Substance of a LECTURE

Delivered at Newcastle, 28th of December, 1773, on the NATURAL POWERS employed in the CIRCULATION of the BLOOD, independent of the ACTION of the HEART.

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[annotated with ***endnotes***[1] by B. Freeman, UNSW, Jan 2012]

—— I need scarcely do more than mention to you, that a muscle is a composition of animal fibres which have a power of contracting and consequently of moving themselves, and whatever is connected with them ; and that the heart is such a muscle, or rather collection of muscles.—The arteries are these vessels that carry the blood from the heart to all the parts of the body, dividing constantly off from one another, like the branches of a tree, till they terminate in the greatest conceivable tenuity[2].—The veins which bring the humours back again from every part of the body, begin in the same attenuated state as the arteries ended in ; and as they unite, they enlarge, till they meet in one great trunk or vein, which brings the blood back to the heart again.—The heart itself consists of four chambers, or rather of two pair of chambers, each pair consisting of an outer and inner one.—Each of these chambers is to be considered as a distinct muscle, or muscular bag, which has a power of contracting itself separately.—Into the outer chamber of the right side, or more properly the fore side, of the heart, the great vein I mentioned, called the Vena Cava, opens and pours in the blood. When that outer chamber, commonly called the right auricle, is full, it contracts by its muscular force and empties itself into the inner chamber, called the right ventricle ; which, when it is filled, also contracts and injects its contents into an artery called the pulmonary artery, which by its divisions and attenuations sheds the blood through the whole substance of the lungs.

In the second pair of chambers of the heart, the like process is transacted over again. The incipient and imbibing veins take in all the blood diffused through the lungs by the arteries, and uniting their forces as they meet, terminate all at last in one great vein, called the

pulmonary vein, which unloads itself into the outer chamber of the second pair of rooms, called the left auricle of the heart, which, when filled, contracts and issues its contents into the inner chamber, called the left ventricle of the heart, which when it is full, contracts also, and discharges itself into the great artery, called the Aorta ; which branching off, and separating into infinite subdivisions, both in regard to their number and tenuity, diffuse the blood in form or in substance to every organ and spot in the animal system.—I need only observe further to you, in order to your distinctly conceiving the actions of the heart above specified, that, each chamber is furnished with a complete set of valves, which, when the chambers contract themselves, exactly shut and preclude any of the blood from being forced back again by the way that it entered.

From this historical account of the perpetual transactions of the heart, you must distinctly perceive, that in the subsequent discourse I do not pretend to disprove it is by the action and force of the contractions of the heart that the blood is thrown out of it into the arteries : But I propose to demonstrate, that these actions have little or no concern in supporting the progress of the blood along the finer arteries, after it is thrown into the great ones, and still less, in having any sensible influence on its motion through the veins back again to the heart.

The circulation of the blood, as above-described, was no sooner ascertained by the celebrated and learned Dr Harvey, than the force and energy of the muscular contractions of the heart was first universally supposed, and then admitted and acquiesced in almost implicitly, as the only considerable moving cause of the whole : And this, with few variations or additions, continues to constitute the sum of the doctrine of the circulation, from the æra of Dr Harvey down to the present time.—The nature of this discourse does not require that I should enter into any particular detail of all that has been suggested or said upon the powers of circulation. I shall take notice of such particulars as I know, or as occur to me, in the course of this discourse. If any other author before me, that I may either have not seen, or not attended to, has advanced what I may imagine peculiar to my sentiments and reasoning in this disquisition, I can content myself with the originality of my own reflections, without contending for the honour of priority with such persons[*].[3]

By the vigorous contraction of the heart, and the elastic or muscular reaction of the throbbing arteries, then, together with that species of lateral resistance, from the atmosphere without us, and what acts as an equivalent to it within us, (without which indeed all motion

[*] Since this discourse was delivered to the printer (Jan. 1774) I have seen, in a list of foreign publications, a treatise in Italian expressly upon the same subject, published at Modena.

would languish and fail) the blood is supposed to be urged on to the finest filaments of the arteries and glands ; and not only so, but to be propelled into the incipient veins, which, uniting their streams, unite also their forces in bringing the blood back to the heart again.—As a supplement to these powers, the late ingenious and learned Dr Whytt[4] suggested, with some reason, the perpetual oscillations of the finer vessels, squeezing the blood forward in the direction of its progress[*]:— to the assistance of the motion of the venous streams of blood in the primary filaments of the veins, the attraction of capillary tubes, by which liquors are disposed to rise in them to certain heights, is suggested as accessory, and also the motion of the muscles everywhere when they act, pressing the vessels.

The first supposition I shall speak to by and by—but that last is so incidental, and the progress of the circulation is in so many instances equally persisting when every muscle is at rest, that little weight can be allowed to that as a necessary and permanent cause.

But notwithstanding all the auxiliary supplements that may have been occasionally suggested, as conspiring in support of the circulation, still the force and momentum given the blood's motion by the muscular contractions of the heart, has been esteemed of such importance, and so sufficient for the weight of the charge, that the most celebrated calculators, such as Borelli, Sir I. Newton, Keil, Jurin, Hales, Haller,[5] &c. have engaged in the nicest experiments and calculations to ascertain with precision, the force of the muscular contractions of the heart,—the quantity of the blood thrown into the arteries by each systole,—the force and velocity with which the blood is propelled into the arteries, &c.

Indeed the fact of the heart's contractions, and the expulsion of the blood out of its cavities thereby, is so certain, and the supposition of its power for accomplishing all that is inferred from it, has the appearance of being so simple, so mechanical, and so natural, that it is no great wander that the subject has hitherto escaped a stricter and more accurate examination.—What escapes the most penetrating geniuses, may sometimes be stumbled upon by very ordinary capacities ; which ought to be considered as an encouragement to every man's industry, let his genius be ever so ordinary.

The intention of this short disquisition, then, is to prove, that the force impressed upon the blood by the heart, is not the power which conveys it to the extreme vessels, makes it

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[*] That there is a perpetual motion of the animal fibres everywhere, while natural heat remains in the body, somewhat analogous to the vermicular motion of the intestines, is pretty certain. It would seem to be maintained principally, by the constant elapse, wandering, and re-absorption of warm active effluvia everywhere ; and by the perpetual action of the nerves or ultimate fibres, as after explained, everywhere.

penetrate every pore and filament of our frame, and from these subtile transfusions recollects it, and returns again, what does return of it, to the heart. This I shall endeavour to do by a demonstration of the following propositions ; 1. The heart is not the fountain or origin of the motion of the animal fluids. 2. The blood in passing through the heart, and being subjected to its impressions acquires no quantity of motion that it was not possessed of before. 3. That the arterial motion of the fluids does not depend necessarily on the impulses of the heart, but can be accomplished independent of any such force. 4. The mechanical force or momentum of the heart's contractions is absolutely insufficient to propel the blood to the extent of the arterial circulations and secretions. 5. There are, in fact, other powerful agents always subsisting in the animal frame, which, by a mechanical necessity, must act in promoting the progressive motion of the blood, more immediately than the heart can do, and where the powers of the heart cannot reach. 6. There are, besides all these, influences presiding in the animal system which can be reduced to no mechanical standard, but, at the same time, without which all the intricate mechanism in our frame, just and unerring as it is, would not be sufficient to support one revolution, nay, nor one moment's progression of our fluids. To these, by way of corollary, I shall add, 7. That both the primary and final intention of the agency of the heart in the animal œconomy, must be some further purpose, very different from, and less obvious than, the supporting of the progressive motion of the blood.

FIRST PROPOSITION.

First then, I say, that the heart is neither the original seat of the motion of the animal fluids, nor the original cause of their motion. It is self-evident, I apprehend, that we must look for the primary cause and powers of the motion of our fluids in the organs, which are constantly employed in taking in that stock of fresh supplies, which the repairs of our constitution, and the support of its motions require ; and here we are necessarily referred to the absorption of the chyle, or of our digested aliment[6]. The pulsations of the heart, or the momentum of its contractions, cannot reach the chyle in the first passages, and force it into the lacteal vessels : these vessels, as absorbents[7], having not the least communication with arteries, can partake of no assistance from them, in taking up the chyle, and transmitting it to the blood. Now the lacteals are a venous system of vessels, and the chyle's motion in them is entirely venous ; that is, it is a concurrent motion, where the vessels and the streams that flow

in them, are always uniting and enlarging*. How much it is the characteristic of all venous systems of vessels to act as absorbents, we shall proceed to consider.

2. In the lymphatics. The discovery of the source of the lymphatic streams, has been of late thought a matter of so much consequence in physiology, as to have been very keenly disputed between two eminent anatomists[8]: so that we may venture to take it upon the evidence of their experiments, that the lymphatics are also a system of absorbent vessels gathering up extravasated fluids, wandering out of the reach of the heart and arteries, among the interstices of the vessels. These then, namely, the lacteals and lymphatics, are two streams in the animal system, that are not only perpetually flowing, but also perpetually supporting the motion of the other vascular fluids, independent of the direct impressions of the heart.

