Classification of the functions of the human body and the principles on which it rests / [Andrew Buchanan].

CLASSIFICATION

OF

THE FUNCTIONS

OF THE

HUMAN BODY,

AND

THE PRINCIPLES ON WHICH IT RESTS.

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TO

THE STUDENTS OF PHYSIOLOGY

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FUNCTIONS OF VERTEBRATED ANIMALS.

I. ORGANIZATIVE FUNCTIONS—Subservient to Organization; forming and modifying the Organism.

I. Distributive.

Absorption.
Circulation.
Excretion.

II. Plastic.

A. Hemoplastic.

Digestion.
Chylification.
Respiration.
Maturation.
Lymph-formation.
Sanguification.

B. Hemolytic.

Nutrition.
Secretion.
Generation.

II. ORGANISMAL FUNCTIONS—Regulating the condition and relations of the Organism. Consisting in the action of the mind; or ministering to the mind chiefly.

I. Operations of Mind — Corresponding mental and bodily conditions.

1st. *Neurocephalous Operations*=Matter acting on mind.
a. Sensations=Passive conditions of mind, not reproducible but through the body.
b. Perceptions=Ideas formed on basis of sensations; belong properly to next class.

2nd. *Encephalous Operations*=Mind acting independently. Formation of Ideas and Laws of Thought.
c. Ideas=Mind-formations: results of thought; active conditions of mind, never passive.
conceived objectively=perceptions.
conceived absolutely.
d. Thoughts=Transitions from one idea to another.

3rd. *Cephaloneurous Operations*=Mind acting on matter.
e. Volitions=Voluntary actions.
f. Passions=Emotive actions; never wholly voluntary; always in part, and sometimes wholly involuntary.

II. Operations of Heat, Electricity, and Light.
III. Motions.
IV. Voice, Speech, and Expression.
V. Sleep.

CLASSIFICATION

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FUNCTIONS OF THE HUMAN BODY,

AND THE PRINCIPLES ON WHICH IT RESTS.

The classification of the Functions of the body is a subject little attended to in modern works on Physiology: either from the authors of these works supposing the subject already exhausted, and not susceptible of farther improvement; or, more probably, thinking that their labour would be more profitably bestowed in extending the survey of the living kingdoms, elucidating structure with the scalpel or microscope, and determining the reaction and relation of organs by the experimental tests of Physics and Chemistry.

Conceding fully the vast, and in the meantime perhaps superior importance of such researches, it is nevertheless always useful in the prosecution of every science to recur to the fundamental principles on which it rests as indicated by its methodical arrangement. Science is methodized knowledge: we do not dignify with that name a mere collection of facts and observations of which the mutual relations are unknown: and just in proportion as any science is perfected, we see the various parts of which it consists stand out before the eye of the mind in a natural order; that is in natural contrast and juxtaposition, and with the proportions and harmony which belong to nature.

The methodized knowledge which we call Physiology is the knowledge of the mode of action of the various organs which together constitute the living body. The only two methods of viewing such a science methodically, must be derived either from the relations of the organs of the body, or from their modes of

action. The former method, which has anatomy for its basis, is the only one which could be pursued in the infancy of the science, and up to the more advanced period when the principal organs of the body had become known to the anatomist, and conjectures more or less plausible been formed as to the uses which they serve. It was then only that the higher mode of arrangement became practicable or, indeed, conceivable—that of arranging the actions of the various organs of the body according to their nature and relations, and the uses to which all of them are subservient in the living œconomy.

The history of the science of Physiology supplies evidence of this natural progress of the human mind in methodizing its doctrines. The most ancient arrangement of the functions of the human body with which we are acquainted is manifestly of anatomical origin. Notwithstanding this mark of primitive rudeness, it maintained its place in the schools of medicine, and in the best writings on Physiology, nearly till the end of last century, and can even be traced, although in a modified form, in the systematic works of the present day—a sufficient proof that the majority of physiologists, finding a system of arrangement ready-made, venerable for its antiquity and answering their purpose, were little solicitous to examine the grounds on which it rested, or to establish a better system in its place.

According to the system in question, the bodily functions are placed in three classes, corresponding to the three great cavities of the body, which are respectively the chief seat of the organs performing the functions of each class. The first class comprehends the functions of the organs contained in the cavity of the head and spine, with which are naturally associated the nerves, organs of sense, and voluntary muscles. The second class comprehends the functions of the organs contained in the cavity of the thorax, associating with them the bloodvessels and other vascular systems. The third class comprehends the functions of the organs placed in the cavity of the abdomen and of the mammæ and testes placed external to it.

Such is the intimate and necessary connection between structure and function, that any arrangement of the functions grounded on a true anatomical basis, cannot fail to be more or less useful in Physiology. In the present instance the advantage obtained was perhaps the very greatest that could be obtained from the mere

juxtaposition of organs. It was perhaps to the detriment of Physiology that those who cultivated it were in this way supplied with a method of arrangement, without being forced to go back to those first principles from which the method of arrangement of every science ought to be deduced. A foreign yoke was, as it were, imposed upon Physiology, and whole centuries elapsed before she was able to shake herself free from it.

The names imposed upon the three classes of functions, considered as parts of a Physiological system, served to disguise their origin. The name of animal functions was imposed upon the first class, referrible to the head: that of vital functions on the second class, referrible to the chest: and that of natural functions on the third class, referrible to the abdomen. The extreme vagueness and want of significancy in these names, shewed the want of all sound physiological principle in the selection of them. What function, it may be asked, of an animal body may not be called an animal function? Can any function of a living body, whether animal or vegetable, not be called a vital function? And is there any action, whether of living bodies or of dead matter, that is not strictly natural?

Neither were physiological characters awanting to justify this arrangement and distinguish the classes from one another. The first class, or animal functions, owing to the general diffusion of the nervous tissue constitutes a true physiological group which has been retained with little alteration in every subsequent classification. It comprehends sensation, intelligence, and voluntary motion. The second and third classes again—the vital and natural functions—are much less accurately characterized. The former cannot be interrupted, even for a very brief period, without danger to life, while the latter are intermittent in their action or can at least be suspended for some time without bad effects. But these characters are merely incidental and not essential, and when we look to the purpose which the functions of these two classes serve in the living œconomy, we find that they are alike subservient to the development and maintenance of the bodily fabric, so that they constitute together only a single physiological group. When we thus conjoin these two classes into one, we obtain a twofold arrangement of the functions of the body, resting solely on physiological grounds; and it is that arrangement which it is my present object to illustrate and endeavour to establish as in consonance with nature.

