An inquiry into the nature of sleep and death with a view to ascertain the more immediate causes of death, and the better regulation of the means of obviating them : being the concluding part of the author's experimental inquiry into the laws of vital functions / by A. P. W. Philip, M.D.

AN INQUIRY

INTO THE

NATURE OF SLEEP AND DEATH,

WITH

A VIEW TO ASCERTAIN THE MORE IMMEDIATE CAUSES OF DEATH, AND THE BETTER REGULATION OF THE MEANS OF OBVIATING THEM.

REPUBLISHED

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For 1827-29-31-33 and -34.

BEING THE

CONCLUDING PART OF THE AUTHOR'S EXPERIMENTAL INQUIRY

INTO

THE LAWS OF THE VITAL FUNCTIONS.

BY

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INTRODUCTION.

THE papers republished in this volume may be regarded as the concluding part of my Experimental Inquiry into the Laws of the Vital Functions. They comprehend all I have done on the subject since the publication of the third edition of that Treatise in 1826. Their chief objects are to apply the results of a great variety of experiments to explain the nature of Sleep and Death, and, by ascertaining the more immediate causes of the latter, to contribute to the better regulation of the means of obviating them.

On the powers of the nervous and muscular systems and the relations these systems bear to each other, all the functions of life depend, and consequently all rational systems of medicine must be founded.

The knowledge of particular functions is necessarily of slow growth. It must be the result of many minute and laborious investigations, and although much has been done in this department by many able physiologists, it must still be regarded as in its infancy. But however carefully individual functions may be studied, it is evidently impossible that they can be understood without a knowledge of the general laws to which all these functions are subjected. This, therefore, is the first object which demands our attention.

Thus it was that, after the revival of science, the attention of physiologists was in the first instance directed to determine the source and nature of the nervous and muscular powers, and the way in which they influence each other in their various functions; and it is not without surprise that we see so little effected by the labours of so many celebrated inquirers. At the time my investigations were begun, disputes prevailed respecting all the most important parts of the subject; and the evidence on both sides seemed so nearly balanced, that it was difficult to say on which it preponderated.

By one party, for example, it was maintained that the power of the muscular fibre is derived from the

nervous system, which by many was regarded as the only source of power in the living animal; by another that it depends on its own mechanism; by one that this fibre can be excited only through the nervous system; by another that in the organs of involuntary motion that system is incapable of at all directly influencing it; and thus the very foundation, on which all correct physiological views must rest, was left in a state of uncertainty, which extended itself to every department: and although it was evident that the nervous system includes powers of the most dissimilar nature, and consequently more than one principle of action (for it was impossible to be blind to the different nature of the sensorial and nervous powers properly so called), no well-directed attempt had been made to draw the line of distinction between them, nor to ascertain with any precision the extent of their functions. And with respect to the nature of the powers of the living animal, there had been no serious attempt even to determine the fundamental question, how far they are peculiar to the living animal, or possessed in common with the inanimate world; yet it is evident that unless all these points can be ascertained, no inquiry into the nature of particular functions can

be successful, because the nature of all more or less depends on them.

Thus it is that in the works even of the physiologists of greatest name, Haller, Bichat, Willis, Winslow, Le Gallois, Hunter, &c., however valuable the particular facts ascertained by them, we find error and consequent confusion respecting the general laws of the animal frame, and error sanctioned by such names has proved doubly pernicious.

We have been taught, for example, that the heart and blood-vessels are placed beyond the immediate controul of the nervous system, an error which has more extensively influenced the practice of medicine than any other into which physiologists have led us; that the powers of the ganglionic system are independent of the brain and spinal marrow; that on its powers all the functions of involuntary motion depend; that the phenomena of sympathy, which may almost be said to include the phenomena of diseases, so powerful is this principle in regulating their course, arise from the connections formed by the nerves in their passage from the central parts of the nervous system to the parts they influence, and other positions equally unfounded, which, supported by such authority, have vitiated all our

reasonings respecting the animal economy, whether relating to its general laws or those which regulate the functions of individual organs, in which its general laws are necessarily included; for however plausible the reasonings by which error is established, they can do nothing to obviate its consequences.

Why, it has been asked, if the heart be independent of the nervous system, does it receive nerves, and why is it influenced by the passions, and yet in no degree subject to the will? Why, if all the functions of involuntary motion derive their power from the same source, is the function of the heart uninfluenced even by decapitation, while the functions of the stomach and lungs are impaired by dividing or throwing a ligature around the eighth pair of nerves in the neck? Why do the motions of the heart continue after it is removed from the body, if, as appears from the experiments of M. le Gallois, its power depends on the spinal marrow? Why does the sudden destruction of a certain part of the spinal marrow so enfeeble the power of the heart that the circulation is instantly lost; while the destruction of the same part by small portions little, if at all, influences it? a difficulty which had almost induced

Le Gallois to abandon his inquiry, and his solution of which, as appears from what is said in the first part of my *Inquiry into the Laws of the Vital Functions*, is altogether inadmissible. Why does respiration cease on the destruction of a certain part of the brain, the medulla oblongata, since the nerves of the muscles employed in respiration arise from the spinal marrow, which the author just mentioned has proved to be capable of its functions independently of the brain? He considers this subject at length in the thirty-fifth and following pages of his treatise, and admits that he can give no explanation of it, calling it, "un des grands mystères de la puissance nerveuse, mystère qui sera dévoilé tot ou tard, et dont la découverte jettera la plus vive lumière sur le mechanisme des fonctions de cette merveilleuse puissance." These and other similar difficulties must be removed before we can understand the general laws of our frame. It is evident that the doctrines which cannot remove them must be erroneous.

In the two first pages of the second part of my *Inquiry into the Laws of the Vital Functions*, on which the present Inquiry is in a great measure founded, the subjects to which the experiments

detailed in that treatise relate are enumerated. These pages I shall quote, with some additions, as the shortest mode of making the reader acquainted with the particular subjects of that Inquiry, and the order in which they are treated.

"It appears from a general view of the structure and functions of the animal body, that, with a few immaterial exceptions, two great systems, the sanguiferous and nervous, pervade every part of it.

"The sanguiferous system, it is evident, may be divided into three parts,—the heart, the vessels of circulation, and the vessels of assimilation, that is, the vessels employed in the process of secretion, and the other processes on which the structure and consequently the function of every part depend. In the following Inquiry I shall in the first place endeavour to ascertain the principle on which the action of the heart and the vessels of circulation depends, and the relation which subsists between them and the nervous system. I shall then consider the principle on which the action of the muscles of voluntary motion depends, a subject immediately connected with the preceding, and the relation which they bear to that system. The comparative effects of agents, acting through the brain and spinal marrow

on the heart and muscles of voluntary motion, will next be investigated. An account of the experiments on these branches of the subject, though not in the order in which they are here detailed, was presented to the Royal Society in two papers, composed while I was engaged in this part of the Inquiry, which did me the honour to publish them in the Philosophical Transactions for 1815.

"The next subject of inquiry will be the principle on which the action of the assimilating vessels depends, and the relation which they bear to the nervous system.

"The principle on which the action of the alimentary canal depends will then be considered, and its relation to that system.

"We shall next inquire into the manner in which the solution of the food in the stomach is effected, and the effect on that process of depriving the stomach of the influence of the brain communicated through the eighth pair of nerves. The effects on the stomach and lungs, of destroying certain portions of the spinal marrow, compared with those of depriving them of the influence conveyed by one or both of the eighth pair of nerves, will then be determined, for the purpose of ascertaining the relative import-

ance of the brain and spinal marrow in the assimilating functions.

"These subjects will lead to experiments and observations respecting the use of the protuberances observed at the junction of certain nerves, with little accuracy included under the term ganglions with similar protuberances on individual nerves; and respecting the cause of animal temperature.

"A set of functions, equally distinct from those of the nervous and muscular systems, the sensorial functions, will then be considered. We shall inquire into the nature and objects of these functions, and particularly how far they are essential to the maintenance of life in the more perfect animals.

"The relation which the various functions of the living animal bear to each other, and the order in which they cease in dying, will form the next subjects of investigation; and lastly, I shall, by the aid of many experiments, endeavour to determine how far we are enabled to advance in ascertaining the nature of the vital powers."

THE foregoing Inquiry was divided into three parts: the first contains a general view of the state of our knowledge on the subject at the time my

experiments were begun; the second, the account of my experiments; and the last, the application of their results to improve our knowledge of the nature and treatment of diseases.

It may seem surprising that, in so many physiological dissertations, I so seldom refer to the labours of cotemporary physiologists. This arises chiefly from their having been engaged in other parts of the subject, while my attention has never been diverted from the study of those general laws of the animal economy, on which all its functions more or less immediately depend.

With the disputes between the followers and opponents of Haller, respecting the nature of muscular irritability, in which (although the evidence, if we except certain positions respecting the relation which the muscular fibre bears to the nervous system, strongly leaned towards his opinions) neither party could claim the victory; and the conclusions of M. Le Gallois, too hastily adopted by the Academy of Sciences of Paris; all attempts to ascertain those general laws of our frame, which for so long a time had engrossed the attention of physiologists, appear to have been abandoned: as if the nature of the

subject did not admit of arriving at any certain conclusions. It would be difficult for me to point out any assistance I have received from the labours of cotemporary physiologists, if I except the valuable facts ascertained by Mr. Brodie, respecting the effects on secreting surfaces and animal temperature, of impairing the powers of the nervous system, detailed in the Philosophical Transactions for 1812 and 1814, and those ascertained by Sir Charles Bell*, M. Majendie †, and Mr. Mayo‡, respecting the different natures of the two origins of the spinal nerves, and the functions of certain branches of the fifth and seventh cerebral nerves ||.

In consequence of the papers republished in this volume having been presented to the Society at considerable intervals, it was sometimes necessary to repeat statements formerly laid before it, and some

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* *Idea of a new Anatomy of the Brain, submitted for the Observations of his Friends, by Charles Bell, F.R.S.E.*

† *Journal de Physiologie experimentale et pathologique, par F. Majendie, &c.*

‡ *Anatomical and Physiological Commentaries, by Herbert Mayo, F.R.S., &c.* Part First.

|| See the 6th and 7th pages of the following Inquiry.

repetition cannot, consistently with perspicuity, be avoided, even where the papers are presented in one volume, except by forming them into a regular treatise. As this occasional repetition, however, will seldom occur in the present volume, it has been judged better not to attempt so great a change, but to give the papers separately, with the occasional additions which further opportunities have afforded.

I shall so far alter the original arrangement as to place the paper on the functions of the nervous system and their relation to the other vital functions first, because it presents a general view of the subject.

Although it will be necessary frequently to refer to my former papers in the Philosophical Transactions, and my *Inquiry into the Laws of the Vital Functions*, I have, with the exception of the general view of the subject, given in the paper just mentioned, repeated nothing in the present volume to be found in these publications.

There are several questions which present themselves in the perusal of that paper, which required farther elucidation. These are considered in the present volume in the four following papers, republished from the Philosophical Transactions for 1827—29—31, and 33, namely, how far the effect

of withdrawing the nervous influence extends to all the assimilating functions; whether the effects of Voltaic Electricity in maintaining these functions is specific, or, as has been alleged, the mere effect of a stimulant; whether the circulation wholly depends on the powers of the heart and blood-vessels, or, in a a greater or less degree, on other powers which have been supposed to be essential to it, and how far it depends on the heart, and how far on the blood-vessels, on both of which subjects opinions so various and contradictory prevail; whether the power of the heart and blood-vessels be of the same nature; how far their relation to the nervous system be such as I had maintained in my papers published in the Philosophical Transactions for 1815, or such as has been maintained in opposition to the views there taken; and lastly, on what parts of the nervous system the power strictly called nervous depends, and particularly how far the ganglions contribute to it.

It is necessary, in order that nothing may be taken for granted, that the reader should have the means of judging of the results on these parts of the subject, before he is presented with the papers which embrace a more general view of the phenomena of the living animal, namely, those which have for their objects

the nature of Sleep and Death; to which the reader, if he pleases, may without inconvenience turn, after having perused the first paper, recurring to the intermediate ones when he wishes to see the proofs of the positions relating to the subjects of these papers, stated in those on Sleep and Death.

Thus the present publication may be regarded as consisting of three parts; namely, 1. The general view of what I had done relating to the subject, given in the first paper; 2. The consideration of those heads, which seemed to require farther illustration, in the four following papers; and 3. The Inquiry which forms the proper subject of this volume, in the two last papers, to which the preceding papers are preparatory.

THE study of the functions of our own bodies, although, in consequence of its forming in conjunction with anatomy the basis on which the science of medicine rests, in a great measure confined to those who devote themselves to our profession, forms a part, and we may surely say the most interesting part, of natural history. For this reason I was induced to address the third edition of my Inquiry into the Laws of the Vital Functions to the public, and to give, in

a short preface, such an account of the structure and functions of the human body as would make every thing said in it intelligible to well-educated persons.

Both for the reason here stated, and because the following papers were, for that reason, addressed not to a medical Society, but one of general science, I endeavoured in them to avoid technical language, and in other respects to adapt them to the general reader.

ERRATA.

Page 12, line 6, for *Cliff*, read *Clift*.
— 58, last line but one, for *cardial*, read *cardiac*.
— 81, line 15, dele *and*.

ON THE NATURE, &c.

I. *On the Functions of the Nervous System, and the Relation which they bear to the other Vital Functions. From the Philosophical Transactions for* 1829.

THE experiments relating to the function of digestion detailed or referred to in a paper* which I lately had the honour to present to the Society, and in papers published in the Philosophical Transactions for 1822 and 1827†, appear to throw light on the functions of the ganglionic nerves, which hold a higher place in the animal economy than those either of sensation or voluntary power.

* The third paper in this volume.

† The contents of the first of these papers is given in the 3rd edition of my *Experimental Inquiry into the Laws of the Vital Functions*. The other is the second paper in this volume.

For many years I have been engaged in an experimental inquiry relating to the laws of the vital functions; and have from time to time laid the results before the Royal Society in papers, which the Society has done me the honour to publish. All the experiments on which the statements are founded, having been made in the presence of competent witnesses, the rule, from which I never deviated, has been to repeat each experiment till no doubt respecting the result remained in the mind of any one present; and it is satisfactory to me to be enabled to state, that, although many of these experiments have been repeated by the physiologists both of this country and the Continent, they have in no instance been found inaccurate. I have always abstained from troubling the Society till I had some additional facts to state, which appeared to me to deserve its attention; and I have generally confined myself to the simple statement of the facts and the means by which they were ascertained.

The present paper is offered to the Society on a different principle. It contains no new fact, but a review of what appears to me the necessary inferences from the various facts which I have had the honour to lay before it; and when the Society considers that

the value of facts depends on the inferences they afford, and that the inquirer, both from his more perfect knowledge of the circumstances, and from his mind having been more particularly directed to the subject, is in several respects better fitted than others for reviewing the inferences, he hopes the following observations will not be unacceptable; especially as they are such as would naturally have made part of my former papers, had it not appeared to me better to confine myself to a simple statement of the facts, till the whole had been laid before the Society. The present paper is offered to it for the purpose of supplying what may be regarded as a defect in those papers. I am fully sensible of the vast extent of the subject, and that it is only the great outline which I have attempted to trace. If this has been accurately laid down, my object has been accomplished.

THE nerves may be divided into two classes, those which proceed directly from the brain and spinal marrow to the parts to which they convey the influence of these organs; and those which enter such ganglions as receive nerves proceeding from different parts of the brain and spinal marrow, whether these nerves have or have not protuberances belong-

ing to themselves which have also been termed ganglions, but which receive only the different fibres that belong to the particular nerve to which they are attached, and from the circumstances in which they are placed, must have a different or at least a more confined relation to other parts of the nervous system. To the former, therefore, I shall, for the sake of distinction, and to avoid circumlocution, confine the term ganglion.

I beg leave to lay before the Society the following extract from lectures delivered by Mr. BRODIE before the College of Surgeons, and which have not yet been published, in which this accurate anatomist and physiologist has given the sum of our knowledge respecting the structure of the ganglions.

" Those bodies which are found in certain nerves which appear to be formed by an enlargement of the nervous substance, and which are denominated ganglia, are of a complicated structure. Into ganglia the nervous fibres may be traced, and from these ganglia the nervous fibres again emerge. SCARPA has paid much attention to the fabric of the ganglia, and he gives the following history of it. He says that the fasciculi of nervous filaments which enter a ganglion are separated and divided from each other, and that

they are combined anew. A nervous fasciculus entering a ganglion divides into smaller fasciculi. These divide again, and cross and intersect each other at various angles. Then the divided fasciculi become again united, and as at first they divided into smaller and smaller fibres; so when they begin to unite they form gradually larger and larger bundles. At last the nerve which entered a ganglion emerges from it with its fibres collected into one or more fasciculi. Sometimes several nerves enter a ganglion, in which case they are all blended together, forming a complicated net-work, in which it is impossible to determine what belongs to one nerve and what belongs to another nerve. Every fasciculus or filament which enters a ganglion passes through it. There is no appearance of any one terminating in it."

"If we unravel the texture of a ganglion, we find that each nervous fibre retains its own peculiar neurilema; but besides this, the spaces left between the intersection of the fibres are filled up with a peculiar soft substance of a greyish or yellowish colour. With the nature of this substance we are unacquainted. Some have considered it as corresponding to the cineritious substance of the brain and spinal marrow; but SCARPA is disposed to regard it

as a soft cellular substance, filled with a grayish and mucilaginous matter in emaciated subjects, and with a yellowish oily matter in those that are fat."

Such then is the structure of the ganglions as far as it is known; and as, for the reason just mentioned, I shall confine the term to those ganglions which receive nerves proceeding from different parts of the nervous system; the term ganglionic nerve I shall confine to those nerves which either enter or proceed from such ganglions, without adverting to their having or not having protuberances resembling ganglions belonging to themselves. It is necessary to keep this explanation in view, because neither the term ganglion nor ganglionic nerve has been employed with much precision.

Physiology has been greatly indebted to the experiments of Sir Charles Bell, M. Majendie, and Mr. Mayo *, for a knowledge of the different functions of the two sets of nerves which form the origins of the spinal nerves, and of the functions of certain branches of the fifth and seventh cerebral nerves. It appears from their experiments, that one of the foregoing sets of nerves, with the facial branches of the fifth

* See the references to the works of these physiologists in the Introduction.

cerebral nerve, are nerves of sensation; the other set, with the portio dura of the seventh cerebral nerve, of voluntary motion; facts which explain many of the phenomena of disease, which had suggested the probability of these functions being exercised by different nerves bound up in the same envelope. Dr. PARRY, in his treatise on the pulse, for example, relates a case where feeling was lost in one arm, and voluntary power alone in the other *. But these are not the only nor indeed the most important functions of the spinal nerves. All of them contribute to the formation of the ganglionic system, on which the life of the animal, as appears from many facts I have had the honour to lay before the Society, immediately depends, this system being as essentially a vital organ as the heart or lungs.

It is evident from what has been said, that the ganglions and nervous plexuses, which accompany them, resemble each other in their nature; and as the nerves which terminate in them come from all, even the most distant parts of the nervous system, some from the brain, and some from the lower

* Independently of such phenomena it seemed difficult to believe that sensation and voluntary power, often simultaneous functions, in the same parts, belong to the same nerve, as they evidently depend on impressions conveyed in opposite directions.

extremity, and all intermediate parts of the spinal marrow, we cannot help supposing, that there is some design in thus uniting nerves from so many sources. One of the most striking differences between the ganglionic nerves, and those proceeding directly from the brain and spinal marrow, is that even independently of the ganglions and plexuses, the former every where freely anastomose, if I may borrow a term from the sanguiferous system; while the latter proceed in a more direct course, being less connected with each other in their progress, to the parts on which they bestow sensation and voluntary power; still further demonstrating the care with which Nature blends the ganglionic nerves. There is even reason to believe that the protuberances resembling ganglions, belonging to individual nerves, serve the purpose of intimately combining the influence of the different fibres of the nerves they belong to, and that all the nerves having such protuberances contribute to the ganglionic system.

What purpose is served by the perpetual intertwining of these nerves? It is impossible for a moment to conceive that it is without an object.

This question is most likely to be answered by inquiring into the nature and functions of the parts

supplied by them; those parts are the vital organs—namely, the thoracic and abdominal viscera, and the vessels even, as we shall find by experiment, where the parts are too minute to be made the subject of dissection, to their minutest ramifications.

If the nerves proceeding from ganglions convey the influence of all the nerves which terminate in them, it would seem that, although to other parts the influence of only certain parts of the brain or spinal marrow is conveyed, the vital organs receive that of every part of them. This question can only be determined by experiment. That it must be answered in the affirmative appears from numerous experiments too simple to admit of our being deceived, which I made many years ago, and the details of which were laid before the Royal Society, and published in the Philosophical Transactions for 1815, and a few years afterwards in my treatise on the Vital Functions. From them it appears that although the muscles of voluntary motion obey an agent affecting no part of the brain and spinal marrow but that from which their nerves take their origin, the heart is influenced by agents applied to every part of these organs, from the very uppermost surface of the brain and cerebellum to the lowest portion of the spinal marrow. The same

was found to be the case with the blood-vessels to their minutest ramifications. Even the extremities of the arteries and veins, where they unite to complete the circulation, it was found, by the aid of the microscope, could be influenced, their action being either increased or impaired according to the nature of the means employed, nay, even finally deprived of power, by agents whose operation was confined either to the brain or spinal marrow, for on the power of the capillary vessels we shall find the circulation in a great degree depends*.

In some animals even of warm blood, as appears from experiments related in my treatise on the Vital Functions, the motion of the blood in the capillaries may be observed for two hours or even more after death, provided neither great and sudden injury to the nervous system, nor great loss of blood be occasioned by the mode of death; that is long after the heart has ceased to beat. The continued action of the capillaries appears from what is there said to be the cause of the large arteries being found empty some hours after death.

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* See the fourth paper in this volume, *On the Sources and Nature of the Powers on which the Circulation of the Blood depends.*

It has also been shown by experiments detailed in the same treatise, an account of some of which has appeared in the Philosophical Transactions, that the stomach and lungs are in like manner under the influence of both the brain and spinal marrow, their functions finally ceasing when they are deprived of any considerable portion of the influence they receive from either of these organs.

The partial connexion with the nervous system of the organs supplied by the cerebral and spinal nerves, and the universal connexion with that system of those supplied by the ganglionic nerves, explain many of the phenomena, both of health and disease. Why are affections of the stomach and other vital organs instantly felt through every part of the frame, while the effects of those of a muscle of voluntary motion, or even an organ of sense, although often a part of greater sensibility, is confined to the injured part? If the eye or ear, or the muscle of a limb, be so deranged by a sudden blow, for example, as instantly to destroy its power, sight, hearing, or the voluntary power of the part is lost, and there the evil ends unless inflammation ensues; but a blow on the stomach, which instantly destroys its power, at the same moment destroys that of every other part. It

is not difficult to answer the question, since the state of the stomach, from the cause just pointed out, may influence every part of the nervous system; and it appears from experiments, an account of which the Society did me the honour to publish in 1815, some of which were repeated by Mr. CLIFF, that a powerful and sudden impression, made on any considerable part of this system, is capable of destroying the circulation by instantly depriving both the heart and blood-vessels of their power.

Here the question naturally arises — For what purpose are the vital organs thus connected with every part of the brain and spinal marrow?