3. The absorption of the lymphatics appears to me so inconsiderable, when compared with that of the proper veins every where in our system, that, if the lymphatics are not destined for a particular species of absorption, which I am inclined to suppose, I can consider them as no more than as provisional auxiliaries to the veins in that office.

4. The nature of the connexion and of the communication of fluids between the unborn infant and the mother, demonstrates that the supply of a venous circulation by suction or absorption, seems to be universally Nature's direct method of communicating vital supplies, and of supporting the internal motion of the fluids of all organical beings, whether vegetable or animal.

When we maturely consider the immense power of absorption in the skin, and not of it only, but of every surface within the body, one would be tempted to infer, that the veins almost wholly terminated in absorbents.

But there is still greater reason for the presumption, if we reflect also that a very large proportion of the animal fluids are always in an extravasated state. If we consider that the immensely largest proportion of the vascular system is of that attenuated kind, which the finest injections cannot reach ; and at the same time, if we attend that the exterior surfaces of all these vessels are constantly in as moist and succulent a state as their cavities, we will see strong reasons to suspect, that, though some of the arteries may pass into continuous veins,

* Some may imagine, that the discharge of the chyle by the lacteal duct into the left subclavian vein, is of small consequence in estimating the powers which move the fluids ; but this is a great mistake : for, as in a sound habit the repairs of nourishment must be equal to the waste, so the power with which these repairs are introduced into the blood must be equal to the circulating powers concerned in the discharges of perspiration, urine, and the animal parts of the feces taken conjunctly.

yet the greater part must be terminated in imbibing orifices, and consequently that the circulation must, in strict propriety, be carried on by the medium of extravasation and reabsorption, incomparably more than by any uniform continuation of arteries into veins.

It is not my intention in this discourse to enter minutely into an investigation of the physical cause of absorption ; but in so far as it appears of such importance in maintaining the circulation of the blood, I must bestow a reflection or two upon it.

First, then, it is generally, for explication, referred to that power by which fluids are said to ascend in capillary tubes. That the power exerted in every kind of attraction or suction may be the same with that which causes liquors rise in capillary tubes, I make no doubt ; but still, as the two motions are very dissimilar in leading circumstances, the ascent of liquors in capillary tubes, as illustrated by common experiments, is a very unsatisfactory illustration of venous suction : for, in the first case, the tubes must be in an empty state when fluids rise into them.—Again, fluids do not continue to rise in capillary tubes, but become stagnant at certain heights.

In venous absorption, on the contrary, the fluids continue ascending and penetrating into vessels that are full, and likewise, they continue advancing progressively, without stagnating or becoming arrested in their motion, at any height or distance from the origin of the imbibing vessels.

Hence, secondly, we must infer, that though all the vessels in the animal composition are full from one end to another, yet there must be a waste or vacuum constantly going on at one extremity of the vessels, in order to give place and make room for what is imbibed by their opposite extremities.—Liquors must cease to rise in any vessel or vessels which are full without waste.—Therefore upon this subject it must, I think, be concluded, that the constant waste and inanitions happening in the animal frame are the direct, though in another sense, the remote cause of its capacity for constantly assuming fresh supplies into the vessels.

What these powers are, which dissipate the materials of our constitution, I shall have occasion to consider more particularly by and by ; but whatever they are, we must view that power of attraction which brings the chyle into vascular motion, in an inseparable connection with them.

By surveying the actions of our frame in this point of view, you must perceive, Gentlemen, that the venous and arterial circulations become indispensibly tied together, and

united in their reciprocal influence upon each other's motions, so as the one must always necessarily imply the other.

I make this observation here, because it may be objected, that though a venous or confluent circulation may not require the impressions of the heart to perpetuate it, yet an arterial or dividing circulation necessarily does—But I say, that if an arterial circulation can be considered as necessarily instrumental in the production of a venous circulation, which has no dependence on the impulses of the heart ; then the power of the heart, which in our constitutions lies between these two extremes, cannot be supposed essentially necessary to an arterial circulation, whose influence reaches to a circulation where the heart as a muscle is not at all concerned.

Hence it is inferred *a priori*, that of whatever importance the modification of the circulation at the heart may be in the construction of animals, yet the heart cannot be said to be essentially and absolutely necessary to the circulation of our fluids.

SECOND PROPOSITION.

The second proposition I have undertaken to demonstrate is, that the blood, in being subjected to the contractions of the ventricles of the heart, acquires no quantity of motion that it was not possessed of before in the veins.

The heart does not act upon the blood as a pump does upon stagnant water, putting it into a motion and course which it had not before.—This simile is not a correct one ; for in fact the principal, though least observed action of the heart, is its power as an exhauster, which I shall also consider : what at present I allude to, is its positive force in throwing the blood into the arteries.—In this respect, I say, it is not like a pump acting on standing water.

In fact, the blood was possessed of as much motion in the veins when it arrived at the heart, as the heart communicates to it in discharging it into the arteries. So that the interposition of the heart's agency in giving motion to the blood, cannot be supposed absolutely necessary to its progress in the arteries, unless it could be proved that the momentum, with which the blood is discharged from the vena cava, was insufficient to preserve its course in the arteries, without the additional assistance of the heart's contractions.—But it is absurd to suppose this, if it can be proved, that the momentum of the blood in the vena cava is as great as the momentum of the blood thrown into the aorta by the heart.

The heart transmits, by its contractions, no blood into the arteries but what it receives from the veins*; therefore it cannot deliver it either faster or with greater momentum than it receives it.—Therefore, also, the momentum of the blood in the veins is equally sufficient, as the contractions of the ventricles of the heart, to support the motion of the blood in the arteries.

Nay more, I say, that the absolute momentum of the blood moving in the vena cava, and consequently in all the veins, is greater than the momentum with which it moves in the aorta, and consequently in all the arteries:—For though the heart can deliver no blood to the arteries, but what it receives from the veins, yet the veins really receive as much resistance to the freedom of the motion of the blood in them, by every contraction of the auricles of the heart, as the arterial blood receives accession of momentum by the contractions of the ventricles ; excepting in so far as the muscular vigour of the auricles and ventricles may differ from each other.

I know that appearances may be pleaded against me, and that it may be alleged that an artery of the same dimensions bleeds with much greater violence than a vein does. But in the first place, it may be replied, that there is no making a comparative estimate between arteries and veins in this respect, on account of the different thickness of their coats—on account of the uncertainty of the contiguous anastomoses—and likewise on account of the different state of the elastic vapour of the blood in arteries and in veins.

Again, all circumstances supposed equal, and allowing the fact to be true, the velocity with which a fluid flows out of an orifice is no proof of its degree of velocity in its vessels, but is rather a proof of its progressive motion not being proportioned in velocity to the power with which it is urged. There is a great difference between being pressed with greater force, especially alternately in the percussive manner, and moving progressively with greater momentum. The first I allow in the case of the arterial blood ; but the last, I deny : at least I am not acquainted with any proof of the contrary.

THIRD PROPOSITION.

Having proved under the last proposition, that the motions of the heart add nothing to the momentum of the circulation—that the force of the blood issuing out of the veins is as sufficient as the force of the heart to support an arterial circulation—and that the venous and

* It is true, that the excretions must be deducted from the quantity that the veins receive from the arteries, but that is compensated for by the supplies the veins receive from the chyle.

arterial circulations are connected together, in the relation of cause and effect, by links that are independent on the power of the heart's systoles[9]; I come now to prove the truth of the same doctrine by examples, that arterial motions of fluids can be supported, and are in fact constantly celebrated without the necessity of the heart's actions, or the interposition of such a forcer in the center between a venous and an arterial circulation.

Because in the particular disposition of our frame, the heart is known to occupy this station, and to preside at the orifices of the great arteries, therefore, by I know not what diversion of our attention, or deception from appearances, it has always been taken for granted, that there was a mechanical necessity for the action of the heart there, and that without it, the momentum of the blood in the vena cava could not have been sufficient to have distributed and divided it in the arteries, through such an infinite number of ramifications, and in such an inconceivable variety of directions, produced by the angles, flexures, and involutions of the vessels, as they divide and decrease.

Though perhaps all motion, strictly speaking, is both impressed and continued by pressure[*]; yet there are certain motions, such as the running of water, the ascent of vapour and the like, that having no sensible appearance of any resistance to their tendency, may in an improper and vulgar sense be termed spontaneous ; and such I take the motion of the fluids both in the veins and in the arteries to be.

The first example I shall adduce of this kind of arterial motion, which is supported without any such impulses as are analogous to the shocks of the heart upon the blood, is the circulation or progressive motion of the sap in vegetables. In them, the fluids ascend of their own accord, as we express it, to the remotest branches, leaves, and fruit of the loftiest trees[†].