Let us first, however, briefly trace the changes which the ancient system of arrangement of Physiology has undergone, taken in connection with the advances of the science.

One of the first modifications of it which was made, consisted in dividing the class of natural functions into two independent classes, by separating those subservient to nutrition from those subservient to generation. The name of natural functions was retained for the former class, while the latter received the names of genital, generative, or sexual functions. This is the arrangement adopted by Haller in his great work, the "Elementa Physiologiæ," published after the middle of last century; in which he treats successively of the vital, the animal, the natural, and the genital functions.

One farther change brings us down to the arrangement usually adopted at the present day. When physiologists at length, though late, began to examine the foundation on which their science rested, they could not fail to perceive both the incongruity of the names of the natural and vital functions, and the purely anatomical character of the boundaries separating them from each other. These two classes were therefore conjoined into a single one under the name of nutritive functions. Thus, out of the fourfold division of Haller sprung the modern threefold division into Animal or Relative functions, Nutritive functions, and Generative functions.

To prevent being obliged to recur to the subject, let us add a few words as to the separation of the generative and nutritive functions. So completely does the function of nutrition, and more especially that part of it which we name growth, correspond with generation in the nature of the physiological actions in which they consist, that the two functions are continually merging into each other, and the physiologist is often at a loss to discriminate between the extension of substance which we should name growth, and that which should be held to constitute a new individual. If then we arrange, as we intend to do, the functions of the body solely according to the nature of the physiological actions in which they consist, nutrition and generation can only be regarded as branches of a common stem, or subdivisions of the class of plastic functions, and neither of them can aspire to the rank of a primary division. The only mode in which, consistently with logical method, the function of generation can be raised to a

higher place, is to introduce a new principle of arrangement—as Bichat and other physiologists have done—constituting the primary divisions of the functions according as they are subservient to the individual or to the species, and only referring to the nature of the actions performed in establishing the subdivisions.

We come now to consider the twofold arrangement of the functions of the body, which I have already spoken of as, in my view, the most natural; and that into which the arrangement of the older physiologists, as well as all those which have since sprung from it, readily resolve themselves when a physiological standard is applied to them. This twofold arrangement is not less ancient than its rival, although it did not enjoy the same favour in the schools of medicine. It was indicated by Aristotle and received the sanction of Harvey and Buffon; but it never attracted much general interest till near the close of last century. At that period, so remarkable in the history of mankind, the shock of a political revolution in France had given a fresh impulse to the minds of men, which extended to every department of human thought, and raised up such men as Bichat, Cuvier, and Magendie to breathe a new spirit into the physiological sciences. The fundamental principles of Physiology, and of the medical sciences dependent upon it, may be said to have been then re-cast by the master hand of Bichat. Adopting as the basis of his system, the condition of the tissues in health and disease, he introduced a method of investigation which has been pursued not only in France, where the name of Bichat is held in fond veneration, but in every country where medicine is cultivated; and which has everywhere produced the same happy results, a greater certainty to the science and, what necessarily follows, an extended utility to the art. Bichat took up zealously the twofold arrangement of the bodily functions; he gave to the two classes of functions the names of animal and organic, which they have since, for the most part, retained; he defined the limits by which they are separated from each other, which have since been generally recognised; and he based the whole fabric on his doctrine of the properties of the tissues of the body. This doctrine, and the application he makes of it to the two classes of functions, we have now to examine, although it is not the most stable monument of the genius of Bichat.

The great object of Bichat was to assimilate Physiology and Medicine to the physical sciences. From a beautiful parallel which

he draws between them, he infers that the superior accuracy and more highly scientific character of the latter is due to the more accurate knowledge we possess of the simple properties of inorganic bodies, while the properties of the tissues of living bodies had never been studied with attention. The first requisite, therefore, according to his view, in order to confer a scientific character upon Physiology and Medicine, was to institute an accurate analysis of the properties of the tissues of the living body. This he has elaborated with great care in his two most celebrated works, his "Researches on Life and Death," and his "General Anatomy." He distinguishes three classes of such properties—1st, physical properties, which are the same as those of inorganic matter; 2nd, properties of tissue, which occur only in organic bodies, but continue in them after the extinction of life; and 3rd, vital properties, which exist only while life continues. These last are Sensibility and Contractility, of each of which there are two species, an animal and an organic, while of the organic contractility there are two varieties, the sensible and the insensible.

On the difference of the vital properties of the tissues Bichat establishes the essential distinction between the animal and organic functions. The animal functions are presided over by the animal sensibility and animal contractility, while the organic functions obey the laws of the organic sensibility and the two forms of the organic contractility. Instead of the well known characters by which Linnæus distinguishes minerals, vegetables, and animals, Bichat distinguishes the first by physical properties alone; the second, by physical properties and all the organic vital properties, excepting sensible contractility; and the last, by physical properties and the whole series of vital properties, animal and organic.

It is now generally admitted that there is no essential distinction between physical properties, and the "properties of tissue" of Bichat; although it be true that the latter depend on the peculiar molecular arrangement of the tissues of the body. Neither is it strictly true that physical properties are always persistent after death. We may instance to the contrary the transparency of the cornea, which only continues while the membrane is permeated by fresh humours; and still more the extensibility of the muscles, which yield during life without the slightest resistance to the action of their antagonists, and in all passive motions, while they

become perfectly rigid after death, and, as Brown-Sequard has shown, have their extensibility restored by the injection of fresh blood into their tissue.

More serious objections still may be urged against the class of vital properties. The very conception of a vital property, inherent as such in any tissue of the body, may be regarded as a misconception of the essentially complicated nature of all vital phenomena. This will be best explained by an example derived from the simpler processes of physical nature. If I speak of flexibility as a property of copper wire, every one will acknowledge that I speak correctly, for flexibility is inherent in the wire from the arrangement of the molecules of copper; but I should err if I were to describe as properties of copper wire, the light and heat which it is capable of emitting, when it is made to connect the two extremities of a galvanic trough. These are physical phenomena appearing, no doubt, in the wire, but not belonging to it as properties; seeing that they are alike dependent on the acid, the zinc and copper plates, and the mode of arrangement of these in the trough: the wire being merely one of the elements necessary for the production of the phenomena in question. Such exactly are all the phenomena of life. They never can subsist in a single tissue. They may be called vital phenomena, but never, without physiological incorrectness, vital properties.