This question is answered by experiments detailed in my treatise on the Vital Functions, an account of some of which appeared in the Philosophical Transactions for 1815 and 1822. From them it was found that the power of secreting surfaces is deranged by abstracting from them any considerable part of the influence either of the brain or spinal marrow; and as the function of secretion is effected by the action of the nerves on the blood, as appears from experiments detailed in the papers just referred to, in another paper which I had the honour to lay before the

Society a few weeks ago*, and from a greater variety of experiments detailed in my inquiry into the laws of the Vital Functions, it is evident that the presence of nervous power in a secreting organ would be useless, were not the blood on which it operates also supplied, and disordered if it were not supplied in due proportion; and consequently its supply varied as the supply of nervous power varies.

We thus see not only why secreting surfaces are placed under the influence of every part of the nervous system, but also why it is necessary that the sanguiferous system should be under the controul of the same laws which regulate the supply of nervous power.

It appears then that by means of the system of ganglionic nerves, the influence of every part of the brain and spinal marrow is bestowed on secreting surfaces, and on those organs by which the supply of their fluids is regulated, and that the influence of every part of the brain and spinal marrow is necessary to their functions. But it is not the secreting power alone that is thus placed under the influence of

* A paper entitled *Some Observations relating to the Function of Digestion,* published in the Philosophical Transactions for 1829, being the third paper in this volume.

every part of these organs; for it is a necessary inference from experiments related in a paper which the Society did me the honour to publish in their Transactions for 1827, the next paper in this volume, that the whole of those processes on which the healthy structure of the part depends are under the same influence*.

The influence therefore of the whole brain and spinal marrow is thus united by nerves from every part of these organs entering ganglions and plexuses, from which are sent to every part of the body, nerves proved by direct experiment to convey the influence of every part of them; and this combined influence of the brain and spinal marrow is employed in forming the various secreted fluids, and supporting the other processes on which the due structure of every part depends; and I have in more than one treatise pointed out how extensively the phenomena and cure of diseases are influenced by this cause.

Such then is the relation which subsists between

* See also the paper entitled, *On the Relation which subsists between the Nervous and Muscular Systems in the more perfect Animals, and the Nature of the Influence by which it is maintained*, published in the Philosophical Transactions for 1833, being the fifth paper in this volume.

the nervous system and those other organs on which life immediately depends; but there is another relation of that system which must be investigated before the nature of its functions can be understood.

The nervous system, in the usual acceptation of the term, is very ill defined, and functions of the most dissimilar nature are classed together under the general denomination of nervous. Those of sensation and volition, for example, are classed with the excitement of a muscle and the formation of a secreted fluid. It is impossible to believe that results so different should arise from the same or similar causes. On the most cursory view of the subject, we cannot help supposing that the nervous system, according to the common acceptation of the term, includes more than one principle of action. We have every reason to believe, that the sensorial is a power wholly distinct from that strictly called nervous; and all doubt seems to be removed by the circumstance, that although the organs of both belong to the nervous system, it is evident they are not the same organs, because the sensorial power, particularly in man, resides chiefly in the brain, while the nervous power, properly so called, resides equally in the brain and spinal marrow; the latter

of which organs is capable of its functions independently of the former, as appears from many of the experiments of LE GALLOIS, which have been confirmed by several of my own.

It occurred to me, on reviewing the whole of these circumstances, that as we can destroy the nervous, without at all impairing the muscular power, it might be possible to remove the sensorial power without immediately destroying that more strictly called nervous, and thus afford an unequivocal proof of the distinct origins of these powers.

I made many experiments, which are detailed in my treatise on the Vital Functions, for the purpose of determining this point; from which it appears that in all modes of death, except the most sudden, (arising from a violent and sudden impression made on the nervous system, by which the whole of the functions are almost instantaneously destroyed,) the sensorial functions are evidently the first which cease, all the other powers of the system remaining for a considerable length of time more or less perfect, and any imperfection which appears in them not directly depending on the loss of the sensorial power.

Of the sensorial functions, sensation and volition

are the only ones which we are called upon to consider here, because they alone have any share in maintaining animal life. That these functions are essential to the maintenance of life in all the more perfect animals, will, I think, appear from what I am about to lay before the Society.

The following may be regarded as the nervous functions properly so called. The excitement of the muscles of voluntary motion, by which, through the intervention of the nervous system, they in their usual functions are subjected to the sensorial power; the occasional excitement of the muscles of involuntary motion, by which under certain circumstances the sensorial power is also capable of impressing them through the nerves, particularly when under the influence of the passions; the act of causing an evolution of caloric from the blood, by which the due temperature of the animal body is maintained; the act of forming from the blood the various secreted fluids, and that of maintaining the other assimilating processes on which the healthy structure of every part of the body depends.

The excitement of the muscles of voluntary motion is universally acknowledged to be a function

of the nervous influence, properly so called; but there has been much difference of opinion respecting the way in which it operates. The older physiologists believed that the muscles derive their power from the nervous system. HALLER* was the first who taught that the muscular power belongs to the muscle itself, to which the nervous power bears no relation but that of a stimulant, and endeavoured to support those opinions by experiment. His opponents, however, objected to his inferences, because, although the division of the nerves may prevent the muscle from receiving more nervous power, it does not deprive it of that already bestowed upon it, either existing in the muscular fibres themselves, or dispersed through them in nerves too small to be removed; and this objection appeared to be strengthened by the muscles of involuntary motion, whose function is supported by stimulants peculiar to themselves, being still supplied with nerves, of the use of which HALLER gave no satisfactory account. It appeared to me that the question could only be determined by some experiment capable of directly ascertaining whether the excitability of muscles is maintained by the influence they receive from the

* Element. Physiolog.

nerves, or impaired as by other stimulants. On trial, the latter was found to be the case. Muscles whose nerves had been divided, sustained the action of the same stimulant longer than those whose nerves were entire, and which consequently were exposed to the action both of the nervous influence applied by the will of the animal and the artificial stimulant*. The power of the muscle, therefore, is independent of the nervous influence, and is affected by it in the same way as by other stimulants.

Details of the experiments by which all the other functions just mentioned, with the exception of the maintenance of animal temperature, have been ascertained to be functions of the nervous influence, I have laid before the Society, which has done me the honour to publish them. From these experiments it appears that the nervous influence acts occasionally both as a stimulant and sedative to the muscles of involuntary motion; and that the secreting and other assimilating functions are always destroyed by depriving their organs of this influence†. That the maintenance of animal temperature is a function of the nervous

* *Experimental Inquiry into the Laws of the Vital Functions*, 3rd edition, Exper. 34, 35.

† Philosophical Transactions for 1815, and *Experimental Inquiry*, Part. II. Chapters 1 and 2.

system, properly so called, might be inferred from a variety of facts generally known, the temperature either of a part or of the whole body being lessened by any cause that impairs the action of particular nerves in the former instance, or of the whole nervous system in the latter. But this position is established in a more conclusive manner by the experiments of Mr. BRODIE, detailed in the Philosophical Transactions for 1812 and 1814, in which the temperature was uniformly lessened by impairing the powers of the nervous system; and in a different way, by experiments detailed in my Inquiry into the Laws of the Vital Functions, (Part II. Chap. VII. Sect. 2. and Chap. 8.) in which the temperature was uniformly lessened by impairing the extent of the nervous system by destroying considerable portions of the spinal marrow.

The question to be determined then is, is the nervous system capable of all these functions after the sensorial power is withdrawn?

At the moment of what we call death, the sensorial functions cease, the animal no longer feels or wills. Whether the nervous functions, properly so called, still continue, can only be determined by experiment.

That the nerves when stimulated are still capable of exciting the muscles of voluntary motion is a fact generally admitted; that they are still capable of exciting the action of the muscles of involuntary motion, appears from many experiments related in the second paper, which I had the honour to present to the Society, and which was published in the Philosophical Transactions for 1815; and that the nervous power under the same circumstances is still capable of forming the secreted fluids, and supporting the other processes by which the structure of every part is maintained, is shown by very frequently repeated experiments on the newly dead animal, detailed in my Inquiry into the Laws of the Vital Functions*. From these experiments it appears that some secretion of gastric juice takes place after what we call death, and that some derangement of structure in the lungs may be produced by dividing the eighth pair of nerves immediately after death; a proof that the processes on which the structure of the part depends, continue for some time after the sensorial power can no longer influence them; and that the nervous system is capable of causing the evolution of caloric, which supports animal temperature after the sensorial power

* Part II. Chap. XI.

is withdrawn, appears from many experiments related in the same Inquiry*.

We may thus trace the existence of the whole of the nervous functions, properly so called, after the removal of the sensorial power. The former therefore have no immediate dependence on the latter: but in the entire animal the nervous, in some of its functions always, and occasionally in all of them, is subjected to the sensorial power. We know that under certain circumstances the action of the heart and vessels, the state of the secretions, the temperature and even the structure of our bodies are under the influence of the mind. The sensorial therefore bears the same relation to the nervous power, as the latter bears to the muscular power, the muscular existing independently of the nervous power, but being influenced by it.

It was this independence of the functions properly called nervous on those of the sensorial power, and the analogy which subsists between many of the former and chemical processes, which suggested that the agent, on which the nervous functions immediately depend, instead of being peculiar to the living animal, may only be an agent employed by those

* Part II. Chap. XI.

powers which are so, in the same way as any other power which the living animal possesses in common with inanimate nature; and it appeared to me that the accuracy of this suggestion would be placed beyond a doubt if the nervous power could be proved to be capable of its function, after it had been made to pass through any other conductor than the nerves; for it will be admitted that the powers peculiar to the living animal can only operate, and, as far as we see, can only exist in the organs to which they belong; the muscular power can exist only in the muscular fibre, the sensorial, only in the brain and spinal marrow.

If then the nervous influence can be made to pass through any substance but that of the nervous system in which it resides, it evidently has an existence independent of the mechanism of that system, and therefore is not peculiar to it. This, after many vain attempts, I succeeded in effecting. It appears from experiments, an account of which the Society did me the honour to publish in 1822, after they had been publicly repeated at the Royal Institution of London, and which have since been repeated with the same result by M. BRESCHET and other physiologists at Paris, that the nervous influence is capable of its

function after it has been made to pass through other conductors than the nerves.

It would seem, therefore, that however generally the nervous influence has been confounded with those powers more strictly called vital, it is only an agent employed by them. This view of the subject seemed to point out the possibility of finding some of those powers which operate in inanimate nature capable of the functions of the nervous influence, properly so called, if brought to operate under the same circumstances; and on trial it was found, as appears from experiments which were also publicly repeated at the Royal Institution of London, and the results of which were published in the Philosophical Transactions for 1822, and which were repeated with the same results by Dr. ABEL*, M. BRESCHET† and others, that voltaic electricity may be substituted for the nervous influence, not only in the more simple, but in

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* The London Medical and Physical Journal for May, 1820, Vol. XLIII. p. 385.

† De l'Influence du Système Nerveux sur la Digestion Stomacale; par MM. BRESCHET, D.M.P., Chef de Travaux Anatomiques de la Faculté de Médecine de Paris, etc.; H. MILNE EDWARDS, D.M.P.; et VAVASSEUR, D.M.P. (Mémoire lu à la Société Philomatique, la 2e Août, 1823.) Extrait des *Archives Générales de Médecine*, Août, 1823.

the most complicated functions of that power. From these and other experiments, it not only appears that voltaic electricity, if applied under the same circumstances under which the nervous influence operates, is capable of exciting the muscles, and causing an evolution of caloric from arterial blood*, but of forming the secreted fluids from the blood, and supporting all those functions on which the structure of every part depends†. How far these facts, whether relating to the nature or functions of the nervous influence, go in proving its identity with voltaic electricity, will be considered more particularly in the fifth and seventh papers in this volume.

On reviewing all that has been said of the relations of the sensorial, nervous, and muscular powers, the question naturally arises—If both the nervous and muscular powers, the immediate agents in all those functions on which life depends, are thus independent of the sensorial power, and capable of their functions after it is withdrawn, why do the more perfect animals for so short a time survive the loss of this power? The cause is, that on the removal of the

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* *Experimental Inquiry into the Laws of the Vital Functions*, third edition, Exper. 80, 81, 82, 83, 84, 85, 86.

† Ibid. Part II., Chap. XI.

sensorial power, respiration ceases; because this function partakes of all the three powers, the sensorial, nervous, and muscular*.

It has been customary to speak of the muscles of respiration as at least in part muscles of involuntary motion. What is meant by a muscle of voluntary motion? It is a muscle, whose action under all ordinary circumstances we can excite, interrupt, retard, and accelerate at pleasure, but it is not a muscle whose action we can at all times controul. There is no such muscle, because the impression on the sensorium tending to call any particular set of muscles into action may be so powerful, that we are unable to controul it. Who can prevent the action of the muscles of the arm when fire is suddenly applied to the fingers? Neither do we mean by the term muscle of voluntary motion, one which we cannot call into action during sleep. If our posture during sleep becomes uncomfortable, we call the muscles both of the trunk and limbs into action for the purpose of changing it. The uneasiness caused by the continuance of the same posture, sufficiently rouses the sleeper to make him will a change of posture,

* *Experimental Inquiry into the Laws of the Vital Functions.* Part II., Chap. XI.

without rendering him at all more sensible to other impressions of a slighter nature, and his sleep continues.

What muscles then are more under command than those of respiration? We can on all usual occasions interrupt, renew, retard, or accelerate their action at pleasure; and if we cannot interrupt it for as long a time as that of the muscles of a limb, this depends on no peculiarity in the action of these muscles, but on the nature of the office they perform; and if we excite them in sleep for the removal of an uneasy sensation, and cannot controul them under a sense of suffocation, that is, in a state of greater suffering than can be voluntarily borne, all this is no more than applies to every other muscle of voluntary motion: but from the nature of our constitution we must breathe many times every minute, and we need not turn ourselves more than once in many hours,—a difference depending on circumstances which have nothing to do with the nature of the muscles we employ in either of these acts.

If we find the breathing going on in apoplexy after all voluntary motion of the limbs has ceased, it is because the sensation exists which excites the patient to inflate his lungs, while there is none which

excites him to move his limbs. In the slighter states of apoplexy, if the limbs be much irritated, the muscles which move them will also be called into action; and in the severer states, if the patient breathes, when no irritation of the limbs can excite him to move them, it is because the want of wholesome air in the lungs, after a certain interval, produces a more powerful impression than any other means we can employ. People have voluntarily held the hand in the fire, but no man ever voluntarily abstained from breathing till the lungs were injured. When at length no irritation, however violent, can impress the sensorium, the breathing ceases and death ensues. The mode of death in apoplexy sufficiently illustrates what is here said. We find the intervals of breathing becoming longer before it ceases. As the insensibility increases, a greater want of fresh air is necessary to excite the patient to inspire, till at length the total privation of fresh air no longer producing any sensation, can no longer excite this effort.

The muscles of respiration then, it would appear, are as perfectly muscles of voluntary motion as those of the limbs, and are never excited but by an act of the sensorium. When there is no feeling to induce us to breathe, the breathing ceases.

That on ordinary occasions we are unconscious of this feeling, in the common acceptation of the term (that is, that it makes no lasting impression on the mind, for this is necessary to what we mean by consciousness), unless the attention be particularly directed to it, is no proof that it has not existed. When we direct our attention to the act of breathing, especially if we breathe more slowly than usual, we can distinctly perceive the sensation which induces us to inspire, and that it is a voluntary act which relieves it.

The same observations respecting consciousness apply to all the more trivial habitual acts of the sensorium. In playing on an instrument, we cannot tell which finger last struck the chord; in walking, we cannot tell which leg we last moved;—yet all such acts are strictly acts of volition: when we attend to them we can regulate them as we please, but in proportion as they are habitual we attend to them the less, and therefore least of all to the act of respiration.

To the consciousness of having experienced any feeling, it is evidently necessary that its strength, or some other circumstance attending it, should be such as to impress it on the memory. We are every hour

performing many acts of volition which are too trivial to be remembered, and consequently at the time we are questioned we have no consciousness of their having existed. The proper feeling excites the act required, but the feeling is too habitual to command the attention.

It may be difficult for a person not accustomed to reflect on such subjects, to believe that every time his leg is moved in walking, he performs a distinct act of volition; but he will be convinced of this if he observes the motions of those whose power of volition is impaired by disease. He will find the patient hesitate which leg to move at every step, and at length his attempts to move the limbs produce a confused and irregular action incapable of carrying him forward.

The act of expanding the chest is an act of volition, it is an act in ordinary breathing rendered extremely easy by the gentleness of the motion required, and the continual habit which renders it familiar, and is excited by a sensation proportionably slight, but which is as essential to it as stronger sensations are to more powerful acts of volition. Thus it is that on the removal of the sensorial power respiration ceases; and the difficulty stated

by M. Le Gallois, admits of an easy solution, the sensorial power ceasing on the destruction of the medulla oblongata.

It may be said, perhaps, that we have no instance of a muscle of voluntary motion continuing to act during life; but besides that this is begging the question, it is to be recollected that the action of the muscles in ordinary respiration is very slight, and performed at considerable intervals, for it is only during inspiration that the muscles act. They are quiescent during expiration, which in our usual breathing is performed by the elasticity of the cartilages and the weight of the parts concerned. There is perhaps no muscle of the body which could not without fatigue maintain a similar action were there a cause capable of exciting it. In certain diseases we find both more powerful and more frequent actions of the muscles of volition continued for years during the whole of our waking hours without any complaint of fatigue.

When the change in the blood, effected by respiration, no longer takes place, many of the pulmonary vessels lose their proper stimulant, red blood; and feel more directly perhaps the debilitating influence of black blood; their functions therefore begin to

fail. In proportion as this happens, the blood accumulates in the lungs. The right side of the heart consequently experiences an increased difficulty in emptying itself, the due supply of blood to the left side fails, and the blood which is supplied to it no longer possesses the properties which belong to that which is the natural stimulant of this side of the heart. By the operation of these causes both sides of the heart, particularly in warm-blooded animals, soon lose their power after respiration ceases. The arteries under such circumstances, it is evident, cannot long supply fluids proper for the purposes of assimilation. The nervous and muscular solids therefore deviate from the state necessary for the functions of life, which at length cease in every part.

The foregoing appears to be the order in which the functions always cease in the act of dying; whether it be occasioned by injury of the sanguiferous or nervous system, or both, for even in the sudden destruction of all the vital powers in the cases above referred to, this succession, however rapid, may still be observed.

Such then appears to be the nature of respiration. The first act is the impression made on the senso-

rium, the sensation excited by the want of fresh air in the lungs. We are enabled to supply it, and thus remove the uneasiness, by exciting certain muscles subject to the will. Through nerves which are fitted for this purpose, we apply a stimulant to certain muscles which perform the act required. Thus respiration is the combined act of the sensorial, nervous, and muscular powers. It is as effectually destroyed by a failure of the sensation which makes us will to inspire, as by that of the nervous or muscular power by which the will effects its object. With this view of the subject before us, and I can see no other which the facts admit of, it will be proper to examine the nature of respiration more in detail, for we shall find in the following papers that there is no other function a clear understanding of the nature of which is, in the more perfect animals, so essential to a just view of so many of the phenomena both of health and disease.

I have already had occasion to observe, that the effort made in ordinary breathing is very slight. It is chiefly performed by the diaphragm, by the contraction of which the cavity of the chest being slightly enlarged perpendicularly, the pressure of the atmosphere readily causes the air cells to be dis-

tended with air; but if any obstacle occurs, tending to prevent the passage of the air to the cells, a greater effort is required, and other muscles are called into action. It seems almost unnecessary to observe, that the sensation which induces us to make this greater effort, must, as the object is still the same, operate in the same way. The more powerful sensation indeed, and the trouble the effort gives us, by calling our attention to it, enables us at once to perceive that it is an effort of the same kind with any other voluntary effort by which we endeavour to relieve ourselves from a painful feeling, and, like any other powerful voluntary effort long continued, it produces the feelings of fatigue. Would any privation of air induce the struggle that we see in severe dyspnœa, if no sensation were excited by it? All that follows is evidently its consequence.

The greater effort when the breathing is obstructed consists in two things, drawing the air into the chest with greater force, that is, expanding the chest more forcibly that the air may enter it with a greater degree of atmospheric pressure, and thus any obstacle to its entrance be overcome; and doing all we can to enlarge the passage by which the air enters.

The action of the muscles by which these objects are effected has been ascribed to a particular sympathy supposed to exist between certain nerves. But to say nothing of the proofs that the phenomena referred to what has been called the sympathy of nerves, depend on changes which take place in the central parts of the nervous system*, if we could in this way explain the effects in question it is not to be overlooked that the same sympathy must exist with respect to the abdominal as thoracic viscera, for the same nerves supply both; and with respect to the central parts of the nervous system, if the eighth pair of nerves which supplies the lungs originate near the nerves of the diaphragm, and of certain muscles of the face, by which the nostrils are expanded, &c., this cannot be said of the nerves of many other muscles equally called into action in severe dyspnœa, the muscles of the loins, &c.

We must therefore look for another principle to account for the relation which subsists between the acts just referred to and peculiar states of the lungs. The principle is at hand. The sensation which induces us to inspire forms a necessary link in the

* Experimental Inquiry, Part II., pages 106 & 107, 3rd Edition.

chain of causes; for every contraction excited in the muscles in cases of difficult breathing, is evidently calculated to relieve this sensation in one of the two ways just pointed out. It either tends to expand the chest, or enlarge the passage of the air. It is impossible in such a case to overlook the act of the sensorium, which is sufficient to account for the phenomena, without the supposition of any particular sympathy of nerves, which on the other hand, as I have just had occasion to point out, did it exist, is insufficient for this purpose.

The muscles employed in extreme dyspnœa are not confined to a particular set. They are the whole muscles of the trunk, and sometimes many of the limbs also, muscles which have nothing in common, except that they are all muscles of voluntary motion, and bear the same relation to the nervous and sensorial systems which all other muscles of voluntary motion do. On the other hand, are not the muscles, usually employed in respiration, employed also in a thousand other acts of volition; and with respect to particular actions of the muscles of the face being associated with the feelings of dyspnœa, were there no specific purpose served by these actions, are not actions of the muscles of the

face equally associated with sensations referred to the abdomen and the limbs, and arising from causes operating in them. Who can have a placid countenance while in agony from the operation of any cause and in whatever part?

It appears from a great variety of experiments to which I have referred, that organs supplied with ganglionic nerves are subjected to the influence not of any one, but of every part of the brain and spinal marrow. No inference therefore can be drawn respecting the sympathies of any ganglionic nerve, as the term is here used, that is a nerve that either enters or proceeds from ganglions, according to the sense in which I use the term, from any particular distribution of nerves, or even from the part of the brain and spinal marrow where any particular nerve which contributes to the power of the ganglionic system originates. The nerves of vital organs are equally connected with every part of the brain and spinal marrow; and if we must not look for such effects from any connexion of their nerves in their other functions, there is still less room, it is evident, to look for them in those functions where the sensorial power is concerned.

The sensorium evidently residing and operating at

the source of nervous power, there receives the various impressions conveyed by the nerves, and there influences those nerves which convey its dictates.

I beg leave to close this paper with a short recapitulation of the principal points which appear to be ascertained by the experiments referred to in it.