It implies no objection to my argument to allege, that in plants the case is not parallel, as in their transfusion of fluids there is no direct or regular transition of arteries into veins. But what then? still the example is conclusive for what it is adduced to prove ; namely, that in their system of circulation, the veins or roots of the plant act by absorption only ; and,

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[*] Though attraction is a term that may be alleged not to define the nature of the power it expresses, but only to denominate the fact, yet as the signification of the word certainly conveys an idea very different from any kind of mechanical impulse, it is to be wished a word for that phœnomenon had been adopted which would have given no bias to the ideas of enquirers.

[†] It is certain, that in the vegetation of some trees, fluids rise higher than either what we know of the suction of capillary tubes, or of the pressure of the atmosphere on fluids in vacuo, will carry them ; therefore, it is a question, whether there may not be still resources for mechanics to raise fluids higher than it is at present supposed fluids can be elevated by artifice.

without the assistance of any vegetable mechanism analogous to the functions of the heart, transfuse their juices to the finest and remotest fibres of the plant, which are its system of arteries.

Again, to come directly to the point, we have in the particular œconomy of the liver a proof of that very species of circulation in our system, without the intervention of any pulsatory action, which has been supposed necessary to give venous blood an arterial direction and momentum.

Though the liver is the most massy and compactly-formed viscus in the whole animal composition, yet the venous blood gathered from all the internal parts of the lower abdomen, entering it, immediately changes its confluent course.—The end of the vein entering a particular part of the liver, (called by anatomists, the portæ or gates) resolves itself into an artery[10], divides into branches, and spreads its ramifications through the whole substance of the liver, where, after furnishing the secretion of the bile, the blood has a second time its course reversed into a venous one, re-collecting it from the extremities of this singular artery, and bringing it back to the general conflux of the blood in the vena cava before it reaches the heart.

In this institution of animal circulation in the liver, the heart can have no immediate concern more than the kidnies, or any other particular organ in the constitution. Therefore we justly conclude that the heart occupies its station not as a *sine qua non*, or indispensable organ in the circulating of animal fluids.

Nay more ; in the regulation of the circulation in the fœtus, or in unborn infants, the Author of Nature has shewed us, that at the heart itself, Nature, the minister of his power, can manage the circulation even there in a great measure, without the heart's assistance.

For, least the lungs of infants, upon their first coming into the world, should be either so over-grown, or so over-charged with blood as to resist the impressions of the first breath of life rushing into them by inspiration, the better half of the blood discharged in born persons into the heart by the vena cava, is in unborn infants conveyed by a canal provided for the purpose, straight into the aorta, or great artery without being subjected to the impressions of the heart at all. So that this moiety proceeds in its course along the aorta, &c. without the assistance of the heart's action.—Nor can it be supposed that this moiety of blood owes its after progress in its arterial course, to the strokes of the heart on the other moiety that passes through the lungs ; the heart's power being only sufficient for the quantity it acts upon.

FOURTH PROPOSITION.

The fourth proposition which I shall endeavour to prove is, that the muscular power of the heart is not of force sufficient to impress that momentum upon the fluids that must be required to carry them to the ultimate limits of the circulation.—I never addicted myself much to these branches of physiology, which depend upon nice algebraical calculations, therefore I will rest my conclusions here upon such general principles as will sufficiently answer my purpose.—For the argument's sake then, I shall in the first place, admit that the muscular force of the heart is as great as any person upon calculation has supposed it to amount to.——

If the progress of the circulation in the arteries depended upon the mechanical force with which the heart threw the blood into them, may it not be asked, What then is the reason that no syringe can be invented that can be made to drive the subtilest and most searching liquor half so far, or into one-tenth of the number (I take a definite for an indefinite here) of the vessels that the heart reaches and fills by its injections ?—If it is replied, that this is owing to the different circumstances that both solids and fluids are in, while subjected to the impressions of the heart's power, from these the dead subject is under, when artificially injected ; I grant that it not only may be so, but that it certainly is so :—But then, it also certainly follows, that these circumstances, and not the heart's force only, are the cause of the success of its injections reaching the finest and remotest filaments and excretories in the animal system.

There are powers in nature, which can insinuate and drive moisture, both into vessels and into the interstices of bodies, so as to overcome an inconceivable resistance to its progress.—By such means, the hardest twisted ropes may be shortened with such power as to move immense weights fastened to them ;—and the roots of trees have been known to open fissures in very massy rocks which resisted their growth and distension.—But in such cases, any power driving such fluids, analogous to the contractions of the heart in the animal system, would prove of as little effect almost in the promoting of such motion, as the fannings of a fly's wings would.—The case is nearly similar in regard to an infinite number of the compact filaments and strainers through which the animal fluids have to make their way.

Again, if we consider the nature of the fluid, I mean the blood, supposed to be so syringed by muscular force, through such a complicated series of meanders and involutions in the slenderest and almost invisible vessels, we shall find it the unfittest liquor that can be

imagined to be driven in its course by main force :—for it must be a force not only sufficient to urge a permeable liquor (which yet is impossible) but it must be a force sufficient to grind down the viscid, glutinous tenacity of the blood, and break down the unequal sizes of the particles of its constituent parts.—That all this can be done by the main force of the contractions of the heart is so impossible, and so palpably so, that it never could have been thought of, but through the greatest inattention.

If it shall be alleged, that the momentum of the heart is not supposed to be concerned in attenuating the blood, and changing it into the subtilty requisite for passing the finest canals and emunctories[11] in its course,—I shall accept of the concession, without making any strict enquiry, whether many physiologists by their mode of reasoning and explaining themselves, have given sufficient cause for the imputation or not.—But if it is allowed, that it is not the momentum given to the blood by the heart that resolves it in the course of the circulation ; then it follows, that there must be some other active power in our frame, which can change the structure and tenacity of our fluids at will. This implies, that that power which changes the blood, when the force of the heart cannot do it, must also be the power which moves the fluids, where they are so changed by it.—For where they must be changed, there they must have stuck if they had not been changed.

In short, every consideration conspires to evince, that the power of moving the fluids, where they are changed or assimilated to the nature of the parts they arrive at, and the power that assimilates them, must be one and the same ;—and what moves by that principle, must move spontaneously, that is, without any occasion for the application or assistance of that power we apply the idea of downright mechanical force to.

There does not appear to be in our constitution any of these strainings and filtrations, that have often been supposed in physiology. Our fluids are digested in such a wonderful manner, and at the same time, the various organs are so wonderfully adapted to them, that whenever they arrive within the influence of each other, the fluids instantaneously resolve, or are metamorphosed, and disposed into a motion conformed to the structure of the organ.—They move, to use the simile, as iron does when it is said to be attracted by the loadstone.

I beg leave to touch upon another consideration relative to this proposition, before I dismiss it. It is another mistake of inattention, and not a small one in my opinion, which physiological calculators have stumbled upon in their computations. They have always

supposed that the heart contracts with the utmost muscular force it is capable of exerting ; than which, in my opinion, there cannot be a greater mistake.

No muscle can be either always, or the half of always in the exertion of its utmost muscular vigour and power.—This, in a very short time, would overset the whole equilibrium of our system. The strength of a man's muscles may be able, by way of essay, to lift and support for some time, by their utmost tension, an hundred or we shall suppose two hundred weight. But if all his life was bestowed in such an exertion, it would become a very short one.—Reaction will always be equal to action ; and this law infallibly holds true in our system, as well as in all other cases. Every violent action has a violent effect, which must affect the whole constitution.—The energy of the smallest muscle exerted every moment, or every other moment, would throw all our other animal functions out of that poise which is essential to life.—A muscle acting perpetually or momentarily at the utmost stretch of its force, would become to the constitution like the power of the spring or weight in a piece of clock work, without a regulator or pendulum.

I am not ignorant that muscles without antagonists are said to be always in a state of contraction, without any of that hazard I apprehend. But no natural involuntary contraction is ever violent or extreme.—The contractions of such muscles are a state of ease and not of force ; it is a gentle play, and not a violent labour ; and such must the action of the heart be.—Therefore the blood cannot require these violent efforts to force it into its course. It must go almost spontaneously, as a ball thrown gently down hill, or that is humoured, so to phrase it, in its tendency.

In fact, I think there is much reason to presume, that almost all the quantity of motion the blood actually receives from the heart, is exhausted in the extension of the vibrating arteries.—The rest of its progressive motion we shall, as we have hitherto done, call spontaneous, until we can discover what other powers existing in the system, preside over and regulate its course ; which brings me to the

FIFTH PROPOSITION,

Which I propose to confirm ; that, namely, there are other powerful agents always acting in the animal frame, which by a mechanical necessity influence the progressive motion of the blood, as well where the powers of the heart can be traced, as where they cannot possibly reach. All arterial circulation terminates either in evacuation—transfusion—or accretion.

As accretion cannot be supposed to be performed by the action of the heart upon the fluids, but by that power which disposes similar substances to coalesce, whenever the quantity of that tendency is greater between them than the tendency of such particles to separate motion ; there is no occasion for being more particular on this article.—We shall therefore proceed to consider evacuation,—Transfusion depending upon it.

