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PHILOSOPHICAL INQUIRIES

INTO THE

LAWS OF ANIMAL LIFE.

IN SIX CHAPTERS.

BY HUGH SMITH, M. D.

Of HATTON-STREET.

With a View to shew the Probability of AIR being the first CAUSE of MOTION in ANIMAL LIFE; to point out the MECHANICAL CAUSES that concur in producing the CIRCULATION of the BLOOD; and to explain the LAWS of RESPIRATION.

These Inquiries are supported by Experiments, and founded on the Principles delivered in a Course of PHILOSOPHICAL LECTURES, in the Beginning of the YEAR 1778.

The Principles are set forth in the Author's SYLLABUS.

L O N D O N:

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WILLIAM HUNTER, M. D.

ANATOMICAL PROFESSOR in LONDON, F. R. S.

And PHYSICIAN EXTRAORDINARY to the QUEEN.

TO you, Sir, this first chapter of my Inquiries is most gratefully inscribed, because from you I received those Rudiments of Science, which enabled me, among my other philosophical attempts, to pursue the study of Human Nature.

PERMIT me, Sir, to congratulate you that London is now become the great School of Physic: your unremitting labours in this Metropolis, towards the improvement of medical knowledge, are so universally known, that the world need not be told, by me, of your superior merit; a consideration which renders it no easy task to find words that may not offend, even in paying this humble tribute of gratitude.

ALL, therefore, I have to hope for, is, that you will condescend to regard my bold attempt with your usual goodness; and, that you will be pleased to pardon my errors: from you, Sir, I am encouraged to look for these indulgencies, for I know that you possess a mind as liberal by Nature, as it is enlarged by Science.

MAY you long continue to enjoy your public honours, as well as those private rewards which ever accompany virtue!

I am, Sir, with respect and esteem,

Your most obedient, and most humble Servant,

WILLIAM LUNTER, M.D.

ANATOMICAL THEATRUM IN LONDON, F.R.S.
AND PHYSICAL EXPERIMENTARY to the QUEEN.

To you Sir, the full extent of my labours is most gratefully indebted, because from you I received those Numbers of *Scraper*, which enabled me, among my other philological attempts, to pursue the study of Human

Nature.

Permit me Sir, to congratulate you that London is now become the great School of Physic: your unremitting labours in the *Museo*, towards the improvement of medical knowledge, are so generally known, that the words need not be told by me, of your superior merit; a confidence which renders it no easy task to find words that may not offend, even in saying the humble tribute of gratitude.

All therefore, I have to hope for, is that you will condescend to regard my bold attempt with your usual goodness; that you will be pleased to pardon any errors; from you Sir, I am encouraged to look for your valuable genius, for I know that you possess a mind in which, by Nature, as it is enlarged by Science,

May you long continue to enjoy your public honours, as well as those private rewards which are so necessary to you.

I am, Sir, with respect and esteem,

Your most obedient and most humble servant,

LUGH SMITH.
M.D. &c. &c.

P R E F A C E.

IN the course of Lectures delivered the beginning of the year 1778, on the Philosophy of Physic, which may justly be called the study of Nature, this was laid down as the leading aphorism: *In all living animals, life, heat, and motion, are inseparable.* To prove this point, I began with considering Air as matter, and by progressive steps advanced to the 34th and last principle, which runs thus—*VITAL AIR, heat and motion, appear to be inseparable in animal life.* It is therefore meant to be insisted on, that Air is the first material cause of every motion proper to life.

AN Operator attended every night to exhibit the experiments on which my arguments were founded ; and the principles have now been submitted to the Public near two years, with an earnest hope on my own part, that any fallacies in them might be detected : the principles, however, at present remain uncontroverted.

IT was thought necessary, in the first instance, to establish the proofs by experiments ; which are for the most part familiar, and none of them repugnant to the known laws of Pneumatics : learned and philosophic men, therefore, may receive sufficient information from my Syllabus alone ; on which account it appears unnecessary to repeat the lectures, and my professional engagements, at this time, would render it very inconvenient to myself. If the principles be admitted, it is all I ask ; for the purpose of the Lectures is thereby fully answered ; and we may, with propriety, pursue the following inquiries—Should the present attempt merit approbation, the Lectures themselves may, perhaps, hereafter be found an useful introduction to this branch of natural philosophy ; in that case they will be at the service

of

of the Public.—This, I trust, will be received as a general and satisfactory answer, to the many and respectable applications made to me to deliver another course of lectures: besides, the subject is too important to be hastily pursued, and it is my sincere desire, that the present thoughts should be most strictly examined; I hope, therefore, these apologies will be received with candour.

It would have been presumption in me, to have styled many of the opinions formerly delivered, more than conjectures: whether or not any of them deserve an higher name, the Public will determine from the present application of them. Some professional men have been pleased to call them ingenious; it is my wish more particularly to claim their attention to this publication. These opinions, if they be, as I hope, found true, must overturn many doctrines now taught, and bid fair to establish rational theories, founded on experimental philosophy, concerning some of the most obstinate diseases.

To regulate physiological reasonings throughout the animal œconomy, on new principles, will prove, indeed, an arduous pursuit: if, however, what is here laid down should be found useful, my industry shall not be wanting to chalk out some rude outlines of their extensive application, which may, at a future period, be more completely filled up by abler men, whereby mankind may be essentially benefited—which is the ultimate wish of the author.

PHILOSOPHICAL INQUIRIES

INTO THE

LAWS OF ANIMAL LIFE.

CHAPTER THE FIRST.

C O N T E N T S.

*Vital Air the first material cause of motion in Animal Life :
Pulsation described : Animal blood a mere passive fluid—
the common menstruum of Nutrition only : the Harveyan
and Boerhaavean theories, concerning the circulation of the
blood, set forth, with the author's objections.*

IN the course of our lectures we entered pretty fully into the subject of animal life ; but as the lectures are not published it may be proper to speak a little to this point, before we consider that mechanical power by which the blood is kept in perpetual motion through the animal œconomy.

WHEN our great countryman found out, and demonstrated by experiments, the circulation of the blood, for this important discovery he was styled the immortal Harvey; and should he be wrong in some of the causes assigned for this wonderful effect, the merit of the discovery is still the same, as he thereby paved the way for farther inquiries: let us then pay the just tribute of praise to the memory of so illustrious a character, and modestly endeavour to trace out the points wherein he, as well as other great men have been mistaken. It is proper to remark, that throughout the whole of our Inquiries material causes *only* have been the objects of pursuit; and that all our reasonings have been supported by experiments.

WHEN it pleased the Almighty to put matter into Motion, we cannot doubt but general laws were ordained, by his most gracious Providence, to support the Works of his Creation: some of those laws, then, respecting Animal Life, we are at this time attempting to discover.

THE proper standard of Vital Air having been fixed by the Author of Nature when he first created Man, we hope to shew that standard is regularly and uniformly maintained by means of the atmospheric air; and that the continuation of life does not depend on any mysterious, or unknown principle existing in the brain, in the nervous system, or in the blood only; but on the constant admission of the common
air

air of the atmosphere into the animal œconomy, which keeps the blood, and all the other humours of an animal body, in perpetual motion: for under the same circumstances of heat, and close confinement in tubes, we have shewn by experiments, a similar effect may be produced by air on other fluids, causing them to circulate in like manner as the blood itself.

WE regard Air, rarified by heat, as the first material cause of motion in Animal Life; and the re-action of the vascular system as the secondary cause. These two causes, taken conjunctively, produce that complete motion, termed Pulsation; by which the blood is conveyed from the heart to the extreme parts of the arterial system; and, if there be no re-action in the venal tubes, it is returned to the heart again by the power of Air.

WE allowed the re-action of the vascular system greatly to depend on the nerves, but endeavoured to shew that the nerves themselves were primarily indebted to Vital Air for their power.

By the propelling force of Vital Air, we presume all glandular secretions to be performed, for the purpose of Nutrition; and the lymphatic circulations to be supported by the same power: and also by means of the Glands, we presume the laws of generation to be maintained.

THE Blood we consider as an elaborated fluid, prepared within the body of every animal, by its own corporeal powers, from proper aliment received; from whence Nutrition is derived by means of the Glands. Even the Mother's milk necessarily undergoes a material change within the body of an Infant, before it contributes to nutrition.

ALL the various nutritive substances received into the stomach of an animal must be digested, and the particles of matter differently arranged, before the nutritive juices are capable of being received into the chyloferous vessels, and conducted to the *vena cava* to mix and circulate with the blood.

THE nutritive juices received into the blood, in form of chyle, must undergo several other changes, before they actually become blood.

IN our lectures we considered the blood of an animal as the common *menstruum* of Nutrition *only*; regarding it in the light of a mere passive fluid, kept in continual motion by the Air constantly admitted into it; and we endeavoured to prove Air to be its invigorating or first moving principle.

THE Hypothesis of life existing in the blood certainly owes its origin to Moses, though first adopted philosophically
by

by Dr. Harvey, who even goes so far as to suppose the blood to be the seat of the soul *.

To this point, in our introductory lecture we expressed ourselves as follows :

WE do not pretend to determine in what part the sentient principle is seated in man ; we know that man has a spirit or thinking principle existing in him, and with this knowledge let us rest contented : for, if this spirit or thinking principle be immaterial, it cannot be an object of our senses ; and if it be not an object of our senses, man's researches after it will ever prove in vain.

WE ventured at the conclusion of the lectures to observe, that if there be a connection between gross material, and immaterial substances, as it must be effected by means of

* IT is not, however, probable that Moses had any reference to immaterial causes at a time he was speaking to the people concerning their daily food. “ Every moving thing, *says he*, that liveth, shall be meat for you, but flesh with the life thereof, which is the blood thereof, shall ye not eat.” GEN. chap. ix.——

THIS appears to be nothing more than a forcible expression to convey fully the meaning of the Lawgiver ; for if the blood of an animal be taken away it surely dies ; and hence Blood is familiarly styled the fountain of life. It is not unlikely that Moses might command the Jews to bleed the animals they were to feed upon, with a view to prevent the flesh becoming too soon putrid ; or perhaps to restrain them from brutish ferocity, and, (making a distinction between man and other animals) to add force to another law given in the same chapter : “ Whoso sheddeth man's blood, by man also shall his blood be shed.”

something intermediate, this union was not unlikely to be formed by some *rare* medium; and if so, we asked, why not by means of that Vital Air by which matter was first animated? And here we dropped the subject; our inquiries being altogether confined to material causes.

DR. HARVEY seems to have wanted nothing but the principle of Vital Air to have enabled him to complete his theory, without having recourse to imaginary or unknown causes—These are his words almost literally :

“ Hence also appears the pre-eminence of the blood, that
 “ pulsation derives its original from it: for as pulsation
 “ consists of two parts, namely distension and contraction,
 “ or diastole and systole; and of these two motions the
 “ distension is first; it is evident the former depends on the
 “ blood, but the contraction is performed by the beating
 “ vesicle in the egg (as by the heart in the chick) by means
 “ of their proper fibres *.”

NOTHING can be more clear than this description. Dr. Harvey speaks to the very facts I shall have occasion to con-

* Hinc quoque apparet sanguinis principalitas, quod pulsus ex eo ortum ducat. Cum enim duæ sint pulsationis partes, distensio nempe et contractio, sive diastole et systole, horumque motuum distensio prior sit; manifestum est actionem illam sanguini competere: contractionem vero, a vesicula pulsante in ovo (ut a corde in pullo) propriis fibris institui—

Vide Harv. de generat. Animal. exercitat. 51.

tend for, but not being acquainted with our principles, he could not make that use of experiments, which I am about to do.