The nerves are divided into two classes, whose functions essentially differ; those proceeding directly from the brain and spinal marrow, which, in the one direction, convey the influence of the parts of those organs from which they derive their origin, and are the sole means of exciting the muscles of voluntary motion; and in the other, impressions which, made on the sentient extremities of the nerves, influence the sensorium; and the ganglionic nerves, which originate from every part of the brain and spinal marrow, and while they also convey impressions to the sensorium, and occasionally excite the muscles of involuntary motion, usually excited by stimulants peculiar to themselves, perform functions of greater importance, and which require the combined influence of the whole brain and spinal marrow, namely, the various functions of secretion and assimilation, and those on which the due temperature of the

animal body depends, and are consequently in the strictest sense a vital organ.

Although the nervous power therefore stands only in the relation of a stimulant to the muscular fibre, whether of voluntary or involuntary motion, in no degree contributing to its power, which depends on its own mechanism; it is essential to the existence of the secreting and assimilating powers.

Such is the relation which the nervous system bears to what may be termed the circumference of the animal body, in contradistinction to the sensorium, which may be justly regarded as its centre, to which that system bears a relation of equal importance; for it may be regarded as the means of intercourse between the organs of the sensorium and all other parts*. In its power this system is independent of the sensorium, for we have seen it capable of all its functions after the sensorial power is withdrawn; but in all of them it is influenced by it, constantly in some, occasionally in others.

* See what is said on this subject in the two last paragraphs of the paper on the relation of the nervous and muscular systems and in the review of the functions of the living animal in the paper on Death.

It therefore bears the same relation to the sensorial organs which the muscles bear to it. As the muscular is independent of the nervous power, so is the nervous of the sensorial power. As the nervous power influences all the muscular functions, those of the muscles of voluntary motion constantly, those of the muscles of involuntary motion occasionally; so the sensorial power influences all the nervous functions, those of the cerebral and spinal nerves constantly, those of the ganglionic nerves occasionally. Thus all those functions of the nervous and muscular systems, by which we are connected with the world that surrounds us, are constantly subjected to the sensorial power, and in such a manner as to be subjected also to the will; while the functions on which life depends, with the exception of respiration, are only occasionally subjected to the sensorial power, and under circumstances in which the will has no controul*. With this exception these are all functions of the nervous and muscular powers alone. To respiration in the more perfect animal the sensorial power being necessary, the

* I shall have occasion in the last of the papers, in this volume, *on the Nature of Death*, to consider the causes which render the vital functions independent of the will.

nervous and muscular powers never in them long survive the loss of this power.

The nervous influence, by means of which all the other powers of the animal body are associated, which effects so many changes in it, and has so large a share in connecting it with the external world, cannot, strictly speaking, be regarded as one of the vital powers of that body, but as an agent employed by those powers; because, as appears from direct experiment, it is capable of existing independently of the mechanism of the part in which it resides, and therefore is not peculiar to that mechanism; and all its functions may be performed by voltaic electricity, made to operate in the same circumstances in which the nervous power operates.

The experiments referred to in the foregoing paper suggested the use of voltaic electricity in those diseases which arise either from a partial or general failure of nervous power; and the success which has attended its employment has afforded another proof of its capability of the functions of that power. The diseases in which it has been chiefly employed are habitual asthma, the various forms of indigestion, affections of the spinal marrow,

and general nervous debility. An account of its effects in the first of these diseases was laid before the Society, and published in the Philosophical Transactions for 1817. An account of its effects in the others is published in the third edition of my Treatise on the Vital Functions.

II. *Some Observations on the Effects of dividing the Nerves of the Lungs and subjecting them to the Influence of Voltaic Electricity. From the Philosophical Transactions for* 1827.

The Royal Society did me the honour in 1822 to publish the results of some experiments, from which it appeared that the secreted fluids of animals are so deranged by dividing the nerves of the secreting organs, and separating the divided ends, that those, formed for the purposes of the animal economy, are no longer capable of their functions; and that after these functions are by such means destroyed, they may be restored by transmitting voltaic electricity through the secreting organs by the portions of the divided nerves attached to them, the due properties of their fluids being thus restored.

In the statement of these results, the attention

was chiefly directed to the function of the stomach. In the present communication I shall make a few additional observations respecting the lungs.

However much the secreting surface of the stomach may be deranged by the means just mentioned, its appearance, owing we have reason to believe to the extreme minuteness of its structure, is the same, or nearly so, as when the nerves have been left undisturbed; and with the exception of occasional efforts to vomit, no symptom shows itself after the division of the nerves indicating the derangement of function which has taken place. Both in the symptoms and appearances after death, the derangement, occasioned in the lungs by the division of their nerves and the separation of the divided ends, is much more evident; the function as well as the structure of the lungs being, from their nature, more readily made the subjects of observation.

Soon after the operation the animal begins to breathe with difficulty, and this symptom gradually increases, and is at length evidently the cause of death. On inspecting the lungs after death, the air tubes and cells, as far as they can still be traced, are found to contain a viscid fluid; and in considerable portions of the lungs, generally more or less according

to the time the animal has survived the operation, every trace of both tubes and cells appears to be obliterated, the lungs both in colour and consistence assuming much of the appearance of the liver, and these portions of lungs sink in water ; and although examined with the greatest care, and the aid of a powerful magnifying glass, both by Mr. Cutler, who was so kind as to give me his assistance, and myself, we could not perceive in them the least remains of the structure peculiar to this viscus.

I wished, however, to ascertain, by means less fallacious than the sight, whether the change of structure in the parts most affected, be such as to cause the total obliteration of their cavities, and Mr. Cutler, at my request, was so obliging as to make the following experiments, the account of which I shall give in his own words.

" If you cut out a portion of each of the eighth pair of nerves in the neck of a rabbit, it seldom dies within eight hours, and rarely survives more than twenty-four hours.

" On examination after death, the lungs are found, in many parts, covered with dark red patches.

" To ascertain the mischief done to the substance of the lungs, I endeavoured to fill them with mercury

by the trachea, but from the delicate structure of the air cells a rupture took place, and the mercury escaped.

" I then endeavoured to inject the air cells through the trachea with the finest vermilion injection. In the healthy lungs the attempt was invariably successful, making the whole of a bright scarlet colour, and, on cutting into them, every part was found to be uniformly filled with the injection.

" After injecting the diseased lungs, the dark red patches remained on their surface: other parts of the lungs were of a bright red colour: some parts were partially injected, and other parts retained their natural appearance.

" This was explained on dissection. Those parts of the lungs which were completely injected had not suffered from disease, other parts had suffered sufficiently partially to obstruct the injection, while some parts were so completely hepatised that not a particle of injection could enter them, or the parts beyond them, which were not equally diseased.

" Those portions of the lungs which were completely injected, sunk in water, from the weight of the injection.

" The hepatised portions, from their diseased state,

sunk also, whilst the portions beyond them, having their natural appearance, floated."

If, as I have repeatedly ascertained, and various members of our profession have witnessed, after the nerves are divided, and the divided ends separated, the due degree of voltaic electricity be transmitted through the lungs, by those portions of the nerves which remain attached to them, no affection of the breathing supervenes; and the lungs, after death, are found quite healthy, unless the electricity has been applied of such power, or continued for such a length of time, as to excite inflammation, and then the appearances on dissection are those of inflammation, not those produced by the division of the nerves of the lungs.

It appears from these facts, that the effect of dividing the nerves of a vital organ, and separating the divided ends, is not merely that of deranging its secreting power, but all those powers on which its healthy structure depends; and that the effect of voltaic electricity, is that of restoring all these powers. It is particularly to be observed, that the voltaic apparatus should be so arranged that its influence may be transmitted through the lungs as soon as the nerves are divided, the delay of even a

short time appearing to give rise to more or less morbid appearance in the lungs.

The Society did me the honour to publish two papers on the same part of the subject with the preceding paper in the Philosophical Transactions for 1817 and 1822. To the last of these papers I have already had occasion to refer, the other was entitled, "On the Effects of Galvanism in restoring the due Action of the Lungs*." The objects of this part of the inquiry were to ascertain whether the nervous influence is essential to the function of secretion, and the other assimilating processes; and whether voltaic electricity, applied as far as possible, in the same way in which the nervous influence is applied, is capable of supplying its place in all these processes. It appears from the experiments, the results of which have now been laid before the Society, that the answer in both instances is in the affirmative.

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* The contents of these papers have, with the consent of the President and Council of the Royal Society, been republished more in detail, in the third edition of my Inquiry into the Laws of the Vital Functions.

III. *Some Observations relating to the Function of Digestion. From the Philosophical Transactions for* 1829.

No arguments are necessary to convince us of the importance of that function on which all parts of our frame depend for their nourishment. In one respect its organs may be regarded as of greater importance than even some of those which are more immediately essential to life. The sympathies of the stomach and first intestine are powerful and extensive, and consequently very generally and in a great number of ways contribute to the causes and influence the course of disease.

I am induced to trouble the Society with the following observations, in the hope that I shall be able to place before them some points relating to the function of the stomach in a clearer point of

view than has hitherto been done. In former papers which the Society have done me the honour to publish, and more fully in a Treatise on the Vital Functions, I have endeavoured by many experiments to trace the different steps of the process of digestion in the stomach. It appears from them that the food remains in a quiescent state, except that the part of it which lies next the stomach, as soon as it has undergone the effect of the gastric juice, is, in consequence of food thus prepared exciting a peculiar action in the muscular fibres of this organ, carried on towards the intestines, the next portion of food thus brought into contact with the stomach undergoing the same process; and so on, till the whole is in a state proper for that part of the digestive process which belongs to the first intestine.

Thus the muscular fibres of the stomach are in continual action during its function; for the gastric juice pervading the contents of the stomach to a certain extent, the change effected by it on each particular portion of the food is far advanced before the food is actually in contact with the stomach, as may be seen by inspecting that of an animal killed a few hours after a meal; and consequently is not

long detained when in contact with it. There is therefore a continual motion of that layer of food which lies in contact, with its surface towards the lower orifice of the stomach, and the less digested part is continually approaching its surface*.

It follows then that a failure of the function of the stomach may arise either from a proper gastric juice not being supplied, or the muscular power of the stomach failing to carry onward the digested part, and thus regularly to present to the stomach a new surface of food to be acted upon by that juice. It further appeared, that for the first of these purposes the influence of the nervous system is necessary, the secretion of gastric juice failing as soon as the stomach is deprived of any considerable part of this influence; but that the nervous influence is not necessary for the other, the muscular power of the stomach still carrying on towards the intestine any digested food which happens to be in the former, or any food which had been acted upon by gastric juice which happened to be in it at the time, however much its nervous power be impaired; and this office is, as far as we can see, as readily

* *Experimental Inquiry into the Laws of the Vital Functions*, Part II. Chap. VII. Sect. I. On the Process of Digestion.

performed as when the nervous power of the organ is entire.

The muscular fibres of the stomach therefore are stimulated by its contents, in the same way as those of the heart by the blood, the usual action of both being wholly independent of the nervous system, an inference confirmed by many other experiments, an account of which I had the honour to lay before the Society*.

I have, as appears from the papers which the Society have done me the honour to publish, attempted to go a step further, and to show experimentally that the office of the nervous power in preparing the gastric juice, may be correctly imitated by exposing the living stomach to the influence of a voltaic pile after the supply of nervous influence is interrupted; and those who were at first inclined to doubt this fact, have since publicly acknowledged, on witnessing the experiments, that the digestive process of the stomach supported by voltaic electricity, is, as far as we can see, as perfect as that supported by the nervous influence itself.

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* Philosophical Transactions for 1815.

It is therefore evident that in the formation of the gastric juice, a chemical power can be substituted for that of the nervous system. I do not mean that, strictly speaking, its formation is to be regarded as a mere chemical process, because it is only in a living stomach that galvanism can have such an effect; but this effect bears too strong an analogy to other chemical results to be wholly separated from them, although what we call life, whatever that may be, is necessary to its production.

The same effect, and one certainly of a very complicated nature, is here produced by the nervous power and a chemical agent; because when the latter is substituted for the former, the same effect takes place. It is a simple matter of fact. But it is maintained by some physiologists that the same effect may be produced by a mechanical agent*. They have related several experiments which appeared to them to prove, that when after a part of the eighth pair of nerves is removed, and thus the due secretion

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* See a paper entitled, Mémoire sur le Mode d'Action des Nerfs Pneumogastriques dans la Production des Phenomènes de la Digestion. Par MM. Breschet et Milne Edwards (lu à la Société Philomatique, le 19 Fevrier 1825).—(Extrait des Archives Generales de Médecine.)

of gastric juice prevented, it may be restored by mechanically irritating the cut ends of the lower portions of the divided nerves. If such be the fact, it must materially influence our views, both with respect to the function of digestion and the other secreting processes of the animal body.

In judging of the result of such experiments, several things must be taken into the account, which appear to have escaped the attention of those gentlemen.

At the time the animal is fed, in preparation for the experiment, there may be some food in the stomach, from previous meals, more or less digested, and there is always some gastric juice ready to act on any new food which may be presented to it. It is evident therefore, that although the secretion of gastric juice cease at the moment of the excision of part of the eighth pair of nerves, some digested food must be found in the stomach for some hours after the operation; for, as I have ascertained by numerous trials, many hours are required in such experiments for the stomach to propel into the intestine the remains of food previously digested, or that digested by the gastric juice previously formed.

When therefore the contents of the stomach are

examined in five or six hours, and generally even in ten or twelve, after the operation, more or less digested food is found lying next the surface of the stomach. But when the animal survives the operation eighteen, twenty, or more hours, undigested food alone is found in it. The cause of so long a time being required wholly to expel the food, which has undergone any degree of the digestive process, appears to be, that as digested food alone excites that action of the stomach which propels it into the intestine, and the more perfectly it is digested, it excites this action the more readily, those parts of the digested food which have but imperfectly undergone the digestive process are expelled very slowly, so that it is very long before food wholly undigested alone is left.

That the longer the animal lives after the excision of part of the eighth pair of nerves, the less digested food is left in the stomach, is a fact now admitted by all who assisted at the experiments. Among the great number who have witnessed and been satisfied with their result, are Sir Humphrey Davy, Mr. Thomas Andrew Knight, and Mr. Brodie, gentlemen whose experimental accuracy, in the opinion of the public, has never been surpassed.

Of this fact, the gentlemen to whose paper I have referred, are not aware. They maintain, indeed, that the only effect on the digestive process produced by the excision of part of the eighth pair of nerves, is, that it becomes more tedious, being as perfect as when the nerves are entire, if a sufficient length of time be afforded. In speaking of the animals in which part of the eighth pair of nerves had been cut out, and comparing them with the healthy animal, they say: "Enfin, si on laisse écouler un espace de temps plus grand encore entre l'operation et la mort des animaux, on pourra trouver que la digestion est completement achevée dans l'un comme dans l'autre cas."

It will easily be perceived to what errors, respecting the effect on digestion, of depriving the stomach of the office of the eighth pair of nerves, this misconception, which probably arose from the animals employed in their experiments not having survived long enough to allow of the whole of the digested food being expelled from the stomach, must lead. Its effect was increased in the experiments referred to, by the different animals in each experiment having been confined to the same quantity of food. The most hungry would of course digest it fastest

and most perfectly, because in them there would be the greatest quantity of gastric juice collected in the stomach before the excision of part of the nerves. To judge fairly of the result of the experiment the different animals must be allowed equally to satisfy their appetite, to eat till, from their manner of eating, it is found that the appetite has equally abated in all. It will be found, I think, that several other experimentalists have allowed themselves to be deceived by the circumstances here enumerated. We thus readily account for the discrepancies of writers. MM. Leuret and Lassaigne state that in horses eight hours after five or six inches of the eighth pair of nerves were cut out, the digestion was going on as usual*, while Mr. Field, whose experimental accuracy is generally acknowledged, and in whose experiments the same animals (horses) survived many times eight hours, found nothing in the stomach but undigested food covered with what appeared to be a layer of mucus, which I have often seen under the same circumstances in other animals.

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* Outlines of Human Physiology, by Herbert Mayo, F.R.S. second edition, page 184 and 185.

Such are the circumstances which I conceive misled those gentlemen who maintain that they can produce a sensible effect on the contents of the stomach by mechanical irritation of its nerves.

They also err in supposing that the muscular fibres of the stomach can be excited by irritating the eighth pair of nerves in the way that a muscle of voluntary motion may be excited through its nerves. The digested food is the natural stimulus of the muscular fibres of the stomach in its usual function, as the nervous power is of the muscles of voluntary motion in theirs; and we cannot through the nerves excite the former as we do the latter class of muscles. The muscular action of the stomach resembles that of other hollow muscles, in being excited by its contents, and, if at all, only occasionally and under peculiar circumstances, by the nervous influence.

Hence, as I have already had occasion to observe, depriving the stomach of the nervous influence has no effect whatever in preventing its propelling the digested part of the food into the first intestine. MM. Leuret and Lassaignec observe, that the only obvious and necessary effect of the operation is to paralyse the sphincter muscle of the cardial orifice of the stomach, an effect of which, in all the experi-

ments I made, I never saw any sign, and which, as far as I know, no other experimentalist has mentioned, for food being found in the œsophagus is no proof whatever of such an effect, and its extreme improbability, while we have undeniable evidence that the other muscular powers of the stomach are entire, is apparent.

The mechanical irritation employed by MM. Breschet and Milne Edwards, in endeavouring to excite the digestive process after a portion of the eighth pair of nerves had been removed, was that of a thread attached to the cut extremities of the lower portions of the eighth pair of nerves and fastened to the neighbouring muscles, by which the motions of respiration kept the part in a state of constant irritation.

In the third edition of my Inquiry into the Laws of the Vital Functions, a similar experiment is related, in which the cut extremity of the lower portions of the nerves was fastened to a thread tied round the neck of the animal, by which it was in like manner kept in a state of constant mechanical irritation; yet in the stomachs of the animals after they had lived more than twenty hours,—for the experiment was made more than once,—nothing but undigested food

was found. This experiment, with some others connected with it, was made publicly in the rooms of the Royal Institution; and all who felt an interest in the subject admitted to see the results, nor was there one who expressed a doubt respecting them.

As, however, in these experiments the position of the nerves was more disturbed, and the thread was not applied as in the experiments performed at Paris, Mr. Cutler, at my request, was so good as to make the following experiment:—Three rabbits, after a fast of the same duration, were fed in the same way. In two of them a portion of each of the eighth pair of nerves was removed. The third rabbit was left undisturbed. In one of those in which the portions of nerve were removed, the cut end of the lower part of the nerves was by means of a bit of thread fastened to the neighbouring muscles, as in the experiments referred to. This rabbit died in ten hours, at which time the others were killed in the usual way.

Mr. Cutler then took out the stomachs of all of them, slit them open, and laid them on the same plate; and Mr. Brodie was requested to examine and give his opinion respecting their contents, without having been told which was which. He at once pointed out the healthy stomach, the whole contents

of which had undergone the action of the gastric juice. After carefully examining, and with an instrument moving about the contents of the other stomachs, he declared he could discover no difference in them. Both stomachs were chiefly filled with undigested food, the animals not having lived long enough after the operation for the expulsion of some imperfectly digested food that still remained in both.

The foregoing experiments convinced those who witnessed their results, that the irritation caused by the attachment of the cut end of the nerves to the muscles, had no effect whatever in promoting the digestion of the food.

Even were it possible, as in the case of the nerve of a muscle of voluntary motion, mechanically to excite the eighth pair to perform its office after its communication with the brain is wholly intercepted, it is surely impossible that this could go on for many hours, which are necessary for the digestion of the food. A nerve of voluntary motion, if kept in a state of excitement after its separation from the brain or spinal marrow, loses its power in a very short time, at most a few minutes.

The result of the foregoing experiment may be known before the death of the animals. It appears

from what was said in other papers which I had the honour to lay before the Society, and which were published in the Philosophical Transactions, that the effect of the excision of part of the eighth pair of nerves on the lungs, as well as on the stomach, is obviated by galvanism, the animals (the dog and rabbit were those on which the experiments were made) breathing under its influence as freely as in health. It is clear, that if the power of the nerve be restored, its restoration must be as evident in the function of the one organ as the other, the functions of both equally depending on these nerves. In the foregoing experiments both the animals, in whom part of the nerves had been removed, were affected with extreme dyspnœa, the mechanical irritation of the nerves having no more effect in relieving this symptom, than in promoting the due action of the stomach.

Since, as far as I know, no reply to the foregoing paper has in the lapse of more than four years been made, I infer that the gentlemen in question admit the accuracy of its conclusions.

IV. *On the Sources and Nature of the Powers of Circulation. From the Philosophical Transactions for* 1831.

It is remarkable that, notwithstanding the great importance of the circulation in the animal economy, the length of time which has elapsed since its discovery, and the constant attention it has obtained, there is hardly any department of physiology respecting which there appears to be greater uncertainty and contrariety of opinion than the sources and the nature of the powers on which this function depends. I propose in the following paper, by comparing the principal facts on the subject, and by such additional experiments as seem still to be required, to endeavour to determine these points. Much has lately been written and many experiments have been made with this view, and it has become

customary to look for the causes which support the circulation to other sources in combination with the powers of the heart and blood-vessels.

It has been supposed that what has been called the resilience of the lungs, that is, their tendency to collapse, by relieving the external surface of the heart from some part of the pressure of the atmosphere, is a principal means of causing it to be distended with blood, the whole weight of the atmosphere acting on its internal surface through the medium of the blood which is thus propelled from the veins into its cavities; and in this way it has by some been supposed that the motion of the blood through the whole of the venous part of the circulation is maintained. A similar effect has been ascribed to the act of inspiration, which it is evident must operate on the same principle; and this opinion has even been sanctioned by the Report of a Committee of the Royal Academy of Sciences of Paris*, and in this country by men whose authority is deservedly high; and the effect of these causes, it is asserted, is increased by the elastic power of the heart itself.

* Report on Sir David Barry's paper, by Baron Cuvier and Professor Dumeril.

However successfully such opinions might be combated by reasoning on the data we already possess, as direct experiment is the most simple as well as decisive way of determining the question, as reasoning on physiological subjects has so often deceived, and the experiments may here be made on the newly dead animal, and consequently without suffering of any kind, I have thought it better that the point should be determined in this way, especially as it is by experiments, which at first view seem to countenance the foregoing opinions, that their supporters attempt to establish them, with the effect, as it appears to me, of withdrawing the attention from the powers on which the circulation actually depends, and introducing considerable confusion respecting a question so immediately connected with the phenomena and treatment of disease.

With a view, therefore, to submit the foregoing opinions to this test, the following experiments were made, in which Mr. Cutler was so good as to assist me.

Exp. 1.—A rabbit was killed in the usual way for the table by a blow on the occiput, and the chest opened on both sides so as freely to admit the air. The lungs were then inflated eight or ten times

in the minute by means of a pipe introduced into the trachea; the circulation was found to be vigorous. On laying bare one of the femoral arteries, it was observed to pulsate strongly; and on wounding it, the blood, of a florid colour, indicating that its colour had undergone the proper change in its circulation through the lungs, gushed out with great force; and on introducing the hand into the thorax, the heart was found to be alternately distended and contracted as in the healthy circulation.

Exp. 2.—All the vessels attached to the heart in the newly dead rabbit being divided, and the heart removed, it was allowed to empty itself. Its contractions continued to recur, and in their intervals it assumed a perfectly flat shape, proving that the elasticity of the heart in this animal is so small that it cannot even maintain the least cavity after the blood is discharged,

It appears from these experiments that the circulation was vigorous when none of the causes to which the motion of the blood in the veins have been ascribed existed. In the first experiment the chest being freely opened on both sides, so that the play of the lungs on inflating them could be seen, all effect on the heart as far as related to the motion

of the blood in the veins either of the resilience of the lungs or the act of inspiration, was evidently prevented; and in the second, it was proved that no sensible elasticity of the heart existed; yet while artificial respiration was performed we could perceive no abatement in the vigour of the circulation.

