogeneous, and therefore such a property as that of inflection (according to the present signification) has no existence in nature.

BLUE SHADOWS AND COLOURS OF THE CLOUDS.

Sitting in the window on a beautiful summer's evening, on the 4th. of June, 1816, the sun setting in the west, his rays passed obliquely through some branches of a neighbouring tree, at about 100 yards distance, and then through the open window, painted blue and orange shadows on the wall. These immediately reminded me of the blue shadows noticed by Buffon. In the month of July 1742, when this philosopher was engaged with accidental colours, and while he was waiting to see the sun near the horizon, that he might look upon it without any injury to his eye, and might thereby be enabled to observe the colours, and the changes of colour made by the impression of light; he observed that the shadows of trees which fell upon a white wall were green. He was at that time standing upon an emminence, and the sun was setting in the cleft of a mountain, so that he appeared considerably lower than the horizon. The sky was clear, excepting in the west, which though free from clouds was lightly shaded with vapours, of a yellow colour, inclining to red. The sun itself was exceedingly red, and was seemingly, at least, four times as large as he appeared to be at mid day. In these circumstances, he saw very distinctly the shadows of the trees, which were thirty or forty feet from the white wall, coloured with a light green inclining to blue. The shadow of an arbour which was three feet from the wall, was exactly drawn upon it, and looked as if it had been newly painted with verdigris. This appearance lasted nearly five minutes, after which it grew fainter, and vanished at the same time with the light of the sun. The next morning, at sun rise, he went to observe other shadows, upon another white wall; but instead of finding them green, as he expected, he observed that they were blue, or rather of the colour of lively indigo. The sky was serene, except a slight covering of yellowish vapours in the east, and the sun arose behind a hill, so that it was elevated above his horizon. In these circumstances the blue shadows were only visible three minutes; after which they appeared black, and in the evening of the same day he observed the green shadows exactly as before. Six days passed without his being able to repeat his observations, on account of clouds; but the seventh day, at sun set, the shadows were not green, but of a beautiful sky blue. He also observed, that the sky was in a great measure, free from vapours at that time, and that the sun set behind a rock, so that it disappeared before it came to his horizon. Afterwards he often observed the shadows both at sun rise and sun set, but always observed them to be blue, though with a great variety of shades of that colour. He shewed this phenomena to many of his friends, who were as much surprised at it as he himself had been, but he says, that any person may see a blue shadow, if he will only hold his finger before a piece of white paper at sun rise or sun set.

Mr. Beguelin observes that, as Mr. Buffon mentions the shadows appearing green only twice, and that at all other times they are blue, this is the colour which they regularly have, and that the blue was changed into green by some accidental circumstance. Green, he says, is only a compound of blue and yellow, so that this accidental change might have arisen from the mixture of some yellow rays in the blue shadow, and that perhaps the wall might have had that tinge, so that the blue is the only colour for which a general reason is required. And this he says, must be derived from the colour of pure air, which always appears blue, and which always reflects that colour, upon all objects without distinction; but which is too faint to be perceived when our eyes are strongly affected by the light of the sun reflected from other objects around us.

To confirm this hypothesis he relates the following circumstances. Being at the village of Boucholtz in July 1764, he observed the shadows projected on the white paper of his pocket-book, when the sky was clear. At half an hour past six in the evening, when the sun was about four degrees high, he observed that the shadow of his finger was of a dark grey, while he held the paper opposite to the sun; but when he inclined it almost horizontally, the paper had a bluish cast, and the shadow upon it was of a beautiful bright blue.

When his eye was placed between the sun and the paper laid horizontally, it always appeared of a bluish cast; but when he held the paper, thus inclined, between his eye and the sun, he could distinguish, upon every little eminence occasioned by the inequality of the surface of the paper, the principal of the prismatick colours. He also perceived them upon his nails, and upon the skin of his hand. This multitude of coloured points, red, yellow, green and blue, almost effaced the natural colour of the objects.

At three quarters past six, the shadows began to be blue, even when the rays of the sun fell perpendicularly. The colour was the most lively when the rays fell upon it at an angle of forty five degrees; but with a less inclination of the paper, he could distinctly perceive that the blue shadow had a border of a stronger blue, on that side which looked towards the sky, and a red border on that side which was turned towards the earth. To see these borders, the body that made the shadow was obliged to be placed very near the paper, and the nearer it was, the more sensible was the red border. At the distance of three inches, the whole shadow was blue. At every observation, after having held the paper towards the sky, he turned it towards the earth which was covered with verdure, holding it in such a manner, that the sun might shine upon it while it received the shadows of various bodies, but, in this position, he could never perceive the shadow to be blue or green at any inclination, with respect to the sun's rays.