THIS is evident from what follows ; for he adds—“ Nor
 “ is the blood to be called an original and principal part,
 “ only, because in it, and from it, motion and the beginning
 “ of pulsation arise ; but also because in it, animal heat
 “ first is bred, *the vital spirit* is produced, and *the soul* itself
 “ resides *.”

WHAT a fine mode of reasoning ! May I be permitted to say, how elegantly ingenious is this hypothesis ? How infinitely near does he approach, and yet does not seem to have the most distant conception, that Air was the unknown principle yet wanting, to produce all those wonderful phenomena, that thus claimed his most curious attention ? and which I hope to be able satisfactorily to explain.

I CANNOT help considering this great man as my valuable and good Ally, but we have a formidable Opponent to contend with—one who has endeavoured to overturn the whole of Dr. Harvey’s theory, in order to establish his own ;

* Nec sanguis solum pars primigenia et principalis dicendus est, quod in eo et ab eo motus pulsusque principium oriatur ; sed etiam, quia in eo primum calor animalis innascitur, spiritus vitalis ingeneratur, et anima ipsa consistit.

Ibid.

I mean the celebrated Boerhaave, who absolutely affirms, “ that the cause impelling the blood from the heart into the “ arteries, and from the veins into the heart, is NOT in the “ blood, but is to be sought for in the heart itself.” * He afterwards endeavours to prove the motion of the heart to be from the nerves ; and to shew the brain, or rather a particular part of it, not the Pineal Gland as Des Cartes imagined, to be the seat of the soul †.

IN pursuit of his own system, Boerhaave was reduced to the necessity of accounting for the systole prior to the diastole, contrary to the order of Nature ‡ ; which has led him and his followers into many difficulties ; notwithstanding which, his hypothesis has obtained the preference over Dr. Harvey’s ; and is at present generally received ; though I think I have been informed, that one of our anatomical professors in this Metropolis has lately mentioned the Harveyan doctrine with respect.

FROM our observations perhaps it will appear that the re-action of the vessels, which Boerhaave and his followers

* *Causa igitur pellens sanguinem ex corde in arterias, ex venis in cor, non est in ipsa mole sanguinis : sed querenda in eo, quod sanguinem cordis proxime complectitur, id est, in corde ipso.*

Vide Instit. Boerh. 180, 181.

† Vide Instit. No. 574.

‡ Vide Instit. No. 189, 190.

make the first cause, is in reality only the secondary cause of the circulation; and that Dr. Harvey was altogether right in making the diastole precede the systole.

It will not, however, be unpleasing to the learned, if we should eventually shew, that both these great men, though totally opposite in their theories concerning the circulation, were neither of them far from the truth. One discovered motion first in the blood, but knew not the cause; the other discovered motion in the vascular system, and mistook it for the first cause: thus each of them saw in part, what I am about to relate; and both had recourse to invention to supply what they did not see: hence, both of them were obliged to introduce imaginary agents.

HAD our new experiments concerning Air been as well known to either of them as they are at this time to many gentlemen, most probably the honour of attempting to explain the laws of the circulation of Animal Fluids would not have fallen to my lot.

WE shall now proceed to our inquiries, without animadverting on that system which maintains the sentient principle in man to be altogether material; that says it depends on, and is derived from, a system of organised matter—This dangerous hypothesis is evidently built on the Boerhaavean foundation, and if it should appear that Boerhaave himself

has been mistaken in regard to the nervous system, his own fabric will necessarily be demolished ; and of course, it must follow, that this more modern superstructure will be buried with it in the ruins.

THE heart of an animal, in the course of our lectures, we ventured to style the centre of motion, respecting animal life.

ANATOMISTS describe the heart to be a compound muscle, composed of fibres of the same nature as those of other muscles : the heart has been considered to have two motions, termed systole and diastole.

THE motions of the heart are thus described : its systole, say they, is when the fibres of the heart contract, its sides swell, and its cavities are diminished, being strongly pressed on all sides. The diastole is when this muscle ceaseth to act ; its fibres being then lengthened, its sides fall, and its cavities become large and wide : it is also particularly noted that the blood is expelled from the heart in the systole, and received into it, in its diastole ; and the circulation of the blood, according to Boerhaave, whose opinion is almost universally embraced, is principally performed by the great power he ascribes to this muscle ; which, however, Anatomists have proved to have no antagonists.

A DOCTRINE so generally established will not easily be overturned; this difficulty I am prepared to meet, as the prejudices of weak minds will not disconcert me—for I consider myself addressing liberal and scientific men at large, on a pleasing branch of natural philosophy; and we can boast of characters in the profession who will pay respect to truth, though it may approach them in a rude and humble garb: however, the subject itself is by no means confined to medical men, although a rational practice of physic must ever be founded on the knowledge of the laws of Nature, respecting Animal Life.

THE mind must first doubt, before it will, in the least, be disposed to disbelieve a doctrine, that has been established for a series of years; a doctrine that has overturned Dr. Harvey's theory, and which has been handed down to us through the respectable medium of learned authorities. As I cannot pretend to the power of persuasion, it would be in vain for me to attempt, in the first instance, to raise a doubt in the breast of any man; yet, perhaps, it may not be considered as time wholly mispent, when I honestly relate that train of doubts and uncertainties that conducted me to the discovery of a contrary system.

MANY years have passed since I first began to doubt the truth of the Boerhaavean theory concerning the circulation of the blood; and I doubted long, before those doubts amounted

amounted to disbelief; when disbelief at length possessed my mind, it necessarily led me to endeavour to find out the fallacy; and this inquiry could be pursued by no other means than an attempt to discover a cause, equal to the effect of keeping the blood, and other juices of the body, in their regular and constant motion; and to which cause I could more readily yield my rational assent.

My doubts arose on many points; and for the readers satisfaction, I shall mention a few: in the first place I could never conceive the muscular force of the heart, considered independently, to be a power equal to the effect contended for; secondly, the heart being alternately dilated and contracted, and no antagonist muscles being discovered, I could not suppose this two-fold operation to take place, without some other cause co-operating with the heart, and thereby supplying the place of antagonist muscles. In the third place I considered the muscles of the thorax, in the act of respiration, as they also are alternately dilated and contracted; and these muscles being allowed to have no antagonists, the same difficulty presented itself to account for their operation.

THUS my doubts encreased, and grew stronger; for these effects were ascribed to causes I could not understand, and consequently could not subscribe to: that the heart stood in need of some co-operating power, to supply the place of antagonist muscles seemed to be implied when animal
spirits

spirits were introduced into the system of organised matter.

BUT when I read of animal spirits issuing from the nerves, and falling, drop by drop, into the muscular fibres, to rarefy the blood, in order to explain muscular motion, it was too mysterious for me to comprehend: being told that upon a drop of the animal spirits falling, the fibres are presently inflated, and the muscles contracted; and as soon as the rarefaction of the blood is over, the muscle is relaxed till the next drop falls from the nerves; and that the systole and diastole of the heart are regularly produced by this wonderful contrivance, without the help of antagonist muscles, or any other co-operating power; I could not help admiring the ingenuity of man, but doubted exceedingly whether he had yet discovered the wisdom of the Author of Nature, in these mechanical operations of Animal Life.

IT may not be improper to mention, that the most glaring absurdity appeared to me to attend this theory, notwithstanding it has been so generally admitted. The only idea I could ever affix to the term Animal Spirits is some fluid, containing so little matter that it might almost be styled an immaterial principle; yet, possessed of much more power than air, or any other fluid, evidently material and perceptible:—if this may be called an idea, it is the one, I believe, usually adopted by scientific men, when

the term Animal Spirits is made use of; and by them, this almost immaterial principle is appropriated to the most laborious material purposes, and universally spoken of as matter; it is on the present occasion specifically described as a fluid, with a property peculiar to fluids, of falling drop by drop:—such seeming contradictions I could not reconcile.

ANOTHER palpable absurdity, may I be permitted to say? attends this theory; for allowing the aid of animal spirits in the contracting power of the heart, the supporters of the Boerhaavean system are reduced to the wretched dilemma of asserting the absence of this power, or in other words the passive state of this muscle, to be the active cause of the distention of the heart; and when this difficulty is got over, take up the animal at what period of life you please, there must be supposed an existing power capable of bringing the blood, or nutritive juice, to the heart, before it can possibly be thrown out of it; so that what is termed the diastole must have existed before the systole could take place. This difficulty would have puzzled almost any other man than Boerhaave; but his surprising force of imagination overcame all impediments, and his superior abilities enabled him to form new laws at pleasure: his arguments also were delivered with such a tone of weight as commanded the attention of his pupils, and they generally received his
 opinions

opinions without distrust; of which the present is a notorious instance: and indeed most authors, since his time, have fallen into this most glaring error of placing the systole before the diastole; which, as before observed, is contrary to the order of Nature.

IN pursuing this train of ideas, can it then be wondered at, that I should be exceedingly averse to the hypothesis of animal spirits?

BEING thus dissatisfied with the present established theory, I began to consider some other muscles which have no antagonists; for instance, the sphincters of the *anus*, and the urinary bladder; which are not alternately relaxed, and contracted, like those of the heart and thorax. In these exceptions I was equally dissatisfied with the reasons assigned—namely, that their force being very weak, their contraction was consequently very small, and differed so very little from their relaxation, as to be imperceptible to us: thus, the power of these muscles seems to have been intentionally softened down, so that the magic aid of animal spirits (which on these occasions would have but little served the cause) might appear to be less necessary.

THIS strange doctrine I could not assent to, because my own experience, by a little attention to my daily evacuations, convinced me of its fallacy: it not only satisfied

me the contracting power of these muscles was very great on the occasion of the expulsion of the evacuations ; but I likewise discovered they afforded me voluntary power to resist the evacuations, for a considerable time ; and it was evident from my observations that the *sphincter ani* was, in the first instance, relaxed by the expulsion of the *fæces*, and the *sphincter vesicæ* by the expulsion of the urine ; but of that power, which produced these effects, I was yet ignorant.

THUS doubts, having long existed in my mind, led to a disbelief of this theory, which prompted me to make new enquiries ; and at length I had recourse to experiments. These experiments informed me “ That air existed in all
 “ matter ; that the spring, or force of air was in pro-
 “ portion to its weight ; that the power of air confined in
 “ a tube, and rarefied by heat, was, by the act of rarefaction,
 “ considerably encreased—that most of the tubes of an
 “ animal body possessed an elastic, or muscular property ;
 “ that the first evident sign of motion produced in fluids,
 “ by heat, was caused by the rarefaction of the air con-
 “ tained in them ; that from the degree of heat peculiar to
 “ animal life, the air in an animal became so much rarefied
 “ as to be continually in motion ;—and, ultimately, that
 “ air did actually exist, in this rarified and circulating state,
 “ not only in the blood, but in all the other fluids con-
 “ tained within an animal body* .”

* Vide the Principles laid down in the Syllabus. Page 22, &c.

BEING in possession of these experimental proofs, which were publickly exhibited at my Lectures *, I was led to consider the arguments against the external atmosphere being admitted into the circulation of our fluids; and to me those arguments appeared altogether inconclusive. I then began to think it not improbable that the action of air might supply the place of antagonist muscles, wherever they seemed to be wanting, not only in the Heart, but throughout the animal œconomy.