This will be seen of all the so-called vital properties of Bichat. The animal sensibility implies consciousness, and is in so far a mental phenomenon; and in so far as it is bodily, it does not belong to the nervous fibre alone, for we must have the organ of sense, the nerve, and the brain, all co-operating to produce it. As to the organic sensibility, or sensibility without consciousness, it involves a contradiction of terms, and has been justly regarded as a mere figment of the imagination. Contractility I long regarded as a genuine example of a vital property, seeing that it subsists in every muscle, and even in the separated fragments of it; as is seen if a stimulus be properly applied to them. But we now know that the contraction of a muscle is in reality an electrical phenomenon, due, like the deflections of the needle of an electric telegraph, to the disturbance of the electric currents, with which both muscles and nerves are continually pervaded during life; that is, during the continuance of the circulation of the blood, which by its reaction on the muscular tissue is believed to generate the elec-

tricity. This is strictly analogous to the illustration of the copper wire and galvanic trough, given above. It applies to all the forms of muscular contractility, and must suggest the same conclusions as to the complex nature of the vital phenomena in which they consist. It is not improbable that ciliary motion also may originate in the same way; for minute as the ciliated cells are, they contain liquids capable of reacting on their membranous substance, and so possibly generating the force on which their vibratile movement depends. It may be still farther urged, that animal contractility implies volition, and is therefore in so far a mental phenomenon.

We thus see that the basis on which Bichat has established the distinction between the animal and organic functions is not a sure one. It has the farther disadvantage of separating from each other and placing in opposite divisions, the two different kinds of muscular action, and also the two different kinds of nervous action, which are in their nature so closely allied to each other.

We often seek far for what is near at hand; and so it has been with respect to the origin of the bipartite arrangement of the bodily functions. The human organism is made up of two parts —soul and body, an immaterial and a material part: and just as certain organs are meant to minister to the material part, so there are other organs which are meant to minister to the immaterial part; and of these the functions never can be understood aright, but by regarding them under that point of view. We do not live solely to take in a certain daily measure of organic and saline matter, of water and oxygen gas; to convert them into blood and tissues; and to decompose these and expel the residue—even if we add over and above the procreation of the species. These are the functions that minister to the material part of the organism, maintaining its chemical and molecular constitution; but these functions are subordinate to another and higher class of functions, which minister to the immaterial or intelligent part of the organism. The organic framework is maintained sound and entire for the purpose of enabling us to feel, to perceive, to think, to will, and to fulfil the commands of the will by calling into exercise the higher physical forces, which are generated within the body mainly for that end. The one class of functions belongs, therefore, to the mere body, or matter of the organism; the other belongs to the mind. The one regulates the combination of chemical elements, and the juxtaposition and relation of molecules, tissues, and organs;

or in one word, it regulates the act of organization: the other relates to the acts of the conscious mind, and the play of the higher physical agencies, which are under the domination of the mind.

But while these two classes of functions are easily distinguishable, it is to be remarked that they are intimately united, and often act in concert. The mind itself, under the phases of appetite and instinct, is subservient to the material wants of the body: and the physical forces of heat and electricity are generated by the chemical action of material elements, and when once developed impart excitement and moving power to both classes of functions.

The names by which we denote these two classes of functions is not a mere matter of indifference, for like those of the higher divisions of natural history, they ought to be characteristic and distinctive. I have already pointed out the deficiency in these respects of the old names—animal, vital, and natural. Nor have those adopted in modern times been much better selected. The names of organic functions introduced by Bichat, and of vital functions, used by Cuvier in the same sense, are alike objectionable. These terms cannot with propriety be restricted to any one class of functions; for all functions are performed by organs, and are therefore organic; and they are all performed in living bodies, and are therefore vital. The names of animal and vegetable functions are sufficiently distinctive, but they want significancy; for they leave unanswered the questions which they themselves suggest—what are the functions which belong to animals, and what are the functions which belong to vegetables? They are besides liable to a much more serious objection, inasmuch as digestion in the stomach and all the other functions of the alimentary canal, which belong solely to animals, require to be placed among the vegetable functions. It is in their general scope and object alone that these functions are allied to those of plants; but the mode in which the object is carried out is so peculiar to animals as to have been regarded as a distinctive character of animal life.

These considerations have led me to adopt two names, derived from the most general view of the nature of the bodily functions and the purposes which they serve in the living œconomy. I distinguish the two classes of functions by the names of Organizative and Organismal. The organizative functions are subservient to the act of organization; that is, they are fitted from the nature

of the actions in which they consist to build up, modify, and maintain the material fabric of the body. The organismal functions again regulate the condition and relations of the whole organism, ministering chiefly to the mind, and directing to their appropriate ends the higher physical powers developed within the living body, chiefly as instruments of the mind. Of the method employed to arrange the functions comprehended in each of these classes an idea will be readily formed by inspecting the prefixed scheme; and so I shall be saved the labour of a formal enumeration, and you the tedium of any farther prolongation of this first part of my address.

I have still, however, to request your attention to some farther explanation of the principles on which the preceding classification is based; or, if I may so call it, the peculiar physiological theory which is here proposed for your consideration.

The fundamental proposition, that the human organism is made up of an immaterial and a material part—of soul and body, does not require from me either proof or explanation. It is one of the oldest articles of belief among men: as old as any of the wisest deductions of sober thinking, or of the best aspirations of the human heart. Every man's consciousness is to him the sole evidence that there exists a mind within him; no discussion could render it more plain to those who so know it by intuition, nor supply any ground of belief in it to those destitute of that intuitive faculty. To the same effect, but in a more imaginative strain, the author of the "Religio Medici" writes,—"There is surely a piece of divinity in us; something that was before the elements, and owes no homage unto the sun. Nature tells me I am the image of God, as well as Scripture; he that understands not thus much hath not his introduction, or first lesson, and is yet to begin the alphabet of man."

Assuming, then, as absolutely certain, that during life there exists a mind within the human body, we must not shrink from the consequences to which that belief inevitably leads us. We must conclude that mind is no exclusive attribute of man, that it is widely diffused throughout the animal kingdom; nay, that there are grounds for believing that in every living being there exists in like manner a material and an immaterial element; and that the state of life consists essentially in that combination.

The first part of this argument may be presented under two

separate, but very similar forms. The one consists in comparing the different species of living beings one with another; the other, in comparing the different conditions of the human organism in the course of its development.