At seven o'clock, the sun being still about two degrees high; the shadows were of a bright blue, even when the rays fell perpendicularly upon the paper, but were the brightest when it was inclined at an angle of forty five degrees. At this time he was surprised to observe that a large tract of sky was not favorable to this blue colour, and that the shadow falling upon the paper placed horizontally, was not coloured, or, at least, the blue was very faint. This singularity he concluded arose from the small difference between the light of that part of the paper which received the rays of the sun, and that which was in the shade in this situation. In a situation precisely horizontal, the difference would vanish, and there could be no shadow. Thus too much or too little of the sun's light produces, but for different reasons, the same effect; for they both made the blue light reflected from the sky to become insensible. This gentleman never saw any green shadows but when he made them fall on yellow paper. But he does not absolutely say that green shadows cannot be produced in any other manner; and supposes that if it was on the same wall that M. Buffon saw the blue shadows, seven days after having seen the green ones: he thinks that the cause of it might be the mixture of yellow rays, reflected from the vapours, which he observes were of that colour.

These blue shadows, our author observes, are not confined to the times of sun rising and sun setting: for on the nineteenth of July, when the sun has the greatest force, he observed them at three o'clock in the afternoon, but the sun shone through a mist at that time.

He says, if the sky is clear, the shadows begin to be blue, when if they be projected horizontally, they are eight times as long as the height of the body that produces them, that is, when the centre of the sun is 7° 8' above the horizon. This observation he says was made in the beginning of August.

Besides these coloured shadows, which are produced by the interception of the direct rays of the sun, our author observed others similar to them at every hour of the day, in rooms, into which the light of the sun was reflected from some white body, if any part of the clear sky could be seen from the place, and all unnecessary light was excluded as much as possible. Observing these precautions, he says that, the blue shadows may be seen at any hour of the day, even with the direct light of the sun, and that this colour will disappear in all those places of the shadow from which the blue sky cannot be seen.

All the observations that this author made upon the yellow or reddish borders of shadows above mentioned, led him to conclude that they were occasioned by the interception of the sky light, whereby part of the shadow was illuminated, either by the red rays reflected from the clouds, when the sun is near the horizon, or from some terrestrial bodies in the neighbourhood. This conjecture is favoured by the necessity he was under of placing any body near the paper, in order to produce this bordered shadow, as he says, it is easily demonstrated, that the interception of the sky light can only take place when the breadth of the opake body is to its distance from the white ground on which the shadow falls, as twice the sine of half the amplitude of the sky to its cosine.

At the conclusion of his observations on these blue shadows, he gives a short account of another kind of them, which, he does not doubt, have the same origin. These he often saw early in the spring, when he was reading by the light of a candle in the morning, and consequently the twilight mixed with that of his candle. In these circumstances the shadow that was made by intercepting the light of his candle, at the distance of about six feet, was of a beautiful and clear blue, which became deeper as the opake body which made the shadow was brought nearer to the wall, and was exceedingly deep at the distance of a few inches only. But wherever the day light did not come, the shadows were all black, without the least mixture of blue."

Nothing can be more confirmatory of the theory of black light, advanced in these pages, than blue shadows. The first question which arises in the mind, is, If shadow (as maintained by Des Cartes, Boyle, and Newton,) be a mere privation of light, what gives the blue and green colours? Surely there can be no reason for supposing, that light illuminating a shadow, a mere non entity should be decomposed without refraction. The following simple experiment developes the real cause of this curious phenomenon.

EXPERIMENT 29th.

At about 12 o'Clock, having placed a lighted candle in the middle of my chamber, on a writing table, I held the flat and black handle of a penknife behind it, in such a manner as to throw the shadow on a quire of white paper, at about the distance of half a foot. Here I perceived two shadows of the black handle, the one of a beautiful and sky blue colour, much dilated and occasioned by the light of the candle, the other of an orange colour inclining to brown, produced by the day light. These two shadows could be approximated or distanced at pleasure, or the one could be made to overlap the other, when a dark gray was produced, bordered at the edges by blue and brown. On removing the entire apparatus into the dark entry, the blue shadow began by degrees to assume a gray and finally a black appearance, it also became more condensed.