I SHALL conclude the present chapter with a few more experiments and observations, that may perhaps strengthen this opinion. It is a fact well known that the hearts of some animals will continue to beat with a regular and

* THE experiments, on which the principles are founded, were usually shewn before each Lecture: but, as I wished no Gentleman might be absent at the proofs of the 27th and 28th Principles, those experiments were exhibited on the sixth night *between the Lecture and Conjectures*; and they were also repeated at the next Lecture. It will most likely be remembered that I then addressed my auditory in the following manner, for the words are taken from my notes: “As some persons have doubted, and others denied, the existence
“ of air in the circulating fluids of an animal body, and more especially in the blood; I
“ wish the matter of fact to be established in the presence of every Gentleman who does
“ me the honour of considering the present important subject. For this purpose the
“ Operator has procured a blood-vessel, secured by ligatures before it was taken from the
“ body of the animal, so that no communication can have been admitted between the air
“ contained in the blood, and the atmospheric air, except what is natural in a living
“ state. He has also a part of the medullary substance of the brain to exhibit: when
“ you, Gentlemen, are satisfied with these experiments we shall begin with our Con-
“ jectures.” I believe all those who saw the experiments admitted that the facts were fully proved; and as they are easily made, any Gentleman, in the least acquainted with the management of an air-pump, may readily obtain ocular demonstration of the Truth of the above principles.

forcible motion for several hours after they are separated from the body ; and I thought it applicable to our present inquiries, to learn how far the spring and force of the atmospheric air might be instrumental to this motion ; for many effects are familiar to us, though their causes lie hid.

E X P E R I M E N T I.

THE Heart of a small Eel, separated from its body, beat twenty strokes in a minute, regularly and forcibly ; being placed under a receiver, as the air was exhausting it increased to twenty-four strokes ; but the motion was more feeble : in three minutes it was scarcely perceptible : by admitting fresh air the motion of the heart returned with equal force as at first ; and, by exhausting it again, the motion regularly decreased. Fresh air was admitted a second, third, fourth, and fifth time ; in each trial the motion of the heart regularly returned ; and it was as sensibly diminished, on the receiver being exhausted : at length, the fluids proper to the heart itself having in a great measure transfused, the muscular fibres became dry, and lost their power of re-action, when all motion ceased.

E X P E R I M E N T II.

ON the HEART of a TENCH.

THE fish was very lively, and weighed near a pound ; when the heart was taken out, it beat twenty-two strokes in a minute, regularly and forcibly ; I could not observe it

it to beat quicker when put under the receiver; if it did, it was not more than one stroke in a minute—but, as the air was exhausting, the motion became visibly weaker, and in four minutes it almost ceased; on the admission of fresh air, the motion returned with full force; and it again ceased, or scarcely moved, when the receiver was a second time pretty highly exhausted. The air was admitted again and again, and also exhausted as in the former experiment; and each time the effects were exactly similar.

The heart of the Tench was much larger than that of the Eel, and when the receiver had been six times exhausted the muscular fibres of this heart still retained their capability of re-action; and, being exposed to the atmospheric air, the heart continued to beat regularly and forcibly for a great length of time.

E X P E R I M E N T III.

THE Heart of a small, but very lively, Eel, when taken from the body, beat sixty bold and regular strokes in a minute; being put under the receiver, and the air gently exhausted, its motion became more feeble, and the heart beat only forty strokes in the minute; the strength of its motion gradually abating, and being almost imperceptible, the air was re-admitted as in the former experiments, when the heart beat again with full force, but not more than forty strokes in the minute, and the experiment continued as before.

E X P E R I M E N T IV.

ANOTHER Heart beat only eight strokes in a minute when taken from the body; these strokes were bold but irregular: this heart being put under the receiver, and the air gradually exhausted, the pulsations quickly increased to the number of eighteen in the minute; they were less forcible, but more regular; when the receiver was nearly exhausted, the motion of the heart was scarcely perceptible, but on the re-admission of the atmospheric air, it returned again with its former force, and the experiment continued as before.

E X P E R I M E N T V.

THE Heart of another Eel being placed under the receiver, and the air expeditiously exhausted, a very fluttering motion was soon discernible; when the receiver became highly exhausted the air proper to the juices of the heart itself transfused, and remained on its surface in transparent globules; in a very few minutes the heart ceased to beat, it appeared dry and withered, and although the atmospheric air was re-admitted no motion returned; for the muscular fibres had lost their power of re-action.

E X P E R I M E N T VI.

THE Heart of an Eel was placed under a receiver, and the air nearly exhausted; another heart at the same time was exposed to the common air of the atmosphere: the motion of the heart under the receiver was feeble and quick;

quick; but it entirely ceased in fifteen minutes; whereas the heart exposed to the atmospheric air continued a forcible and regular motion for an hour and half; then, gradually declining, it stopped in about two hours and an half.

E X P E R I M E N T VII.

THE Heart of an Eel was placed under the exhausted receiver, about six minutes; till its motion was no longer perceptible; but, being taken out and exposed to the atmospheric air, the motion of this heart instantly became strong and regular; and it continued to beat nearly as long as another heart which had not been placed under the receiver*.

FROM the above experiments this general conclusion, I think, may fairly be drawn; that not only the strength of the

* THESE experiments require great attention: the health of the animals, and perhaps the size of them should be regarded; the goodness of the air pump, the dimensions of the receiver (that I lately used, was $1\frac{3}{4}$ inches in diameter, and $6\frac{1}{2}$ in altitude) whether the receiver be hastily or slowly exhausted, and how highly. I object to the use of oil in this, and every other experiment on animal motion. Care should be taken not to wound the heart; sometimes I have not divided it from the liver and other intestines, but the effect was nearly the same. I have frequently taken off its *pericardium*; this, however, must be done with a nice hand; I think the motion is then slower, but more regular and bold, and the experiment more beautiful.

I MADE many experiments to learn why some hearts beat quicker than others when taken from the body, and am not yet thoroughly satisfied: it is proper to remark the Eels were small, and perhaps some of the hearts might be injured; or, coagulated blood might *more or less* obstruct the admission of the air into all of them: some did not beat more than six or eight strokes in a minute, others from 10 to 20, and so on to 40 and 60; but I do not

the motion of the heart, but also the continuation of its motion, seems to depend *altogether* upon the weight and spring of the atmospheric air. In proportion as the receiver became more highly exhausted, in every experiment, we observe the action of the heart to become more feeble: and when the hearts ceased, or nearly ceased to beat, by introducing fresh air, motion constantly and forcibly returned; except in those cases where the muscular fibres had lost their power of re-action.

I SHALL leave the application of these experiments to my readers; and if what has been advanced in the present chapter should incline learned and philosophic men to think we are treading on solid ground, I hope, from our future inquiries, they may also be induced to think with me it is highly probable that the atmospheric air is continually received into animal bodies, in order to support that standard peculiar

recollect that any two beat exactly alike. While the air was exhausting, the motion of some of the hearts became slower, others did not vary in the number of strokes, others again became quicker—I am equally at a loss to account for these different effects, if they may not be ascribed to the causes before mentioned.

EXPERIMENTS we know will vary, and these remarks may prove agreeable to the curious; they may assist them in farther pursuits; the subject is copious, perhaps important: I will thank any Gentleman who shall hereafter communicate to me his observations. It may not be improper to remark, for the information of such as are not well acquainted with the laws of Pneumatics, that the spring and force of the atmospheric air is abated by taking away a part, in proportion as it is rendered lighter; it is likewise abated by humidity, in proportion as it is rendered humid; yet, when air becomes rarefied and expanded by

peculiar to VITAL AIR ; by which power the circulation of our fluids is uniformly maintained : and likewise that the spring and force of air supplies the place of antagonist muscles, not only in the heart but throughout the animal œconomy.

THE doctrine of Vital Air, and the natural means of supporting its standard, by the constant admission of the atmospheric air into animal bodies, may *perhaps* be new ; yet, I am by no means singular in opinion, that the action of air may supply the place of antagonist muscles : tho' many learned men have denied, others have ascribed this power to the atmospheric air ; but I believe they have gone no farther : be this as it may, true philosophy must ever be built on experiments ; and, without this solid basis, the opinions even of the wisest men should be received with caution : for which reason I wish not, on the present occasion,

by the power of heat, whether it be dry or humid, if this air be confined in tubes its spring and force will be prodigiously encreased, by the act of rarefaction.

I SHALL make one more observation. As we presume the power and spring of air to be the first cause of motion in the heart of the Eel when taken from the body, how are we to account for the heart's motion continuing, even for a short space of time, under what is termed an exhausted receiver ? I answer, in the same manner as we account for some animals living much longer than others in the above situation. Were it practicable, totally to exhaust the air from a receiver, and in an instant of time, I apprehend that all animals would be as quickly deprived of motion and life by this means, as by the act of drowning, or many other modes of sudden death : but, by the use of the air-pump we only take away part of the air, whereby that which remains, *expanding*, becomes specifically lighter, and thereby loses a certain

caſion, to avail myſelf of the ſanction of any names, however high and reſpectable : my conjectures, ſuch as they are, originate from my own experiments : my errors and miſtakes I lay at no man's door ; and if there be any truth in what I advance, I am perſuaded that in the paths of ſcience TRUTH will make its own way.

certain portion of its ſpring and force : hence, thoſe animals that naturally exiſt in a lighter or leſs elastic atmosphere are not ſo quickly deprived of life, by means of the air-pump, as thoſe that uſually breathe the heavier air common to us. Aquatics come under the denomination of thoſe that naturally breathe an humid and leſs elastic atmosphere ; the Tench and Eel, therefore, are not eaſily to be deprived of life by means of the air pump : and as we perceive the motion of the heart, when taken from the body, can be ſupported for ſome hours by the weight and ſpring of the atmospheric air, can we be at a loſs for a reaſon why it ſhould continue to beat a few minutes under the receiver ? It is ſubmitted to the public, how far theſe experiments may be applicable to our inquiries, concerning the importance of the atmospheric air in animal life.

END of the FIRST CHAPTER.

PHILOSOPHICAL INQUIRIES

INTO THE

LAWS OF ANIMAL LIFE.

CHAPTER THE SECOND.

C O N T E N T S.

The most material objections of Dr. Boerhaave and others, against the admission of the atmospheric air into the blood by the lungs, examined: farther reasons assigned for rejecting Boerhaave's theory of the circulation of the blood: a description of the heart: a new theory of the circulation proposed; and the mechanical causes attempted to be explained: the contradictory opinions of Dr. Harvey and Dr. Boerhaave in some measure reconciled.

THESE INQUIRIES ARE THE FIRST OF TWO VOLUMES

LAW'S OF ANIMAL LIFE

CHAPTER II SECOND

OF THE NATURE OF THE BLOOD

The great natural objections of Dr. Boerhaave and others against the admission of the atmospheric air into the blood by the lungs examined: farther reasons assigned for rejecting Boerhaave's theory of the circulation of the blood: a description of the heart: a new theory of the circulation proposed; and the mechanical causes attempted to be explained: the contradictory opinion of Dr. Harey and Dr. Boerhaave as to the nature recorded.

PHILOSOPHICAL INQUIRIES
INTO THE
LAWS OF ANIMAL LIFE.

CHAPTER THE SECOND.

IN the first Chapter of our Inquiries we had recourse to the atmospheric air, as the natural means of supporting the standard of that VITAL AIR, which we suppose to be the first material cause of motion in animal life : it will, therefore, be necessary to take a review of the most material objections that have been advanced against the admission of the atmospheric air into the circulation of our fluids ; and from this review, perhaps, the candid reader will perceive we have not hastily formed our own opinions.