The evacuations of the circulating fluids, then, are performed either without the body, that is from the surface of the body, to which the common air has access ; or—within the surface of the body. The last, namely, the evacuations within the surface of the body, are—either drained off by glandular secretion, or—by accidental escape of humidity into all the interstices and exterior surfaces of every vessel and fibre.

These then I would have you to consider, Gentlemen, as the leading circumstances, which not only give direction to the motion of the fluids, but which actively sollicit them in their course, as I shall afterwards shew more particularly.

Let us next consider what are these requisites in the fluids themselves, which dispose them to what I shall be well enough understood in calling *self-motion*.—The first requisite then is, that a fluid be endowed with an evaporable degree of heat : Such a degree as disposes it to press towards a colder place and state, and to fly off in vapour where-ever it can escape or get vent. This quality the blood is possessed of in a very remarkable degree. It discovers more vapour or volatile effluvia in it, than any liquor of the same degree of tenacious viscidity that we know would do, under an equal degree of heat.

The *second* requisite is, such a mixture and composition of principles in the fluid, as disposes it to that peculiar kind of intestine motion, called *fermentation*, by which the liquor expands itself, runs into new combinations and generates new principles.—Thus, by fermentation, spirituous liquors are generated out of saccharine ones, and acids are generated out of spirituous liquors, or such as might become so : And out of animal liquors, allowed to run into the same kind of intestine motion, are generated fœtid and volatile spirits.—Now there is a double tendency of this fermentable kind always existing in the blood ; the vegetable part of our chyle or concocted food is, by this intestine process, always assimilating into the animal nature, and the animalized parts of our fluids are so disposed to that fermentation which terminates in putrefaction, that nothing could preserve them from it, but the directing of its nisus[12] from that tendency, into a progressive motion.

The *third* active principle in liquors disposing them to self-motion is, the tendency in all liquors disposed to ferment, to generate and extricate very volatile elastic effluvia of particular kinds, now commonly, though perhaps improperly, called *fixed air* :[13] and this, most probably, is one cause of the remarkable abundance of elastic vapour, which I observed already was so copious in the blood.

Whenever vents are opened to liquors strongly disposed to self-motion, by any or all of the above circumstances, thither its whole nisus must be intended. A familiar and striking instance of this we have in liquors put into bottles, and corked before their fermentation is finished. We all know with what violence they will not only discharge the corks out of the bottles, but throw themselves out of them in *jet d'eaus*[14].

It is one of the manifold strokes of infinite penetration and sagacity discovered in the regulation of our fabric, that the innate disposition in our fluids, arising from their commixture, to degenerate from their animal state, should continue so long to be exactly so far and no further exerted, than to determine them [our fluids] by its nisus into progressive motion ; and that, at the same time, this very progressive motion should prove that very critical check which restrains the nisus to putrefaction in animal fluids, from advancing any further towards a pernicious change.

The first series of passages, above mentioned, prepared for the progressive course of the blood disposed for motion, as just now described, are the pores of the skin ; which are of three kinds:—The terminations of arteries—the excretories of these glands immediately under the skin, commonly called the sebaceous glands—and the accidental, we may call them, vents, through the intertexture and agglutination of the vessels of the skin, which give passage to such portions of the extravasated effluvia as approach these orifices.

All liquors, which, from their attenuation, warmth, and divided state, are evaporable, have a tendency to fly off into a cooler and less confined region, and to recede from that degree of warmth which volatilises them, whenever they can. This course they take where-ever the air has access to them, as on the surface of the body, the lungs, &c.—Upon the same principle, the particles next in succession to these that have escaped, take their place, and those immediately behind them again occupy theirs : And so the same principle has its influence backward to the very rise and source, not of the arterial circulation only, but to the remotest venous absorption also.

This, I apprehend, is nearly what is performed in vegetable circulation ; and this power, in common with vegetables, we have constantly exerting itself in promoting our circulation.––But though we have this power in a degree as much more active in us as our fluids are warmer and more evaporable than theirs, yet it is far from what is sufficient to accomplish all the intricacies in the motions and secretions of the animal fluids.

Though it may be questioned whether there is in the compass of nature such a thing as a strict and proper vacuum, yet we certainly find everywhere such improper vacua as answer all the purposes of absolute ones, by not only giving free access to the motion of grosser and more consistent bodies in them, but by really giving the motion of all such bodies a direction and tendency towards them.—Whatever is the mechanical cause of this, I have no occasion to enquire into it just now : It is sufficient for my purpose at present, that this matter may be depended on as a fact.–Where-ever then there is the secretory or excretory duct of a gland, there, or in the course of the liquor secreted from that gland, there is to be found such a vacuum as necessarily influences the course of the humours arriving at it : it does so as necessarily, as a cupping glass either swells the part, or draws the blood into it, where it is applied.

Let us illustrate this by an example where this influence is most obvious. In each of the kidneys there is a cavity, called the pelvis, into which all the secretory vessels of these glands open : Of course, when that cavity is empty, thither will the liquor in the secreting vessels flow, and thither will all the liquors in the vessels communicating with the secretories strain their motion and tend.—If these cavities, called the pelves, had no vent from them, whenever they were full, the tendency of more liquor into them would be at an end, and the circulation in the kidney would stop of course ; except in so far as the regurgitation might be relieved by absorbent veins.—But there is a long canal opens into the pelvis of each kidney, and runs from that down into the bladder. By emptying the bladder, there is a comparative vacuum made, equivalent to the size and quantity of the urine it contained before it was emptied.—I call it a comparative vacuum, because the room of the full bladder, when emptied, is occupied only by the elastic effluvia contained in the intestines pressing the lower abdominal parts into the vacuum made by the discharge of the urine. So of course, the bladder becomes as necessary and effectual a drain from the pelves, or cavities of the kidnies, as these are to the kidnies themselves.

The case is precisely the same, though perhaps not so obviously so, with regard to every gland in the body—each has its secretory either more immediately or more remotely sucked

by the influence of some one comparative vacuum or another.—I say, sucked, not because of the physical propriety of the term, but because it emphatically expresses the agency that I would have you conceive these vacua have upon the fluids contained in vessels that they correspond with.

By what means of the same kind there is carried on a constant extravasation of effluvia, which bedews and keeps plump and succulent all the parts of the body, exterior to the vessels and fibres every-where, will be best understood by my explaining the important vacua, by which the venous flux of the blood is immediately affected and preserved.

Ever since the ascertaining of the circulation of the blood, that is, for above these hundred years past, physicians have treated the momentum of the heart's contractions throwing the blood into the arteries, as a subject of the greatest attention and importance both in physiology and in the practice of medicine.—But none, that I know of, has bestowed that attention which is due to the essential part the heart acts in the promoting of the venous circulation, not by its impulses, but by its depletions : yet nothing can be more absurd than to suppose the one, or more inattentive than to neglect the other.—The sole support and. preservation of a venous current of blood to the heart, depends upon a vacuum being momentarily provided where the veins shall unload themselves.[15]

I have shewn already, in the mode of circulation instituted at the liver, that the impelling pulsations of the heart are not of essential necessity either to its arterial or its venous circulation. But in the mode of circulation established at the heart, its evacuations, or its alternate states of emptiness become indispensably necessary to the whole system of the venous circulation. Let us only examine this point with some attention more circumstantially.

When the veins are all full, and the auricles, or chambers into which the veins empty themselves, are full also—Where is the collected stream in the veins to go next? There is no room for more in the auricle : What must be done?—Why, the auricle contracts and empties itself. What is the consequence? Why, a sudden vacuum, equal to what the auricle could contain—the turgid veins rush their contents into the auricle to fill up the vacuum again, and all behind moving in the venous direction advances so much forward, with such force, that the veins near the heart sustain a pulsation from the regurgitation of this impetuous stream, when the auricle shuts upon it to empty itself.—In short, the full auricle occupies a determinate quantity of room in the breast : When it is emptied, there is a non-resisting vacuum of so much space as was full before, and thither there is a mechanical nisus from the

remotest filament of a vein over the whole body, which becomes conspicuous in the torrent that rushes every other moment from the mouth of the vena cava into this vacuum.

Thus not only the continuous veins, such as there may be, but every humid interstice and all the extravasated effluvia within the surface of the body, is sucked, attracted, or impelled, call it what you please, as it offers into the direction of the venous streams.—All this is so mechanically necessary and so consequential, that I cannot help repeating my surprize that it has so long remained unascertained. But here I must not omit doing justice to the great Haller, who seems to have conceived some idea of the influence of vacuums on the circulation, when, some where in his physiology, he specifies a *vis derivationis qua sanguinem a sede majis compressa ad sedem laxiorem et minus resistentem ducit*.[16] Which power of derivation, he says, is not sufficiently known yet ; and which I have here endeavoured to ascertain and explain.