This simple experiment, within the reach of every person, throws considerable light on a hitherto mysterious subject; informing us that, the blue was produced by the rarefaction of the black shadow, blended with, and illuminated by the day light coming through the window. On the other hand, that the orange was produced by the rarefaction of the black shadow by means of the candle light, for on removing either light, the shadow became black and condensed.

It may be objected, that a black shadow is often illuminated without this blue appearance, but it must be recollected, that a certain degree of intensity is necessary. Whenever the phenomenon takes place, whether in the open air or in a room, we may be sure that two species of light illuminate the object. At sun rise and sun set, one species of light is immediately modefied by the sun, the other species is reflected from the clouds: nor are these blue and brown shadows ever seen, when the intensity of the one overcomes that of the other. If Mr. Beguelin saw these blue shadows at mid-day, they were occasioned by a mist or fog. On bringing the blue shadows into the sun shine, they immediately vanish. The green shadows noticed by Buffon, were caused by a partial transmission of the green rays through the leaves; for by holding the bough of a tree before a white wall at sun set or sun rise, I could make the blue shadows assume a green colour, especially when the one set of shadows was brought within the area of the other. Or this fact can be more easily shewn in the chamber, by holding a green spectacle glass behind a lighted candle and receiving its shadow on a quire of white paper, when it appears tinged with green, from the partial transmission of the coloured rays. The two shadows in this experiment, are brown and green, not brown and blue as in the former one, when the black handle of the knife was used.

Mr. Melville and M. Bouguer, attempted to reconcile these blue shadows with the Newtonian opinions. But I think it perfectly unnecessary to follow them through the mazes of an intricate theory, unless the experiments I have advanced should be hereafter called in question. As to the opinion of Mr. Beguelin, that these shadows derive their colour from that of the blue air, it is answered by the experiment itself, for we have found that one shadow is blue, the other orange inclining to brown, certainly the orange shadow could not arise from the blue air. On holding the paper between the light of the window and that of the candle, I have likewise perceived the shadow to be perfectly blue. Indeed we must infer that shadow or black light, when blended in a certain manner with transparent and vision-making light can assume all the different colours in nature. The ancients had vague and undefined notions, that colours arose from light and shade, too tedious and uninteresting to enter on.

Sir Isaac Newton supposed that the colours of the clouds depended on the different size of the globules, into which the vapours are condensed. Can we for an instant suppose, that every change in the colour of the sky, is accompanied with a sudden change in the size of the globules? The experiment with thin plates informs us, that a stratum or plate of vapour can be condensed or rarefied into different colours. Therefore we have only to suppose that heat and cold produce the same effect in the atmosphere, that the pressure of the hand does on the vapour between two glasses; and we have an easy solution of the colours of the clouds.

RADIANT CALORIC.

It is well known, that when the solar rays are condensed by a burning glass, nearly the most powerful heat with which we are acquainted is produced. By this means Archimedes is fabled to have burned the Roman fleet off Syracuse. For a particular history of radiant caloric, I must refer the readers to Dr. Murray's or Dr. Thompson's able systems of chemistry, and shall in these outlines merely take into consideration the heat of the solar rays, after passing through a prism.

Dr. Herschel being employed in viewing the sun, through differently coloured glasses, observed that in using some of them, he felt a sensation of heat, though with little light, while others gave much light without any sensation of heat. It occurred to him, therefore, that the prismatic rays might have the power of heating bodies very unequally distributed among them, and this led to a series of experiments by which he thought the conjecture was fully demonstrated.

In a piece of pasteboard, mounted on a frame, so as to be moveable, an opening was cut, a little larger than the ball of a thermometer, and of a sufficient length to let the whole extent of one of the prismatic colours pass through. A prism being placed at right angles to the solar rays, and turned until its refracted spectrum became stationary, the moveable frame with the pasteboard was adjusted, so as to be perpendicular to the rays coming from the prism; and beneath were placed very delicate mercurial thermometers, which could be more or less advanced, so that one only of the prismatic coloured rays should fall on the bulb.