To take the latter first. Our memory carries us back to events and appearances that belong to our earliest childhood—between three and four years of age, or perhaps earlier—and we find running through the whole period intervening between that early age and the present moment an unbroken chain of our own identity, which satisfies us that we were then the same conscious beings that we are now. At what earlier period, then, did our minds become associated with our bodies; or were they from the first so associated? We here lose hold of consciousness for our guide, and must rest satisfied with observing the phenomena of infantile and intra-uterine life. Comparing the child with the infant we see merely the gradual expansion of a mind already associated with the body at the time of birth. During the latter periods of intra-uterine life the physician knows how to evoke the sensibility of the fœtus, and obtain from it an active response, indicative of vitality. Thus far, then, we have clear indications of the existence of mind in the human organism, revealed to us all along by its ordinary manifestations, and made certain by the testimony of consciousness, from about the end of our third year till our latest breath. During the earlier half of fœtal and the whole of embryonic life, again, we have no direct evidence of the presence of mind: but on the other hand, the organism undergoes no signal change to indicate that it has been deprived of its principal constituent element; and the phenomena which it presents are still quite different from the mere reactions of matter, and quite akin to those presented by the more mature organism. Till, therefore, some evidence be produced of the elimination of mind, we may fairly hold that the constitution of the organism has undergone no radical change: but we must, at the same time, necessarily infer that mind is combined with matter in the organism for other purposes than those usually supposed, and that its presence must be judged of by a different class of manifestations.

The second form of this argument is very similar to that just stated, the similarity depending upon the law of organic life, according to which the successive conditions observed in the development of the higher animals correspond with the permanent

conditions which we observe in the progressive series of living beings. This law holds strictly true with respect to their intellectual endowments. It is impossible to deny the existence of a principle analogous to the human mind in the animals that most closely resemble man in organization. They have the same organs of sense, sometimes more perfect than his; they have a brain and nerves, and a muscular system; and they perform actions in which we clearly discover sensations, perceptions, a certain amount of intelligence, volitions, and passions; while some of them exhibit unequivocal evidence of high moral affections. The endowments which we concede to the higher mammalians we cannot deny to the lower; nor if to them, to birds, to reptiles, and to fishes. The little Lancelet* bridges over the chasm that separates the vertebrate from the invertebrate tribes: but it is much inferior in endowments to many of the latter, in which we observe not only organs of sense and a corresponding sensibility, but the peculiar form of mental activity which we name instinct. As we pass farther down to the lowest forms of animal life, and from these to plants, we lose all trace of mental attributes, just as we do in the first rudiments of the human embryo. And here, again, the same considerations present themselves as to the evidence that the material element is necessarily eliminated because it no longer reveals itself by the ordinary mental manifestations; and suggest, as before, the opposite explanation, that the mind is still present, acting in a different way, and recognizable by a different series of phenomena.

All that can, in the mean time, be strictly inferred, from what has been stated above, is that there exists an immaterial element combined with the matter of the organism in all vertebrate and in the higher invertebrate animals when they are fully formed, and back to a very early period in the course of their development: and that with respect to the lower forms of organization, both those presented in the permanent conditions of the lower organisms and in the early stages of development of the higher; as the phenomena they exhibit are altogether analogous to those exhibited by the most perfect and mature living beings, and totally different from those exhibited by any known combination of mere material elements; there is, in consequence, no evidence that the immaterial element, admitted to be present in the higher organisms, does not

* Amphioxus lanceolatus.

also exist in the lower, but on the contrary, a strong presumption in favor of such a combination. But the rest of the argument must be pursued on other grounds.

We are now to view the union of mind and matter under an aspect unknown to Psychology, but of the highest importance to the Physiologists who, like Stahl, regard the union of mind and matter as the foundation of the science of Physiology. The main object of the psychologist is to analyse the operations of the mind, and to shew that it is capable of existing apart from the body, and in pursuing these objects he takes little heed of the links of connection by which they are bound together. But to the physiologist these links of connection must be made a subject of serious inquiry; however dark and unprofitable such a speculation may at first sight appear to be.

When we consider the modes of union by which two substances may be connected with each other, we find, in the first place, that they may be united so very intimately that their identity is lost; each of them being, as it were, absorbed into the compound, which thus becomes a *tertium quid*, distinct in all its properties from the two primary substances. This is what happens in true chemical combinations, as we see in the neutral salts, so different in their properties from the acids and bases, or the metals and acid radicals by which they are constituted. In the second place, we may have, as in the case of two horses in the same yoke, a partial union of an intimate kind along with a certain amount of freedom of action in the two constituent elements. Now, there are four possible forms of such free action, for each of the two substances may be capable of acting upon the other, and each of them may also be capable of independent action, in which the other is not involved.

There are thus five different modes of union of the two substances, and a like number of different modes of action resulting therefrom. Assuming it, then, as quite certain, that in man the organism is made up of a material and an immaterial part, and inferring from the manifest analogy of structure and modes of action that a similar combination exists in all living organisms, is it not possible from observation of the modes of action to deduce the modes of union which nature has adopted in the constitution of organic beings? It seems to me not difficult to reply to this question, by showing that Nature has adopted, in the constitution of organic beings, the whole five modes of union mentioned above;

two of them universally, and the other three more or less, according to the degree of intelligence with which the organism is endowed.

It is advisable to commence this inquiry with respect to man, thus reversing the natural order of proceeding from what is simple to what is more complicated. The reason of this is obvious, for we must proceed from the known to the unknown : and it is only through consciousness that we have any knowledge of mind, and we have no direct access to the teachings of consciousness but in man; although the results so obtained may be thereafter extended to other living beings, by comparing their actions with those of man.

In man, then, we find manifest traces of the whole five modes of union and of action, indicated above.

It is obvious, in the first and second places, that the mind and body are capable of acting, each upon the other. In all sensation, and consequently in perception, which is dependent upon sensation, a change produced upon the body necessarily precedes the affection of the mind; on the other hand, in all volition and emotion a change in the state of the mind necessarily precedes the affections of the body, which we denominate action and expression. Such, then, are two of the laws according to which mind and matter are bound together in the human organism; and we have, corresponding to them, the neurocephalous and cephaloneurous modes of action.

Still farther, in the third and fourth places, matter and mind are in man capable of acting according to laws of their own, quite independently of each other. We see this with respect to the material element in the effects of gravity, as indicated by the motion of the fluids, the falling down of the ribs in expiration, and the position of the limbs and of all the other segments of the body, which most frequently oppose their weight as a resistance to the action of the muscles; we see it in the permeation of the tissues by absorbed substances, whether liquid or gaseous; and in the act of osmosis. We see it not less in the chemical combinations and decompositions that take place within the living body, exactly in the same way in which they take place in our laboratories, whenever we can succeed in bringing together the same reagents, in the same or like circumstances; as has been done so extensively of late years in the ingenious synthetical experiments of Mon.