THE illustrious Borelli was firmly persuaded, that the heavy and elastic air of the atmosphere was admitted by the lungs
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into the blood, which the learned Boerhaave takes notice of, but denies the fact *. He positively says, “it cannot be by the arteries; nor, *does it appear from any argument to be, by the veins.*” We readily grant the former part of this assertion, that the atmospheric air cannot be admitted by the arteries, on account of the resistance it would there meet with from the blood moving in a contrary direction; and Boerhaave himself does not assert, *it cannot be admitted by the veins*; he only says, it does not appear from any argument. We allow no arguments had been urged, at that time, sufficient to induce him to believe the atmospheric air was admitted into the blood, by the pulmonary veins; yet, from this peculiar mode of expression, it is apparent Boerhaave was far from thinking it impossible; for, his very words seem to leave the matter of fact open to future inquiry; and we hope to be able, *by many arguments*, to set forth the moral certainty of it; which is, perhaps, the highest degree of evidence we shall ever arrive at concerning the laws of respiration.

LET us then examine the objections advanced by Dr. Boerhaave against the admission of the atmospheric air into

* An autem partes graves, et elasticæ, aëris hinc miscentur sanguini pro vitali elasticâ oscillatione, ut docet eximius Borellus? id nequit fieri in arteriis, nec ullo argumento constat in venis. Quin creditur obesse aër vesicas extendendo venas comprimens in inspiratione; vis comprimens thoracis venas arctans in expiratione; singularis hinc arteriæ in venam commutatio; difficilis aëris transitus in meatus parvos, aquæ pervios, oleo, et spiritibus; humor lubricus membranæ succingentis interiora trachææ; aëris sanguini infusi noxia.

the blood by the pulmonary veins: he observes that this air, by extending the vesicles of the bronchia, compresses the veins in inspiration; and he says, the compressing force of the thorax narrows the veins in expiration; both these assertions, however, appear to me to be improbable. It is a well known fact, that not only air but all other fluids put in motion will take that direction where they meet with the least resistance; hence the vesicles of the bronchia readily yield to the propelling force of air in inspiration: and it appears to me to follow, that the veins, distended with blood, resist the compressing force of these inflated vesicles; for the power of any given quantity of air is abated, in proportion as it is divided, and subdivided, into parts that are kept asunder from each other; and the innumerable cells of the bronchia seem admirably contrived by the Author of Nature to prevent this very compression contended for by Dr. Boerhaave. Nor, in expiration can we suppose the channels of the pulmonary veins to be narrowed by the compressing force of the thorax, because the vesicles of the bronchia as readily yield to this power; and as the air received into them by the act of inspiration is at this time discharged, the vesicles themselves must occupy less space: where then is the necessity of the pulmonary veins being narrowed in expiration by the compressing force of the muscles of the thorax? We cannot indeed conceive it to be natural, either in inspiration or expiration, that any considerable compression should take

place in the pulmonary veins, as it would be an impediment to the circulation of the blood itself, which respiration is intended to promote.

FROM the foregoing observations, one point, at least, seems clear; that as the atmospheric air is discharged from the vesicles of the bronchia in the act of expiration, if it be admitted from the vesicles into the blood at all, it must enter the veins during that period; and this is a circumstance particularly to be remembered, when we speak of the laws of respiration.

IN the next place Boerhaave takes notice of the singular changing of the artery into a vein in the lungs. A very laconic mode of expression; but to have said more might perhaps have made altogether against his opinion: for a singularity takes place in the bronchial arteries and veins, (which are appropriated to the nourishment of the lungs,) by their frequent *anastomoses* not only with each other, but particularly those of the bronchial artery with the pulmonary vein: do not these *anastomoses* evidently shew that something more than nutrition was provided for in these important organs of respiration? — Another observation occurs in this place, namely, that the ramifications of the pulmonary artery are more numerous and larger than those of the pulmonary veins; this indeed is singular, as in all other parts of the body the veins exceed the arteries both

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in number and size; and this singularity, likewise, will hereafter command our attention.

BOERHAAVE farther urges the difficult transit of air into narrow passages, (by which I presume he means pores) pervious to water, oil, and spirits. The matter of fact in this instance is against him; for it is well known to those who have made experiments on air, that under certain circumstances air will pass through cavities impervious to such fluids; and here we must beg leave to observe also that there is a cellular membrane proper to the lungs, and in contact with the vesicles of the bronchia: all the bronchial cells, Malpighi particularly remarks, are surrounded by a very fine reticular texture, of the small extremities of the pulmonary arteries and veins, which communicate every way with each other; and M. Helvetius asserts, that by blowing into this membranous substance, the air thus admitted will compress the lobes of the lungs; and he farther says, which more particularly makes for our purpose, that by blowing forcibly into the bronchial vessels, the air passeth insensibly into this interlobular substance. Thus it appears by the experiments of this very accurate observer, that there is a passage which admits air to the extremities of the pulmonary arteries and veins: this also deserves particular notice.

BOERHAAVE adds another impediment, which is, the lubricating humour of the membrane that lines the trachea; he might have carried this objection farther, as we will allow the like humour to exist through all the vesicles of the bronchia; it is a glandular secretion, proper to tubulous parts and membranous surfaces; and we will venture to say, it is a mucus, secreted by the power of vital air, evidently intended to prevent injurious friction on all occasions, and, in the present instance, to defend the parts against the force of the atmospheric air, in its transit through the trachea, and the bronchial vesicles, into the pulmonary veins. Malpighi's experiment of injecting ink into the pulmonary artery, and thereby tinging this lubricating humour that lines the trachea, also proves that there are channels of communication between the arterial tubes and the trachea: when therefore we take into consideration these experiments of Helvetius and Malpighi, although we may not allow them to be proofs altogether satisfactory, we must acknowledge they are strong presumptions in favour of the passages contended for.

IN the last place Boerhaave asserts the noxious effects of air infused into the blood. This likewise is a very laconic expression. Improperly admitted, we grant its full force; because the power of air may destroy animal life; but the structure of the lungs, and particularly of the bronchial cells, is so admirably contrived by the Author of Nature

as sufficiently to guard against this injury, in an atmosphere friendly to animal life ; and it is well known, by excluding the common air of the atmosphere from an animal, that death soon ensues.

It does not appear that Boerhaave intended to make a distinction, in this last objection, between a pure and an impure atmosphere ; and, indeed, if the air only acts upon the blood in the lungs, by its weight and pressure without mixing with it, the purity or impurity of the air we breathe, should seem to be a matter of indifference, provided its specific gravity was not materially altered. In justice, however, to the memory of so illustrious a character, it is proper to mention that many important discoveries, familiar to us, concerning the properties of air, and its various combinations with other particles of matter, were altogether unknown to Boerhaave. But, at this time, even from experience, we may, with some degree of propriety, speak of the noxious effects of impure air infused into the blood, and circulating in the animal œconomy.

In one of my lectures on diseases, I had occasion to dwell much on this point. In the small-pox, for instance, both in the natural way, and by inoculation, I endeavoured to shew that the unfriendly stimulus producing the disease must necessarily float in air ; that in the natural way it is chiefly received by the lungs—but in inoculation by the excretory

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glands of the skin: and I endeavoured to account for the secretion of the variolous matter from the stimulating property of this noxious air.

It is, likewise, well known not only to medical practitioners, but to most men, that the putrid effluvia of a sick chamber may, and too often do prove fatal to those, who are either compelled by duty, or induced through humanity, to breathe in so impure an atmosphere. If this be allowed, can we doubt the rational probability of the admission of the atmospheric air into the blood, in its circulation through the lungs? It would be tedious to enumerate all the objections which, from mistakes and prejudices, have been advanced against the admission of the atmospheric air to the heart, by means of the lungs; out of respect, however, to the established reputation of Dr. Needham we shall take notice of a few more difficulties set forth in his treatise *De Formato Fœtu*.

For his first objection he quotes high and learned authorities, “that the pulsation of the heart does not exactly correspond with respiration* ;” and this I believe has hitherto been regarded by many as an insurmountable difficulty. We readily admit the fact; it is well known, in

* CERTE magni momenti est illud *Higmore-Boylanum*, nempe quod pulsus respirationi non accuratè respondet—adeò ut, sive systole, sive diastole recipiatur, neutrà inspirationi synchronica est, sed aliam prorsus motuum suorum proportionem observant.

the action of diving, for instance, and by other experiments, that the circulation may uninterruptedly continue for many seconds, including at least an equal number of pulsations, although respiration be suspended : nor is it necessary, according to our theory, for pulsation to be *synchronous*, or exactly correspondent in time with respiration ; for we do not consider respiration as the first cause of pulsation, though it be essentially necessary to its continuance after the birth of an animal ; and had not the Author of Nature been thus provident, our corporeal tenement would be more brittle than it is.

THIS objection, therefore, does not, in the least, affect our principles—it is by the power of Vital Air that we presume the circulation of the blood is regularly and uniformly maintained ; and we regard the lungs of an animal only as one order of excretory glands, by which a just and adequate portion of the cooler and heavier air of the atmosphere is constantly received into the blood, and the lighter air of the body as regularly discharged ; for we mean to contend that a similar operation takes place by the excretory glands of the skin ; and there are also other channels by which an heavier air is occasionally introduced into the circulating fluids, which we shall speak of in the proper place.

THUS we shall endeavour to make it appear that animal bodies are amply provided with the means by which a cooler
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and heavier air than that existing in them is continually admitted, in order to support the spring and power peculiar to Vital Air; and thereby to maintain that proper standard necessary to life itself, not only in the human species, but throughout the whole animal creation: for the spring and power of Vital Air we presume to be different, in different animals: hence, we may rationally account for the degrees of heat proper to animal life, in the various orders of animated beings; and also for their existing, some in warmer or dryer, others in colder, or more humid atmospheres; yet all according to the general law of our omniscient Creator; and this law appears to us to be that of the atmospheric air, proper to each distinct order of animated beings, being somewhat colder, and heavier than their own vital air. These remarks may perhaps be pleasing to those acquainted with the use of the air-pump, and to enlarge farther on this point would be foreign to our present design, and altogether superfluous; for beginning with the lower orders of animated beings, proceeding experimentally and gradually ascending to the most animated, the rule seems to be universal*.

DR. NEEDHAM also observes, “the atmospheric air cannot be admitted to the heart by means of the lungs, in many animals, because they have no lungs.” We certainly shall not attempt to prove air may pass through the

* For farther information on this subject, vide note, p. 27 & 28. chap. 1.

lungs of animals that have none, and readily grant the Doctor every thing he could wish in this argument—*except the conclusion*: for it is universally allowed that the animals alluded to have vesicles for the reception of the atmospheric air, through which it may be transmitted to the circulating fluids. Whether such cells be termed lungs or not, or in whatever part of the body they may be placed, is to us altogether a matter of indifference: so that a communication between the atmospheric and vital air be constantly maintained, 'tis all we ask; and without this communication *we can prove* animal life cannot be supported. This objection, therefore, appears to be nothing more than a scholastic quibble; and what has been advanced will perhaps be received as a direct answer to his observations concerning birds; since experiments on the air-pump sufficiently convince us, that the plumed race are equally dependent upon a constant supply of atmospheric air for their existence, with every other animated being.