It is to be observed, that all the foregoing causes can act only in one way in promoting the circulation, namely, by giving to the heart the power of suction; that is, by producing a tendency to vacuum in its cavities, in consequence of which the pressure of the atmosphere propels the blood from the veins into them, that of the arteries being prevented from returning to the heart by the valves at their origins. But all, as far as I know, who have either made experiments with a view to prove the supposed effect of these causes on the circulation, or who have sanctioned the inferences from such experiments, have overlooked the circumstance that the veins being tubes of so pliable a nature that when empty they collapse by their own weight, whatever may be said of the effect of such causes in favouring a horizontal or descending motion of the blood, it is impossible that an ascending motion could be produced in them on the principle of suction. As far as the heart may possess

any such power, its tendency must be to cause the vessel to collapse, not to raise the fluid it contains.

That the resilience of the lungs, as far as they possess this property, and the act of inspiration, tend to dilate the heart and large vessels within the chest, is evident; but the former is very trifling, if it exist at all, except as far as it depends on the mere weight of the lungs; and the latter in common breathing is little more efficient, although the effect of respiration on the brain, when any part of the cranium is removed, sufficiently attests that it has a certain effect. When the breathing is so laborious as essentially to influence the circulation, it evidently tends to derange the regular flow of the blood towards the heart, inspiration of course acting interruptedly; whereas it is only necessary to inspect the chest of any of the more perfect animals immediately after death, and while artificial respiration is being performed, provided death has not been caused by great loss of blood, or an extreme and instantaneous impression on the nervous system, to see that the blood flows uniformly towards the heart, with no interruption but that which the contractions of the heart itself occasion.

The elasticity of the heart is greater in some animals than in the rabbit; but it is in all cases

very inconsiderable. The heart of the tortoise is the most elastic I have examined; yet even it, when the blood is no longer propelled into it, for the alternate contractions and relaxations of the heart continue after it is separated from the body, may be compressed, during the intervals of its contractions, by a force not sensibly greater than is sufficient to compress other muscles in a state of relaxation. Besides, the auricles possess little or no elasticity; and whatever the elasticity of the ventricles may be, it can have no effect on the blood in the veins, because they receive their blood from the auricles which are contracting during the dilatation of the ventricles. To these statements it may be added, that in many of the inferior animals the foregoing supposed causes of the venous part of the circulation evidently have no existence, and that, with the exception of the elasticity of the heart, they have no existence in the fœtal state in any.

We have just seen, from direct experiment, that, in the perfect animal, the circulation of the blood goes on as usual when none of these causes can operate.

I shall now take a rapid view of the facts which, as far as I am capable of judging, leave no room for

doubt respecting the sources of the power on which this function depends.

It is so evident to those in the least acquainted with the animal economy that the contractile power of the heart is one of the chief of these sources, that it would be superfluous to enumerate the proofs of it; yet, such is the love of singularity, that even this position has been denied. The opposite error, however, is the more common; and not a few have ascribed, and even still do ascribe, the motion of the blood throughout the whole course of circulation to the contractile power of the heart alone, although it would not be difficult to prove that to drive the blood through one set of capillary vessels, and still more through two or three sets of such vessels,—for in man himself, in one important part of the circulation, it is carried through two, and in some animals through three, sets of capillaries before it returns to the heart,—I say it would not be difficult to prove that to drive it through one set of capillaries, at the rate at which the blood is known to move, would require a force capable of bursting any of the vessels. But here, as in the former instance, it is better to appeal to the evidence of direct facts than to any train of reasoning; and there is no want of such

facts to determine the point before us, some of which I formerly had the honour to lay before the Society, and others are stated in my Treatise on the Vital Functions. The most decisive is, that the motion of the blood in the capillaries continues long after the heart has ceased to beat, and the animal in the common acceptation of the term is dead, and even in the warm-blooded animal, if it be favourably circumstanced, for several hours, and it is not for some time sensibly affected by the heart ceasing to beat; nor does this arise from some imperceptible impulse still given by the heart, because when all the vessels attached to this organ are secured by a ligature and the heart cut out, the result is the same*.

That the circulation in the capillary vessels is independent of the heart, may be shown by various other means. On viewing the motion of the blood in them, with the assistance of the microscope, it may generally be observed that it is moving with different degrees of velocity in the different vessels of the part we are viewing, frequently more than twice as rapidly in some than in others. Were the motion derived

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* Experimental Inquiry, Experiments 66 and 67. Third Edition.

from a common source, this could not be the case. It is impossible, in the motion of the blood in the capillaries, in the least degree to perceive the impulse given by the beating of the heart, which causes the blood in the arteries to move more or less per saltum, the motion of the blood in the former being uniform as long as they retain their vigour, and the necessary supply of blood is afforded from the larger vessels. I have found by experiments very frequently repeated*, that the motion of the blood may be accelerated or retarded in the capillaries by stimulants or sedatives, acting not through the medium of the heart, but on these vessels themselves. Nay, so little effect has the action of the heart on the motion of the blood in the capillaries, that when the power of the capillaries of a part is suddenly destroyed by the direct application of opium to them, the motion of the blood in them instantly ceases, although the vigour of the heart and that of every other part of the sanguiferous system be entire†.

If the circulation in the capillaries be thus inde-

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* Experimental Inquiry, Part III. Chap. II., and the Introduction to the second part of my Treatise on Febrile Diseases. Fourth Edition.

† Ibid.

pendent of the heart, it is evident that the influence of that organ cannot extend to the veins. On comparing the whole of the foregoing circumstances, is it not a necessary inference that the motion of the blood in the veins, like that in the capillaries, depends on the power of these vessels themselves? But that we may not trust to any train of reasoning, where it is possible to have recourse to direct proof, I made the following experiment, with the assistance of Mr. Cutler.

Exp. 3.—In the newly dead rabbit, in which the circulation was maintained by artificial respiration, the jugular vein was laid bare for about an inch and a half; a ligature was then passed behind the part of the vessel nearest to the head, and the animal was so placed that the vein was brought into the perpendicular position, the head of the animal being undermost, so that it was necessary for the vein, in conveying the blood to the heart, to convey it perpendicularly against its gravity. The ligature, which was placed at what was now the lowest part of the exposed portion of the vein, was suddenly tightened, while Mr. Cutler and myself observed the vessel. The blood in the part of the vein between the ligature and the heart was instantly and completely expelled,

as the transparency of the vessel enabled us to perceive. The vessel itself wholly collapsed, proving that all its blood had entered the heart, so that to a superficial view there seemed to be no vessel in the part where a large dark-coloured vein had just before appeared. In the mean time, on the other side of the ligature, the vein had become gorged with blood.

In the foregoing experiment we see the blood rising rapidly against its gravity, where all causes external to the vessel on which the venous part of the circulation has been supposed to depend, had ceased to exist, and the vis à tergo was wholly destroyed by the ligature.

By a similar experiment, the power of the arteries in propelling the blood may also be demonstrated.

Exp. 4.—In a newly dead rabbit, the circulation being supported by artificial breathing, the carotid artery was laid bare for about an inch and a half. The animal was so placed as to keep the vessel in the perpendicular position, the head being now uppermost. A ligature was passed behind that part of the vessel which was next the heart, and Mr. Cutler and myself observed the vessel at the moment the ligature was tightened. The artery, of course, did not collapse as the vein had done in the

preceding experiment; but the blood was propelled along the vessel, so that it no longer appeared distended with it. It was at once evident, from the change of appearance in the vessel, that the greater part of the blood had passed on in a direction perpendicularly opposed to its gravity. It is worthy of remark, that the blood of the artery was propelled neither so rapidly nor so completely as that of the vein, the cause of which will be evident in the observations I am about to make on the nature of the function and powers of these vessels.

When the whole of the preceding facts are considered, it will, I think, be admitted that the circulation is performed by the combined power of the heart and blood-vessels themselves, and that no auxiliary power is necessary for its perfect performance. Here, as in other cases, the more we study the operations of nature, the more direct and simple we find them. The resilient power of the lungs and elasticity of the ventricles of the heart, as far as they exist, favour the free entrance of the blood into these cavities, an office adapted to the feebleness of such powers, which, in many animals we have seen, have no existence. Their operation is similar, but probably much inferior, to the elastic power of the

arteries, by which the ingress of the blood suddenly impelled into them by the conraction of the heart, is rendered more free than it would have been had these vessels tended to collapse in the intervals of its contractions. Had the blood flowed into them in a continued stream, and been carried through them by their own powers alone, their elasticity would evidently have impeded, not promoted, the circulation through them. It could only have encumbered the effect of those powers. Thus the veins, in which these conditions obtain, are so pliable that they collapse by their own weight, and hence it was that in the preceding experiments the vein carried on its blood so much more rapidly and completely than the artery, which felt the want of the impulse it receives from the heart, that at once assists in propelling its blood, and through the blood stimulates the vessel itself; while the action of the vein was perfect; because it possessed all its usual powers, which reside in itself alone.

It only remains for us to inquire into the nature of the power by which the heart and blood-vessels maintain the circulation. Respecting the nature of the power of the heart there cannot be two opinions.

It is evidently a muscular power. The structure of its parietes is similar to that of other muscles, and they obey all the usual laws of the muscular fibre.

Is the power of the vessels of the same nature? This is a question which has frequently been discussed. The chief arguments which have been adduced in favour of the affirmative are;—the nature of their function; the fibrous appearance observed in some of the vessels, which is more evident in some other animals than in man; and the minuteness of most of the vessels, which, if they are muscular, accounts for the difficulty with which the muscular structure is detected in them. The chief arguments against the muscularity of the vessels have been, that they could not be made to obey an artificial stimulant in the way that the heart and other muscles are found to do, and that their chemical analysis gives no evidence of fibrin. Of the latter of these objections Dr. Young observes, that a part may be muscular although it does not contain fibrin, and refers in support of this opinion to the crystalline lens. The former of these objections no longer exists, the vessels having been found to obey both stimulants and sedatives as readily as parts more evidently muscular. It appears from many experi-

ments related in my Treatise on the Vital Functions, that the action of the capillary vessels is as easily influenced both by stimulants and sedatives as the heart itself *; and although the larger vessels are not so easily excited artificially as the heart and muscles of voluntary motion, yet several physiologists have succeeded in exciting them both by mechanical and chemical agents. But there is another argument in favour of the muscularity of the vessels, which, I think, may be regarded as no less powerful. I endeavoured, in papers which I had the honour to present to the Society, and which appeared in the Philosophical Transactions for 1815, to ascertain the relation which the heart bears to the nervous system, which is different from that of the muscles of voluntary motion. It appears from the facts there adduced, that this organ is not only like the muscles of voluntary motion, independent of that system, although capable of being influenced through it either by means of stimulants or sedatives, and that even to the instantaneous destruction of its power; but that it equally obeys either set of agents, whether applied to the brain or

* Experimental Inquiry, Part II. Chap. xi. and Part III. Chap. ii.

spinal marrow, and to whatever part of these organs it is applied, provided it be to a part of considerable extent; while the muscles of voluntary motion obey no stimulus acting through the nervous system, unless it be applied to their nerves themselves or to the particular parts of that system from which their nerves originate. I found from repeated experiments that the vessels bear the same relation to the nervous system as the heart does, their power being independent of this system, but equally with the heart capable of being influenced by either stimulants or sedatives applied to any considerable part either of the brain or spinal marrow, and that even to the instantaneous destruction of their power. They in all respects bear the same relation to the nervous system with the heart, the strongest presumption that their power is of the same nature*.

From the various facts stated or referred to in the foregoing paper, the following inferences appear to be unavoidable;—That the circulation is maintained by the combined power of the heart and blood-vessels; and that the power of both is a muscular power.

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* Inquiry into the Laws of the Vital Functions.

V. *On the Relation which subsists between the Nervous and Muscular Systems in the more perfect Animals, and the Nature of the Influence by which it is maintained. From the Philosophical Transactions for* 1833.

In the last paper which I had the honour to present to the Society, and which appeared in the Philosophical Transactions for 1831*, I endeavoured, by comparing the various facts relating to the circulation of the blood, and by such additional experiments as seemed to be required, to free the subject from the confusion in which it had been involved by the various and contradictory experiments and statements of writers, and to ascertain the source and nature of the powers on which the motion of the blood depends.

In the present paper I propose to consider in the same way, another subject of equal importance, intimately connected with the preceding, and which has,

* The preceding paper in this volume.

by the same means, been involved in equal, and, from its more complicated nature, apparently greater perplexity; namely, the relation which subsists between the nervous and muscular systems, and consequently, between the nervous system and organs of circulation; for I think it will be admitted, from the statement of facts made in the paper just referred to, that the power of the vessels, like that of the heart, is a muscular power, and that on the combined power of the heart and vessels, the motion of the blood, in the ordinary states of the circulation, wholly depends. Having considered this part of the subject, I shall endeavour to point out how far we can proceed in ascertaining the nature of the nervous influence, and the means by which the relation between the nervous and muscular systems is maintained.

I need hardly observe that in experimenting on a subject so complicated as the living animal body, much practice as well as caution is necessary in order to guard against erroneous conclusions, and thus obtain for physiology the certainty which can alone entitle it to be regarded as a science. There is none of its branches which has not suffered from the inaccuracy of experimentalists, and, from the complicated nature of the subject, none which has

suffered more in this way than that to which I am about to call the attention of the Society.

Throughout the long inquiry in which I have been engaged, I have always been more anxious to secure any ground I had gained by a careful repetition of the experiments than to proceed to farther attempts. The rules which, as I have already had occasion to observe, I have always followed, and which, if I may presume so far, I would recommend to all engaged in such inquiries, are, to make the experiments in the presence of competent witnesses, and to repeat them as long as any doubt remains on the mind of any individual present. Were these rules strictly observed, physiology would cease to be perplexed by the inaccuracies in which the inexperienced and precipitate are constantly involving it.

But this has not been the only cause of perplexity in the subject of this paper. The evil, both here and in other branches of physiology, has, in a great degree, arisen from writers either having been too apt to enter upon their inquiries and detail their experiments without having made themselves acquainted with the state of our knowledge at the time, and without having sufficiently weighed what had been done by others, even as far as they were acquainted

with it; or, when little had previously been done, having drawn their inferences from too partial a view of facts. Thus, much confusion and contradiction have often been introduced even where the immediate results of their experiments were accurately observed and recorded, and they have been prevented from so directing their labours as to conduce to a gradual and steady accumulation of knowledge.

As the early physiologists present to us the results of their own imaginings, without even pretending to be possessed of any facts which directly support them, the later and more rational inquirers have, from the causes just enumerated, been often betrayed into conclusions equally erroneous: and even in making important additions to our knowledge, they have frequently done what they could to render them useless and sometimes injurious to the cause of science; which inferences, from a partial view of facts, often are, to a greater degree than those which are evidently suppositions, because they assume the semblance of legitimate deductions.

Thus it was that M. Le Gallois taught that the power of the heart is independent of the brain, but derived from the spinal marrow, and that the powers of circulation in every part of the body depend on the

corresponding part of that organ: inferences apparently supported by the facts he adduces, but wholly inconsistent with others which escaped him: and yet, at first view, so much the necessary results of his ingenious experiments, all of which were correct, that the Royal Academy of Sciences at Paris, after they had been repeated in the presence of the celebrated Humboldt and other eminent academicians appointed by the Academy to witness their repetition, adopted all his conclusions, and were for some time followed by the learned of other countries. Many similar instances might be adduced*.

In order that I may distinctly lay before the Society the nature of the first question to be considered in the following paper, it is necessary to observe that it appears from experiments detailed in papers which the Society did me the honour to publish in the Philosophical Transactions for 1815, and since re-

* It was thus that Haller inferred, from finding that the heart cannot, like a muscle of voluntary motion, be excited through its nerves, that this organ cannot be directly influenced by the brain and spinal marrow. The fact on which this inference is founded depends not on the heart being placed beyond the direct influence of the brain and spinal marrow, but on the nature of the ganglionic nerves.

published in my Inquiry into the Laws of the Vital Functions, that the power both of the muscles of voluntary and involuntary motion is independent of the nervous system, yet in both equally capable of being influenced by it, the nervous influence being the constant stimulant in the functions of the former class of muscles, and an occasional stimulant in those of the latter, which in all their usual functions are excited by stimulants peculiar to themselves; but that these classes of muscles are influenced by it in very different ways, each of the muscles of voluntary motion being under the influence of no part of the brain and spinal marrow but the particular part from which its nerves arise; while each of the muscles of involuntary motion is under that of every part of these organs, from the upper surface of the brain and cerebellum to the lowest portion of the spinal marrow.

In subsequent papers, published in the Philosophical Transactions, and in the experimental Inquiry just referred to, I endeavoured to trace the final cause of this arrangement; and found that the functions, with the exception of the circulation, to which the muscles of involuntary motion administer, namely, secretion and the other assimilating processes, require

for their due performance the united influence of every part of the brain and spinal marrow; while the muscles of voluntary motion are concerned in no function but that of giving motion to the different parts of the body to which they are attached, and consequently have no direct influence on the functions of life.

From the whole of the experiments on which is founded the view I have thus been led to take of the functions of the nervous system, and its relation to the different classes of muscles, it would appear that the brain and spinal marrow are the only active parts of that system; the nerves, whether cerebral or ganglionic with their ganglions and plexuses, being only the means of conveying, and, where the organs, the functions of which require the influence of every part of the brain and spinal marrow are concerned, combining the influence of the various parts of these organs.

But as this inference is less direct than the other inferences arrived at in the foregoing publications, and as very different opinions have been maintained both by preceding and subsequent physiologists, it appears necessary to review this part of the subject with more care, particularly as our view of many of

the phenomena, both of health and disease, must be essentially modified by it. This, therefore, is the first question I propose to consider.

The various parts concerned in the functions of the living animal may be divided into active and passive, those in which the power resides, and those which only obey that power, but which are equally essential to the function. Thus, the belly of a muscle is the active; the tendon, the passive part of the organ. In the production and application of the bile, synovia and other fluids prepared for the purposes of the animal economy, the gland is the active, the ducts, as far as the peculiar office of the organ is concerned, the passive part of that organ; and I know of no way of ascertaining which is the active and which the passive part of any organ, but by observing which obeys the other in the function of the part.

It has been pretty generally admitted with respect to what may be called the cerebral part of the nervous system, that is certain parts of the brain and spinal marrow, with the nerves immediately proceeding from them, that the former are the active, the latter the passive parts of these organs; because we find that the power of the nerves is always proportioned to the excitement of the brain

and spinal marrow, as that of the tendon is proportioned to the excitement of the belly of the muscle. Even this position, however, has by some been controverted, and it has been maintained that the nerves themselves in part supply the influence on which their functions depend.

But in whatever manner this part of the question, which it will be necessary to consider more particularly, may be disposed of, there is certainly, from the more complicated structure of the parts, better reason for regarding the ganglionic nerves with their ganglions and plexuses, as active in the formation of nervous influence, than the simple nerve which connects the cerebral mass with the muscle which it excites; and it has consequently been the opinion of many physiologists that the ganglionic system is concerned in the production of this influence, and some have gone so far as to regard it as independent of the brain and spinal marrow, and therefore the only source of the power of its own nerves.

As soon as it was found that the organs supplied with ganglionic nerves obey every part of the brain and spinal marrow, it was necessary to abandon the latter opinion, and we could see a reason for the complicated structure of the ganglionic system, inde-

pendently of its supplying any part of the nervous influence. As each of the vital organs is sensible to the action of every part of the brain and spinal marrow, some apparatus capable of combining the influence of all these parts is evidently necessary, and none apparently could be better fitted for the purpose than that system, which, both by its ganglions and plexuses, and the frequent anastomoses, if I may use that expression, of its nerves, seems even at first view intended to combine the power of the various parts from which it receives nerves; and when those proceeding from the ganglions and plexuses are found by direct experiment to convey the influence of all those parts, and this fact is compared with the preceding positions, the inference that to combine and convey the influence of the various parts of the brain and spinal marrow are the exclusive functions of the ganglions, their plexuses and nerves, appears almost unavoidable.

We here have a proof that the organs supplied by ganglionic nerves obey the influence of all parts of the brain and spinal marrow, and consequently that in the ganglionic nerves is combined and conveyed the influence of all those parts; and it is contrary to what we observe of the simplicity of the operations

of nature that there should be another source of that influence.

In another fact we find an additional objection to such a supposition, for it appears from many experiments related in the papers and Inquiry above referred to, that exactly in proportion as we increase or impair the power of the brain and spinal marrow, the functions of the ganglionic nerves are increased or impaired; still pointing out the brain and spinal marrow as the active, and the nerves with their ganglions and plexuses as the passive parts of the system; and these observations come with the more weight because those who have maintained that the ganglions supply nervous influence, have not even pretended to support their opinion by any facts directly bearing on the point.

If however it also appears from direct experiment that the ganglions and plexuses are capable of influencing the power of the ganglionic nerves, independently of any change induced on the brain and spinal marrow, however improbable the fact may at first sight appear, we must admit that there is in the former organs an additional source of the power possessed by those nerves.

It has been found that the action of the heart is

immediately influenced by agents, whether stimulants or sedatives, affecting any considerable part either of the brain or spinal marrow*. Can its action, in like manner, be affected by agents making their impression on the ganglions and plexuses? For the purpose of determining this point, the following experiment was made, in which Mr. CUTLER, and Mr. FIELD, the well-known veterinary surgeon, were so good as to assist me, Mr. FIELD performing the operative part.

The heart continues to obey the effect of agents, whether stimulants or sedatives, applied to the brain and spinal marrow for a certain time after what we call death, that is, the removal of the sensorial powers†; and this time is much prolonged if the circulation be maintained by inflating the lungs at proper intervals; for in all modes of death, except where the nervous system is so powerfully and suddenly impressed as almost immediately to destroy all the functions, the nervous as well as the muscular functions for a considerable time survive the removal of the sensorial

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* Papers in the Philosophical Transactions for 1815, and Experimental Inquiry into the Laws of the Vital Functions.

† First paper in this volume, and Experimental Inquiry.

powers *; and the newly dead is on several accounts a better subject than the healthy animal for such experiments as the following, although the result is still more satisfactory if the animal can be so prepared as to destroy the sensibility as far as the experiment is concerned, without so completely destroying it as to interrupt respiration †, because it is impossible in several essential respects by artificial respiration to imitate the natural process and consequently to support the circulation and the functions which depend on it so effectually as by that process. I shall have occasion, in the last paper in this volume, to point out the circumstances in which artificial necessarily differs from natural respiration.

Mr. FIELD partially divided the spinal marrow near the head in an ass in such a manner as to destroy the sensibility, as far as the experiment was concerned, but not to interrupt the respiration, thus bringing the animal into the best possible state for

* The first paper in this volume, and Experimental Inquiry.