Berthellot. Last of all, we see it in the identity of the laws which govern the higher physical elements—heat and electricity in the processes of inorganic nature, and in those that occur within the living body: as we see in the generation, diffusion, and expenditure of animal heat; in the electric currents of muscle and nerve, and in the contraction of the muscle, which ensues on breaking or again completing the circuit.

Perhaps the most complete proof of the identity of ordinary physical forces and those operating within the living body is that supplied by the recent experiments of M. Hirn, by which he shews that chemical affinity, heat and mechanical force, are convertible into each other in the body of man, according to the same laws that regulate the conversion of them in the working of the steam engine. When a man is at rest the whole heat generated within his body, by the absorbed oxygen combining with carbon and hydrogen, is again evolved as such—that is in the state of heat; which passes off in the exhalations from the lungs and skin, with the air expelled from the lungs, or by radiation and conduction. When, again, the body is no longer at rest, but elevated in a vertical line to a given height by the action of its own muscles, then is the heat evolved no longer equal to that which the absorbed oxygen is capable of generating by combination, but short of that amount by a quantity of heat exactly equivalent to the mechanical force required to raise a weight equal to that of the body to the given height.*

The free action of the material element both according to physical and chemical laws, is common to all organisms. On the contrary, the free action of mind, independent of and unfettered by matter, occurs only in man; except where we discover faint traces of it in the animals most nearly allied to him in organization. In the neurocephalous and cephaloneurous operations the mind acts through the instrumentality of bodily organs, without which these operations could not possibly take place. But the mind thinks by its own energy; at least there is no evidence that any bodily organ plays a part in the formation of ideas that have no external prototype, in the trains of thought or the succession of ideas that pass through the mind, in the exercise of judgment or of reason, or in the higher moral sentiments which address themselves more to the understanding than to the feelings.

* Revue des Deux Mondes, December 1866.

Neither are the phenomena of madness any objection to such a view: for it is the reciprocal action of mind and body, the neurocephalous and cephaloneurous operations that are therein implicated; the mind continuing wildly free, deceived on the one hand by erroneous perceptions and associations, and on the other hand giving its impulses to parts of the brain which are over-excited or callous, and which so fail in either way to produce the expressions and actions that belong to mental sanity.

The phenomena of dreams give the same testimony. The mind seems to be at all times active. We know this certainly as to our waking hours, for we can at any time arrest the current of our thoughts, and tracing them backward, satisfy ourselves that the mind has been in exercise. But of the trains of thought that pass through the mind we remember very few, and only those that either are in themselves remarkable or are accompanied by some marked sensation or action. It is exactly the same in sleep, and it is then almost always some co-existent sensation that excites our dreaming thoughts and impresses a memorable character upon them. Those who wait upon the sick during sleep can often read their dreams in their bodily expressions and attitudes, and occasional mutterings; and guess more or less plainly as to the cause of them. All such phenomena are quite irreconcileable with the theory of Lord Brougham that our dreams take place only at the very moment of awakening. The states of mind which he describes are very like those of a man suddenly roused from a profound reverie to consciousness of what is going on around him, and are highly interesting as exhibiting a vivid picture of the activity of the mind in a person suddenly roused from incipient sleep.

The doctrine here stated, that the intellect acts independently, and without the intervention of any bodily organ, may serve to reinstate man in his former place in the imaginations of those who conceive him to have been degraded by the recent anatomical discoveries, that the brain of the higher monkeys resembles the human brain even in the minutest points of structure. But this is exactly what might be expected if we regard the brain as solely subservient to the neurocephalous and cephaloneurous operations, which are common to man and to brutes. In that case a greater size of the organ in adaptation to a wider range of ideas is all that could be looked for, and that is at least all that is actually found. But the true superiority of man over the brutes consists

in the possession of a mind far higher in intellectual and moral attributes, and capable of acting freely by its own energy without the encumbrance of bodily organs, which alone could have given to the anatomist after death indications of its existence and superiority.

The action of the mind in sensation, perception, and volition is gradually circumscribed as the brain deviates from the human type. Mere diminution of size seems to correspond with a narrower range of ideas. The want of centralization in the nervous system due to the dwindling of the cerebral hemispheres, as well as to the greater relative development of the other ganglia which constitute the encephalic mass, is most probably connected with the instinctive endowments of brutes; in which we observe a very accurate range of ideas on a single subject conjoined with a great deficiency or total absence of ideas of every other class.

At what precise point in the series of living beings we can no longer recognize the action of a conscious mind—whether in the lowest invertebrate animals the nervous system is not a mere physical instrument intended for the concatenation of the bodily movements; or whether there is not a certain amount of perceptive power wherever a nervous system is present; and whether even in animals destitute of nerves like the simple hydra, there may not be sensation although without perception,—these are all of them problems which the Physiology of the present day is unable to resolve.

Of the possible modes of union of the material and immaterial elements which compose the organism we have still to speak of the fifth, or that first mentioned above; in which the union of the two elements is so intimate that they form something like a true chemical compound, having a mode of action and properties of its own quite different from that of either of the component elements.

To prove the existence of such an union may be deemed a vain attempt. It will certainly be regarded in that light by those who do not believe in the existence of mind as distinct from matter. But to those who respect the testimony of their own consciousness as to the existence within them of a thinking and impalpable element, as well as of a palpable element incapable of thought; and especially to those who have not regarded as mere idle words the attempts already made to shew that mind and matter as associated in the human organism are capable of acting, each of them separately and independently, and each of them the one

upon the other, I should seem to leave my task unfinished, were I not to endeavour to determine whether there are any rational grounds for believing in this last mode of union.

Assuming it then in the first place as a mere hypothesis, what is implied by it? There is implied the existence of compounds having properties and a mode of action altogether peculiar. Now the tissues of all living bodies are compounds which have a structure and other properties quite peculiar; and farther, they cannot be produced by any powers of inorganic nature, but are continually being produced and subsequently modified by processes in which they themselves play a principal part, and which go on within the body as long as life continues, but are at once arrested by death. The various processes by which the tissues are produced and modified we name collectively the act of organization, of which the most remarkable character is, that it is intermediate in nature between a material and a mental act; resembling the former in so far as it produces and modifies material forms and structures, but according to laws totally different from those that regulate the actions of inorganic matter; and resembling the latter in having a manifest intention or purpose which it follows out by different means in varying circumstances, but without the consciousness which accompanies all true mental acts of an intentional kind.