SIXTH PROPOSITION.

Notwithstanding all the completeness of mechanical provisions we find established for securing the circulation, yet they can be considered as no more than auxiliaries or accessories, seeing the motions of the animal system could not be kept in play one moment by them all, without the presidency and uninterrupted influence of a power, which I will not say is unmechanical, but which we cannot reduce either to distinct mechanical rules or ideas. I mean that active principle existing every where in the system of animals, which I call *life*.—I do not mean that immaterial immortal part in us, whose concerns are more elevated and permanent than the regulation and support of a temporary material automaton.—I mean that supreme principle of natural life, which exists in every point of our frame, and disseminates its universal vitality in the irradiations of sensations, affections, volitions, &c. of every kind.

The structure of our brain and its nerves, obliges us to consider this essential principle, at the same time that it is existent and in constant activity every where, as a real glandular secretion. Therefore, in its private office, the constant flux of this vital principle from the head to every point of our frame, must be considered as essential to the perpetuating of the circulation in the head, as the secretions of other glands are to the maintenance of the circulation in them.

Yet what is truly wonderful of this secretion, and may with propriety be proposed as a paradox, or phænomenon of the most difficult solution, is that it is a secretion without a

waste, or without any consumption of the stock from which it is drawn*.—This renders the mode of the circulation in the brain different in its circumstances from all other parts of the body, the heart, the liver, or any where else ; because, as I apprehend, the blood which goes into the brain by the arteries is all returned undiminished back again by the veins : So that we cannot have at least that direct recourse to the influence of a vacuum there, that we have in solving the phænomena of the circulation in other glands. But at the same time that perpetual efflux constantly streaming off from the nerves, and animating every particle and fibre by its energy, must have a powerful influence on the circulation of the animal fluids, through the substance of the brain, both as a director and as a motive power.—This I call the private office of this secretion.

That the nerves also shed their influence universally and intimately to every part and recess of our substance, is, I think, what no one doubts ; though few have reflected that it must, by a necessary consequence, produce active vital effects, both upon the motions and dispositions of the fluids in every part.—I shall attempt to ascertain this fact by an argument, which, if it should be thought new, will not, I hope, be rejected merely on that account, if, upon weighing, it proves conclusive.

Nothing can be more certain and undoubted, than that the senses, passions, and volitions have not only a most powerful, but in many instances a most instantaneous and most sensible effect upon the motions of our fluids ; in some cases, throwing immediate colour and heat into particular parts of the body, and in others, throwing the whole frame into a colourless rigour, and spreading a languor over all the motions of the fluids :–in some instances, filling the whole machinery with an instantaneous lightness and vivacity in all its motion ; in others, as suddenly oppressing and in a great degree choaking all the vital powers.

Now, can it be supposed that that vital principle, distinct from all that we know of the mechanical composition of our frame, adjusted for maintaining the complicated motions of our fluids, could effect its motions so instantaneously, if it was not always present, and indispensably accessary to them at all times?—In short, it proves, that that very principle, which is constantly blazing in us in living sensations and passions, is as incessantly employed

* Thus it is that electrics *per se* are supposed to draw their electrical fire from non-electrical bodies, and to issue it always longitudinally into whatever direction the conductor is bent or twisted ; tho', if sollicited by the approach of any non-electric, it is ready to burst out side-ways at any part of the length of the conductor. This obviates another difficulty in regard to the motion of the vital principle along the nerves. If it is so subtile as to penetrate their substance in all directions, how can it hold its course according to their lengths, and discharge its influence regularly where they terminate?

in promoting and regulating every living movement of our fluids in every part.—It could not act as it does in such instances as I have hinted at, unless it was constantly acting.

It has always appeared very strange to me, that many have been so curious in estimating all the mechanical circumstances they could conjecture to themselves, that might conspire in the circulation, and in calculating their powers ; as if any satisfactory sum total of the moving powers could be ascertained upon such principles.—In what we call mechanical, mechanics do all ; but in a living machine they do nothing.—It is life immediately and directly that does all ; and mechanism is no more than a subordinate arrangement, seconding its operation, and a channel for life to move in.—What in physics are called the powers or laws of nature, are not more fundamentally essential to mechanics, than what I call *life* is to them in the animal system.—In the human frame, life occupies the known properties and tendencies of matter by means of mechanics ; but no mechanics can be conceived by the human capacity which can perform what the living principle does.—Yet physiologists often reason and discuss their subject, as if life was the effect of mechanics, instead of considering them as only the tract in which life moves, and the foot-stool of its powers.

The exertion and powers of the nervous system, acting uninterruptedly, and diffusing their virtue constantly in the same directions with these in which the animal fluids move, must efficaciously promote their progress.—Besides that animated vital character which the effluxes of that system superadd to the warmth and chemical commixture of the animal principles, in every solid and in every fluid particle of our frame, it instantly inverts, changes the arrangement, and disposes the habit of each moving particle, so as to become entirely metamorphosed, and invested with the particular character of the particular part where it either flows, is secreted, or accresses[17].

If we advert that life is but another name for self-activity, and consequently that the very essence of life lies in that activity, it is impossible but that the fluids in which that life resides, as much as in the solids, must enjoy activity as a principle of their constitution, and not yield to motion by mechanical impulses only, like inert passive masses. So active is this principle in us, that we cannot call our sensations or perceptions themselves more vivid than it is in every part.—Indeed our sensations themselves are not any thing else than perceptible copies of the instantaneous activity of this principle residing in the solids and fluids which compose every organ of sense, in receiving, and variously modulating itself to every impression that the course of nature without us can possibly make upon these organs.

But to drop the abstracted discussions that this branch of physiology suggests, and to be brief.—It is this principle of life, that gives that facility and momentum to the universal circulation of the animal fluids, which deserves the name of spontaneity ; without which, all the injectings and mechanical contrivances in nature could not open the recesses of the vascular system, and render them pervious to the most searching and penetrating fluids.—It is this inherent, or rather constantly influent principle, that renders all, both solids and fluids, so active, so vigorous, so consistent ; and at the same time so placid, so obedient, and so permeable, infinitely beyond the reach of merely mechanical impressions.—In short, it is this, and not the diameters of vessels, the angles at which they divide, their elongations, flexures, or involutions, that renders all so lubricious[18], so various ; and yet upon every change and secretion, so characteristic, and so uniform. This work is not performed by the stubborn, robust agency of grinding, or dividing, by separations and percolations, strainings and squeezings of refractory combinations and commixtures of heterogeneous fluids : But every moving active particle of the fluids is presently, and without one protracting renisus[19], transmuted into the nature and habit which the organ it arrives at disposes it to assume.—This living temper and warmth oscillates in every solid fibre, and fans the fire of nature in every fluid particle that approaches them : While these again return the quickening vibration to every solid, and diffuse it reciprocally among themselves.

SEVENTH PROPOSITION.

From what I have, I hope, proved, it necessarily follows, that both the primary and the final intention of the pulsation of the heart in the animal œconomy, must tend to some purposes distinct from the necessary support of the progressive motion of the fluids. I shall bestow a few reflections on what some of these purposes may be.

First, then, it must be attended to, that the alternate pulsations of the heart necessarily imply a correspondent alternation of the effluxes, or powers of the nervous system, and of their origin the brain ; at least in so far as their powers immediately respect the action of the heart.

Physiologists generally suppose that the chambers of the heart, namely, the auricles and ventricles of the heart, are in a paralytic state during the time of their diastoles, or during the time they are filling again with blood, after they have emptied themselves by their systoles or contractions. It is also now supposed by some ingenious physiologists, that the heart is constantly roused out of this paralytic state, by the irritation of the blood that fills these

cavities from time to time. But this theory wholly rests upon the supposition, that the relaxed state of these muscles is owing to some peculiarity in their structure, by which they cannot preserve their muscular contraction above an instant at a time, and that they cannot recover it but by the reiterated action of a stimulus upon them.

Now all this is so contrary to every thing that we know of the nature and tendency of muscular fibres in other cases, that the supposition ought not to be admitted upon less than a demonstration, that it cannot be explained upon other principles more agreeable to the animal œconomy. We have instances of the natural contractile power of muscular fibres being relaxed by irritation, as happens to both the sphincters of the principal excretories in the body when they are sollicited to a discharge : But I do not remember one instance of muscular fibres whose natural contraction depends on irritation, excepting the circular fibres of the iris.

No sound muscle can be in a relaxed paralytic state, except from a defect of the influence of the nerves which communicate with it upon it. Hence it follows, that the intermissions of muscular action in the heart, must proceed from an intermission in the action of the brain and nerves upon it. There must be established intermissions there of the effluxes from these organs of life upon the heart, which determine its alternate states of action and inaction.