† It appears from what is said in the publications just referred to, that in the more perfect animals, respiration is as much a function of volition as the motion of a limb, and consequently ceases when the sensibility is wholly destroyed. See the first and sixth papers in this volume.

the experiment. It lay as still and suffered as little during it, as an animal quite dead in the usual sense of the word, while the circulation was more perfect than it could be under any artificial inflation of the lungs. In another respect, the state of the animal was particularly favourable, for he succeeded in exposing the semilunar ganglion and its plexuses with a very trifling loss of blood, not I believe four ounces. The heart was found to pulsate sixteen times in ten seconds, as ascertained by the pulsation of the arteries in the neighbourhood of the ganglion. The ganglion and its plexuses were then irritated by the point of the scalpel, and at length cut across in various directions; but although the beats of the heart were repeatedly counted during these operations, they continued uniformly of the same frequency. Spirit of wine was then applied to the wounded ganglion and plexuses, but without the least change in the beats of the heart. A strong infusion of tobacco in water was now applied, but with the same result, the beatings of the heart being still sixteen in ten seconds; nor could any variation in the force of the beats be observed in any part of the experiment.

It appears from this experiment that we cannot influence the organs supplied by the ganglionic

nerves by causes affecting the ganglions and plexuses, independently of the brain and spinal marrow; and the inferences from this and the preceding facts are unavoidable, that the former organs make only a part of the channel through which the influence of the latter is conveyed, and that the peculiar office of the ganglions and plexuses is to combine the influence of the nerves which terminate and are blended in them, and send off nerves endowed with their combined influence, in consequence of which the parts which receive the nerves proceeding from them, become subject to every part of the brain and spinal marrow.

Such being the case with respect to the ganglions and plexuses, it is not likely that we shall find the nerves themselves, whether ganglionic or cerebral, capable of supplying any part of the influence they convey; but that nothing may be taken for granted, this also is a point which must be determined by an appeal to facts.

It is to be recollected that here, as in other cases, the onus probandi rests with the asserter. This would still be the case, although his position were less improbable than that, while there is an evident and acknowledged source of nervous influence, and that adequate to the production of the phenomena,

another source of it should exist, and that in organs which evidently perform a function of so different a nature. Those who maintain such an opinion must adduce the proofs of it. Let us inquire to what they amount.

While the connexion of the nerves with the brain and spinal marrow exists, the nerves are capable of exciting the muscles both of voluntary and involuntary motion, causing the evolution of caloric which supports animal temperature, forming the secreted fluids from the blood, and supporting the other processes of assimilation by which the structure of the various organs is maintained*; but as soon as this connexion is intercepted, all these functions begin to fail, and soon cease, nor do we possess a single fact to prove that there are any means in the nerve itself of maintaining or renewing any of them. By mechanical impulse the power which remains in a separated nerve of the cerebral class, for even this is not the case with respect to the ganglionic nerves†, may be directed to its extremities and made evident by the

* First paper in this volume, and Experimental Inquiry.

† It is true that the heart has been excited by galvanism through the medium of its nerves, but they may here act merely as conductors.

excitement of the muscle in which it terminates; but independently of such an impulse we have no means of exciting a nerve separated from the brain and spinal marrow, even during the short time it retains the influence it has received from those organs*.

The very circumstance of the nerves being the means of conveying the influence of the brain and spinal marrow affords a presumption that they are not themselves the source of a similar influence. The former is evidently their peculiar function, and it is so improbable that they should perform another of so different a nature, that it would require the most unequivocal proof of such a fact to induce its belief. The power of the nerves is not only, as far as we see, derived from the brain and spinal marrow, and soon ceases and cannot be renewed when they are separated from these organs, but is, as I have already had occasion to observe, at all times proportioned to the degree of excitement in them; nor can an instance be adduced in which a cause of increased nervous power makes its impression on the nerves

* In the living animal a nerve cut off from direct communication with the brain and spinal marrow, but otherwise uninjured, will, as Mr. Brodie has shown, long retain this power, as we should à priori have expected. It retains its healthy structure, and its communications with other nerves.

themselves. For its degree as well as existence, then, the power of the latter seems wholly dependent on the former organs; and this observation applies as strictly to the ganglionic as to the cerebral nerves. The brain and spinal marrow, therefore, possess all the characteristics of the active, the nerves of the passive parts of the system.

It may appear at first sight that the phenomena of what has been termed the sympathy of nerves oppose the preceding views. On a careful review of these phenomena, however, they will be found to afford them additional support. They are all such as depend on changes in the central parts of the nervous system, and in no degree on any influence of the nerves on each other in their progress. As I have nothing to add to the statements I have already published on this subject, for the facts on which these positions are founded I beg to refer to the 106th and 107th pages of the third edition of my Inquiry into the Laws of the Vital Functions.

I take this opportunity of directing the reader's attention to a law of sympathy which, as far as I know, has been overlooked, but which has an extensive influence in determining its effects, and consequently the phenomena and progress of disease.

It appears from what is said in the first paper in the present volume, that the functions of the animal body may be divided into two classes, those of the sensitive and those of the vital system. Now, the individual organs do not sympathise equally with the organs of both these sets of functions. Some sympathise most powerfully with those of the sentient and some with those of the vital functions. If we except the brain, whose extensive sympathies are necessary consequences of its functions, the stomach and liver are the organs of most extensive sympathies. Of these organs the former sympathises most with the sentient, the latter with the vital organs. Hence it is that affections of the stomach are more immediately felt in every part of the frame, while those of the liver have a greater influence on the course of disease. The liver being an organ of dull sensation, the share it has in influencing the course of many diseases has often been overlooked, few sensations being referred to the region of this organ, and thus the success of our plans of treatment greatly abridged. I beg to refer the reader to what is said of the sympathies of the liver, and the manner in which the course of various diseases is influenced by them, in my Treatise *on the Influence of minute Doses of Mercury, com-*

bined with the appropriate treatment of various Diseases, and the Principles on which it depends.

An opinion respecting the function of the nerves has been maintained, and lately by a writer of great respectability*, which deserves to be considered, because it claims the support of experiment, and if well founded, must essentially affect our opinion of the nature of the nervous influence.

Dr. HENRY appears to admit the independence of the muscular power, but thinks he has rendered it more than probable that the nervous influence, instead of being only one of many agents, is the only one capable of exciting the muscular fibre; and consequently that all others act through it, so that they are not in fact stimulants to that fibre, but to the nerves alone through which they influence it.

It is true that as mechanical impulse affecting a nerve of voluntary motion is capable, after its separation from the brain and spinal marrow, of exciting, through it, the muscle in which it terminates, and we cannot be assured that we have separated from

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* Dr. WILLIAM CHARLES HENRY's Critical and Experimental Inquiry into the Relations subsisting between Nerve and Muscle, in the 110th Number of the Edinburgh Medical and Surgical Journal.

the muscular fibre the whole of the nerves with which it is so intimately blended; if we were in possession of no other facts on the subject, we should be led to the inference, that the excitability of the muscular fibre can only be influenced through its nerves; but when instead of a mechanical, we employ a chemical agent, we find the result very different. We attempt in vain to influence a muscle through the nerve which terminates in it by the most powerful agent of this description, the operation of which is confined to the nerve itself; yet such an agent, when applied to the muscular fibre, excites it as readily as the mechanical agent, which is supposed only to affect it through the nerve.

Even if the power of the chemical agent be gradually increased until the structure of the part of the nerve to which it is applied is destroyed, not only the muscle in which it terminates, but even the other parts of the nerve itself, remain wholly unaffected. The nerve has not even the power of communicating the change to its adjoining parts. This was shown by the experiments of FONTANA, and confirmed by those of Dr. HENRY related in the paper just referred to.

What reason then have we for supposing, when a

chemical agent applied to the muscular fibre excites it, that it operates through the nerves which still adhere to it. Such an inference implies that nerves in their progress wholly change their nature, a supposition for which there is not only not a shadow of proof, but against which the most convincing proofs, which analogy can supply, present themselves. Besides, it appears from many of the experiments, the detail of which I have had the honour to lay before the Society, that muscles remain for many hours obedient both to mechanical and chemical stimulants after all the acknowledged functions of the nervous influence have ceased in the organs to which they belong.

Dr. HENRY indeed adduces in favour of the opinion of agents affecting the muscles only through the intervention of the nerves, a fact which is well ascertained, and which I amongst others have frequently witnessed, that the excitability of distant muscles may be impaired by chemical agents applied to the sentient extremities of the nerves; but here the brain and spinal marrow intervene between the nerves to which the agent is applied and the muscles influenced. The effect of the agent is communicated through the nerves to these organs, and the debility

of the muscles is the effect of the morbid impression made on them.

For the same reason a similar effect is produced on the muscles by what surgeons call concussion of the brain. A strong solution of opium or tobacco thrown into the cavity of the abdomen, or suddenly applied to any other extensive and highly sensible surface, has, more or less, the same effect on distant muscles as a blow on the head. It affects them in consequence of the brain and spinal marrow being influenced, and probably, where the cause is most powerful, even to the derangement of their finer mechanism, by the impression made on the sentient extremities of the nerves; so that we have here only an instance of a well-known fact, that certain affections of the brain and spinal marrow are capable of impairing the excitability of the muscles through the medium of the nerves, the only medium of course through which they can operate*.

How can we suppose, it has been said in support of the same opinion, that a muscle covered by a membrane of condensed cellular substance, or in other instances by the more complicated serous or

* Philosophical Transactions for 1815, and Experimental Inquiry.

mucous membrane, should be affected by a chemical agent applied to the opposite surface of such membranes, if not through the medium of its nerves?

If the agent does not pass through the membrane, and is thus immediately applied to the fibres of the muscle, by what other means can the effect be produced? We have just seen that the nerves are incapable of communicating the impression except where the brain and spinal marrow intervene, and then the effect is general, not local. Besides, those who adopt this explanation forget that in many instances at least, I believe in all, the agent, independently of transudation through membranes, is as little in contact with the nerves as with the muscular fibres. The cuticle possesses neither nerves nor vessels, yet, through it, chemical agents influence the muscles; and are not such agents actually received through the cuticle and conveyed into the mass of blood?

It seems to be a general law of the animal system, that all membranes are pervaded by certain chemical agents. The air comes not in contact with the blood unless it be through the membranes of the lungs; yet who doubts that the changes effected in this organ are the consequence of transmission of an agent to or from the blood?

When a more stimulating blood produces a more powerful action of the heart and blood-vessels, can it arise from any other cause than the transmission of the more stimulating agent through the fine membrane which lines these cavities? Without such transmission it is no more in immediate contact with the nerves than with the muscular fibres; and if it were, we know that the impression it makes could not be conveyed through them. The membrane which lines the internal is more delicate than that which lines the external surface of the hollow muscles, and, as we might à priori expect, the agent pervades the former more readily than the latter. Hence it seems to be that a strong solution of opium thrown into the cavities of the heart, intestines, &c., immediately destroys their power; while applied to their external surface it makes no, or comparatively little, impression on it, the final cause of which it is not difficult to perceive. It is necessary that the muscular fibres of those cavities should be exposed to the stimulus of their contents, but their external surface only requires to be supported by the firmness of its membranes.

Must not the chemical agents which influence the nose, the mouth, the fauces, the bowels, the

bladder, &c., pervade the fine membranes which line them before they can act either on their nerves or vessels?

It would appear that there are but two modes of impairing the excitability of the muscles independently of the immediate application of the agent to the muscular fibre itself; the one I have just had occasion to mention, the effect of powerful agents on the brain and spinal marrow, through them affecting the muscles; the other, the excessive excitement of their own function, too powerful and long-continued contractions.

The poisons which impair their excitability affect them only in one or both of these ways, except as far as they act by their immediate application to them. Opium, which was employed by Dr. HENRY in the experiments just referred to, acts in all the three ways. But the exhaustion produced in the muscles of voluntary motion when an animal is killed by opium, although in part arising directly from its effects on the brain and spinal marrow, particularly when it has been suddenly applied to a very sensible and extensive surface, is, under other circumstances, chiefly the consequence of the violent spasms excited in them.

The spasms produced by an over-dose of opium always assume the form of opisthotonos, but they are still more subject to remissions than in the disease properly so called; and, as in that disease, they are, during the remissions, often readily renewed by the slightest causes*. Even the touch of the finger, although the sensibility, as far as feeling is concerned, is wholly destroyed, is sufficient for this purpose; so that in making the experiment the spasms may be rendered more or less frequent according to the circumstances in which the animal is placed. On examining the state of the muscles of voluntary motion after death, as I have repeatedly done, in animals killed by opium, one being left undisturbed, while in another a constant succession of spasms had been maintained, their excitability in the former I have found little, in the latter greatly impaired. All will admit that the general spasms here arise from the state induced on the brain and spinal marrow by the opium, and not from any particular change in the nerves; any cause exciting by its action on the former organs, or in any other way,

* See the account of the Experiments relating to the modus operandi of opium and tobacco, in my Treatise on Febrile Diseases.

the same contractions, would, we know, produce the same exhaustion.

On reviewing all that has been said, it appears that we have no reason to suppose that the nervous influence excites the muscles on any other principle than that on which all other stimulants operate, which it also resembles in the circumstance of its sudden and excessive application acting as a sedative. I have been at much pains, in the last edition of my Inquiry into the Laws of the Vital Functions, to point out that all agents capable of influencing either the nervous or muscular system, and whether they make their first impression on the mind or body, act either as stimulant or sedative according to the degree in which they are applied, the stimulant effect always arising from the less, the sedative from the greater application of them, and different agents being better fitted to produce the one or other of these effects.

Thus with respect to the nervous influence, the more powerful, within certain limits, the action of the agent on the brain and spinal marrow, the greater is the stimulant effect on both classes of muscles; but if it be extreme, as when a severe blow is inflicted on the head, instead of exciting the muscles, it

directly impairs their power; in the same way that they are more or less, according to its degree excited by a moderate application of electricity; but deprived of all power by its excessive application.

The reader will perceive, from what is said in the last paper in this volume, how extensively this law operates in the phenomena of disease, and particularly its influence in producing, in a large proportion of cases, the more immediate cause of death; and from what is said in my Treatise on the Effects of Minute doses of Mercury, how much the beneficial effects of this and other powerful medicines depend on keeping it in view. It appears, from what is said in that Treatise, that it is to the circumstance of increasing the dose of mercury beyond the limits, within which it acts as a stimulant, that all its bad effects are to be ascribed. Within these limits it increases instead of impairing the powers of the system, to which, and the circumstance of our being thus enabled to repeat the dose at short intervals, the effects of this mode of employing it, in gradually recalling the vigour of the debilitated organs, are to be ascribed.

THE observations just made on the modus operandi

of the nervous influence, are strikingly illustrated by the facts which have been ascertained respecting the nature of this power.

As it has been found to perform its functions in the animal economy after it has been made to pass through a space not less than a quarter of an inch between the divided ends of a nerve, we must suppose either that, like magnetism or gravitation, it is capable of extending to a distance from the body to which it belongs, or of passing through other conductors than the nerves. Were the former opinion correct, the influence of a nerve would extend in all directions, which we know not to be the fact; nor would the presence of the nerve be necessary to its functions, which we uniformly find to be the case. The conclusion then from the foregoing fact is unavoidable, that the nervous influence is capable of its functions after having passed through, and consequently existed in, other conductors than the nerves. It is therefore not peculiar to the nervous system, but capable of existing elsewhere, and consequently is not to be regarded as, strictly speaking, one of the vital powers of the animal body, but as an agent employed by them. On the other hand, we find that voltaic electricity, applied under the same circum-

stances, is capable of all its functions, of exciting the muscles, of causing an evolution of caloric from arterial blood, of forming from the blood the various secreted fluids, and maintaining all the other processes of assimilation on which the healthy structure of every part depends*.

A vital power has no existence except in the particular mechanism to which it belongs, and its functions are of a nature which admits of the substitution of no other power. The muscular power has no existence but in the muscular fibre. The peculiar powers of the brain and spinal marrow are inseparable from these organs; and for none of these powers can any other power be substituted.

The nervous influence is therefore an inanimate agent, if this expression may be used; that is, one capable of existing in inanimate nature, and, consequently, independently of the mechanism to which in the animal economy it belongs, and the functions of which can be performed by an agent which we

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* Philosophical Transactions for 1817, 1822, 1827, and 1829; and Experimental Inquiry: see also the paper on the Nature of Death, in which I found it necessary to enter more minutely than in the present paper, into the mutual dependence of the vital functions, and the nature of the stimulants which maintain them.

know to be of this description; and, as appears from what has been said, the action of this influence on the muscles obeys the same laws as that of other inanimate agents capable of exciting them.

The results of the experiments, on which the foregoing positions rest, are stated in papers which the Society did me the honour to publish in the Philosophical Transactions just referred to, and detailed more at length in the third edition of my Inquiry into the Laws of the Vital Functions. These experiments, I have already had occasion to observe, were publicly repeated, with the same results, at the Royal Institution, in the presence of many of the first physiologists of this country, Sir HUMPHRY DAVY, Mr. ANDREW KNIGHT, Mr. BRODIE, &c.*, and also on a larger scale, a great variety of animals being employed, by M. BRESCHET and other physiologists at Paris †.

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* Journal of the Royal Institution, Vols. XI. and XII.

† Recherches Expérimentales sur les Fonctions du Système Nerveux. 1er Mémoire; "De l'Influence du Système Nerveux sur la Digestion Stomachale," par M. BRESCHET, D.M.P., Chef des Travaux Anatomiques de la Faculté de Médecine de Paris, etc. H. MILNE EDWARDS, D.M.P., et VAVASSEUR, D.M.P. ("Mémoire lu à la Société Philomatique le 2 Août, 1823"), "Extrait des Archives Générales de Médecine, Août, 1823."

When the nature of the preceding positions,—for it will be admitted that the manner in which they have been ascertained precludes any doubt of their accuracy,—and the necessary inferences from them are carefully considered, it will be found difficult to deny that the nervous influence and voltaic electricity are powers of the same nature, although I have not been able to succeed in causing the former to affect the galvanometer*. It is found in like manner that the electricity of electric animals is incapable of affecting the electrometer†.

As the nervous influence is capable of existing independently of the organs in which it operates in the living animal, and therefore is not a power peculiar to these organs, it must either be a power sui generis, yet capable of existing in textures of the most

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* The galvanometer I employed was a chemical one; I have not had an opportunity of repeating the experiment with any other.

† A paper entitled, "An account of some Experiments and Observations on the Torpedo (*Raia Torpedo*, Linn.) by John Davy, M.D., F.R.S., Assistant Inspector of Army Hospitals," in the Philosophical Transactions for 1832. In page 262, Dr. Davy observes, "In accordance with Mr. Walsh and my brother, I have in no instance seen the torpedo affect the common electrometer, or exhibit any the slightest indications of a power of attraction and repulsion in air."

dissimilar description, or one of those powers employed by nature in her other operations. All will admit that the latter supposition is the most probable. The better we understand the operations of nature the more simple we find them. We see an endless variety of results from modifications of the same principle. Whether the most probable opinion is here the correct one, can only be ascertained by determining whether any one of the powers which operate in the production of other phenomena is capable of all the functions of the nervous influence. When it is found that such a power exists, all doubt must necessarily cease.

I have, as far as I know, in the preceding paper laid before the Society, or referred to, all the circumstances which ought to influence our judgment respecting the relation which subsists between the nervous and muscular systems of the more perfect animals, and the nature of the influence by which it is maintained; and shall conclude by shortly recapitulating the more important results.

It appears from all the facts which have been stated or referred to,—

1. That the power of the muscles both of voluntary and involuntary motion is independent of the nervous

system; but that both are subjected to its influence, this influence being the constant stimulant in the functions of the former, but only an occasional stimulant in those of the latter, which in their ordinary functions are excited by stimulants peculiar to themselves.

2. That to the muscles of voluntary motion it is supplied from those parts of the brain and spinal marrow, from which the nerve of the particular muscle takes its rise; to each of the muscles of involuntary motion, from every part both of the brain and spinal marrow.

3. That the brain and spinal marrow are the only active parts of the nervous system, and that the cerebral and spinal nerves on the one hand, and the ganglionic nerves with their ganglions and plexuses on the other, are only the channels through which their influence is conveyed, the power of both systems of nerves being at all times proportioned to the excitement of the brain and spinal marrow, and soon ceasing, and not to be renewed when their influence is withdrawn, and being uninfluenced by causes acting, independently of these organs, on either set of the nerves themselves or on the ganglions and plexuses.

4. That the ganglionic system of nerves, and their ganglions and plexuses, are the means of combining the influence of every part of the brain and spinal marrow, and bestowing it on the muscles of involuntary motion, as well as on the various secreting and other assimilating organs; those muscles being subservient to the functions of these organs, which it appears, from direct experiment, require for their due performance, the combined influence of every part of the brain and spinal marrow.

5. That the phenomena of the sympathy of nerves depend on changes effected in the brain and spinal marrow, not on any operation of the nerves themselves; a position which, independently of the more direct facts on which it is founded, is a necessary inference from the preceding positions.

6. That the manner in which the nervous influence affects the muscular fibre is not essentially different from that in which this fibre is affected by other stimulants and sedatives.

7. That this influence is not an agent peculiar to the nervous system, but capable of existing elsewhere, and consequently not a vital power properly so called; which further appears from an agent which operates in inanimate nature being capable of all its functions.

8. That the brain and spinal marrow, therefore, so far from bestowing on the muscular fibre its power, only supply an inanimate agent, which, like all other such agents capable of affecting it, acts on it either as a stimulant or sedative, according to the degree and suddenness of its application*; and,

9. That the whole of the facts relating to this agent, prove it to be a power of the same nature with voltaic electricity, which has been found experimentally to be capable of all its functions †.

We cannot review the phenomena of the animal economy without being struck with the extent and variety of the functions of the nervous influence. We not only find the intercourse between the animal and the external world maintained by it, the heart and vessels subjected to its control, and the maintenance of animal temperature and the secreting and other assimilating processes immediately dependent on it‡,

* See what is said of the laws which regulate the effects of agents on the living animal in the paper *On the nature of Death*.

† See what is said of the nature and effects of this agent in the paper *On the nature of Death*.

‡ So completely are the assimilating functions dependent on the nervous influence, that, as appears from what is said in the second and third papers in this volume, if the eighth pair of nerves be divided in the neck, and one of the divided ends folded back, in order to prevent any passage of nervous influence between

but that by its means the animal body is formed into a whole, every part of it being capable of influencing every other*. Can we be surprised then that it more extensively than any of the other powers of that body influences its morbid states? In two treatises on the various effects of Indigestion and on the prevention of Organic Diseases, I have endeavoured to point out the share it has both in the production and in the extensive and varied effects of these derangements; and how much, therefore, both their prevention and proper treatment depend on correct views of its agency.

From all that has been said, we are unavoidably led to the conclusion that the same principle which

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them, the structure of the lungs is, in from fifteen to twenty hours, so deranged, that in many places not even a vestige of their natural structure remains; and so perfectly does voltaic electricity sent through the lungs as soon as their nerves are divided, and maintained in such power as supports a gentle twitching in the fore legs of the animal, perform the functions of this influence, that the structure of the lungs under its operation is found in all respects as perfect as if their nerves had remained uninjured. Philosophical Transactions for 1822, and Experimental Inquiry.

* In an Appendix to the seventh edition of my Treatise on Indigestion, I have at some length considered that function of the nervous influence by which the animal body is formed into a whole, and the manner in which it so extensively influences the phenomena and treatment of diseases.

operates so extensively in other parts of nature, no less extensively operates in our own frames. It is capable of acting in concert with the vital powers, properly so called, as well as with the other powers of the inanimate world, thus forming the link, if I may be allowed the expression, by which these powers, so dissimilar in their nature, are enabled to co-operate.