As the laws of organization are quite peculiar, we exclude from it, as having no direct share in the process, all actions that take place within the body according to laws merely physical. We thus exclude all chemical actions, for these seem to take place according to the ordinary laws of affinity among complex bodies circumstanced as in the organism during life. We exclude also many physical actions as those of gravity and osmosis, which are regulated according to ordinary laws. By this process of exclusion we divest the act of organization of all conditions that are extraneous to it, just as we reduce a complex mathematical expression to its simplest terms. We thus at length bring it within the grasp of the human faculties, which it serves only to bewilder, so long as we endeavour to conceive it as an act involving all the physical and chemical actions of the body; and capable of modifying, or as Bichat will have it, of antagonizing them all. There is, in fact, only one physical action that is involved in the act of organization, and signally modified by it; and that is the intermolecular action, or action of the particles of matter one upon another, by which all

forms and structures are produced, both among organic and inorganic bodies.

But we find a remarkable contrast between these two great divisions of natural bodies, as to the kind of intermolecular action that occurs among them. Among inorganic bodies we see it producing crystalline forms, and the aggregation of these into larger masses; among organic bodies, again, we see the same power producing cells and fibres, and the transformation of these into tissues and organs, which arrange themselves in the form that constitutes the type of the species. If we had only to account for the formation of cells and fibres, the laws of intermolecular action would suffice, and we should regard these as the crystalline forms into which the plastic liquid passes on consolidation. But it is the subsequent transformation of the cells and fibres that calls for some totally different principle of explanation; for in no two places is it the same—not even in any two cubic inches of the whole mass of the body, but is modified in every region and more circumscribed locality, so as to carry out the gradual development and ultimate perfection of the specific structure and form. This is quite irreconcileable with the supposition that there is only a single force, like simple molecular attraction, here concerned. A plurality of forces alone could produce results so infinitely varied. To take an illustration from a parallel case in physical nature,—if the planetary bodies of our solar system were only influenced by a single force impressed upon them, they would all of them move in a rectilineal course; how comes it, then, that each of them follows a curvilineal path peculiar to itself, and that each of them is continually deviating from that path and returning to it again in endless aberrations, which for no two of them are alike. It is simply because a second force is in continual action at every point throughout the system at which any planet can be placed, and that this force varies directly as the mass, and inversely as the square of the distance. To take a farther illustration,—it has been shown by Becquerel that a continuous slow current of electricity is capable of so modifying the molecular attraction of inorganic matter as to produce crystals of a shape quite peculiar. Two forces, then, can effect what never could be effected by one; and if one of the two forces be variable, an infinite diversity of effects may be the result. We must infer, therefore, that there are at least two forces in operation to produce the ever-varying

structures which present themselves at every point of an organic system. There must be some force everywhere present throughout the system, and everywhere varying, to control the affinities of the organic molecules. But what physical force, even if its presence could be demonstrated, is adequate to the production of such effects? Is it then, I may ask finally, a mere crude conjecture, to be at once repudiated by sound philosophy, that the mind is diffused over the whole organism, in combination with its plastic elements, of which it everywhere modifies the molecular attraction in conformity with the laws of its own development?

Such, then, is essentially the physiological doctrine I have delivered to you, and to your predecessors on these benches for many years past. As first taught by me it had much more of the French dress, in which I received it from my own teachers. But it has gradually assumed its present shape during the period, now exceeding a quarter of a century, that I have been engaged in teaching Physiology in the University of Glasgow; as will be seen in the seven different editions of the Syllabus of my Lectures, which I have successively made public.

It may contribute still farther to perspicuity, after describing this doctrine positively, if I briefly, and in the way of contrast, characterise it also negatively, by saying, that it is not Materialism, that it is not Organicism, that it is not Vitalism, neither is it the pure Animism of Stahl.

Materialism refers all the phenomena of life to physical laws, and excludes mind from all participation in them. I believe, on the contrary, that life consists essentially in the union of mind and matter. While, therefore, I freely admit the wide range of physical laws, I regard mind as having a sphere of operation not less extensive. In proportion as we ascend in the scale of organised beings, the manifestations of mind become more and more conspicuous. It acts at first only in combination with matter, and, perhaps, unconsciously, like a physical agent; and this simplest mode of action belongs to all living beings. The reciprocal action of matter on conscious mind and of conscious mind upon matter next emerges, but in its perfect form it belongs only to the higher animals; while it is in the human species almost alone that the mind is capable of acting freely, and independent of all bodily fetters.

Organicism differs from materialism, in so far as it merely ignores

the operation of the mind, without formally either denying or affirming its existence.* It supposes the tissues to be formed out of the plastic liquid of the living body, just as crystals are formed out of solutions of inorganic matter; and it thereafter assumes the tissues and their properties as the basis of all physiological investigation. I have already spoken of the difficulties which beset the theory that the diversified organic structures are formed by any single physical force, like molecular attraction, or even by a plurality of such forces, could they be demonstrated to exist. To begin with the tissues and organs is, therefore, to postulate too much. It is to begin in the middle, as if it were an epic poem, instead of a science that was to be constructed. But admitting, to enable us to pursue our argument, that the tissues and organs are so produced, and assuming them when produced, as the basis of physiology—broad as that basis is, it is still too narrow for the whole science to rest upon. In all purely physical operations occurring within the living body, the changes of structure chemical combination and relations among the material elements is, of course, the only subject for investigation. Still farther, in the organizative actions which are so completely beyond the control of mere physical laws, we must still follow the same method of investigation; for all we know of the primary evolution and subsequent development of the body has been obtained by watching carefully the successive changes which the bodily organs undergo. Lastly, even in the higher processes of physiology, marked by the intervention of a conscious mind, the condition of the bodily organs must still be taken into account; but what conclusions could be deduced from these alone, when the primary subject of investigation is the corresponding change that takes place in the condition of the mind.