THE whole of Dr. Needham's difficulties respecting fishes are easily and readily to be solved, by attending to the explanation of our 13th principle; which shews motion and heat to be relatively dependent on each other: we shall not, therefore, enter into his detail, since it is well known that the inhabitants of the waters require a change of air in common with other animals, although they are capable of existing in a less elastic atmosphere than that we breathe; less

elastic, on account of the air being rendered more humid by the water. But when water is put into brisk motion the air becomes more elastic, and we then observe distinct globules of air, and that each globule is inclosed within its proper tunic formed of the water, in like manner as when heat is applied; and we may farther take notice, that when the bubble bursts, this elastic air escapes: when, therefore, we consider the formation of the mouth and the gills of fishes, and their uses, can we be at a loss to imagine how the generality of fishes are constantly supplied with a colder and heavier air than that existing in their own bodies?—and we may rest assured that the Author of Nature has not neglected those which possess little or no loco-motive power, since he has so wonderfully displayed his wisdom in thus providing for the superior inhabitants of the watry region.

HAVING thus answered every objection of the learned Dr. Needham, which appears to make against our opinions, we shall observe, that from many experiments exhibited in support of our principles, other arguments may be drawn in favour of the admission of the atmospheric air into the circulation of our fluids; and, when we come to speak of the laws of respiration, we have yet farther proofs in reserve, that more immediately appertain to the mechanical construction of the lungs themselves.

LET us now return to the immortal Harvey, who, reasoning on the motion of the blood, takes particular notice that the beating vesicle, as also the auricle of the heart when completely formed, whence pulsation begins, is irritated to the motion of contraction by the distending of the blood * : and speaking of the cause of its distension, he says the diastole is made by the blood swelling up, as if by an internal spirit † : from whence he draws this conclusion, that the opinion of Aristotle concerning the pulsation of the heart, happening after the manner of ebullition, is in some measure true ‡ : and my great oracle farther adds, “ that which we daily behold in milk heated by fire, “ and in the fermentation of beer, the same happens in the “ pulsation of the heart §.” In confirmation of this assertion of the illustrious Harvey, we have fully proved, by experiments ||, that these effects are produced by the power of the air contained in those fluids.

* Certumque est vesiculam dictam, ut et cordis auriculam postea, unde pulsatio primum incipit, a distendente sanguine ad constrictionis motum irritari.

† Fit, inquam, diastole a sanguine ab interno quasi spiritu intumescente.

‡ Adeoque Aristotelis sententia de pulsatione cordis (fieri eam, scilicet, ad modum ebullitionis) aliquatenus vera est.

§ Quod enim in lacte ab igne calefacto et cervisæ nostræ fermentatione quotidie cernimus, idem etiam in pulsu cordis usu venit.

|| Vide Principle 14, &c.

THIS leads me to take notice of one more objection against the admission of the atmospheric air into the circulation of our fluids, on which the followers of Boerhaave, who place their faith in animal spirits, seem greatly to depend: namely, that the air within us is always in equilibrium with the air without us; and consequently, they say, the pressure of the atmosphere can neither promote, nor retard, the contraction of the thorax, nor the dilatation of the heart; and those bewitching spirits would not suffer them to consider the possibility of the atmospheric air reaching the heart, by means of the lungs; nor the increased power of that air, rarefied by heat, and, in a circulating current, confined within tubes.

THAT there must be a just balance continually preserved between the atmospheric air, and that circulating in an animal body, in order to preserve life, I could readily assent to: but as the technical term equilibrium is derived from the Latin *æquus*, equal, and *libra*, weight; if the expression be thus used, to shew, that a given quantity of air within an animal is equal specifically in weight to the same quantity of atmospheric air, the argument is altogether fallacious. The contrary has sufficiently been proved by experiments; and the matter of fact is at this time, I believe, well known to philosophic men.

THE numerous proofs exhibited in support of our principles fully authorised me to explode this idea; and when we reflect on the encreased power of air, rarefied by animal heat, and circulating in the vascular system, and take into consideration the external coverings of animal bodies—can we be at a loss to preserve the equilibrium necessary to life, between vital air, and the surrounding atmosphere?—No more, than to balance any given weight, by regulating the powers of the steel-yard; or to account for the mechanical operation of the fire-engine: hence, reason and reflection founded on experiments, in my mind, at least, quieted those perturbed spirits, and consigned them peaceably to the tomb of oblivion.

THE magic spell thus broken, I found myself at liberty not only to pursue the operations of respiration, and the circulation of the blood, but to follow the digestive faculties, the reception of the chyle into the blood, and the numerous glandular secretions for the purpose of nutrition, together with the discharges of excrementitious particles of matter from the animal œconomy: throughout the whole of these researches, I had the satisfaction to find that air, the first cause of motion in animal life, continued to act in the production of all the various effects, necessary to the maintenance and support of life itself. I could not then but yield my rational assent to the truth of this theory; which led me, with profound reverence, to contemplate the

wisdom of the Author of Nature ; and, admiring the simplicity of the means made use of in all the wonderful operations of an animal body, to attempt to prove, by experimental philosophy, that air is the primary agent in animal life.

THE arguments already used, to obviate the most material objections against the admission of the atmospheric air into the circulating fluids of an animal, may perhaps induce some to think with us it is highly probable that this air is received into animal bodies ; yet, we wish such readers not to fall in with the present opinions too hastily, and caution others against condemning them too rashly ; and that no one may inadvertently be misled, we shall make a few remarks upon the whole that has been advanced.

ALTHOUGH we have shewn air does actually exist in the blood, and likewise in the medullary substance of the brain, those experiments were not intended to prove any thing farther ; they cannot convince us that this air was in an active state in the living body. The same thing is to be observed with regard to the experiments on the hearts of some animals when separated from the body ; for if the spring and weight of the atmospheric air, as we believe, is the first cause of the regular and forcible motion of the heart in this detached state, we are not authorised to conclude, from thence, that air is the first cause of animal motion.

motion. We wish it, therefore, to be fully understood, it is not any experiment, *singly*, nor any number of such experiments, however they may appear to strengthen our opinions, on which we mean to build our new doctrine concerning the circulation of the blood.

To comprehend the full force of our arguments, the reader must condescend to examine the chain of principles set forth in the Syllabus, together with their experimental proofs; otherwise he cannot, however learned, enter with us philosophically into this subject. One great object of the course of Lectures was to endeavour to investigate the simple elements of Pneumatics, so far at least as they might be supposed to appertain to the laws of animal life. We began first with considering air as matter, and secondly as a fluid; we then pointed out its peculiar properties, and set forth how it differs from other fluids: we afterwards proved air to exist in all bodies, both fluid and solid; and after shewing its various combinations with other particles of matter, we proceeded to explain and confirm, by experiments, the effects of heat and motion on the air existing in different fluids; till, at length, by a regular connection of simple elements we arrived at a moral certainty, from the degree of heat and motion proper to animal life, that the air existing in animal fluids must be in a rarefied and active state. We then shewed that air, in this rarefied and active state, was capable of producing a circulation in a fluid
confined

confined in a tube, without the aid of re-action of the tube itself—from whence this conclusion seems fairly to be drawn, that VITAL AIR is endowed with power sufficient to produce a circulating motion in the fluids contained within an animal body. On this basis our definition is established. “ Air
 “ rarefied, in motion, detained in animal bodies by glandular secretions, or circulating with the fluids in the vascular system, permit us to call VITAL AIR *.”

ON this foundation our doctrine is built; and from the truth of it all our arguments derive their importance. Other collateral proofs have and will occasionally be advanced in support of our general principles; as such we consider the experiments on the blood vessel and some others—for many men have denied the existence of air in the blood of an animal; it was, therefore, incumbent on us to establish the fact: but we depend on our principles to prove the activity and power of this air in the living body; and so long as our simple elements remain unimpeached, this very important point must necessarily be admitted.

IN all subjects not strictly mathematical, it is allowed, the highest degree of proof we can aim at is that of rational probability; for instance, in natural philosophy, it will be granted that similar causes produce similar effects: by this

* Principle 33.

rule then, let us examine the present doctrine. We have proved by a chain of experiments, *that air does exist in animal fluids; that this air is necessarily in a rarefied and active state, and capable of giving motion to fluids that are confined within tubes.* What inference is to be drawn from hence?—As we know by experience that a part of the fluids is continually passing off from animal bodies, and consequently a portion of this rarefied air along with them, it is evident that animal life requires a supply of air. This will readily be admitted: but, perhaps, it may be urged that this supply is derived from our daily aliments. We know that a certain portion of air, sufficient to propel the chyle through the chyloferous vessels into the blood, is received by means of our nutriment, as we shall explain when we come to speak of the laws of digestion and nutrition: but if it be said that the chyloferous vessels are the only channels through which an heavier air than that existing in animal bodies is received—how is this supply to be derived in times of long fasting?

BESIDES, we know that air is rendered lighter by taking away a part, and of course weaker; hence, if animals did not receive a *constant* supply of heavier air, in proportion to the continual waste of vital air, the regular circulation of fluids could not long be supported.—This argument shews the necessity of air being continually admitted into the blood. We also know that muscular motion, the cir-

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culation

culation of the fluids, and life may continue, for some days, without meat or drink; but not many minutes, if the common air of the atmosphere be excluded from an animal.—Can this necessary supply of air, then, be effected so regularly and uniformly, by any other means, as by the constant admission of the atmospheric air into the blood?—And as we have farther seen that a change of the common air of the atmosphere, as well as its being cooler and heavier than vital air, is necessary to the continuance of life—is it not highly probable that a change of air naturally takes place within the body, to support the spring and power of VITAL AIR?—From our simple elements, therefore, independent of other experiments, are we not authorised to hope and believe we have arrived at a moral certainty, that the cooler and heavier air of the atmosphere is continually received into animal bodies, to produce this necessary change of air, and thereby to preserve that standard peculiar to VITAL AIR?

IF then the atmospheric air be admitted, it will, perhaps, no longer be disputed that the lungs are among the number of channels by which it is likely to enter into the blood. This is all we need contend for at present, for we shall endeavour to support our conjectures, as to the manner in which the cooler and heavier air is received into animal bodies,

bodies, and the lighter air discharged, in order to support the standard of VITAL AIR, when we come to speak of the laws of respiration.

HAVING thus endeavoured to combat the Boerhaavean theory of the circulation of the blood, which, however ingenious, was by no means satisfactory to me; I shall not farther trouble my reader with the opinions of other men, but endeavour to convey my own thoughts on this important subject, with clearness and precision: but, before we speak concerning the circulation of the blood, it will be proper for the information of some readers, not professional men, and not already informed, to enter a little into the branch of anatomy, so as to give a descriptive view of the form, [and mechanical construction of that muscle called the heart, which we have styled the centre of motion in animal life; this necessity will be received as an apology to them, for the use of some technical terms generally applied on this occasion; we mean, however, to describe the heart only so far as to convey a clear idea of it, considered as a mechanical agent in the animal œconomy. It will be unnecessary to enter into the component parts of this muscle, it being sufficient for our purpose to understand it possesses all the properties of a muscle; which, together with its peculiar structure and situation, enable it to perform its stated functions.

THE heart is placed in the middle of the thorax, between the two lobes of the lungs; it is inclosed within the pericardium, which may be considered as its tunic, or outward coat; a thin limpid fluid, separated by certain glands, is found within this tunic; the use of this fluid, as allowed by anatomists, is, to prevent injuries that otherwise might arise from friction, in the action of the heart itself.