Therefore before physiologists take upon them to determine the use of the contractions and relaxations of the heart, it becomes a necessary previous enquiry, to discover what may be the use of these intermissions in the vital organs where they originate ; because possibly the importance of these alternations there, may be greater than in the heart, where they appear more sensibly, though only as an effect. I cannot propose here to enter more minutely into this disquisition : I shall therefore dismiss it with this reflection. Seeing reaction must always be equal to action ; and as no effect can be greater than its cause, therefore the alternate efforts of the brain on the nerves that agitate the heart, must have as great an effect on the brain itself and its effluxes, as it has secondarily on the heart itself and the fluids whose course it regulates.

Secondly, there is good reason and ground to suppose, that the concussions of the heart have also a direct effect forward, upon the system of the solids in which the fluids agitated by the heart move. I do not mean merely that passive expansion and pulsation which it causes in the arteries, though I include it ; but that every shock of the heart excites a reciprocal orgasmus, or active tension, through the whole series of the solids, which keeps them always prepared and enlivened for admitting and acting upon the fluids every where, in the manner I

have attempted above to express my conception of*. Whether the arterial and venous systems connected with the ventricles and auricles of the heart by tendinous-like beginnings, act as antagonists to the muscular contraction, I shall submit to the decision of further enquiry and observation.

Thirdly, that the contractions of the heart also momentarily irritate and rouse that vital principle animating every fluid particle, I have no doubt of. But in order to comprehend fully the influence of the heart's contractions upon the fluids immediately passing through it, the circumstances and qualities of the blood brought by the veins to the heart must be considered.

We are not, I have intimated already, to consider any part of the vascular system as a congeries[20] of merely passive canals for the fluids. The importance of the veins, distinct from that of their being canals, has not been duly considered. Their office consists of two parts.

First, that of thoroughly animalizing the recent chyle, which has undergone only an arterial course.—It is evident from the secretion of milk, that some of the finest filtrations of arterial circulation remain still acescent[21] : But the veins complete the change, and render all the fluids in them perfectly animal, and of consequence, they must exalt the animal nature of such of the fluids as pass through them a second or a third time.

The second branch of the office of the veins is, to elaborate the fluids into that form and composition which we know by the name of red blood. That this is the peculiar province of the veins is self-evident, I apprehend : For though there may be accidentally a continuation of some arteries containing red blood in veins, yet it is certain there cannot be a continuation of such a quantity as to supply the twentieth part of the red blood found in the larger veins. It must therefore be concocted by the veins out of the finer fluids they receive by absorption or otherwise.—In short, the ultimate office of the arteries is to resolve the blood into the various animal fluids and secretions ; and the business of the veins is to combine and regenerate them again into red blood ; for the arteries generate none, they only receive it already composed.

The blood, then, in the *vena cava ascendens*, is not only perfectly animal itself, but it receives an accession of blood from the liver, which is still more highly animalized, having

* There is some reason to question whether the mere mechanical force with which the blood is thrown into the arteries, is the direct and only cause of the force wherewith the arteries vibrate. I have seen an aneurism in the arm that would have moved more pounds of weight than the artery either above it or below it, if I guessed aright, could move ounces. How that momentum was generated there, I leave to the reflexions of attentive physiologists.

undergone a complete course of both arterial and venous circulation a second time ; by which it becomes so highly exalted as not only to tend to dissolution itself, but to affect the rest of the blood with the same disposition, if it was to perform its course through the heart and arteries again without the supplement of fresh materials taken into the stock, which moderate its tendency, and furnish it with qualifying combinations, or mixtures.

On the other hand, though the blood of the *vena cava descendens* must be as perfectly animal as that in the *ascendens*, yet its nature is no less diluted and let down, by the constant accession of fresh chyle poured into the left subclavian vein, than the blood of the *cava ascendens* is exalted, by the accession of the hepatic blood.

These two then gush into the first chamber or right auricle of the heart ; there they are confounded, and undergo first the conquassation[22] of the auricle throwing it into the ventricle, and then the conquassation of the ventricle intimately mixing the two differently disposed liquors, and throwing the compound out by the pulmonary artery, through the whole substance of the lungs, even into, I had almost said positive, contact with the air we inspire.

The great and important intention of this course of the blood through the lungs is in order to ingross another ingredient, namely a portion of fresh common air, at each inspiration, into the composition, in exchange for an equivalent portion of the most volatile effluvia of the blood, exhaled from the lungs at every expiration. With this addition, the blood is returned again from the lungs by the pulmonary vein, into the outer of the second pair of chambers of the heart, called the left auricle, where again it is agitated, or churned, and thrown into the left ventricle, where it sustains a fresh commixture by the contraction of the ventricle, which passes it at the same time into the great artery, called the aorta.—By these means the heterogeneous parts of the blood are so blended as to prevent the homogeneous parts from associating or combining, as they would be apt to do ; and instead of that, they are disposed to that common elaboration and influence upon each others different qualities, which renders the whole mass fit for, and more susceptible of, the various changes and secretions it is intended to undergo in its course.

Many physiologists have supposed the blood to undergo an actual fermentation, which implies a change of its nature, in the heart ; but the stay of every portion of it there, is so momentary, and the mechanical agitation it is there put into, is so great, that that supposition is next to impossible ; the animal changes not being so rapid as in the ebulitions of naked alkalis and acids.—There is no doubt however but that agitation is intended, not only to

augment the heat of the blood, which disposes it to press outward, as all heat in bodies under its influence does, but so to mix the heterogeneous parts, as to prevent any combination of similar parts, which might obstruct their so readily yielding to the animal mutations and exaltations they are destined for, under the influences of the powers of life.

There is another circumstance in the state of the blood passing the heart, unattended to, which renders the shocks it receives there very necessary, and that is the great quantity of the fluids which are in the state of smoaking volatile effluvia, and the great tendency of all the parts of the blood, that are not combined in gluten[23] or in red particles, to expand themselves into that state.

If the blood was not thus mixed, and these effluvia kept equally dispersed among the other parts, portions of the effluvia would be apt to collect into an elastic mass by itself, and very suddenly coagulate or otherways stop the course of the rest of the blood. It is this accident, this elastic force of the effluvia, that sometimes bursts the heart contracting upon it, and becomes the occasion of the most sudden of all deaths, commonly, though falsely, imputed to an apoplexy.

The large quantity of fluids disposed to expand into vapour is easily demonstrated in the extremities of the body, by the great expansion of the veins beyond their natural size, whenever the parts are exposed to a greater than ordinary heat. On the contrary, in a state of greater than ordinary coldness, the veins collapse so much as to be scarcely discoverable.

Elastic vapour and air have been so confounded in all ages, on account of their common property of elasticity and expansion by heat, that it is with stricter propriety, or at least with a more direct reference to this circumstance, than we now apprehend, who have lost sight of that predominant quality in the blood, that the Ancients, especially regarding it, gave the name of arteries, to that system of vessels into which the heart throws the blood ; at the same time implying the air taken into the blood from the lungs, which it is part of the office of the arteries to subdue, so as to render it a constituent part or agent in the process of animalisation. The present philosophy would call this, rendering the air in the blood *fixed* : But I have not so clear conceptions of that matter so as to authorize me to adopt the phrase*.[24]

* The fixed air which has become so fashionable a subject of investigation of late, said to be so noxious in the form of air, and so salutary united again with water or other fluids, is nothing else than a highly volatilized and active mineral acid, in the state of its first remove from, or last approach to the form of phlogiston. In all effervescence, during its action, some of the acid particles become so irritated, by the impetuous neutralization of others, that they are rendered highly volatile, collect in the fluid into little parcels of steam inclosed in small aqueous bubbles, which rise through the liquor and

There is one other consideration which suggests to us a very strong presumption, if not proof, of the large proportion of this elastic vapour in the blood, and that is the proportions of the cavities of the heart to the proportion of blood that can be supposed to pass through it every pulsation.—I have not the least hesitation in declaring it absolutely impossible, that the auricles and ventricles of the heart receive and discharge either one-half or one-quarter of the quantity of blood it would require to fill them, at every pulsation.—The unequal sizes of the cavities of the heart, among themselves, is a certain proof of this.—Another is, the impossibility of even half a ton, far less two tons and an half, of blood passing through the lungs in the course of twenty-four hours.—One principal object, therefore, of the disproportion between the size of the cavities of the heart, and the quantity of blood they must receive between every pulsation, must be to give room for the expansion of the effluvia in the blood, that, by the contractions of the heart, it might be employed to divide the blood more effectually, and be mixed with every portion of it more intimately.