Vitalism is a doctrine less easily defined, both on account of the

* That Bichat believed firmly in the existence of mind as distinct from matter, we have the testimony of his friend and relative, M. Buisson, in his work entitled "De la Division la plus naturelle des phenomènes physiologiques," a work which agrees very much with the present in fundamental principles, although differing in superstructure. Speaking of the doctrine that it is the brain which perceives, thinks, and wills, Mon. Buisson says, "Nothing is more opposite to the sentiments of citizen Bichat, as it is easy for any one to convince himself from his courses of physiology; in which he formally recognizes, that the brain is to the mind what the senses are to the brain."

ambiguity of the principles on which it rests and of the language which has been employed to express them. The term has been applied, in the first place, to those physiological doctrines in which the functions of living beings have been compendiously explained, by referring them to certain hypothetical agents supposed to reside chiefly in the nervous system, such as the excitability of Brown, the sensorial power of Darwin, and the vital principle of Abernethy. The term has also been employed to denote certain actions occurring in the living body, which have been named vital, to distinguish them from physical and mental actions. If so defined, a vital action would correspond closely to an organisative action, as defined above. But the attempt so to restrict and specialise the meaning of the term "vital," after it has been employed for centuries in such a multiplicity of different senses, can scarcely be regarded but as hopeless of success. The actions that take place in the living body are viewed above as belonging either to matter or to mind, or as a combination of them. The material actions are either physical or chemical. The conjunct action is the act of organization. The mental actions are the reciprocal actions named neurocephalous and cephaloneurous; and the encephalous, or purely intellectual action.

The doctrine of Stahl is that which corresponds most closely to that delivered above, in as much as it distinctly recognises the agency of the mind in carrying on the functions of the living body. It must be admitted, however, that Stahl, in his indignation against materialism, and his zeal to vindicate the supremacy of the immaterial part of the organism, has ascribed to mind modes of action, such as the production of mechanical force, which the more accurate researches of modern times have shown to be of physical origin. Another very remarkable feature in the doctrine of Stahl is, that he regards the acts of organisation as the purest examples of the exercise of the "rational soul"; while "ratiocination," and the other acts of the conscious mind, are, according to his view, marked by human imperfections, arising from the interference of the bodily organs by which they are carried on.

I conclude with a few remarks on the relations of Physiology to the Science of Mind. Do I agree with Mon. Comte in regarding the latter as a mere branch of the former? Assuredly not. I look upon them as distinct sciences, but as having a large province in common, in which neither of them can claim, nor, without

mutual detriment, assume a separate jurisdiction. They are like two intersecting circles, of which a large portion of the area belongs to both. The encephalous functions, or operations of the pure intellect, are the special domain of psychology, comprehending the laws of thought and the ideas thence originating. On the other hand, the neurocephalous and cephaloneurous operations belong alike to physiology and psychology. To discuss sensation and perception without reference to the organs of sense, the nerves, and the brain; or to discuss the emotions and passions without reference to the action of the brain and cord on the muscular system, with or without the intervention of the will, is simply impossible: so that the choice is merely between the vague ideas derived from popular belief, and the more accurate ideas derived from the science of physiology. It is gratifying to see these essential views adopted by some of the leading psychologists of the present day, as by Mr. Bain of Aberdeen, whose standard work on the Intellect is illustrated with diagrams, with which you are all familiar in your books on physiology. Last of all, the small success which has resulted from the labour of so many centuries bestowed on the isolated study of the mind, might of itself be an inducement to make trial of a different course. What that success has been may be judged of from our present knowledge of the act of perception; with respect to which the pyschologists of the present day are divided into two great sects, diametrically opposed to each other, and which, therefore, cannot be both right, while it is quite possible that both may be wrong, since each of them has to contend with a formidable difficulty of its own. The one leads its disciples, by a strictly logical process, to doubt the existence of an external world: while the other requires of them to bely their own consciousness, when it testifies that it can give them no direct knowledge of matter, nor of anything save the conditions of the conscious mind.

ON THE FORCE OF THE HUMAN HEART.

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(LANCET, November 12. 1870.)

As the force of the human heart is a subject that can never lose its interest to physiologists, I desire to submit the following observations upon it, suggested by an estimate of it recently made by the Rev. Dr. Haughton, of which an account is contained in the *Dublin Quarterly Journal of Medical Science*, vol. xlix., p. 47, under the title "On the Mechanical Work done by the Human Heart." I merely premise that I wish to speak of the reverend gentleman with the most perfect respect, and that I am not the less indebted to him for his testimony on behalf of my opinions that it has been unintentionally and, indeed, unconsciously given.

I shall first endeavour to show that the solution of the problem of the heart's action proposed by Dr. Haughton is, so far as it goes, essentially the same as that which I laid before the profession nearly two years ago. I shall next endeavour to show that Dr. Haughton's solution, although capable of determining the mechanical equivalent of the work done by the heart, cannot be employed to determine more minutely the work which the heart actually performs, and gives us erroneous ideas when we attempt so to employ it.

Let it, in the first instance, be taken for granted that there is no error in the data on which our respective computations are based, so that we may have nothing to consider but the use which is made of them.

The three elements which Dr. Haughton assumes as the groundwork of his computation are, that the heart contracts 75 times in a minute; that at each contraction the left ventricle of the heart discharges three ounces of blood; and that the hæmastatic column in man stands at a height of 9·923 feet. He now multiplies the quantity of blood discharged at each contraction by the height of the hæmastatic column ($3 \times 9{\cdot}923 = 29{\cdot}769$) and regards the product as indicating the number of ounces that are raised one foot by each contraction of the heart. He again multiplies the product by the number of contractions of the heart in 24 hours, and so he obtains 80,708 foot tons as the measure of the daily work done by the left ventricle of the heart.

In addition to Dr. Haughton's three elements, I avail myself of a fourth—viz., the area of the ventricular orifice of the aorta, which I estimate with Kiel as equal to ·4187 of a square inch, and which I regard as an element of the very highest importance in the solution of the problem of the heart's action, and the more so that it can be determined with ease, and is therefore more worthy of reliance than are some of the other elements.

Supposing, then, that we add the element just mentioned to Dr. Haughton's other three, the following is the mode in which I employ these elements to determine the force of the heart. The weight of a cylinder of blood 9·923 feet in height, and having a base of ·4187 of an inch, is 30·20838 ounces. Three ounces of blood, which the heart discharges at each contraction, fill of such a cylinder 11·8245 inches, or ·985375 of a foot. Now, multiplying together the two numbers thus found, I obtain a product of 29·769, the identical result obtained by Dr. Haughton—

$$30{\cdot}208 \times {\cdot}985375 = 3 \times 9{\cdot}923 = 29{\cdot}769.$$

I had therefore reason in saying that Dr. Haughton's computation is essentially the same as mine, seeing that their results are identical.