THE form of the heart approaches to that of an inverted cone, its apex, or point, being at the bottom, and its basis at the upper end; it is rather inclined to the left-side, whereby the right auricle is placed a little lower than the left; this inclination is rationally accounted for, viz. to facilitate the circulation of the blood throughout the animal œconomy.

THE heart of an animal may properly be described as the turning point of a reflex tube, the blood entering in at the right auricle, from the two vena cava's, and passing out at the left ventricle into the aorta: and, having already premised that the blood must necessarily be brought to the heart, before it can be discharged, we shall follow other authors in describing the course of the circulation.

THE vena cava ascendens, and descendens, which bring the returning blood to the heart, unite in the right auricle, where

where they empty themselves, and the blood, by the ordinary course of the circulation, runs into the right ventricle; at the mouth of which there is a proper valve, to prevent its return into the auricle; from the right ventricle, it proceeds to the pulmonary artery, at the entrance of which there is another valve, aptly contrived, to prevent its return: the blood is now distributed throughout the lungs, by means of the branches of the pulmonary artery, and it is conveyed again *immediately* to the heart, by the branches of the pulmonary veins: these veins enter at the left auricle, from whence the blood is conveyed into the left ventricle, and by a proper valve prevented from returning; from the left ventricle it is again pushed forward into the aorta, or great artery, to perform a new circulation throughout the arterial and venal system; at the entrance of the aorta there is also another proper stop to prevent the return of the blood into the left ventricle.

I HAVE endeavoured to describe this compound mechanical agent in terms the most simple; if, however, a clear idea be conveyed of the construction of the heart, to those who have not made anatomy their study, my intention is fully answered.

ON this occasion it is obvious to remark the importance of the lungs in the animal œconomy; we perceive that the blood every time it is returned to the heart, is directly dif-

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performed throughout the lungs, and *immediately* reconveyed to the heart, before it is permitted to begin a new circulation : I may add, before it is capable of performing a new circulation : for had there been no real necessity, we may boldly assert, this operation of its passing through the lungs would never have taken place.

THE world are indebted to anatomical researches for the discovery of this very peculiar circumstance attending the circulation of the blood ; and the matter of fact is all we have occasion to insist upon.

IN the study of Nature, throughout all her works, however complex the machine, the simplicity of the mechanical powers claims the first attention of a speculative mind ; this observation is beautifully illustrated on the present occasion ; and I believe it will be admitted by every one that the blood, after having performed one round throughout the animal œconomy, undergoes some new and important change, in its transit through the lungs, essentially requisite to support a second circulation.

WHAT this important change is, has been the subject of this enquiry, and were it necessary to prejudice the reader by the opinions of other men, I could here quote some very respectable authorities, besides the great Borelli already mentioned, that have supposed it probable, at least, for a part of the air, received into the vesicles of the bronchia

chia, to mix and unite with the blood ; but opinions, however respectable, unsupported by facts, are not to be admitted ; the present doctrine must stand or fall by the balance of probability, founded on the experimental proofs which we have advanced.

A NEW THEORY of the CIRCULATION of the BLOOD.

WE regard VITAL AIR as the first material cause of motion in animal life.

WE presume the proper standard of vital air was fixed, by the Author of Nature, at the time of the creation.

FROM experimental philosophy it appears highly probable, that the atmospheric air is the natural means of supporting the standard of vital air, not only in man, but in all other animals.

THE heart we have considered as the centre of motion in animal life.

IT is allowed, that the atmospheric air is received into the vesicles of the bronchia, in the act of inspiration : and, as the lighter air is discharged from the body, together with other excrementitious fluids, by expiration ; we presume the atmospheric air, at this time, presseth into the pulmonary
veins

veins; and, incorporating with the venal blood, accompanies it in its return to the left auricle of the heart.

THE lungs, then, we regard as one of the channels appointed by our Creator for admitting the atmospheric air, to support the spring and power of vital air*.

NOT only the heart itself, but the arterial tubes are composed of muscular fibres; and it is admitted universally, that a muscular substance possesseth the power of contraction. We presume, therefore, the re-action of the tubes is the secondary † cause of motion in animal life, assisting the propelling force of vital air to produce that complete motion termed pulsation, by which the blood is propelled through the heart and through the whole of the arterial system; and, if there be no re-action in the venal tubes, the blood is returned through them to the heart again by the power of VITAL AIR.

BUT, the Author of Nature has most providentially guarded animal life, by causing an operation, nearly similar to that carried on by the lungs, to take place by means of the excretory glands of the skin. Here too, a certain

* When we come mechanically to consider the laws of respiration, we hope to be able to explain how the atmospheric air presseth into the pulmonary veins.

† THE re-action of the vascular system appears to be dependent on the nerves, but in our lectures we endeavoured to shew, that the nerves themselves were primarily indebted to vital air for their power.

portion of vital air is continually passing off, together with other excrementitious fluids; and the heavier air of the atmosphere as constantly preffeth into animal bodies through the same channels, to supply the place of what is thus discharged, and to give an additional force to vital air, in order to reconduct the blood regularly and uniformly to the centre of motion.

How admirably *simple* are the means by which this first grand operation in animal life appears to be performed!— And the familiar instances that may be called to mind, in the use of mechanical * POWERS obtained by human invention, support the probability of our mode of reasoning: if, then, we may dare to mention the wisdom of Omnipotence, in the formation of man and other animals, we have reason to think the Author of Nature has disposed and arranged the particles of matter, so that throughout life the same first material cause of motion, VITAL AIR, should *invariably* produce the same effect; and also that its spring and power should as constantly be maintained by the common air of the atmosphere.

THE little sparrow on the house-top, has a natural common right to the atmospheric air, equally with the great

* The pump, ventilator, fire-engine, pulse-glass, &c. &c.—By the pulse-glass it is clearly proved that air, rarefied by heat, is capable of giving motion to fluids confined in tubes.

Lord that inhabits the stately mansion: place this small bird under a receiver, and exhaust the atmospheric air, then vital air will soon lose its spring and power, the blood will cease to circulate, and death follows—Exclude the external atmosphere, and thereby cut off the common tenure of life from man, and like the diminutive sparrow, he too must fall to the ground.

It is with peculiar satisfaction, I am now enabled to speak to the opposite opinions of two such great men as Harvey and Boerhaave. The proofs produced by both are admitted, discarding only their imaginary agents, as we have shewn *experimentally* that vital air is the first cause of animal motion. We allow a propelling power existing in the blood, and also the power of re-action of the arterial tubes: and have endeavoured to prove that both these powers contribute to the circulation: by thus uniting *their* opinions we have formed our own theory; and, perhaps, reconciled their seeming contradictions.

WE want no imaginary agents in the blood itself; no animal spirits, nor antagonist muscles, for the heart or the arteries; we may plainly perceive, the heavier air of the atmosphere is momentarily admitted to maintain the standard of vital air, which gives motion to the blood, and produces that swell in the heart, *discovered by Dr. Harvey*, termed its diastole; and, likewise, that the re-action of the muscular fibres

fibres causeth the contraction *ingeniously accounted for by Dr. Boerhaave*, called its systole; which, together make up that complete motion termed pulsation, the object of our present inquiry:—but, hence-forth, if our principles be received, let this mechanical operation be known by the more familiar, yet not less expressive terms of ACTION and RE-ACTION.

END of the SECOND CHAPTER.

PHILOSOPHICAL INQUIRIES

INTO THE

LAWS OF ANIMAL LIFE.

CHAPTER THE THIRD.

Preparatory to the Laws of Respiration.

C O N T E N T S.

THE province of reason — Imperfection of the senses — Of matter — Causes and effects — Heat and cold — Motion and rest — AIR *as a distinct element of matter*, unknown — Not to be exhibited *per se* — Some of the properties of air, in its compounded state, discoverable — How AIR may be the cause of animal life — The principles on which these Inquiries are founded applied to natural Phenomena — Of Ventilators — Observations on the action of air — Of the forms of bodies — Of solids and fluids — Of the sensible causes HEAT and COLD — Remarks on the process of distillation — Observations deduced from the application of the laws of pneumatics to fluid bodies.

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P R E F A C E.

AS it would appear remiss to pass over in silence the particular solicitations I have been honoured with from many gentlemen, speedily to publish the remaining part of these Inquiries, it is incumbent on me to make a respectful apology to them for delaying the Third Chapter till now.

I CAN with truth say, that a close attention to the duties of my profession, joined to the fatigue of study in hours of retirement, rendered some degree of relaxation altogether necessary to my health; and it is well known that but little advantage, in the application of the laws of pneumatics to fluid bodies, can be derived from books, to assist me in these speculations: I hope, therefore, not only to stand excused in the opinion of my friends for the present delay; but also to claim the farther indulgence of time; to render what may hereafter appear, in some small degree worthy their consideration.

ON my own account this unavoidable procrastination is altogether a matter of indifference, as I have not the most
distant

distant view of emolument from these publications. The object with me is that of my leisure time being rationally filled up: for, should the maxims be found true, I am fully persuaded it is the rising generation will be chiefly benefited; and though my opinions have been favoured with the approbation of some learned men, they are ever *with diffidence* submitted to the public; yet, *without fear of their suffering* by any illiberal attack, open or disguised.

THE anonymous Author of observations on my two former Chapters and enlarged Syllabus, who thought proper to dedicate and send his little pamphlet to me, cannot I think seriously expect any notice to be taken of it in this chapter, though he is pleased to say *it would afford him the highest satisfaction*. It is not my intention to reply to any publication to which the writer does not put his name; but, if this gentleman continues to be pleased with his own performance, he may rest assured I am not offended at the rudeness of his remarks; and that I really believe he speaks the truth in saying — *he has learnt nothing from my enlarged Syllabus*.

PHILOSOPHICAL

PHILOSOPHICAL INQUIRIES
 INTO THE
 LAWS OF ANIMAL LIFE.

CHAPTER THE THIRD.

WHEN a Philosophical Subject admits not of ocular demonstration, we must have recourse to reason; and on many other occasions, as well as the present, close reasoning founded on experiments, and the general operations of Nature, as established data, is equally conclusive, and perhaps as satisfactory as mathematical demonstration. We shall, therefore, endeavour by fair arguments to apply our principles, that are supported by experiments, to certain phænomena in Nature. Two great obstacles, however, may prevent success; *first*, the difficulty of clearly, and with propriety, arranging my own ideas; *secondly*, the task of conveying them concisely and forcibly to
 B others.

others. The candid and informed Reader will make great allowances, and may probably be able to supply my defects; but I am fearful lest some should continue to complain of ambiguity, for want of being sufficiently acquainted with the experimental proofs and principles I proceed upon; for which reason a part of what follows has been taken from my notes for the information of such gentlemen as were not present at the lectures in which the principles were explained. It should, however, be remembered, that I am not at this time teaching the elements of philosophy, but humbly submitting my thoughts to the contemplation of learned and philosophic men; and it is to be hoped they will excuse my errors and pardon my mistakes.

SHOULD we be fortunate enough, by arguments drawn from experiments, and in conformity to the general laws of Nature, to make it amount to a high degree of rational probability that the atmospheric air is constantly pressing into animal bodies by the lungs, and that the lighter air is as constantly discharged from the body by the same means, it is all we aim at in physiological reasoning. Did the subject admit of ocular demonstration, argument would become unnecessary, and controversy would cease; it would then be the province of the anatomist to exhibit the channels of communication: but as the most curious anatomical researches have hitherto failed in point of actual proof, we must depend upon reason for our present guide, which may perhaps assist
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the diligent anatomist in his farther pursuits; nor am I altogether without hope of future success.