I shall conclude this discourse, with a remark upon this propagation of animal life and motions by alternate action and remission of action, both in the brain and heart.—I will say nothing of the primary cause of it ; nor will I enquire how far it is, or whether it must not be, if abstractly examined, the necessary mode of all action. Only this we may venture to say,

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break and discharge their effluvia on the surface of it. Of the same nature (only produced from vegetable substances) is that gas generated in and issuing from fermenting liquors. I remember, some years ago, to have seen a real kind of dulcified acid spirit distilled from a fermented, or rather fermenting, liquor ; the singular taste of which I taught the distiller to correct, by mixing some absorbent with the spirit. I am persuaded that such an expedient for correcting such accidents, can be no secret to the distillers by trade. If Gentlemen of a philosophical turn would, in their researches, converse more with tradesmen, they would often find solutions of very obscure problems in their practices. Sir John Pringle's fair and accurate historical detail, at the conferring the Royal Society's last premium on Dr. Priestly, of the slow progress made in the still imperfect discovery of the nature of Fixed Air, or mephitic air, is a striking proof, that there is no unlocking Nature's secrets without a key, nor searching into them without a light : without these we may torture Nature by our experiments long to little effect. Whereas the discovery of the proper key would save a great deal of that trouble, and it is often very easy to be found.

The fire-damp in coal mines is a highly elastic petroleous effluvia, bursting from deep seams of fatter and less consolidated veins of coal, by reason of the want of a sufficient resistance or circulation of the common air in such mines. The steith or mephitis is dephlogisticated sulphureous vapour, generated in a like manner in other mines.

The three mineral acids are the universal acid, diversly modified by subterraneous, marine, or

The three mineral acids are the universal acid, diversly modified by subterraneous, marine, or aerial concoction. In the form of vapour they are all strongly elastic, and have been mistaken, under certain circumstances, for species of air. Each of these acids gives a specific modification to phlogiston ; which they all either closely unite with, or comprehend in themselves, as somehow essential to their constitutions.

that it seems to be a favourite mode of supporting nature, both in the great world and in the little world, as the human frame is often called.—The final cause, or the end for which it is established in our frame, seems to be for the more effectual relief and support of nature, when it languishes, or is in hazard of being overpowered, or the motion of the fluids suspended and stopped by any sudden accident ; as in the cases of great fear, horror, grief, or any extreme agony or struggle of contending passions.—When the native vigour of the solids, and nervous system, in such cases, becomes relaxed, and loses that reaction on the fluids, which is necessary to preserve their motion ; then the heart throbs, palpitates, and redoubles its efforts to revive the languishing motions, warmth, and vigour of every part.

In such cases, it is evident, the redoubled action of the heart is not from an encreased[25] quantity of fluids brought to it, but the contrary ; and the immediate encreased acceleration of its contractions is not so much to fill the vessels, which must be supposed fuller than before the constitution fell into these circumstances, but to react upon the languishing solids, and re-animate their prostrate vigour:—a certain proof this, that the actions of the heart have as immediate, nay a more immediate, connection with the nervous system, the secretories of life, than with the immediate motion of the fluids as a mechanical cause thereof.

In short, the respective powers and compounded influences of the brain and the heart upon the human frame, may, with great propriety, be compared to the agency of the sun and moon upon the great world.—The sun pervades all nature, and sheds his influences in its most intricate recesses, elaborating out of one whole, according to its various circumstances, and assortments, an infinite variety of properties and forms : while the moon, by a special regulation and flexion of his influences, disposes that great mass of fluids, which are the immediate organs of his energy, and the subject of all his operations and productions, into these tides and reciprocations of ebbing and flowing, which is, according to the constitution of things, so necessarily subservient to their being conveyed in a proper disposition, into all these elaboratories[26] into which the sun, from whom nothing is hid, reaches.

Just so in the microcosm, the brain, by the mediation and irradiation of its nerves, penetrates and animates every point of our frame, and particle of our composition, disposing every fluid particle to a spontaneous motion and accommodation of its nature to the character and structure of the parts to which it attinges[27] ; while the heart, by its reiterated impressions and shocks on both the solids and fluids of our system, gives an additional vigour to the animation and dispositions of the whole, and causes these perpetual collisions which irritate and invigorate the living flame that is glowing in every part.

I cannot, Gentlemen, take upon me to warrant the infallibility of every thought or suggestion I have risked in this lecture ; and the compass it restricts me to, has debarred me from further enlargement upon any of them. Several of these may be allowed to be problematical, without the main questions being affected thereby ; but I persuade myself that I have proved them, my general proposition, and the seven inferior ones, under which, for the greater clearness and distinctness, I have distributed the evidence.—I have delivered my sentiments on this subject with the greater assurance, that they have the sanction of my friend Dr. Hall's approbation, whose judgment and abilities, independent of our friendship, I very highly esteem———[28]

Endnotes by B. Freeman, UNSW (Jan. 2012)

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[1] The original punctuation and spelling has been retained where possible.
[2] Quality or condition of being tenuous; lack of thickness, density, or substance.
[3] The book published at Modena referred to this footnote is: Spallanzani, Lazzaro. *De' fenomeni della circolazione osservata nel giro universale de' vasi; de' fenomeni della circolazione languente; de' moti del sangue independenti dall'azione del cuore; e del pulsar delle arterie ...* Modena, Società Tipografica, 1773. 4°.
Spallanzani's book was translated into English in 1801: *Experiments upon the Circulation of the Blood, throughout the Vascular System: On Languid Circulation: On the Motion of the Blood, Independent of the Action of the Heart: And on the Pulsations of the Arteries. With Notes, and a Sketch of the Literary Life of the Author by J. Tourdes.* Translated into English, and Illustrated with Additional Notes; by R. Hall, M.D. J. Ridgway, London (1801).
[4] Robert Whytt (1714–1766) MA, St Andrews, 1730; MD, Reims 1736; MD, St Andrews, 1737; FRCPE Edinburgh, 1738 and President, 1763-6; Professor of Theory of Medicine at the University of Edinburgh from 1747; FRS, 1752; Whytt studied medicine at Edinburgh, Paris and Leyden.
[5] Giovanni Alfonso Borelli (1608–1679), Italian physiologist, physicist, and mathematician. Sir Isaac Newton (1643–1727), English physicist, mathematician, astronomer, natural philosopher, alchemist, and theologian. James Keil [Keill] (1673–1719), Scottish physician, and philosopher. James Jurin (1684–1750), English scientist and physician. Stephen Hales, (1677–1761), English physiologist, chemist, inventor, parish priest. Albrecht von Haller (1708–1777), Swiss anatomist, physiologist, naturalist and poet.
[6] Chyle (Greek: *chylo*s, juice) is a milky, bodily fluid consisting of lymph and emulsified fats, or free fatty acids, taken up by lymph vessels (lacteals) in the small intestine during digestion of fatty foods. Human chyle was described as having a white colour, smelling like milk, having a sweetish taste, and a consistency thinner than blood or milk. (*Pantologia*, 1813).
[7] absorbents – contemporary name for terminal lymphatic vessels, especially lacteals.
[8] This refers to the controversy started by Alexander Monro Secundus (1733–1817), Scottish physician and medical educator, who attacked John Hunter (1728–1793), Scottish surgeon and anatomist; see: Eales, N.B. The history of the lymphatic system, with special reference to the Hunter–Monro controversy, J. Hist. Med. 29 (1974) 280–294.
[9] independent of the power…
[10] Perhaps at this time it was believed that the ramifications of the portal vein merged with the rami of the hepatic artery.
[11] excretory ducts.
[12] impulse, effort.

[13] Carbon dioxide; studied by the Scottish physician Joseph Black (1728–1799) in the 1750s. Black found that limestone (calcium carbonate) could be heated or treated with acids to yield a gas he described as 'fixed air' because the gas could be absorbed or fixed by strong alkali – when bubbled through an aqueous solution of lime (calcium hydroxide), it would precipitate calcium carbonate. Black observed that fixed air was denser than air and supported neither flame nor animal life. He found that fixed air is produced by animal respiration and microbial fermentation.
[14] fountain jets.
[15] Proved in experiments on dogs by G.A. Brecher, *Venous Return*, 1956.
[16] I have been unable to obtain a translation of this Latin text or locate it in writings of Albrecht von Haller; it may be a derivation from §XL in Vol. 2 of his *ELEMENTA PHYSIOLOGIE CORPORIS HUMANI,* NEAPOLI, MDCCLXXVI, *Tome 2* (pp. 214–): *Vis derivationis. Sectio IV. Motus sanguinis per venas reducit:* pp. 321-358.
[17] accumulates
[18] slippery
[19] counter-action; resistance
[20] aggregation (sing.)
[21] Acescent: sour or turning sour. Chyle was described as having an 'acescent nature, it somewhat restrains the putrescent tendency of the blood' (*Pantologia*, 1813).
[22] agitation
[23] white (e.g,, of cells involved in clotting to form a glutinous mass)
[24] Terms in footnote: phlogiston – substance hypothesized to be liberated in burning; dulcified – made sweet; absorbent – neutralizing substance; mephitic – see mephitis (below); fire-damp – flammable gases, especially methane; fatter – of a type of coal suited for high-temperature, dry distillation to produce coal gas and also as raw material in coal blending for making coke; steith – stith (Durham dialect) stench; mephitis – poisonous or foul-smelling gas emitted from the earth; dephlogisticated – the state following combustion when phlogiston was presumed to have been lost to the air.
[25] increased (obs.)
[26] laboratories (obs.)
[27] touches lightly (obs.)
[28] The text of the 1773 lecture continues here with two more paragraphs and a substantial POSTSCRIPT (with two footnotes) mainly on the classification of diseases. This missing text is:

….having first subjected it to the examination and castigations of a person, the clearness of whose understanding on these subjects, as well as his impartiality, I have a very high opinion of[28].[Footnote: [28] I mean my friend Dr Hall, of Newcastle, distinguished for the quickness of his parts, and the liveliness of his apprehension, by all who know him; and yet who, in his practice, examines the complaints and symptoms of his patients disorders, as minutely as the slowest and most deliberate genius can do. It were to be wished, that people of vastly inferior capacities would adopt so good and so prudent an example of circumspectness.]