The same coincidence holds with respect to my own computation, and comes out still more strikingly owing to the greater simplicity of the numbers. I assume that the heart beats 72 times in a minute, that it discharges two ounces of blood at each contraction, and that the height of the hæmastatic column in man is 88 inches. Now the weight of a cylinder of blood 88 inches in height, and having a basis of ·4187 of a square inch, is 22 ounces. Further, two ounces of blood, the quantity discharged at each contraction, fill exactly, of such a cylinder, 8 inches. Dr. Haughton's computation is 2×88, and that is exactly equivalent to my computation, 22×8; the common product being 176, which denotes the number of ounces which are lifted one inch at each contraction, and by dividing 176 by 12 we obtain the number of ounces that are lifted one foot—viz., 14·66. Dr. Haughton's number for each contraction is more than double, 29·769; but, in addition, he makes the heart beat 75 times in a minute, instead of 72 times, so that his total estimate of the day's work is to mine in the proportion of 30·774 to 14·66. But this difference does not depend on any difference in our modes of computation, which lead exactly to the same result, but merely on the different magnitudes assumed of the elements which form the base of the computations.

Neither are these accidental coincidences; for it is easy to show that the numbers obtained by Dr. Haughton's method are necessarily the same as those obtained by mine. For let W denote the weight of a cylinder of blood having a base of ·4187 of an inch, and a height (H) equal to that of the hæmastatic column, and let h be the portion of that cylinder equal in volume to the blood emitted from the heart at each contraction, while w denotes the weight of the same quantity of blood. Then, as the weights of any two portions of the same liquid are as their volumes, we have—

$$w : W :: h : H; \text{ and consequently}$$
$$wH = Wh$$

Now Dr. Haughton's method consists in calculating wH, and mine consists in calculating Wh, quantities which are necessarily equal, so that the two methods must in all cases lead to the same result.

I have thus shown that the solution of the problem of the heart's action proposed by Dr. Haughton is, so far as it goes, essentially and necessarily the same as that which I laid before the profession nearly two years ago, and I now proceed to show that Dr. Haughton's solution, although capable of determining accurately the mechanical equivalent of the work done by the heart, cannot be employed to determine more minutely the work which the heart actually performs, and misleads us when we attempt so to employ it.

To determine the work actually performed by the heart, is a problem quite different from that of determining the mechanical equivalent of the work done. The very same effective force is required to raise one pound to a height of ten feet, as to raise ten pounds to a height of one foot, or five pounds to a height of two feet, or two pounds to a height of five feet. In all of these cases, and others innumerable if we descend to fractional numbers, the mechanical equivalent is the same, or ten-foot pounds; but the operations themselves are very different, and with respect to any organ acting in the living body, or any inanimate machine, we would not rest satisfied till we knew which was the operation it actually performed. Now it is just so with respect to the heart. There are questions in physiology, as Dr. Haughton has shown, to answer which the mechanical equivalent of the heart's action, or the total amount of its effective force, is all that we require to know. But there are other and more important questions for which that meagre knowledge is insufficient. The physiologist wishes to know, not only the amount of the effective force of the heart, but also in what precise way or ways that force is expended within the body. What is wanted will be better understood when I say that the effective force of the heart communicates to the blood its momentum, and that the momentum of the blood is expressed by ($q \times v$) the mass of blood which is set in motion multiplied by the velocity with which it moves. Now we should at once attain our end if we could determine the respective values of q and v. But it is just because we cannot do so directly, that we are obliged to have recourse to empirical formulæ. But such formulæ are only valuable as they agree, term to term, with the rational formula ($q \times v$). Now Dr. Haughton's formula ($w \times H$) and mine ($W \times h$) cannot both agree, seeing that the terms are inverted—that which expresses the mass moved in the one, expressing the velocity in the other. We must judge, therefore, which of these formulæ gives the most probable view of the moving mass and velocity of the blood. Taking Dr. Haughton's data, and viewing them in the light of his own formula (wH), we have 3 ounces of blood moved over 9·923 feet at each beat of the heart, or with an initial velocity of very nearly 750 feet per minute; which is manifestly a *reductio ad absurdum*. But if to the same data we apply the formula (Wh), we invert the ratio of the mass to the velocity, and find 30·2 ounces of blood moving over ·985 of a foot at each beat of the heart, or with an initial velocity of 73·875 feet in the minute; which though a high rate, is no longer so extravagant as to be incredible.

In conclusion, I may be allowed to say that I am still inclined to think favourably of my own more moderate estimate—that the heart at each contraction exerts a force which would be in equilibrium if counterbalanced by a weight of 22 ounces + 129·28 grains. The mode in which this force is expended is most easily explained by supposing that we have a tube 88 inches in height and ·4187 of an inch in base, that this tube is exactly filled with blood, and that at each contraction of the heart two additional ounces are forced into it at the lower end, lifting the whole column over a space of 8 inches, and causing an equal overflow at the top. This represents accurately the labour of the human heart, and supplies us with two numbers to express it; the one, 22 ounces, being the weight of the column of blood; and the other, 8 inches, the space over which the column is lifted. The former of these numbers denotes the resistance that has to be overcome in forcing two ounces of blood into the aorta, and pushing before it the whole mass of blood in the bloodvessels; the latter, again, denotes the velocity with which the blood issues from the heart. Multiplying these two numbers together, we obtain the momentum which the heart communicates to the blood—22 ounces moving with a velocity of eight inches during the period of a pulsation, or of 10 inches per second, or 50 feet per minute. This is equivalent to 176 ounces (22×8) lifted one inch, or 14·66 ounces lifted one foot, during the period of a pulsation; or of 65·9 foot-pounds in a minute, or 42·3 foot-tons in twenty-four hours.

P.S.—The facility with which the force of the heart, in whatever aspect we choose to contemplate it, can be obtained from the weights and volumes of the columns of blood A, B, C, which have severally a basis of ·4187 of an inch, seems to me to show well the importance of assuming the area of the ventricular orifice of the aorta as an element in computing the force of the heart.

A is the calculated hæmastatical column.

B is the observed hæmastatical column.

C is a column equal in volume to the capacity of the left ventricle of the heart.

	Weight in oz. av.	Volume, as height of column, in inches.
$A =$	22·301	..... 89·165797
$B =$	22·	..... 88·
$C =$	2·	..... 8·

Force of Heart.

1. Statical equivalent = A = 22 ounces + 129·28 grains.
2. Dynamical equivalent = $B \times C$, the weight of the one into the volume of the other.

$$\left.\begin{matrix} 22 \times 8 \\ 2 \times 88 \end{matrix}\right\} = 176 \text{ inch ounces} = 14\tfrac{2}{3} \text{ foot ounces.}$$

3. Momentum of blood as emitted from heart,
= weight $B \times$ volume C = 22 ounces moved over a space of 8 inches at each pulsation, or with a velocity of 10 inches per second.

Glasgow, Oct. 1870.