WHILE we are truly grateful for the little we do know, we have to lament that man's senses are too imperfect fully to comprehend the secret and wonderful operations of Nature. We talk of matter, very familiarly, and though some of its properties we may be acquainted with, yet the most learned knows only so much as ought to humble him in his own opinion—What rational idea has any man of uncompounded matter? We speak of causes and effects:—they are terms to which by common consent ideas are affixed, and so far they answer the purpose of man conversing with man. But who will discover to me a cause that is not itself an effect proceeding from some other cause? And if we attempt to pursue this idea beyond material agents; *that is*, beyond the reach of our senses; we are immediately lost in the regions of fancy: there is not a single conductor to lead man one step forwards, except indeed he proceeds at once to the first GREAT CAUSE of all natural effects.

FROM this humble consideration I dared not to trust myself beyond the scanty limits of sense, and therefore drew the line by styling Vital Air the first material cause of motion in animal life—no prior cause being evident to the senses.

MUCH has been written by studious and learned men concerning heat and cold ; but, though we may be acquainted with some of their effects, are they any thing more than relative terms ?—Who will explain to me the ultimate power of heat ?—or point out the extreme degree of cold where there is absolutely no heat ?

THE wisest men have found it equally difficult to explain their ideas concerning motion and rest. Familiar as these terms appear to be, and are thought to be understood, they do not convey absolute significations. Where is absolute rest to be found in bodies ? — Motion appears to be altogether necessary for the maintenance and support of every thing in this world. The forms of bodies cannot be produced ; they cannot be supported ; nor can they be dissolved without the help of motion. Yet, thus much we may depend upon, *that natural effects of the same kind have the same causes.* According to this simple rule laid down by the great Newton, we shall pursue our inquiries.

THAT all space in and about this earth is filled with air, will not at this day, I believe, be denied : but, speaking of it as a distinct element of matter, what is air ?—The philosopher will reply, he knows not.—But this we do know, that air exists in all matter, and that all bodies may be rendered so minutely divisible as to float in air ; nor can we, by
any

any known process, obtain air uncompounded and free from other particles of matter. The world are infinitely indebted to many ingenious men whose labours have proved successful in discovering some of the properties of air; and to these points our observations are principally confined: but as we cannot exhibit air *per se*, pure, and unmixed with other matter, so as to make it evident to the senses; how can any man speak of the form of air? Yet, from a knowledge of certain properties of air in that compounded state which does render it evident to our senses, air is allowed to be matter. Matter, we say, is of itself inactive, but capable of being put into motion. If it be asked how air can prove the first material cause of animal life? we answer, by its peculiar property of rarefaction. We know that air is rarefied by heat, and that animal life cannot exist without heat; therefore, we presume to say the air contained in animal bodies must be in a rarefied state. Experiments also convince us that air in a state of rarefaction becomes active; and by way of emphatical distinction we have stiled that portion of air, circulating in an animal body, that gives motion to the blood and juices, *Vital Air*.

IN the course of our experiments we supported by facts the following distinct principles:

I. AIR is matter.

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II. MATTER

2. MATTER is of itself inactive, but capable of being put into motion.

3. AIR, as matter, is capable of different arrangements, modifications, and combinations, in obedience to the general laws of Nature.

On this principle we are compelled to consider all the factitious airs (perhaps improperly so called) obtained from different bodies to be the same air as that of the common atmosphere; though it may be differently arranged and combined with other particles of matter: for we learn—

PRINCIPLE 4. Air is a fluid—but has properties peculiar to itself and different from other fluids.

5. AIR is an elastic fluid; and the force of its spring is proportionable to its weight*.

6. AIR possesses the property of rarefaction or expansion.

7. HEAT, by which we mean a similar effect to that produced by fire, will rarefy or expand air.

Air may also be rendered more rare by taking away a part when the external atmosphere is excluded; for that which remains will, by its power of expansion, still occupy the whole space; there-

* Viz. Under similar circumstances.

fore, this air becomes more rarefied in an exact proportion to the quantity exhausted. It also becomes lighter in the same proportion as it is rarefied; which does not happen when air is rarefied by heat. This is fully proved by the Madrafs experiment*; and as the natural causes are not the same, it satisfactorily accounts for the effects being different. This observation appears to be worthy attention, as some persons imagine a cold air is always heavier than that which is warmer.

8. AIR possesses the property of compression or condensation.

9. EXTERNAL pressure will condense, or compress air.

10. COLD will condense or compress air.

* Vide the Meteorological Diary kept at Fort St. George. Phil. Trans. vol. 70. p. 251 and 266.

	Therm.	Barom.	Wind.	Weather.
1777				
May 29 at 6 in the morning	81	— 29 : 16	— S.W.	— Fair.
The same day at noon	100	— 29 : 16	— W.	— Fair.
1778				
May 18, at $\frac{1}{2}$ p. 5 in the morning	82	— 29 : 17	— W.	— Fair.
The same day at noon	104	— 29 : 18	— W.	— Fair and exceeding hot.

FROM the whole of this table, as well as from the above observations, it appears that there is little or no alteration in the weight of the atmosphere produced by heat; or, what the atmospheric air may lose in weight by the influence of heat, is fully compensated by the additional spring and power acquired by its rarefaction.

11. AIR *then* is rarefied by heat, and compressed by cold.

12. AIR exists in all bodies, fluid and solid*.

Man's proper element is that atmosphere which every where surrounds this Globe, and the laws of his existence require him to breathe that air; it is therefore proper to observe the common air of the atmosphere on all occasions is alluded to, though it may be spoken of, as under the particular influence of heat or cold. In all the operations of Nature it is likewise discoverable that the atmospheric air is the first grand agent employed by the Parent of Nature, throughout these his lower works. It not only surrounds all bodies, but we also learn (Prin. 12.) that it exists *in* all bodies. Life cannot be supported if air be excluded. Without its presence fire would cease to burn, nor could the operation of fire be applied to other bodies. Neither the eggs of animals nor the seeds of plants will burst into life if deprived of air. We may add too, that life cannot long be supported in a stagnating air. And as air is rarefied by heat and compressed by cold, we regard rarefaction and condensation as the natural means of preserving its perpetual motion; without which it is highly probable that the whole animal and vegetable creation would perish; and perhaps this globe might undergo some wonderful change.

* Vide Syllabus, p. 23, 24 and 25.

LET us now apply the principles here laid down, and consider first, how ventilators act; with a view to enlarge our knowledge of the effects and properties of air. By a ventilator we do not mean such a contrivance as is vulgarly called so, a whirligig placed in a door or window; the use of this instrument is to disperse the air admitted into a room through the hole of the door or window in which it is placed; and it has merit; for by its motion the air is prevented from passing in a right line, which might injure a person standing or sitting in, or contiguous to its direction: but such a contrivance, speaking of it as a ventilator, has no power; it is merely passive and acted upon by a current of air; a common hole would answer every other purpose, except that I have mentioned, equally well: for when the external atmosphere and the air within the room are brought to equal spring or weight, this machine is deprived of motion, because the current of air no longer continues. It may indeed be put into motion if the air of the room becomes so highly rarefied by heat as to overpower the pressure of the external atmosphere; for this current of rarefied air passing out through the hole will produce the same effect upon a whirligig. Its motion, then, we perceive originates from the power of air, and it will continue so long as the air of the atmosphere and that within the room are of unequal spring or weight and no longer; for as soon as they are brought to an equilibrium, as before observed, the motion of the whirligig stops.

THE following observations, however, are to be collected from what has been said concerning this curious little instrument.

OBS. 1. Bodies are acted upon by air.

OBS. 2. A body aptly disposed for motion, and apparently at rest, may be put into motion by the power of the atmosphere.

OBS. 3. Motion may also be produced in the same body, by the spring and power of rarefied air.

OBS. 4. This motion, which way soever arising, ceaseth as soon as the air on both sides is possessed of equal spring and force.

THESE observations will be hereafter referred to, and may perhaps be found of some consequence, though they do not come up to my idea of a ventilator; for it appears to me the act of ventilation cannot take place till the confined air has an opportunity of escaping, and that such powers only are to be regarded as ventilators as are capable of putting air into motion and of discharging it;—for then the atmospheric

atmospheric air will necessarily press in. Heat seems naturally to possess the requisite properties; and the two grand ventilators we mean particularly to advert to are SOLAR HEAT and TERRESTRIAL FIRE: by the influence of the sun exhalations arise; and by culinary heat noxious vapours may be discharged. We may therefore, I hope, with some degree of propriety add two more observations, as they appear to be laws of Nature.

Obs. 5. The heavier air of the atmosphere will regularly press into any given space from whence the lighter or rarefied air is passing off, unless it be impeded by art.

Obs. 6. *Speaking philosophically*, such powers only are to be termed ventilators as are capable of rarefying and of discharging air.

FROM what has been said it will appear that we regard the lungs as a ventilator, from their natural power of discharging the lighter and highly rarefied air from the body of an animal, and not from the circumstance of the atmospheric air being first admitted into the vesicles of the bronchia by the act of inspiration; which takes place at the birth of every animal: for we consider it to be there deposited as in a reservoir, and that it does not press into the pulmonary veins till expiration commences, and vital

air is passing off: and without this most wonderful provision, we shall hereafter endeavour to shew, the act of respiration could not be performed.

WE are now prepared to make a few cursory remarks concerning the forms of bodies. All material substances are called bodies, that assume a figure or shape evident to our senses; and such figures or shapes are called their forms. We cannot conceive an idea of form without figure or shape. All bodies therefore must have certain boundaries; some intermediate space, then, must exist between one body and another; and this space between bodies, it is now universally acknowledged, is possessed by air.

As all bodies may be resolved into parts, their figures or shapes may be changed; and hence we regard the forms of bodies as natural effects. If we can discover natural causes that operate to produce changes in the forms of bodies, the same mode of reasoning, perhaps, may lead us to a knowledge of those natural causes that maintain the forms themselves.

PHILOSOPHERS term that a solid body whose minute parts are connected together, so as not easily to give way or slip from each other; and that a fluid body whose particles are

so loofely connected that they readily move out of their places when preffed with the leaft force one way more than another: but fome farther obfervations altogether neceffary to be noticed concerning folids and fluids have occurred to me. All folid bodies, even thofe of the greateft denfity, are allowed to be porous; and, by the help of glaffes of no very great magnifying power, thefe pores are rendered evident to our fenfes. From the pith of elder to the moft denfe metal thefe pores or cells are fo many void fpaces in regard to the bodies themfelves; and experiments convince us that they are filled with air; nay, even the intermediate folid little fubftances between the pores, by the affiftance of good glaffes, appear alfo to be porous. Thefe obfervations may, perhaps, tend to fupport the truth of the principle, *that Nature abhors a vacuum.*

HAVING thus endeavoured to fhew that air does pervade the moft denfe bodies, it appears highly probable that the air peculiarly exifting in folids, is more compressed by the furrrounding matter, than the air contained in fluids, whofe parts readily move out of their places; and this hypothesis may in fome meafure account for its being heavier, though in my opinion it is not altogether fatisfactory. Some philofophers have termed the air thus exifting in folid bodies *fixed air*; in oppofition it is prefumed to that in fluids, which they have, with much more propriety, called elastic air.