The different heating powers of the different rays were thus ascertained, and were as follow: The thermometer rose in the red rays in ten minutes 7° of Fah; in the green rays, the rise in the same time amounted only to $3^{\circ}\frac{1}{2}$; and in the violet rays, in the same time, to 2 degrees.*

Dr. Herschel also found that, the heating power extended beyond the visible spectrum on the edge of the red rays, and that half an inch beyond it, the thermometer rose in ten minutes 6 and a half degrees; the heating power being greatest at about this point, one inch beyond the visible light of the red rays, the thermometer rose in this ten minutes $5\frac{1}{4}$ degrees, and the heating power was discoverable to the extent even of half an inch. Beyond the violet rays on the other side of the spectrum, there was no heating power.

Dr. Herschel then infers, that since the calorific rays occupy a larger space than

* Philosophical transactions for 1800, page 258.

the visible rays, they must be of a more extensive refrangibility. It follows also, that when the solar rays are concentrated by a lens, the focus of the rays of heat must be different from the focus of the rays of light. On making the experiment, he found reason to conclude that the focus of heat was farther removed from the lens than that of light, and probably not less than $\frac{1}{4}$ of an inch.

These experiments have been repeated and confirmed by those of Sir H. C. Englefield, made with a differently arranged apparatus, so as to guard against the thermometer being affected by any foreign heat reflected from any part of it. A prism was placed in the proper position, in an open window; the coloured spectrum from it was thrown on a lens of four inches in diameter, and about 22 inches focal length. The lens, as well as its mounting, was covered with a thick white pasteboard screen, in which was cut a slit of three inches long, and half an inch wide over the centre of the lens, and through which any of the prismatic colours could be transmitted, while the others were excluded. A sensible mercurial thermometer, with a naked bulb, was placed, so that the bulb was in the focus of the lens, and the coloured rays were successively thrown on the slit in the screen covering the lens, and of course on the bulb of the thermometer. The rise was as follows: degrees.

In the blue, in	3′	from 55° to 56°=	1
——green, in	3′	from 54 to 58 =	4
——yellow, in	3′	from 56 to 62 =	6
——full red, in	$2\frac{1}{2}$′	from 56 to 72 =	16
——confines of the red,	$2\frac{1}{2}$′	from 58 to $73\frac{1}{2}$=	$15\frac{1}{2}$
Quite out of visible light, ..	$2\frac{1}{2}$′	from 61 to 79 =	18

From these experiments it was inferred, and generally believed, that the prism, not only separated the component rays of transparent light, but also separated rays of radiant caloric from visible light; and that the heating power of the solar rays does not depend on the rays of visible light, but on the associated rays of radiant caloric, which being of different refrangibilities, and likewise of a more extensive refrangibility than the rays of light, are spread over and beyond the visible prismatic spectrum. Where this matter is most completely separated from visible light, and where there is no illumination whatsoever, the heating power is about its maximum; and as this is receded from it diminishes, until at the other extremity of the spectrum, or in the violet rays, it is extremely weak: from which Dr. Herschel infers, that the heating power, exerted by the visible rays, is not a property belonging to them as light, but is owing to the intermixture of rays of caloric.

If these experiments and inferences be admitted in their full force, (and as yet they have been called in question by no person, except that excellent and scientific experimenter, Mr. Leslie of Edinburgh,) we must not only reject the identity of heat and light, but also subscribe to the following conclusions. 1st. That seven differently coloured rays, each ray having a different quantity of sensible heat, in the immense proportion of 1 to 16, should travel in company from the sun to our earth, (91 millions of miles,) without coming to an equilibrium of temperature. 2ndly. That those different rays of visible light and invisible radiant caloric, after resisting any separation by means of the refractive power of the atmosphere, should yet be separable by means of a prism.

Indeed I cannot help thinking it strange, to suppose, that a triangular piece of glass could, under any circumstances, divide two such attenuate fluids as heat and light. We may as well talk of separating or cutting the heat and light asunder with a broad sword or a pair of shears. In the former part of this work, I have given experiments, tending to prove, that the prism never decompounded the incident light into colours, so I shall now by a simple experiment endeavour to shew, that the same instrument has never separated the heat and light of the solar ray.

EXPERIMENT 30th.