I have endeavoured, in the third part of my *Experimental Inquiry into the Laws of the Vital Functions*, to apply the various facts ascertained in that Inquiry, a cursory review of the most important of which has been given in the first paper in this volume, to explain the nature and improve the treatment of diseases.

The additional facts ascertained in the other papers tend farther to promote those ends; and I have, from the whole of the facts which have been laid before the reader, endeavoured, in a Treatise, above referred to, on the Influence of minute Doses of Mercury, to trace the steps by which change of structure is induced by continued causes of irritation; and the manner in which that active medicine and other means of invigorating the nervous and sanguiferous systems tend to obviate their effects.

On the due action of the nervous influence on the blood in the extreme parts of those systems, we have seen the secreting and other assimilating functions, and consequently the structure of every part depends. It is evident, therefore, that all causes interfering with the healthy state or due supply either of that influence or of the fluids on which it operates, must tend to affect the structure of the parts exposed to them.

The brain and spinal marrow, we have seen, are the only active parts of the nervous system. Causes affecting the nervous influence, therefore, must make their impression more or less directly on these organs, and thus while the derangement is confined to that influence, the seat of disease, to whatever part referred, is in them alone. Unless the cause acts directly on them there is no actual disease of the part on which it operates till the vessels partake of the derangement; and therefore it is only in proportion as they partake of it that there is any tendency to derangement of structure.

The first effect, on the vessels, of derangement of the nervous influence is to debilitate those with which it co-operates in the assimilating functions—namely, the capillaries, in consequence of which they allow

themselves to be more or less morbidly distended by the *vis a tergo*, constituting, as appears from experiments above referred to*, a proportional imflammatory state of the part. Thus it is that causes of nervous irritation only dispose to change of structure in proportion as they excite this state, and consequently that the means of prevention consist in whatever tends to obviate it.

In all cases in which such causes induce organic disease, if the part be so situated as to be submitted to examination, more or less of an inflammatory state of it is found to precede change of structure, and, from the nervous system forming the animal body into a whole, to pervade the whole system. The pulse becomes more or less tight, and particularly when the part affected is essential to life or of considerable extent, other symptoms of fever show themselves.

It is owing to the peculiar influence of mercury in exciting the extreme vessels and nerves that it so powerfully co-operates with the other means of allay-

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* Inquiry into the Laws of the Vital Functions. Part III., Chap. II., and the Introduction to the second part of my Treatise on Fevers and Inflammations.

ing the inflammatory tendency in the prevention of organic disease; but it is evident that it is only while it acts as a stimulant to the debilitated nerves and capillaries that it can have this effect. As soon as its sedative effect prevails, it co-operates not with the means of cure, but the cause of the disease; and tends farther to debilitate both the nerves and vessels.

Hence, and from the possibility of repeating the dose so frequently, that the effect of one still remains when the next arrives, and thus more or less of the beneficial effect becomes permanent, the advantage of giving mercury in such doses as are within the range of its stimulant power; and the inefficacy and often the mischief of those doses which exceed this limit, and which, in order to avoid their injurious effects, must be given at such intervals, that the impression made by one dose, being lost before the next is taken, only temporary relief, in the more obstinate cases, is obtained.

THE reader is now prepared to consider those parts of the subject which embrace a view of all the powers of the living animal, and form the proper subject of this volume, the nature of Sleep and Death.

VI. *On the Nature of Sleep. From the Philosophical Transactions for* 1833.

Of all sciences Physiology is most exposed to causes of inaccuracy. The subjects of experiment are here the most complicated, and the phenomena at once the most varied, and bearing the least resemblance to those we are accustomed to contemplate. Hence it is that the groundless theories of our predecessors have been succeeded by the erroneous inferences of modern times, and the student is bewildered by contradictory evidence, until the conclusion is often forced on him, that, with the exception of some of the great outlines which have been established by such evidence as cannot be questioned, the subject is from its nature too perplexed to admit of a clear and satisfactory exposition. It will readily be admitted by those who are accustomed to contemplate the works of nature, that such a result is less

the fault of the subject than the mode of investigating it; for although physiology is not a demonstrative science, it is as open to observation and experiment as any other; but greater caution in our inferences is required, in proportion as the sources of error are more numerous and less easily detected.

If the attempt to free some parts of this science from the confusion in which it has been involved, should expose me to the charge of presumption, because it can only be done by judging the labours of others, I have at least the apology of the necessity of the task, and of not a short life, in a great degree devoted to the subject; for although it is not more than twenty years since I commenced the investigation, the progress of which the Society has done me the honour to report, my experiments on subjects immediately connected with that inquiry were commenced within a couple of years after I had begun the study of medicine, and have, with intervals, been continued ever since.

The two last papers which I had the honour to present to the Society on the circulation of the blood, and on a subject immediately connected with it, the relation which subsists between the nervous and muscular systems, were written with the view here

stated. The present paper is written with the same view, and forms indeed only a continuation of the subjects of these papers. It is evident from the most cursory view of the phenomena of sleep, that their subjects must be imperfect without an inquiry into the nature of a state which so materially influences the relation of the nervous and muscular systems.

There is no question relating to the living animal which involves a more general view of its phenomena than the nature of sleep, and, probably for this reason, none respecting which opinions are more vague and unsatisfactory. I propose to review these various phenomena for the purpose of ascertaining the organs in which its immediate cause exists, the laws on which it depends, and the effects it has on those parts of the system which are not concerned in its production.

We can perceive no final cause of the alternation of watchfulness and sleep, but such as has its origin in the imperfection of our nature. The end of life is enjoyment, and as sleep, if we may not regard it as a positive evil, prevents uniformity in the accomplishment of this end, to say nothing of the occasional inconveniences which attend it, were we as well

acquainted with the principles of the animal, as we are with those of the solar system, we should probably find this defect, in the nature of things, as unavoidable as the recurrence of darkness and a degree of cold which benumbs, and of heat which overpowers our faculties.

We shall never, perhaps, be able to tell why certain organs are capable of constantly maintaining their functions, while others require intervals of repose; but it is not difficult to perceive the necessity of the former part of the arrangement, because the permanent functions are those on which the life of the animal immediately depends, the intervals of repose belonging to those alone which are the means of intercourse with the world that surrounds him, and which, therefore, have no direct tendency to destroy life.

In tracing the relation of the nervous and muscular systems in the last paper I presented to the Society*, I had occasion to recall to their recollection the different relations which the muscles of voluntary and involuntary motion bear to the nervous system, and to point out that the two sets of nerves, which

* The preceding paper.

form the medium of connexion between the active parts of that system, and these classes of muscles, obey different laws; each nerve of the one set conveying the influence of only certain parts of the brain and spinal marrow, each of the other conveying and combining that of the whole of these organs. The former, it is now to be observed, while they are associated, on the one hand, with the organs of sense and the muscles of voluntary motion, are associated, on the other, with those parts of the brain and spinal marrow on which the mental functions depend*: the latter being associated, on the one hand, with all parts of the brain and spinal marrow, and on the other, with the muscles of involuntary motion and the organs on which life depends.

Thus we find in the more perfect animals two systems in a great degree distinct from each other; the former may be termed the sensitive system, that by which they perceive and act, and consequently are connected with the external world; the latter the vital system, that by which their existence is main-

* It has been shown experimentally in my Inquiry into the Laws of the Vital Functions, that the spinal marrow partakes of the sensorial functions. This is very little the case in man, but to a great degree in some animals.

tained. To understand the nature of sleep, we must determine the laws peculiar to each of those systems which have relation to that state, and the manner in which each is capable of influencing the other.

When the reasoning powers are fatigued by continued attention, the feelings by the excitement of the passions, the eye by the exercise of sight, the ear by that of hearing, the muscles of voluntary motion by powerful and repeated contractions, &c., the organs of all these functions cease to be excited. In order again to excite them, either stronger stimulants must be employed, or they must be refreshed by repose, during which, the functions of life still continuing, their due degree of excitability is restored; and they thus again become sensible to the usual stimulants of life.

The operation of this law in the sensitive system may be observed under all degrees of excitement. We can perceive a very sensible effect from slighter degrees of exhaustion than that which produces sleep. After sleep there is a vigour which gradually declines till we sleep again; so that every degree of excitement is followed by its corresponding degree of exhaustion. This law of our frame is so prevalent that physiologists have generally regarded it as

belonging to every part of the system. But any degree of excitement which produces weariness, must, by a certain continuance of it, produce inability. It is evident, therefore, that were the organs of life to obey this law, a total failure of their functions must soon ensue. The sensitive system is restored because its stimulants are withdrawn and the powers of life remain; but if these powers suffer a similar exhaustion, by what means can their restoration be effected, or life itself maintained? This consideration alone might have convinced physiologists that their excitement is regulated by other laws.

It is evident indeed that the circulation continues uninterruptedly; but this has been explained by supposing that the heart and vessels during the intervals of their contractions recover their excitability, the exhaustion of which, during each contraction, has been regarded as the cause of the relaxation which succeeds it.

This theory appeared to apply well to the heart because during the intervals of its contractions the stimulus which excites it is withdrawn; but we find it wholly inapplicable to the vessels from which the stimulant is never withdrawn, and which can support the

motion of the blood, as has been ascertained by many experiments, independently of the heart *. An organ exhausted by the action of any stimulant will never recover its excitability under the operation of the same agent which has exhausted it. The retina will never recover under the same degree of light which has impaired its power, nor the nerve of the ear under the same degree of sound.

A very simple experiment, however, demonstrates that the theory is as erroneous with respect to the heart as the vessels. If in a newly dead animal a ligature be thrown around the arteries attached to the heart so that it continues gorged with blood, its contractions, although ineffectual, still continue to recur with the same regularity as before the ligature was applied. When salt is sprinkled on the muscles of the newly dead animal, the effect is not permanent contraction succeeded by permanent relaxation, but a constant succession of contractions and relaxations, notwithstanding the continued application of the same stimulant, till their power is exhausted.

An experiment, suggested by Dr. WOLLASTON,

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* Experimental Inquiry, Part II.

and with which he used to amuse his friends, strikingly illustrates the interrupted nature of muscular contraction, even where it is as nearly permanent as the nature of the muscle in its healthy state admits of*. If the elbows be made to rest on a table, and the end of a finger of each hand be pressed steadily on that part of the ear which covers the external passage so as to press it down forcibly on the end of that passage, we hear a rapid succession of distinct concussions. This he ascribed to our thus being made sensible of the motion of the blood in the vessels. But did it proceed from this cause, the repetition of the concussions would correspond with the beats of the heart. That it arises from the rapid succession of the contractions of the muscles of the arm by the action of which the end of the finger is pressed against the ear, may be proved by making the experiment in the following manner. Let the arms rest on the table in such a way as to press by their weight on the fingers which stop the ears, care being taken that the stopping of the ears be left to the weight

* We have reason to believe that in spasm the muscle is in a state of permanent contraction, probably the cause of the pain which attends this state.

of the arms, and in no degree produced by the action of the muscles. When we succeed in this attempt, all sense of concussion immediately ceases. It will be found that just in proportion as we succeed in preventing the action of the muscles, the noise abates, and when we perfectly succeed, ceases altogether. The same property of the muscle may be made perceptible to another of our senses. If a bird be allowed to rest on the finger, we perceive by the finger its weight alone. It so balances itself that the continued action of its muscles becomes unnecessary. But if the finger be moved, so that the bird is obliged to cling to it to maintain its place, we perceive a thrill which consists of the same rapid succession of concussions as in the former instance is perceived by the sense of hearing. The larger the bird is, they are of course the more distinct.

It is quite evident from all that has been said, that the state of the muscle is wholly different in the relaxation which intervenes between the contractions, from that which has supervened when the same stimulus can no longer excite it. Now it is not the first but the last of these states which indicates any loss of power in the muscle.

The whole phenomena of the animal body demon-

strate that although it is true that a muscle may be exhausted by powerful and repeated contractions, it is not subject to the law which prevails in the sensitive system, that all degrees of excitement are followed by proportional exhaustion.

Thus it is that the muscles of voluntary motion often suffer exhaustion, because, being under dominion of the will, they are frequently exposed to excitement which is excessive either in its degree or duration, or both. Their exhaustion does not interfere with health, and for their restoration means are provided in the usual functions of the system. But the muscles employed in the vital functions obey a better regulated stimulant, which never, except in disease, produces any degree of excitement that impairs their power. In many diseases, we see the effect of such excitement. If it does not abate soon, and we cannot by artificial means in a short time reduce it, death is always the consequence: and even a short continuance of it produces a degree of debility that so impairs the powers of life as to render their restoration both slow and difficult. Thus it is evident that on the capability of the muscular fibre to be moderately excited, without suffering any degree of exhaustion, life immediately depends.

This property belongs equally to the muscles of voluntary as those of involuntary motion, the exemption of the latter from exhaustion in the healthy state of the system, not arising from any peculiarity in the nature of these muscles, but from the circumstances in which they are placed. In many diseases we find the muscles of voluntary motion in a state of excitement, that is, in a state of constant contraction and relaxation, which constitutes their state of excitement, during all our waking hours, that is, during all the time that those parts of the nervous system with which they are associated are capable of exciting them, without a sense of weariness or any other sign of exhaustion in them. The muscles of respiration which are, in the strictest sense, muscles of voluntary motion*, are in a state of constantly renewed and gentle excitement during life. It is only in asthma and other cases, where their excessive action is required, that they experience any degree of exhaustion.

Thus the muscular fibre in its laws of excitement differs essentially from the other organs with which

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* The first paper in this volume, and Experimental Inquiry, Part II., Cap. XI

it is associated in the sensitive system. It is neither like them in the healthy state capable of uniform excitement, nor in it are all degrees of excitement followed by proportional exhaustion. But in the vital system, although all its other parts are capable of uniform excitement, the muscular fibre is not the only organ in which certain degrees of excitement are unattended by exhaustion. The same is true of the ganglionic nerves and those organs of the brain and spinal marrow from which they derive their power, and which, it appears from direct experiment, are distributed throughout the whole extent of both.

The secreting organs indeed, as well as those of circulation, are less vigorous in sleep than in our waking hours; but this, we shall find, besides that a diminished excitement cannot restore impaired excitability, but must, in proportion to its degree, still add to the exhaustion, is the necessary consequence of causes very different from their partaking of the exhaustion which prevails in the sensitive system. It is in disease alone that they suffer any degree of exhaustion, which in them produces a different species of debility, not an exhaustion analogous to that of the sensitive system; which it is even

a means of preventing by impeding the functions of life, and thus indirectly proving a cause of irritation to this system, in consequence of which, in many diseases, sleep forsakes us.

It appears from all that has been said, that in the sensitive system alone we find organs capable of exhaustion from all degrees of excitement, and the exhaustion of which is consistent with a state of health, namely, the nerves of this system and those parts of the brain and spinal marrow with which they are associated; but it is a necessary inference from the facts stated in the last paper I had the honour to lay before the Society*, that the former of these only obey the latter. To the latter alone therefore we must look for the exhaustion which is the immediate cause of sleep.

The parts of the brain and spinal marrow which are associated with the nerves and muscles of the sensitive system, gradually, from the effect of the usual stimulants of life, suffer such a degree of exhaustion that those stimulants can no longer excite them; and their functions, unless stronger stimulants be applied,

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* The preceding paper *On the Relation of the Nervous and Muscular Systems.*

necessarily cease. Impressions from external objects consequently are no longer perceived, and therefore cannot produce their usual effects either on mind or body. Thus the expenditure of excitability in those parts of the brain and spinal marrow, and consequently in the nerves and muscles whose functions depend on them, being arrested, the vital functions still continuing, such an accumulation of it takes place in all these organs as again renders them sensible to the usual stimulants of life, and the activity of the sensitive system is restored.

On the parts of the brain, and, in some animals, of the spinal marrow, as I have already had occasion to observe, which are associated with the nerves and muscles of the sensitive system, the mental functions depend. Hence the phenomena of dreaming, on which I shall make a few observations, immediately connected with the other parts of this paper, after considering the manner in which the vital, is influenced by the state of the sensitive, system in sleep.

We are now to consider the effects of sleep on those organs which have no share in its production.

One of the most important circumstances relating to the state of the sensitive system in sleep is that its

exhaustion is never so complete as, under all circumstances, to prevent its excitement. On this alone it depends, we shall find, that sleep has no fatal tendency. The degree of sensibility which remains in sleep is the distinguishing mark between it and the torpor of disease. That sleep alone is healthy from which we are easily roused. If our fatigue has been such as to render it more profound, it partakes of disease, that is, as will appear more clearly from what I shall have occasion to say of the different species of apoplexy, the vital system partakes of the debility, or some cause is operating which prevents the restoration of the sensitive system.

Distinct as the vital and sensitive systems are, we know that neither can long survive the other. In a paper which appeared in the Philosophical Transtions for 1829*, I stated or referred to the facts which prove that in all modes of death, except the most sudden, arising from causes which so impress the nervous system as almost instantly to destroy all the functions, those of the sensitive cease several hours before those of the vital system. The animal only dies when his means of enjoyment and inter-

* The first paper in this volume.

course with the world which surrounds him, no longer exist. This consequence is constant and never long delayed. It is necessary therefore to a clear view of the state of the functions of the animal body in sleep, to determine the bonds of union between the sensitive and vital systems, at first view so distinct, which render their existence, except for a very limited time, inseparable.

That the sensitive cannot exist independently of the vital system, is evident, on the slightest consideration; but the dependence of the latter on the former is much less so. The facts stated in the paper just referred to, prove that in the more perfect animals, the function of respiration, being the only vital function which requires the co-operation of the sensitive system, is here the bond of union. It appears from those facts that the muscles of respiration are, in the strictest sense, muscles of voluntary motion, the excitement of which consequently depends on the powers of that system. When the power of sensation wholly ceases, we cease to breathe.*

So confused have been the ideas of physiologists

* See what is said of respiration in the first paper in this volume, *On the Functions of the Nervous System*, page 25, et seq. Also in the last paper, *On the Nature of Death*.

on this part of the subject, that to account for the continued action of the muscles of respiration and their intimate connexion with the vital sytem, they have supposed a third class of muscles partaking of the nature of both the others, those of voluntary and involuntary motion, to which it has been alleged the muscles of respiration belong. If this be the case, these muscles must change their nature every instant, because they are the same muscles which are employed in a thousand other acts universally acknowledged to be mere acts of volition; and, on the other hand, when powerful causes impede the breathing, all the muscles of the trunk are employed in this function. Besides, the facts which have been laid before the Society prove not only that there is no such class of muscles as that here supposed, but that the laws of excitability are the same in all muscles, the difference between the muscles of voluntary and involuntary motion depending wholly on the nature of their functions and the circumstances in which they are placed. The nervous influence, although equally capable of influencing both, is supplied to them in different ways and for different purposes, the usual functions of the muscles of voluntary wholly, of

involuntary motion in no degree, depending on that system. The action of the muscles of respiration continues during sleep, because the exhaustion of the sensitive system is not complete, and the cause which influences this system in their excitement, continues in our sleeping as well as waking hours; and the same is true of all other muscles of voluntary motion, as far as the causes which induce us to excite them are applied. In the soundest sleep we move our limbs if their posture be rendered uneasy. Are we not obliged to guard against these causes in sleep, else the motions they would excite would quickly rouse us. Those of respiration are too gentle to produce this effect.

The only change which takes place in the action of the muscles of respiration during sleep is, that in proportion as the sensibility is impaired they are necessarily excited less readily, and the act of respiration is thus rendered less frequent, a more powerful application of the cause being required; the consequence of which is, that when they are excited, the air is drawn in with greater force; hence, and from the relaxation which is apt to take place during sleep in the parts about the fauces, particularly in

those advanced in life and those of relaxed habits, the cause of snoring*. Thus we generally observe that the snoring is the louder the slower the breathing, that is, the relaxation of the fauces being the same, the more profound the sleep. The loudest snoring I ever heard, so loud as to startle the attendants, was in the last ten minutes of the life of a person who died of a disease of the brain impairing the sensibility, and who only breathed three or four times during that space.

The other changes observed in the vital system in sleep are evidently the consequence of the diminished frequency of respiration. This necessarily produces a proportional diminution in the frequency of the pulse; the properties of the blood being less frequently renovated in the lungs, it less readily excites the heart and vessels, and the diminished force of circulation is as necessarily attended with a diminished formation of the secreted fluids. The state

* Such facts are adduced in the first of the papers just referred to as I believe will be admitted to prove that respiration is at all times an act of volition, excited by the sensation caused by the want of fresh air in the lungs; and the more the sensibility is impaired, the want must be allowed to become the greater, in order to excite the effort which relieves it.

of the vital organs, in its turn, influences the sensitive system, and thus the sleep is rendered more profound. While health continues, however, no change takes place in the vital powers to prevent the perfect restoration of those functions by which the animal is again fitted for intercourse with the external world, for, as appears from what has been said, these powers are never impaired in sleep, but only less readily excited.

The foregoing positions are well illustrated by the symptoms of apoplexy, in which a cause exists that prevents the restoration of the sensitive system, and which consequently point out to us in a more striking manner the influence of the sensitive on the vital system. Here we find that in proportion as the sensibility fails, the respiration, and with it the pulse, continue to become slower; and when it has failed altogether, so that no cause of irritation can excite any sensation, the respiration ceases, and the loss of circulation soon follows. In this way the patient dies in the most unmixed cases of sanguineous apoplexy, where the cause of derangement is a gradually increasing pressure on the brain, in consequence of which its sensibility is at length extinguished. Here there is no original disease of the

vital organs. Could the sensibility be sufficiently maintained to preserve a due frequency of respiration, and nourishment from time to time be introduced into the stomach, life would go on as in sleep, unless the increasing affection of the brain, extending from the sensitive to the vital parts of that organ, so deranged the assimilating processes as to destroy life in this way. In all ordinary cases of sanguineous apoplexy this more or less takes place. The diseased state of the sensitive spreads more or less to the vital parts of the brain and spinal marrow, for it is rare for the cause, as in the case above referred to, to continue to the last wholly confined to the sensitive system, so that the immediate cause of death is merely the ceasing of respiration in consequence of a total loss of sensibility.

The accumulation of phlegm in the lungs in apoplexy arises from the assimilating processes being deranged by the failure of nervous influence, in consequence of the vital parts of the brain partaking of the cause of the disease. I shall have occasion, in the next paper, to recur to, and farther illustrate this part of the subject. I have repeatedly, in sanguineous apoplexy, removed the accumulation of phlegm, the breathing becoming as free as in health, by causing

voltaic electricity to pass through the lungs in the direction of their nerves. This, it is evident, can have no direct tendency to remove the disease, although by its means life may often be prolonged, and thus more time afforded for the application of the means of cure, this accumulation of phlegm greatly impeding the due change of the blood in the lungs, and thus conspiring with the diminished frequency of respiration to deprive it of its vital properties*.

A short comparison of apoplexy from compression, with that which is with great propriety termed nervous, will throw additional light on this part of the subject.