THE air in solid substances we allow may not have so easy and familiar an intercourse with the atmospheric air as that existing in fluid bodies; nor may it be so soon affected by the changes of heat and cold, so as to produce an alteration in the form of the body itself; nevertheless experiments prove that an intercourse may and does take place between the air peculiarly existing in solid bodies and that of the atmosphere, and that their forms may also be changed: we cannot therefore subscribe to the propriety of this term *fixed air*. But, if it be allowed to speak of air as fixed during its existence in a solid body, this air must be rendered elastic in the very act of separation; when, therefore, it is totally detached from the body and becomes elastic, it appears to me to be a very great mistake to term it then *fixed air*. This misnomer has not been taken notice of for the sake of cavilling at words: but because the term conveys a false idea, and in my humble opinion ought therefore to be rejected.

WE need not enter into the component parts of solid bodies, nor have we occasion to speak of inflammable substances, as such: the principles laid down, however, appear to me to be applicable to both; and may, perhaps, if health and leisure permit, be hereafter made use of in the course of my inquiries. But to return to our subject: the idea impressed on the mind when speaking of water is that of a fluid body; yet, place water in a situation below a certain number of degrees of heat, on the scale of the thermometer,

mometer, and this fluid will be changed into a solid form ; and when the thermometer is again raised above the freezing point, this same solid body will reassume a fluid form : on the contrary, it is well known the most dense metals may be rendered fluid by fire ; but, by the return of cold, or in other words by the absence of a certain degree of heat, this fluid form is destroyed, and the metals again become solid.

By this familiar mode of reasoning we are in possession of another fact.

OBS. 7. Heat and cold are natural causes capable of producing changes in the forms of many bodies, both solid and fluid.

NOR can we doubt of the air existing in these bodies being expanded by heat and compressed by cold ; this, in the first instance, seems to account for the expansion of metals by heat. Perhaps it may lead us also to conjecture why ice becomes specifically lighter than water. When the action of the elastic air existing in water is overcome by cold, it will necessarily be more compressed ; hence this aqueous body may be capable of receiving an additional portion of air ; for the atmospheric air, meeting with less resistance, we know will press in more abundantly : it appears then not to be

be highly improbable that ice is charged with a larger quantity of air, and that this air likewise is heavier than that peculiar to water. We know the particles of a fluid body readily move out of their places, when pressed with the least force one way more than another; and when we consider that the spring of air is proportionable to its weight, may not this heavier air in the act of freezing force the aqueous particles somewhat farther asunder, and thereby encrease the bulk of the body? If this mode of reasoning be admitted, as air is more than 800 times lighter than water, we cannot be at a loss to account for ice becoming specifically lighter than water.

It has long been, and with rational intentions, a subject of inquiry to learn what other particles of matter float in air, when it possesses the property of converting water into ice: at present it does not concern us to examine this point; for, however it may be compounded, it is still atmospheric air, and the natural cause of this effect most evident to our senses is *cold*: from this phenomenon we may safely draw the following conclusion.

OBS. 8. The cold atmosphere does possess a power sufficient to overcome the elastic force of that air peculiarly existing in water.

This may perhaps be illustrated by shewing that a contrary effect is produced by heat.

It appears from experiments, that on the application of heat to a fluid, the first evident sign of internal motion is an air bubble (Prin. 14.) and the tunic or coat of every distinct bubble is formed of the surrounding fluid, (Prin. 17.) also that these bubbles of air being specifically lighter than the surrounding fluid tend to the surface; and there soon bursting, this rarefied air escapes and mixes with the common atmosphere, unless it be prevented by proper recipients. (Prin. 21. *) On these principles the operation of boiling, which is no more than the evaporation of a fluid body by the power of heat, may be satisfactorily explained.

As the water grows hotter the air contained in it becomes more rarefied by heat; hence, its spring and power encreasing, this highly rarefied air forces off and is united with a portion of the water; and this intimate combination of heated air and water is called steam. This is no vague conjecture, but a fact established by many familiar proofs; and, being supported by experiments, we are authorised to say that the power of steam depends upon the spring and force of heated air, which is one of its component parts.

It is a mistake many ingenious men have fallen into, in supposing it practicable to discharge all air from a fluid or any other body; and in consequence of this false hypothesis

* Vide Syllabus, p. 27, 28, and 29.

it is no wonder they have been led into erroneous opinions. There is no natural power, that we know of, capable of producing this effect; and the experiments, that seem to favour such a supposition, fail in point of proof. It is true, by hermetically sealing a tube, at the very instant the steam is passing through it, the external atmosphere may be prevented pressing into the heated fluid; but a certain portion of heated air must remain within the glass; not only in the steam but in the fluid itself; and the fallacy has arisen for want of a thorough knowledge of this fact. When this steam is condensed, and the fluid becomes cold, by the contrivance of excluding the external atmosphere, the air contained in the fluid, and the adjacent air within the glass are rendered of an equal spring and weight.

ON this principle * that curious little instrument the pulse-glass is constructed; and upon the application of a small degree of heat or cold many pleasing phenomena are exhibited: these effects are readily produced by means of the highly rarefied and confined air; and for this plain reason, because there is little resistance to overcome. If any gentleman yet doubts the truth of this conclusion, founded on the laws of pneumatics, as applied to fluids, all I ask of him is, to employ only a small portion of his time in making experiments to shew the contrary; and then perhaps we shall think nearly alike.

* Thermometers appear to be constructed on the same principle.

BUT as air has been proved to be 850 times lighter than water, if it be asked how it happens that air should be found in boiling water till the last drop be evaporated? We answer, *for the present*, it is one of the laws of Nature. Experience shews if 1000 gallons of water be evaporated to one, the last gallon will contain its proper portion of air. It would be wandering from our purpose to enter into the theory of heat, and without doing so, we cannot attempt to explain this curious phænomenon: perhaps, hereafter, it may be attempted; but it would involve the present subject with unnecessary difficulties; besides, we are speaking of immediate causes and their sensible effects. In the operation of boiling we perceive the form of water is changed by heat; yet, the effect produced is totally opposite to that arising from cold: for, instead of the fluid becoming a solid body, its component parts pass off in vapour. By this process we also learn,

Obs. 9. The air peculiarly existing in water, by the application of heat, may acquire spring and force sufficient to overcome the action of the atmosphere pressing on its surface.

THE weight of the atmosphere pressing on the surface of the water is considerable: the ingenious Fahrenheit has shewn that under different circumstances of the weight of the atmosphere from 28 to 31 inches, the heat of boiling
water

water increases, so as to rise 8 or 9 degrees, when the atmosphere is heaviest; and so long as the weight of the atmosphere continues the same the observation of M. des Amontons holds good, that boiling water will not grow hotter by any increase of fire. This regularly leads us to the process of distillation, in which, the pressure of the external atmosphere is as much as possible excluded; and for that reason, the steam may be thrown off in this operation with a lesser degree of heat than in an open cauldron. The rarefied air passing off from the fluid contained in an alembic * is also prevented from mixing with the atmosphere, by a proper recipient.

THE process of distillation, though very common, perhaps few operators have attended to it, to make philosophical observations. When the head of the still is luted, and the external atmosphere in a great measure prevented pressing on the water, by the application of heat to the fluid the steam readily ascends to the head of the still, and passes on from thence to the worm, placed in a tub of cold water: by which means the steam is condensed; not by coming into contact with the cold water, for that only surrounds the worm; but by the degree of cold proper to water; *that is to say*, by a degree of cold equal to the temperature of the atmosphere: the steam being

* The alembic here alluded to is the worm still.

condensed, re-assumes its original form, and runs out of the lower end of the worm as a common cold fluid.

THE generation of steam has been already explained, in speaking of evaporation and boiling; but the latter part of this process remains to be spoken to. Water, we know, preserves its form through many degrees of heat; and a degree far above that of the atmosphere is here required to produce steam: yet, this steam is immediately condensed, and the restored fluid loses its heat, by a momentary application of a degree of cold not below that of the atmosphere. We may venture to say this effect could not be produced, if heated air was not the immediate cause of steam. For, if steam could be supposed to be nothing else but heated water, by the application of so small a degree of cold, this water transmuted into steam could not so suddenly, not only be brought back to its original form, but re-appear divested of all sensible heat. We know that heated water mixed with as much cold, will lose its heat only in proportion to the mean of the quantities of heat; for instance, if the thermometer stands at 212 in boiling water, and at 56 in the cold water added, the sum of the extremes being 268, the quicksilver will fall to a little below 134; and that it does fall below that degree is owing to the cold communicated by immersing the instrument.

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BUT

BUT in the process of distillation, as the steam does not come into contact with the cold water; and as we find the effect produced by 212 degrees of heat is instantly overcome by a degree of cold only equal to that of the atmosphere; we must have recourse to some other cause that being thus acted upon is capable of producing these effects. Call that agent Elastic Vapour, or by any other name, we know of nothing but air that is thus rarefied by heat, and compressed by cold; and all vapours, however generated or compounded, appear to derive their elasticity and force from heated air. From what has been advanced we may, I think, be allowed to deduce the following observations; and, by so doing, we shall farther apply the laws of Pneumatics to fluid bodies.

OBS. 10. The air existing in fluids is in an elastic state.

OBS. 11. There is an easy and familiar intercourse between the air in fluid bodies, and the circumjacent air.

OBS. 12. So long as this elastic air is capable of resisting the compression of the fluid body, and the power of the atmosphere acting upon it, the form of the body will not be changed by COLD.

OBS. 13. So long as the power of the atmosphere is capable of resisting the spring and force of the air existing in fluids,
 evaporation

evaporation cannot take place; nor will the form of the body be changed by HEAT.

OBS. 14. It is *therefore* necessary for the action of the elastic air contained in fluids, and the reaction of the atmosphere to be equal, or nearly equal, in order to preserve the form of a fluid body.

OBS. 15. Heated air passing off from a fluid body is the immediate operative cause of steam.

OBS. 16. The force of steam depends upon the spring and power of highly rarefied and heated air, which is one of its component parts.

By endeavouring to shew that heat and cold in an extreme degree, are natural causes capable of rarefying and condensing the air in fluids, so as to produce changes in the forms of such bodies; we are led to conclude that the presence of a certain moderate degree of heat is the natural cause of supporting the elasticity of air peculiarly existing in and essential to the form of fluid bodies: tho' some fluids, gelatinous for instance, may require a larger portion of heat than others; yet, in all, the power of heat must ever be equal to the effect contended for; namely, so far to rarefy the air contained in each, as to render it sufficiently

ciently elastic to resist the compression of the fluid itself; and the weight of the atmosphere acting upon it.

LET us not puzzle ourselves at this time to hunt after more remote causes, which probably might lead to fruitless controversy; and, by resting contented with a knowledge of these immediate causes of natural effects, familiar and evident to the senses, we shall subscribe to another rule laid down by Sir Isaac Newton, “*that we are not to admit more causes of natural things than such as are true, and sufficient to explain their phænomena.*”

IN the next chapter, some of the preceding observations will be applied to certain phænomena, attending experiments made on animal bodies with heated air; and the power existing in them of generating cold, under such particular circumstances, is meant to be explained. Should my remarks prove satisfactory, some of the gentlemen engaged in those curious pursuits may, perhaps, re-consider the subject of animal heat; and they may possibly anticipate me in applying those very experiments, to support the truth of my theory of the circulation of the blood. It is farther intended to mention some causes of difficult respiration; and to speak of the non-respiration of a Fœtus, before we enter upon the
LAWS OF RESPIRATION.

END of the THIRD CHAPTER.