Having fixed a piece of pasteboard in the frame of a dressing glass, in which I cut an opening or slit, a little larger than the bulb of a thermometer, and of a sufficient length to let the whole extent of one of the prismatic colours pass through; and having placed a very sensible mercurial thermometer on an inclined plane of wood, covered with white paper, I placed the plane behind the frame, sustaining the pasteboard on a table. I now set a prism, moveable on its axis, in the upper part of an open window, at right angles to the solar ray, and turned it about, 'till its refracted spectrum became stationary on the table, placed at a proper distance from the window. The experiment was so regulated, as to let the rays of one colour pass through the opening in the pasteboard, and fall on the thermometer, which when placed in the shade behind the screen stood at 60.*

Having arranged the thermometer, I allowed the red, or more correctly speaking the orange

* The thermometer was about three feet from the prism: Dr. Herschel has not informed us on this point, but Mr. Leslie justly remarks in a paper, to be seen in Nicholson's journal, that the high rate of the thermometer, was an objection to the experimental inferences.

rays to fall on the bulb, in five minutes it rose from 60 to 68, or eight degrees. I now lowered my thermometer again to 60° by plunging it in some dry sand at that temperature, and replaced it on the inclined plane: on bringing the green rays of the spectrum through the opening, so as to immerse the entire thermometer as in the former case, it rose from 60 to 64, or gained four degrees.

Having again reduced my thermometer to 60, I placed it on the inclined plane, and, having allowed the violet rays to fall on it, the rise was from 60 to $61\frac{1}{2}$, or one degree and a half. So far these experiments, assimilated as much as possible to Dr. Herschel's, would seem to confirm the inferences drawn by that justly celebrated astronomer. I now removed the frame, and in its place, received the coloured spectrum on a quire of white paper: I gradually approximated it, to within one inch behind the prism, where it was properly fastened on a stand. The spectrum at this distance was a quarter of an inch in breadth, bounded on the one side by orange and yellow rays, and on the other by blue and violet, transparent light occupied the middle. I immediately remarked, that this transparent light was much more powerful and luminous than the surrounding sun beams. Indeed it appeared exactly like the light concentrated in the focus of a convex lens, which made me strongly suspect, that it was likewise more calorific. Nor was I mistaken, for on placing the thermometer in those rays, it rose in ten minutes to 81, the heat of the neighbouring sun-shine being only 70°. The thermometer rose and fell alternately, as it was removed in and out of the spectrum.

EXPERIMENT 31st.

June 24th 1816. At about half past two in the afternoon, the sun shining through an open window, fronting the west, I placed a highly sensible and correct thermometer on a sheet of white paper, resting horizontally on a writing table. In five minutes, it rose, in the full sun-beams, to $82\frac{1}{2}$ degrees. After remaining some time stationary, I held a large prism at about one inch distance immediately over it, and in such a manner, as to converge the emergent rays as much as possible to a prismatic focus, and likewise to immerse the entire thermometric bulb and cylinder, in the spectrum of transmitted light. I need scarcely here remark, that the spectrum at this distance, of about one inch from the prism, was bounded on the one side by orange and yellow rays, and on the other by blue and violet. In five minutes, the thermometer rose, in the median and transparent light, to 101°, or in other words, the rays were heated $18\frac{1}{2}$ above the full sun shine, by merely passing through the prism. On removing the prism, the thermometer in five minutes, fell to 85, and on again immersing it in the spectric light, it rose to 101. About half past three, I ended these experiments, simple in their manipulation, and obvious in their inferences. The day was cloudless and extremely favorable. Afterwards, I could never raise the thermometer so high; however, the difference was never less than 12 degrees, a rise fully sufficient to justify all the inferences I have drawn. I now placed three very sensible and correct thermometers in the spectric light, at about one inch distance from the prism; the one in the orange rays, the second in the median and transparent light, and the third in the blue rays. Their march was synchronous, and ended at 101°, that is, the blue and violet rays were as calorific as the red and yellow. We therefore must look for the cause of the different degrees of heat in the coloured rays, from some power, acting between the distance of one inch and three feet from the prism, and not from any difference in the heating power of the solar rays previous to incidence. It was my intent to have given the heats of the coloured rays at different distances, but I shall reserve them for a separate work on heat.* However, I may remark, that the principal cause of this

* After Mr. Leslie's able work on heat, another on that subject may be thought unnecessary. However, the author hopes to give some new experiments.

phenomenon seems to be, the greater diffusion of the violet &c. which occupies in some instances nearly six times the space in the reflected spectrum, occupied by the red. When we consider that the rays of light are more bent at the refracting angle than at the base, it is evident that the prism must have both a calorific and luminous focus.

END OF THE FIRST VOLUME.

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