If any person should be disposed to derogate from the importance of the discovery, as of little consequence to the practice of medicine; there is one short and silencing answer to such detractors, which every Gentleman of the faculty present will see the conclusiveness of[28]. [Footnote: [28] I should not have inserted this remark, calculated only to obviate private detraction, in the publication, which is an appeal to the public candor, but that I was advised, by the Gentleman mentioned in the last note, to print the lecture just as it was delivered, that it might appear just what it was, not a finished treatise on the subject, but such a survey of it, as suited the audience, and could be comprehended in the compass of a lecture. I hope this will sufficiently apologize for any thing else in the discourse that may appear to be local, and to have little connection with the subject itself.] If the discovery of the circulation was received with the greatest applause over all Europe, as of the greatest consequence to medicine, certainly the knowledge of the causes of the circulation must be of equal importance. The question then only is, How far we have attained that discovery in the preceding dissertation? If any of the

Gentlemen, my hearers, are desirous of entering into conversation upon that subject, I will be proud of an opportunity of joining them in it, when and where it shall be agreeable to them to appoint.

GENTLEMEN, I return you thanks for your company and attention during this tedious discourse, which I really could not abridge further, without injuring the distinctness I have aimed at preserving in it.

POSTSCRIPT.

THE theory and the practice of medicine are so intimately connected with each other, and so reciprocally dependent on one another, that the soul or the body might with as much propriety say the one to the other—I have no need of you—as any practitioner in physic can say, I have no use for theory to direct my practice. Libertines can see no excellency in religion: Fools feel no deficiency from their want of wisdom: And ignorant persons can perceive no necessity for the drudgery of searching for knowledge. There is not one point of knowledge, either known or attainable, that does not as necessarily imply a practical inference, as a cause does an effect, or as the major and minor of a syllogism do a consequence. Truth of every kind is a, connected series, a chain of many links, and a ladder of many steps; which, though you cannot perceive the summit of, yet every step you advance leads you to another, and renders it accessible to you.

It must certainly be for some very wise reason, that the Author of Nature has in so many instances rendered effects so sensible and obvious, while their causes are latent and veiled. It cannot be designed to prompt men to rest in appearances, and carry their prospects no further. I should rather apprehend that this plan of things was meant to inculcate upon our understandings, that while sensible things were abundantly furnished out for the security and felicity of our lives, insensible things were proposed for the exercise and improvement of our rational faculties: That we might, if we pleased, distinguish ourselves as much as possible from the brute creation, who are necessarily limited to the narrow circle of sense and instinct.

I would not wonder much, if, notwithstanding my caveat, some persons should still say, and even really think, that whatever probability or truth there is in the above doctrine, it can have little connection with or influence upon practice.—If such a surmise is groundless, I am really bound to ask pardon of the public for suggesting it; for I own, it is but an ill-favoured imputation upon the understanding of any person professing the practice of medicine, to suppose him capable of imagining a distinct knowledge of the active principles of our constitution can have little or no connection with the cure of diseases; all which are no more than a viciated state of these powers, or some oppressive load or obstruction upon one or other of them, manifesting itself by proper symptoms either universally or topically.

If there is any justice in the doctrine contained in the above discourse, it suggests a new and useful method of arranging diseases. I do not mean that it supersedes other arrangements already known: But certainly, the greater variety of views we can take of objects which have any intricacy or obscurity in them, and the more different lights we can place them in, we have the better chance of knowing them more distinctly.

The method of classing diseases that I allude to, is diseases arising from arterial obstruction; diseases depending upon any defect of venous absorption; such diseases as more immediately refer to the state of what I have called the vital principle, than to either of the former; and diseases that arise from some error in the concoction or animalization of the fluids. Indeed all the powers acting in our frame are so interwoven into one piece, and each is so necessary every where, that no one can be said to be affected by itself: Yet as every disease must originate somewhere, some one part of the system must be more originally, more immediately, and more principally affected than another.

Wherever diseases become divided into new classes, or are susceptible of a new distribution, medicines of course fall into the same line of distinctions; seeing the intentions of cure must always, or at least ought always, to suggest the means or medicines appropriated for effecting it. The new classing of diseases is also of great consequence in suggesting new intentions of cure, and consequently new means and expedients for attaining that end.

The above doctrine, if well grounded, ought to reform the doctrine of the pulse in a great measure; which, according to it, is to be considered as the result, and not the cause, of the diseases by which it is affected.

But in no case can this doctrine, so far as it may be depended upon, be more useful, than in enabling practitioners more clearly to distinguish between real diseases, and these salutary symptoms of the inherent strength of many constitutions; which subdue and purge off the vices that have insinuated themselves into them. The mistaking of these, for real diseases, is, to the shame of many practitioners, the annual ruin of hundreds.

I cannot give a more striking example of this than in the case of the itch. That it is an infectious disease, often though not always, there is no doubt. That it is also a disease that may often be prevented by cleanliness, &c. is very certain; and that it may, under certain circumstances, be safely cured by live sulphur, is true also.

At the same time it is no less certain, that it is not a disease caused by animalcula, of which sulphur is the poison; that it is the true acescent scurvy; that it is an endemic in mountainous moist countries, where they feed almost solely upon oaten bread, and where it is so[,] preserves from other diseases; that it comes often without infection; that there are several species of it, and degrees of malignity in it, and that hundreds are annually murdered by its being treated with sulphur externally only. It is truly melancholy to reflect upon the ignorance and self-sufficiency of many practitioners, who, with an air of importance and sagacity, will instantaneously decide upon all these points, by inspecting the wrinkles between a man's fingers, who has the itch. How many consumptions, one of the *opprobria medicorum* [Endnote by BF: Disgraces of physicians, i.e., referring to diseases that they cannot cure], might have been prevented by not repelling that disease! and how many, that are otherwise incurable, might be cured by recalling it, if possible, after the seat of the disease is so translated.

I cannot blame this age in general, whatever imputations may rest still upon particular places, for want of a spirit of enquiry; it was to excite it in this place that was the intention of composing this lecture: I shall be very glad if the success answer my intention.

But there is one thing I would beg with submission to observe upon the present biass to experiments. I am no enemy to them, but it is not safe for those who have not made them, or seen them made, either to reason from them, or to trust to the reasoning of others upon them. We have seen not only different results of experiments reported, but different conclusions drawn from them. As scarcely two men can make an experiment, either with exactly the same intention, or with the same attention to circumstances, or as scarce one can make an experiment with attention to all circumstances; one's observation being engrossed by one thing, and another's by another.

Besides, how often are experiments instituted to discover, explain, or illustrate the nature of operations they have not the least relation to, in their situations and circumstances. What connection, for example, can there be between two liquors, allow them to be individually the same; the one committed to its own ferment and intestine mutations, in a capacious vessel communicating with the common air, whose unexplained agency is so necessary to the inversions and generations of all unorganized mixed liquors: What relation, I say, can there be between this state of a liquor, and even the very same, excluded from all access of more air than is mixed in it, constantly exhaling into vessels, and moving progressively in them, the diameter of whose orifices may not be the thousandth part of an inch, and constantly irradiated upon by powers that can concoct or change its nature, character, consistency, nay even its colour at pleasure, so to speak, in a moment. So that learning in general is often not so much profited or advanced by this mode of philosophising, as is supposed or might be expected.

Observation, attention, and close extensive reasoning, I think not only a safer tract, but a more promising course for the advancement of knowledge. Nature furnishes facts equivalent to all the experiments that can be made; and a close and accurate inquisition, by induction from her powers, and the products of them, without previous hypothesis or assumed principles, promises fair to carry one's

views farthest. The philosophy that assumes one principle that is not an uncontrovertible fact, must in the end infallibly entail upon our minds a train of ill-digested (however plausible) conjectures; which, adopted by persons who comprehend what other people say, but who cannot think for themselves, or walk but in leading-strings, [Endnote by BF: Straps of fabric attached to children's clothing, which originally functioned as a sort of leash to keep a child from straying or falling as the child learned to walk.] will form into inveterate prejudices against whatever they have not learned, or whatever does not tally with what they have been taught. So that frequently, when people think they are promoting knowledge, they are actually raising ramparts against its progress.

FINIS.