It is shown by experiments detailed in papers which appeared in the Philosophical Transactions for 1815, that although the power of the heart and vessels is independent of the brain and spinal marrow, causes operating on these organs are capable of influencing them, and that even to the total destruction of their power. When, therefore, the cause of apoplexy, instead of being a gradually increasing pressure of the brain,—which I have found by expe-

* Experimental Inquiry, third edition, Part III. On the Application of the Experiments to explain the Nature and improve the Treatment of Diseases, Chap. I.

riment, however powerful it may be, has no direct influence on the action of the heart*,—is of such a nature as, while it impairs the sensibility, also directly impairs the power of the heart and blood-vessels, we have a disease of a very different nature from apoplexy from mere compression. In the latter, if we can remove the cause of pressure and prevent its recurrence, we invariably cure the disease. There is no other cause of derangement. The vital functions are only impeded by the want of the due change of the blood in the lungs, in consequence of a less frequent respiration, and as far as the cause of the disease spreads to the vital parts of the brain, which it never here does in such a manner as directly to influence the heart and blood vessels†, the deranged state of the assimilating functions. Death in sanguineous apoplexy is necessarily slow, because it always requires some time for the gradually increasing pressure either to destroy the sensibility, and consequently wholly stop respiration, or so derange the assimilating processes, as in this way to prove

* Experimental Inquiry, third edition, Part III. On the Application of the Experiments to explain the Nature and improve the Treatment of Diseases, Chap. 1.

† See my papers in the Philosophical Transactions for 1815.

fatal, for, from some peculiarity in the cause, the effect of which more readily than usual spreads to the vital parts of the brain, death, in apoplexy from compression, sometimes appears rather to arise from this derangement than the loss of sensibility, the phlegm gradually accumulating in the lungs till it wholly prevents the necessary change of the blood effected in them.*

But when the cause, which impairs the sensibility, also through the ganglionic system immediately enfeebles the heart and blood-vessels, the course of the disease is very different. We have here a cause at once impairing the powers of circulation; and when it is excessive, death is often instantaneous. Such is the cause of death from blows on the head, which, when not sufficient to produce instant death, produce what is called concussion of the brain, in which a state analogous to syncope is combined with impaired sensibility. The circulation is doubly assailed by the direct diminution of the power of its organs, and a failure in the stimulating power of the blood, in consequence of its less perfect renovation in

* This accumulation of phlegm in the lungs has been found experimentally to be the uniform consequence of lessening the supply of their nervous influence.

the lungs; and the former, being the more powerful cause, obscures the effects on the vital organs of the latter. The pulse, instead of being slow but regular, and of unimpaired strength, is feeble, irregular, and fluttering, and a general paleness of the surface indicates a degree of failure of circulation, far beyond what is observed in cases of compression.

All sudden and excessive affections of the brain may produce the same effects as the blow on the head. Thus, people have instantly expired from fear, rage, or excessive joy, and thus in the mobs of Lord George Gordon, some, from the sudden effect on the brain through the nerves of the stomach, expired on taking a draught of spirit of wine which they had mistaken for common gin.

But it is not necessary that the cause, as in these cases, should be either sudden or violent to produce this species of apoplexy. A long-continued recurrence of slighter causes weakening the powers of the brain, often, along with them, gradually impairs those of the heart and blood-vessels, in the same way that an infusion of tobacco, applied to the brain in the experiments above referred to, impaired their powers. These are the most common causes of nervous apoplexy; and in proportion as their operation

has been slow, the course of the disease is less rapid.

Thus we see it supervene in those who have been long exposed to the irritations which attend the more serious and confirmed cases of indigestion or long-continued causes of anxiety, particularly in gouty habits, in which there is often a great tendency to debility in the vital organs; and we readily perceive, from what has been said, why apoplexy from such causes is so generally fatal. The powers both of the nervous and circulating systems are undermined, and with them the secreting and other assimilating processes which depend on them. The powers which ought to respond to our remedies have failed. Our efforts, therefore, are for the most part equally unavailing, in restoring either the sensibility or the powers of circulation, and both are necessary to recovery*.

FROM a review of the whole of the facts which have been laid before the Society, it appears,—

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* In the following paper it will be necessary to enter much more minutely into the nature of nervous apoplexy, which we shall find to constitute the last stage of an extensive class of diseases.

1. That in the brain and spinal marrow alone reside the active parts of the nervous system.

2. That the law of excitement in the parts of these organs, which are associated with the nerves of sensation and voluntary motion, is uniform excitement followed by proportional exhaustion, which, when it takes place to such a degree as to suspend their usual functions, constitutes sleep; all degrees of exhaustion which do not extend beyond them and the parts associated with them, being consistent with health.

3. That the law of excitement in those parts of the brain and spinal marrow which are associated with the vital nerves is also uniform excitement, but which is only, when excessive, followed by any degree of exhaustion, no degree of which is consistent with health.

4. That the vital, in no degree partaking of the exhaustion of the sensitive system in sleep, only appears to do so from the influence of the latter on the function of respiration, the only vital function in which these systems co-operate, in consequence of which its organs, without being in any degree debilitated, are less readily excited.

5. That the law of excitement of the muscular

fibre, with which both the vital and sensitive parts of the brain and spinal marrow are associated, is interrupted excitement, which, like the excitement of the vital parts of these organs, is only, when excessive, followed by any degree of exhaustion. And

6. That the nature of the muscular fibre is everywhere the same, the apparent differences in the nature of the muscles of voluntary and involuntary motion depending on the differences of their functions, of their relation to the brain and spinal marrow, and of the circumstances in which they are placed.

I shall close this paper with a few observations on dreaming, immediately connected with the preceding parts of the subject.

Had we, independently of experience, been made acquainted with the nature of sleep, we might have foretold that dreaming,—pretty much as we find it,—would be its consequence.

We here find the sensitive parts of the brain, to which the powers of mind belong, and the parts associated with them, in a state of exhaustion, but not such exhaustion as prevents their being excited by slight causes, while other parts of the system are still in a state of activity. But it is only in the

most perfect state of health, and such as we rarely enjoy, that the vital functions are performed without slight causes of irritation arising in some of their various and complicated processes, which tend to disturb the repose of the sensitive parts of the brain. Thus it is that indigestion and other internal causes of irritation produce dreaming. Such causes act partially, and therefore only partially excite those parts.

It seems greatly to influence the phenomena of dreaming, that in order to favour the occurrence of sleep, and thus as far as we can prevent unnecessary exhaustion, means are always employed at its accustomed times, to prevent, as much as possible, the excitement of the external organs of senses, and consequently those parts of the brain associated with them. This renders us the more sensible to causes of excitement existing within our own bodies, while, by the inactivity of the parts of the brain which are associated with those organs, we are deprived of the usual control over such parts of the mental functions as are thus excited; the effect of which is greatly increased by the rapidity of the operations of the memory and imagination, when not restrained by some of the various means employed for that purpose

in our waking hours. These are often objects of the senses, as written language, diagrams, sounds, and sometimes even objects of touch; but the most common is the mere use of words, independently of any object presented to our senses.

Any one may easily perceive how difficult it is to pursue a train of reasoning without this means of detaining his ideas for the purpose of steadily considering them and comparing them together. Now, in sleep, in consequence of the excitement of the brain being so partial, we are deprived of all these means; and our ideas pass with such rapidity as precludes all consideration and comparison. Our conceptions, therefore, are uncorrected by experience, and we are not all surprised at the greatest incongruities. Why should we be surprised at our moving through the air, when we are not aware that we have not always done so? The mind of the dreamer differs from that of the infant in having been variously impressed, and therefore in the capability of having its impressions recalled. But it is only as far as it is excited, that any impression can be recalled. With this exception it is as void of the results of experience as the mind of the infant; and therefore, in its partial excitement, of the means of

correcting any particular train of ideas suggested. In general, there is neither time nor subject for reflection, and, consequently, there can neither be doubt nor hesitation.

Such is the rapidity of our thoughts in dreaming, that it is not uncommon for a dream, excited by the noise that awakes us, and which, therefore, must take place in the act of awaking, to occupy, when put into words, more than fifty times the space in the relation. It is a good illustration of what is here said, that when we dream that we are conversing, and are thus obliged to employ words, the usual incongruities of dreaming do not occur. The ideas are sufficiently detained to enable us to correct the suggestions of the imagination. No man ever dreamt that he was telling another that he had been flying through the air.

Thus the peculiarities of dreaming arise from the partial operation of the causes of disturbance, and some of the sensitive parts of the brain being capable of excitement without disturbing the others; and thus it is that the more near we are to awaking, the more rational our dreams become, all parts of the brain beginning to partake of the excitement; which has given rise to the adage, that morning dreams are true.

VII. *On the Nature of Death. From the Philosophical Transactions for* 1834.

I NEED hardly say, that in such a communication as the present, I have no intention of entering into the part of the subject of this paper which may justly be termed metaphysical. The veil which separates it from experimental science must ever remain impenetrable, there being no source of information respecting it, but a direct revelation from the great Author of our being, or the instincts he has implanted in our nature, for all knowledge is not acquired. We come into the world with knowledge essential to our existence. The infant knows as well how to breathe and how to suck as the adult, and these acts depend as much on mental operations as those which are the results of experience. He perceives his wants and he knows how to relieve them; and the extent to which this species of knowledge exists in some animals, whose reasoning powers are extremely

limited, justly excites our wonder and admiration. They know what is essential to their condition with an accuracy which sets at defiance all the efforts of human reasoning, for their knowledge is the knowledge of their Creator.

To the physiological part of the subject alone I wish to direct the attention of the Society. It forms part of the same subject with the three last papers I had the honour to present to it, published in the Philosophical Transactions for 1831 and 1833; namely, the relation which the different powers of the living animal body bear to each other. In these papers I endeavoured to trace the nature of their influence on each other while their state of vigour remains; in the following paper I shall attempt to point out the manner in which they influence each other in their state of decay.

In the course of my Inquiry into the Laws of the Vital Functions, it became necessary to determine, with more precision than had been done, the line of distinction between the sensorial and nervous functions.

The function of the muscular system, from its nature and the peculiar structure of its organs, is

readily defined; but in the nervous system we perceive more than one set of functions, and yet, both from the variety of ways in which they are interwoven, and from the peculiar mechanism of the active parts of their organs being so minute as to escape our senses, and consequently the investigations of the anatomist, the difficulty of correctly distinguishing them is considerable. It is only by experiments instituted for the purpose, and founded on the very different nature of these sets of functions, that the line of distinction can be drawn.

In order to render the results more certain, I endeavoured to ascertain this line by two sets of experiments, conducted on different principles; the object of the one being to ascertain what functions remain after the sensorial power is withdrawn, and of the other, what functions fail on withdrawing the nervous power; and in prosecuting this subject, I found it requisite to study the process of dying, to determine the steps by which the body of the more perfect animal becomes subject to the laws of inanimate matter.

The experiments by which this was more immediately attempted were not laid before the Society as were the other parts of the investigation. They are

detailed at length in the second part of my Inquiry into the Laws of the Vital Functions. I have there, however, entered no farther into the nature of death than was necessary for the purpose I then had in view. I am now about to compare the results of these experiments with those of others, made since the publication of that Treatise, with a view, as far as experiment can apply to it, of explaining the nature of death.

It appears to me that the various facts ascertained in the course of the inquiries in which I have been so long engaged, throw light on this subject. I shall, as I proceed, refer to the passages, either in my papers in the Philosophical Transactions, or Inquiry into the Laws of the Vital Functions, where the proofs of the different positions I shall have occasion to state, will be found.

In the last of the papers above referred to, I had occasion to observe, that there is no question relating to the animal economy which involves a more general view of its phenomena than the nature of sleep. The nature of death also includes a general view of the functions of health, for such we shall find are the laws of our frame, that these functions alone necessarily lead to death; but the nature of death is

a more complicated question. It includes the various ways in which the functions are influenced by disease, the effects of which are so numerous that they seem at first view a train of countless phenomena which defy all attempts to refer them to general principles.

I need not say that many advantages would arise from a correct knowledge of the immediate cause of death, and of the different sources from which the state that constitutes that cause arises. The most important would be, that it would give to the physician a clearer view of the tendencies of disease, and consequently of the indications of cure; but it would not be the least of its advantages, that it would tend to strip a change which all must undergo, of the groundless terrors with which, we have reason to believe, the timid and fanciful have clothed it.

It appears from the experiments in question, that in the more perfect animals there are three distinct classes of functions, the sensorial, the nervous, and the muscular, which, having no direct dependence, are yet, through their organs, dependent on each other; for the destruction of any one of these classes of functions more or less immediately destroys the organs of all.

We know that the immediate organs of the nervous and sensorial functions, although both residing in the brain and spinal marrow, are distinct sets of organs, because they have not the same locality; the former, as appears from direct experiments, being distributed throughout the whole brain and spinal marrow, and, as far as experiment can determine, equally so, except that the lower part of the spinal marrow either partakes of them less, or they are there of less power*; while the latter, in all the more perfect animals, are chiefly, and in man almost wholly, confined to the brain; and because in disease we often see the functions of the one class greatly impaired without those of the other being at all affected, and in the process of dying, we shall find all the sensorial functions finally lost, while all the nervous functions remain, and are only indirectly impaired by the loss of the former.

The sensorial functions constitute the sensitive system,—that by which we perceive and act,—and consequently are connected with the world which

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* Philosophical Transactions for 1815, 1829, and 1833, and my Experimental Inquiry into the Laws of the Vital Functions. Part II., Chap. II. Third Edition. Wherever this Inquiry is referred to, the references are to the third edition.

surrounds us. The nervous and muscular, the vital system, that by which we are maintained.

From the same experiments it appears, that what is called death consists in the loss of the first of these classes of functions, the sensorial, the nervous and muscular functions still continuing, which are lost in consequence of the failure of respiration, the only vital function to which the co-operation of the sensorial power is necessary.

Many hypotheses have been framed for the purpose of explaining why the motions of the heart and blood-vessels are not, like those of the limbs, subjected to the will. Among these is the hypothesis of Dr. JOHNSTONE of Worcester*, adopted from Winslow, Prochaska, and other writers, which professes to rest on the evidence of experiment, and ascribes to the ganglions the power of intercepting the influence of the brain, and consequently of the will. We have seen, however, that the influence of both the brain and spinal marrow reaches the heart and blood-vessels as readily as the muscles of voluntary motion†.

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* Essay on the Use of the Ganglions, published in 1771.

† Philosophical Transactions for 1815, and Experimental Inquiry, Part II. chap. i. and ii.

All that has been written on this question seems only to perplex it. When we dismiss the various hypotheses on the subject, the answer appears easy. There are evidently two conditions necessary to render a muscle subject to the will: the stimulus which excites it must be so, and it must be capable of effecting an end desired. If we had no wish to handle, the muscles of the hand would never have become subject to the will. The heart and blood-vessels in all their usual motions are excited by the blood, the stimulating properties of which the will can neither increase nor impair; and what act of volition could be performed by these organs? The only internal organs which can effect an end desired, are the rectum and bladder, when their contents have accumulated to a certain extent; and they are both, under such circumstances, subjected to the will. Their action here may be said to be vital functions, to which the co-operation of the sensorial power is necessary; but, to say nothing of the sensorial power, under all circumstances not being essential to them, they are not so immediately essential to life as to be comprehended in the term vital functions, according to its usual acceptation.

When the animal no longer feels and wills, his breathing ceases, and he is, according to the common acceptation of the term, dead, although his body still retains its other powers, which, while they last, prevent its obeying the laws of inanimate nature*; but the changes which after this take place, of course no more affect the individual than if they took place in any other mass of matter.

In inquiring into the physiological nature of what is called death, therefore, it is to the ceasing of the sensorial functions alone that the attention must be directed. Thus the subject divides itself into two parts; the final loss of the sensorial functions, which in common language has obtained the name of Death; and absolute death, that is, the loss of all the functions, which we shall find in the more perfect animals is the necessary consequence of the loss of the sensorial functions.

The latter functions, as I have already had occasion to point out in the preceding paper, belong to those parts of the brain and spinal marrow which are associated with the nerves of the sensitive system,

* Experimental Inquiry, Part II., Chap. xi. Third Edition.

and which, it appears, from another paper which the Society did me the honour to publish in the same part of the Transactions, are the only active parts of this system; those on which the power of all its other parts depends. To them, therefore, we must look for the immediate cause of failure when the functions of the sensitive system, whether temporarily or finally, fail. It is here we found that the immediate cause of sleep exists; and it appears, from what has just been said, that to the same parts we must look for the immediate cause of what is called death.

The state which immediately precedes the last act of dying, then, according to the common acceptation of the term, and sleep, depend on a failure of function in the same organs. In what, then, consists the difference of these states? The most evident is, that the one is a temporary, the other a final failure; and it will appear, that in the only death which can strictly be called natural, the state of the sensitive system which immediately precedes death differs from its state in sleep in no respect but in degree.

The cause of sleep, as appears from the paper above referred to, is uniformly the same,—a diminished excitability of the sensitive parts of the brain

and spinal marrow, in consequence of the action of the ordinary stimulants of life; but a loss of excitability in those parts we shall find is never the sole cause of death, and often makes no part of its cause. In sleep we have seen that the sensitive parts of the brain and spinal marrow regain their functions in consequence of the continued vigour of the vital system, by which their excitability is restored. To render the exhaustion which constitutes sleep permanent, therefore, the powers of this system also must fail; and if any cause of failure in these powers occur, it is evident, that whatever be the state of the sensitive system, its powers must fail with them.

The natural death of the animal is the death of old age; and as this is the simplest form of death, it is that which I shall first consider. We shall find that the state which immediately precedes this death, and must consequently be considered as its cause, must, in the nature of things, differ from sleep in no other respect than the less vigorous state of the functions of both systems, and consequently that these states are identical; the greater or less general vigour making no difference in their nature.

We are not necessarily born to suffering. All

natural states, with the exception of child-bearing, (and in its most natural state even this is hardly an exception,) are more or less pleasurable. It will appear from the nature of our constitutions, that the last feelings in natural death are necessarily of the same nature as those which precede sleep. It is only where the course of our decay is disturbed, that suffering of any kind attends it.

From a knowledge of the animal economy, we might, independently of experience, have foretold that a state of sleep would be that which immediately precedes the last act of dying from old age.

It appears from what was said of the nature of sleep in the paper above referred to, that although the vital organs do not, in it, partake of the peculiar state which constitutes sleep, their functions are all, for the time, impaired by the exhaustion of the sensitive system. The respiration, we have seen, is rendered less frequent, in consequence of which the activity both of the circulation and the other assimilating functions which depend on it, is, for the time, lessened.

Now, as the death of old age arises from the gradual failure of those functions, it must necessarily take place at the time at which their vigour is most

impaired. If the vital powers are still capable of restoring the sensitive system under the disadvantage of a diminished frequency of respiration, it is evident that, if their decay be gradual, nothing occurring suddenly to accelerate it, they cannot fail to maintain the functions of that system during the short time which intervenes before the recurrence of sleep again exposes them to the same difficulty. Their failure necessarily takes place at the time when their functions are most difficult. The death of old age, therefore, is literally the last sleep, uncharacterised by any peculiarity. The general languor of the functions in the last waking interval is attended with no peculiar suffering, and the last sleep commences with the usual grateful feelings of repose, the last feelings experienced; for with what takes place after them, the feelings, being suspended, have no concern.

The only difference between the last, and the sleep of former times, is, that the exhaustion of the sensitive system, which is at first, as in the latter case, only partial, (for in the beginning of that sleep the sleeper may be roused by more powerful stimulants than those which preceded it,) becomes in its continuance, in consequence of the failure of those

powers which formerly restored the sensitive system, complete.

As it is by the continued action of the vital parts in sleep that the sensitive parts are restored, the less active the former become, they necessarily effect their restoration the less readily; and when they can no longer effect it, the individual awakes no more; but the circumstance of the vital being no longer capable of restoring the sensitive system, makes no alteration in the nature of its exhaustion. It is still, while it lasts, the same exhaustion which constitutes sleep. The sleep proves final; but the sleeper is wholly unconscious of the cause which renders it so; and there is nothing in its commencement to inform us whether it will be final or not. Thus the sensibility is extinguished, and consequently respiration ceases. The extinction of the sensibility is the last act of dying, in the common acceptation of the term. As the ordinary stimulants of the day produce the sleep of daily occurrence, those of life produce the sleep of death.

Although the sleep of each day restores the sensitive system from the exhaustion which causes it, the daily recurrence of the exhaustion has the effect of permanently lessening the excitability of that system;

a change not to be perceived from day to day, but which, from many phenomena, becomes sensible in the course of years. As the sensitive system becomes less excitable as the day advances than on first awaking, in like manner it becomes less excitable as life advances than in childhood; and in like manner, as the repeated excitement of the sensitive system tends to the final decay of its sensibility, the continued excitement of the vital system, as we might *à priori* have supposed, has a similar tendency with respect to the excitability of this system. We find the pulse becoming slower as we advance in life, in consequence of the lessened excitability of the heart and blood-vessels, and the vital organs less readily influenced by the parts of the nervous system associated with them, proving that their functions are also under the process of decay. On these parts and the powers of circulation all the assimilating processes depend; and the shrinking frames of the aged indicate their weakened state, and the approach of their final extinction; for those were deceived who taught that there is nothing in the laws of our frame which should lead us to believe that it is not formed to last for ever.

The greatest degree of excitability, either in the

sensitive or vital system, is not that which produces the most vigorous state of health. We may be too excitable as well as too little so. Many of the more serious diseases of children arise from this cause. The derangement of the digestive organs, which in the adult produces the nervous irritations of indigestion, produces in the infant inflammation of, and effusion on, the brain. The irritation of the gums, which produces pain and restlessness in the former, in the latter produces convulsions and death. Thus it is that the habit of the child is less firm and vigorous than that of the adult, which has acquired steadiness by the diminution of its excitability, in consequence of the continued action of the stimulants of life; but, after a certain period, the fault is a deficiency, not a redundance, of excitability, a defect apparently the necessary consequence of the laws of our frame, and to which every day unavoidably adds.

The redundance of excitability in children, the cause of many evils, we may be assured answers some important end. There is reason to believe that it is on it that the growth of the body depends, and that the due proportion between the excitability and the stimulants of life, by the gradual diminution of the

former, determines the period at which the growth is completed in each individual. While the excitability continues redundant, the ordinary stimulants of life necessarily support a greater activity of the functions than is required for the mere maintenance of the body, and thus its volume enlarges, on the same principle that we have just seen it shrinks in the aged, in consequence of their excitability having become defective. It seems to be on this principle, namely, by a premature exhaustion of the excitability, that the hardships of life, that is, the greater than usual applications of its stimulants, check the growth. On the same principle we should expect to find that the growth would cease soonest in the most excitable habits, because in them the excitability will soonest be reduced to a due balance with the stimulants of life. Thus it seems to be that the growth of women, who are more excitable than men, generally stops sooner, and consequently that they are of shorter stature, large women, for the most part, having less of the habit peculiar to their sex; and that by far the greater number of the most excitable men, who, in consequence of this constitution, make the greatest figure in their day, are men of short stature, while giants are generally of an opposite

habit of body. There must, of course, to such rules be many exceptions. Where so many causes are operating, no result can be uniform.

THAT above described, is the only form of death which, strictly speaking, can be regarded as natural. In all its other forms the regular course is disturbed by adventitious causes. But the causes which interfere with the regular course of nature and which make their impression either directly on our bodies, or through the medium of our mental powers, are, in civilised society, so numerous and complicated, that it is rare to see an instance of such a death. At whatever period death arrives, it is almost always the effect of disease; and at advanced periods of life we only become more liable to death in consequence of our weakened powers rendering us more subject to disease.

Of the various instances of death I have witnessed, there was none that could be regarded as wholly the effect of age. It was always possible to point out some one or more of the vital organs more deranged than the rest, to which death was chiefly to be ascribed. We have, however, accounts of death from old age alone, which were such as has just been

described, so that the inferences afforded by the laws of the animal economy are here confirmed by experience.

If we wish to prolong life we must keep the attention so far directed to the health as to watch the first tendency to failure in any of the vital functions. In a great majority of instances, to a very late period of life, the failure in the commencement is capable of being corrected. It becomes obstinate, by the power of habit, and by the laws of sympathy complicated; and on both these accounts difficult of cure. We may be assured there is, in all, the capability of long life if they can escape the effects of disease. Thus it is that those who lead a quiet and retired life, little exposed to powerful impressions either of mind or body, often attain a great age. It is an additional motive for watching the state of health at advanced periods of life, that the longer we live the less in general is our suffering at the last; the nature of death partaking the more of that old age. For the further consideration of this subject I beg to refer to my Treatise *On the Preservation of Health, and particularly the Prevention of Organic Diseases.*

ALL modes of death, with the exception of that

from old age, may be regarded as more or less violent; but in considering their nature, we must not confound the last act of dying with the suffering which precedes it, and which is often no less when it terminates in recovery than in death, which equally relieves it; and as death, in the usual acceptation of the word, from whatever cause it arises, consists in the loss of the sensorial functions alone, the act of dying is, in this respect, in all cases essentially the same. In all my experiments I found the nervous and muscular surviving the sensorial functions*.

When the animal no longer feels and wills, he is what we call dead; but for a certain time the motion of the blood in every part of the system still continues, and all the assimilating functions still go on, as may be demonstrated by dividing the vital nerves immediately after death, which produces the same change of structure in the organs supplied by them, though in a less degree, as during the life of the animal †; and that all this would be the case, a knowledge of the animal

* Experimental Inquiry, Part II., Chap. xi. Wherever this Inquiry is referred to, the references are to the Third Edition.

† Ibid. pp. 175, 176, compared with a paper which the Society did me the honour to publish in the Philosophical Transactions for 1827, entitled, Some Observations on the Effects of dividing the Nerves of the Lungs, &c., the second paper in this volume.

economy would have told us, independently of the aid of experiment, if we could, without this aid, have acquired it.

The removal of the sensorial powers neither destroys the muscular power nor deprives the muscles of involuntary motion of the stimulus which excites them. The heart, indeed, is incapable of its function, because, from the interruption of respiration, its left side is no longer supplied with the kind of blood which is its natural stimulant; and the accumulation of the blood in the lungs from the same cause affecting a great proportion of its vessels, prevents the right side from emptying itself. These are the necessary and almost immediate effects of the interruption of respiration; but the change in the blood of all the capillaries, with the exception of those which belong to this class of vessels, necessarily takes place more slowly. A certain time must always elapse before the stoppage of respiration greatly affects it. It has been sent to these vessels more or less in its proper state, and it still finds its vessels capable of being influenced by their usual stimulant*. Thus, as I have ascertained by many experiments,

* Philosophical Transactions for 1833.

the motion of the blood continues in these vessels for several hours after respiration has ceased, that is, as long as the blood can be drawn from the larger arteries—the cause of these arteries being found empty some time after death*.

But this is not all; the nerves of the ganglionic, as well as cerebral system, retain their power for a certain time after the supply of that power from the brain and spinal marrow has ceased†. The blood, therefore, still finds the secreting surfaces in a state more or less capable of their functions, and the secreting processes, as I ascertained by frequently repeated experiments, still go on‡: nor is even this all, for the brain and spinal marrow depend for the continuance of their functions on the same powers as other organs; and I found, by an experiment made on so large a scale, that it was impossible to be deceived in the result, that there is an actual supply of nervous influence after the sensorial functions have ceased, that is, after what is called death§.

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* Experimental Inquiry, Part II., Experiments 66, and 67.

† See the Observations on the experiments, which prove the evolution of caloric from the blood after what is called death, in the second part of the Inquiry just referred to.

‡ Ibid. Experiments 65, 69, 70.

§ Experimental Inquiry, Part II. Experiment 65.

Such is the natural decay of our frames, but, as I have already had occasion to observe, it is very rare for it to run its course uninterruptedly, particularly in civilised life. It is almost always disturbed by adventitious causes accelerating it, or the decay of particular parts, which, in consequence of the mutual dependence of the various functions, disorders the whole. Although these causes are of infinite variety, the laws of our frame are limited, and, therefore, many must operate on the same principle. This leads us to believe that, however varied the causes of disease, it may be possible to reduce their more ultimate effects to a few general heads. The exhaustion of the sensitive system, for example, is of the same nature, whatever be the cause of excitement; and other forms of debility, affecting either the sensitive or vital system, cannot be very various, however various the causes which produce them. We have reason to believe that the endless variety of disease depends more on the peculiar nature and functions of the different organs affected, and the peculiar manner in which different causes affect them, than on any great variety in the states which constitute the more immediate causes of death. However various the effects of disease, there must be but a few

points to which they all tend, because the last in the chain of causes which produces what is called death, we shall find, is always the same, and seated in the same parts. On these principles we may hope to reduce the effects of the adventitious causes of death to a few heads, and thus to obtain such a view of the subject as shall enable us to trace the nature, and consequently the operation, of the causes of our decay in individual instances, and therefore to perceive more clearly the operation of the means which tend to counteract them. In the prosecution of the subject I shall commence with those causes of disease whose operation most resembles that of the wholesome stimulants of life; and in pursuing, by means of the various experiments which tend to unfold the laws of the animal economy, the consequences of these causes, we shall be led to the effects of such as have nothing in common with them.

It appears, from what was said of the nature of sleep, that all degrees of excitement in the parts of the brain and spinal marrow associated with the nerves of the sensitive system, are followed by proportional exhaustion. The only limit to this law is the capability of bearing in those parts. Exhausted

by mental excitement, the criminal is often awakened for his execution; and the soldier, both by mental and bodily excitement, sleeps by the roaring cannon.

Now, although the usual stimulants of the day never, except in old age, where we have seen all our powers have long been in a state of decay, produce such exhaustion as to endanger life; the exhaustion from stimulants of greater power cannot with safety be frequently repeated, because by their continued operation the sensitive parts of the brain and spinal marrow being both more exhausted than is consistent with the due state of the functions before sleep takes place, and roused before they have been refreshed to the usual degree by repose, a state of disease is induced; and all diseased states affecting the system generally, if their causes continue to operate, necessarily prove fatal.

Although in ordinary sleep the vital functions are for the time impaired, in consequence of the lessened sensibility rendering the act of respiration less frequent, the state both of the vital and sensitive system is as much a state of health as in our waking hours. The insensibility of the latter only extends to the effects of the daily stimulants of life; and there are ample means in the functions of health for

the restoration of this system, the powers of the vital system, as I have already had occasion to observe, being in no degree diminished, but only, in consequence of a slower respiration, less readily excited.

As soon as a diseased state of the sensitive system is established from the causes just mentioned, it begins to affect the vital system otherwise than through the intervention of respiration, the only medium, we have seen, through which the healthy exhaustion of the former affects the latter; for such is the sympathy between the sensitive and vital parts of the brain and spinal marrow, that any deviation from the healthy state of either is immediately felt by the other.

The characteristic of the mode of death I am considering, is the tendency of its causes to produce sleep in the first instance. So far their operation is the same, but greater in degree, with the common stimulants of life. At this period, if the cause of suffering be removed, the sleep is only more profound than on former occasions; and, as on them, it continues till the sensitive system again becomes obedient to those stimulants; if not, this system soon partakes of a species of debility so different from the healthy exhaustion, that instead of being

relieved by the continued action of the vital parts of the brain and spinal marrow, it spreads to them. Hence the nutritive and other vital processes begin to fail*, and the various irritations which attend their failure, still further contribute to the debility of the sensitive system, and consequently, indirectly, to increase the cause of their failure. The derangement of each system thus aggravating that of the other, the evil proceeds not by simple addition, but in an increasing ratio, till all their powers are extinguished.

WHATEVER be the suffering which precedes what is called death, the moment of that death is but its termination, but the conclusion, as far as our feelings are concerned, of the process of dying. As soon as disease is established the act of dying is begun, and we have no reason to believe that, as far as the body is concerned, its nature is in any respect changed in

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* That the assimilating processes depend on the action of the nervous influence on the blood, appears from various experiments, an account of which has been laid before the Society. Many of these experiments are detailed at greater length, and others, illustrating the same position, added, in my Inquiry into the Laws of the Vital Functions, Part II. chap. v. vii. and viii.

what is called its termination. It is, from the first to the final ceasing of all the functions, a more rapid than natural decay of the powers of life, with, while sensibility lasts, more or less suffering, according to the cause which produces it. In recovery, our suffering terminates by the removal of that cause; in what is called death, by our becoming insensible to its effects; the bodily process being in no other way influenced by our total insensibility, to which the name of death is applied, but that the consequent ceasing of respiration accelerates it.

The body at this moment can no more be regarded as in the act of dying than at any other period of the disease; and the removal of the offending cause will not only in many cases at this period, if proper means be employed, but in some, even a short time after it, be followed by recovery. Thus, even after the period at which, according to the common meaning of the word, the process of dying is completed, it is, under certain circumstances, not too late to arrest that process, and restore the sufferer to the perfect enjoyment of his faculties. Recovery may take place after respiration has, from submersion, for a few minutes ceased, and the sufferer is, in the common acceptation of the term, dead, his sensibility,

and consequently his respiration, independently of artificial means, being finally extinguished.

That this may happen, it is necessary not only that the vital system should have been just before in a state of healthful vigour, but also that the respiration should not have failed from the failing sensibility, but the operation of the offending cause. Here the sensibility fails from the failure of respiration, not, as in other cases, the respiration from the failure of the sensibility; but this difference in the succession of events makes no difference in the general nature of the actual state induced.

The recovery depends on our being able, more or less perfectly, to restore the function, the failure of which has caused the failure of all the others, as far as it has taken place, before the process of dying has proceeded too far for the restoration of the sensitive system. If no artificial means are employed, the date of death here is the time at which the sensibility ceased, and justly, because at that time death, according to the common meaning of the word, has taken place. The individual no longer feels and wills.

If there were even the last remains of sensibility, breathing would take place without external aid, as

happens when the submersion has not been long enough wholly to extinguish it. The individual has, without such aid, finally ceased to feel and will, and is therefore what we call dead. His blood still continues to move, and all the assimilating processes, as appears from the experiments above referred to, are still going on; but this is no more than happens, more or less, in all cases after what is called death; the only difference being that from the nature of the offending cause, and the short duration of the disease, these functions are in a state of greater vigour than when the loss of respiration has been the effect of the loss of sensibility, which makes no difference in the nature either of their remaining powers or the circumstances in which they are placed, and would not prevent their ceasing, as usual, if no means were employed to arrest the dying process. I have dwelt the longer on this case, because it affords a good illustration of some of the preceding as well as following parts of the subject*.

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* From the experiments which have been laid before the Society (Philosophical Transactions for 1822, 1827, and 1829, and Experimental Inquiry, Part II. chap. xii.), we have reason to believe that the effects of artificial respiration in restoring those whose breathing has been interrupted till the sensibility is destroyed, would be greatly aided by the use of voltaic electricity

The approach of death, if we are aware of it, must always be more or less impressive, not only

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sent through the lungs in the direction of their nerves, and that many might thus be restored in whom inflation of the lungs alone fails. The inflation of the lungs in such cases acts in two ways. It gives to the blood of the smaller vessels of the lungs some of the arterial properties by which they are often excited, and acting through the blood of these vessels, it communicates to that of the larger vessels, and of the heart itself, more or less of the same properties, independently of the blood already changed being moved on towards this organ; for M. LE GALLOIS has shown that after the circulation has permanently ceased, the blood may, to a certain degree, be changed by inflating the lungs, not only in the trunks of the pulmonary veins and the heart itself, but even in the great arteries.

There is reason to believe, from the whole of my experiments, that the lungs should not be inflated more than eight or ten times in the minute, and that the injection of large quantities of air and great force in its injection should be avoided, and consequently the patient placed in the position in which the chest expands with greatest ease*. One of the chief defects of artificial breathing is, that in it the chest is expanded by

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* Experiments relating to the effects of artificial respiration in the newly dead animal. Experimental Inquiry, Part II. chap. xii. If the air be thrown in more frequently or in greater quantity than the remaining powers of the lungs are capable of employing, it acts as a cooling process, and is highly injurious. One of the chief defects of artificial respiration arises from our not being able to ascertain either the precise quantity of air or the frequency of its injection required by the particular state of the circulating system in the lungs. We know that in the case before us the demand cannot be equal to what it is in health.

because we are about to undergo an unknown change, but are leaving all that has hitherto interested and been grateful to us. Even here, however, for the most part, the laws of our nature are

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the pressure of the injected air, whereas in natural breathing the air enters in consequence of its expansion. But the most essential difference between natural and artificial breathing in such circumstances is, that there cannot, till recovery is far advanced, be the proper supply of nervous influence, the due action of the vital parts of the brain and spinal marrow only being restored in proportion as the due force of circulation returns. Now it appears, from what is said in the Philosophical Transactions for 1822 and 1827, and more fully in my Inquiry into the Laws of the Vital Functions, that voltaic electricity sent through the lungs in the direction of their nerves, is capable of performing as perfectly as that influence itself, the part which belongs to it in respiration, which is so essential, that the more perfect animal always dies from impeded respiration if the nervous influence be withdrawn from the lungs, unless voltaic electricity be supplied, which enables it to breathe as well as when the nervous influence is entire.

A proper apparatus, therefore, for sending voltaic electricity through the lungs in the direction of their nerves, and in due power, should be added to the other means of resuscitation, which would render them, and probably to a great degree, more successful. The force of this observation will be perceived when it is considered that it is at the time of the first application of the remedies that the chance of recovery is greatest, and consequently that the immediate application of the whole means of healthy respiration, as far as we possess them, is of most consequence. It appears from what has been said, that the due functions of respiration cannot be restored till the due degree of nervous influence is supplied, and this cannot happen from inflation of

merciful. Most diseases of continuance (for we shall find there are some exceptions) not only gradually impair our sensibility, but alter our tastes. They not only render us less sensible to all impressions, but less capable of enjoying as far as we are still sensible to them. The sight of a feast to a man who has lost his appetite is disgustful, and a similar change takes place in a greater or less degree with respect to all other means of enjoyment.

These circumstances constitute a great part of the difference of our feelings with respect to what, in common language, is called a violent and a natural death. In the latter, as far as the sensibility is impaired, we are more or less in the state of old age, and, in addition to this change, our tastes are perverted. By these means the relish for life is in a great degree destroyed before we lose it. Thus in disease, the most timid often meet death with

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the lungs till the due force of circulation returns. The fact, explain it as we may, is, that voltaic electricity so perfectly supplies the place of the nervous influence in the lungs, that their functions are equally perfect under the influence of either. The one can only be supplied at an advanced period of recovery, that is, in fact, only in those cases where the success of our endeavours can be secured by other means; the other is, in all cases, within our reach on the instant.

composure, and sometimes, as I have repeatedly witnessed, with pleasure. I have even known the information that the danger was passed, received only with expressions of regret.

To the form of death I am considering, belong a large proportion of the diseases of long standing, and whatever else tends gradually to exhaust the powers of the sensitive system, great mental excitement, too laborious a life, &c. The diseased state of the sensitive parts of the brain and spinal marrow, thus induced, spreading to the vital parts of those organs, terminates in a state of nervous apoplexy, the nature of which I had occasion to explain in the paper on Sleep, and to contrast with that of apoplexy from compression, in the most unmixed cases of which the offending cause only producing a state analogous to the healthy exhaustion of the sensitive system, but greater in degree, its influence is throughout confined to that system*. In the former case we

* It appears from experiments related in my Inquiry into the Laws of the Vital Functions, that simple and uniform pressure of the brain does not produce such a state of the vital parts of that organ as to derange the circulation, the effect of such pressure on the sensitive organs of the brain being of the same nature, as far as relates to the vital system, as the exhaustion occasioned by the

see all the vital functions deranged; in the latter the breathing alone affected, except as far as its state affects the others, death arising merely from respiration ceasing in consequence of the loss of sensibility; and so exclusively is this sometimes the case, that I had occasion to refer to an instance in which the patient breathed only two or three times in the last ten minutes, but each time drew the air freely into the lungs; a proof that he died without any accumulation of phlegm there, and consequently without any disorder of the vital functions, but such as arose from the increasing insensibility*. Here the failing

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exercise of their functions; which further appears from the whole functions of health being immediately restored on the removal of the pressure, which only proves fatal by its continuance more and more impairing, and at length destroying, the sensibility. (Experimental Inquiry, Part II., Experiment 18.) Many years ago, a man in whom the ossification of the skull had never been completed, exhibited himself in this country. By pressure made on the unossified part, he was immediately brought into a state of apoplexy, which always disappeared, leaving him wholly uninjured, on the removal of the pressure.

* It has been shown by many experiments, detailed in the Philosophical Transactions, and in the second part of my Inquiry into the Laws of Vital Functions, that derangement of the assimilating functions is always attended with accumulation of phlegm in the lungs, this being the first indication of derangement of these functions in them.

powers of the sensitive affected the vital system in no other way than in sleep, the only difference being the degree in which the sensibility was impaired. Such cases are extremely rare. In by far the majority, from some inequality in the effects, or other peculiarity of the cause of pressure, at the same time that the sensibility is morbidly impaired, either a diseased state of a different kind is induced on the sensitive parts of the brain, which, as soon as established, begins to spread to the vital parts of that organ, or the cause of the disease itself more immediately affects the latter.

In the more rapid cases, the diseased state of the sensitive, which spreads to the vital parts of the brain and spinal marrow, supervenes without being preceded by a state of exhaustion, only differing from sleep in being greater in degree, in proportion as the stimulants which produce it are more powerful and protracted.

The effects of diseased states of the sensitive on the vital parts of the brain and spinal marrow, differ according to the nature and degree of the offending cause. When they are such as in the first instance to produce a state analogous to sleep, their injurious effects are necessarily more or less gradual, the first

operation of the agent differing only in degree from that of the usual stimulants of life; but where the offending cause is more powerful in degree, or of a more injurious nature, the stage of exhaustion is lost, and the immediate effect on the sensitive system is that species of debility which the vital parts of the brain and spinal marrow having no power to relieve, partake of; and when the cause is both violent and sudden, its effects on these parts are often such as immediately to destroy the circulation.

The Experiments, an account of which the Society did me the honour to publish in two papers in the Philosophical Transactions for 1815, prove that, although the heart and vessels do not derive their power from the brain and spinal marrow, it may be destroyed by impressions made on them. Thus it is that violent passions, either of a pleasurable or painful nature, in consequence of the sympathy which subsists between the sensitive and vital parts of these organs, have sometimes proved instantly fatal.

Here we have an effect from the causes of disease wholly different from that of the usual stimulants of life. The direct operation of the agent produces a state of debility in the sensitive system altogether of

a different nature from that which constitutes the healthy exhaustion of sleep; and it will assist the memory and facilitate the means of reference to regard as the second form of what, for the sake of distinction, I call violent death, that which arises from all those causes which produce in the sensitive system this species of debility in the first instance, that is debility without previous excitement, in whatever degree they have this effect, regarding, as the first species of such a death, the form of death we have been considering, that in which the cause, in the first instance, produces the stimulant effect, and consequently the exhaustion of sleep.

When the cause of the second form of violent death, according to this division of the subject, is extreme, no time is afforded for its less powerful effects to show themselves. When it is less violent, so that the circulation, though impaired, still goes on, we find all the vital functions impaired along with it. The assimilating processes are doubly assailed by the failing supply of nervous influence and the lessened powers of circulation*. These effects, we have seen, may arise from the excess of

* See note in page 180.

the stimulant operation of agents*, but they are not necessarily the consequence of any operation of this kind, but may be as much the direct effect of the agent as the stimulant effect itself. It is, the offending cause and state of body being the same, when the operation of that cause is most powerful, that its debilitating effect is most unmixed. In proportion as it is less powerful, the case partakes more of the nature of the form of death, in which the first effect of the offending cause is that of a stimulant.

This is readily explained. I have been at much pains, in my Inquiry into the Laws of the Vital Functions, to point out that all agents capable of affecting the living animal, whether making their first impression on the mind or body, applied in a certain degree, act as stimulants; in a greater degree, as sedatives; that is, as means of directly impairing the power of the part they act upon†. We know of no exception to this law, and the stimulant and

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* See pages 179 and 180.

† Experimental Inquiry, Part II., the last ten pages of chap. XII., and the observations on the term sedative in my Treatise on the Influence of Minute Doses of Mercury, which, from the want of some more appropriate term, I shall here employ for all agents which impair the power of the whole or any part of the animal frame without previous excitement.

sedative effect of different agents bear no particular proportion to each other; but the greater the stimulant power of the agent, it must be applied to the greater extent to produce the sedative effect, and the greater its sedative power, in the smaller extent, to obtain from it the stimulant effect. The proportion which the stimulant and sedative effects of the same agent bear to each other is always the same, that is, its mode of application and the state of the body being the same, for the more gradual the application, the more the stimulant; the more sudden, the more the sedative effect prevails; and the less vigorous the functions, the less they are capable of the stimulant, and the more they are subject to the sedative effect. Thus torture, which produces sleep, that is the exhaustion which is the effect of the stimulant operation, in the hardy savage, acts as a sedative in the less robust European. While the former sleeps the latter dies; and the more sudden its application the less the constitution is capable of resisting it.

The sedative effect, in whatever degree, is of a nature so different from the exhaustion which constitutes sleep, that its tendency always is to prevent the latter; and when the stimulant operation of the

causes of disease exceeds that of the usual stimulants of life, and thus tends to the sedative effect, in the same proportion the tendency of these causes, although in the first instance to produce sleep proportioned to their stimulant effect, is eventually to prevent it. There is a degree of fatigue the repetition of which produces fever, not sleep.

Such being the principles on which all agents capable of affecting the living animal operate, we readily perceive why the more sudden and powerful the cause of disease, the more it inclines directly to produce a state of debility, and when it is most so, why this tendency is unmixed with any degree of the stimulant effect.

But it is not necessary, as appears from what is said of nervous apoplexy in my paper on Sleep, that the operation of the agent should be either violent or sudden, to produce, even in the first instance, more or less of the sedative effect, if it be of a nature suited to produce it. In proportion as its application is less powerful, however, its peculiar effects are necessarily so also. Instead of preventing the tendency to sleep, it only impairs it; and the morbid state of the brain and spinal marrow shows itself by symptoms which less immediately threaten

life. The sedative effect of agents may exist in all possible degrees, from the effect of the rage and joy which has produced instant death, to that of the settled grief, which only in the course of years destroys its victim; from the pain of a scald so extensive as to produce death in a few minutes, to the irritations of confirmed indigestion, under which the patient often lingers for a great portion of life. Whether the effects be sudden or gradual, the tendency, in all such cases, is the same, to terminate in a state of general debility, that is nervous apoplexy, in which all the powers of the system are equally impaired.

The first impression of the cause is on the sensitive parts of our frame, which, without previous excitement proportioned to the debility which ensues, impairs their functions; and this debility, in consequence of the sympathy which exists between the sensitive and vital parts of the brain and spinal marrow, spreads to the latter, and thus the vital functions are, more or less quickly, so impaired that they can no longer maintain those of the sensitive system.

The nature of this death is well illustrated by the effects of severe accidents, many of which operate on

the same principle as the scald. The effects of severe blows on the head and spine are very complicated. They at once impress equally the sensitive and vital system; but when the cause of injury is confined to less vital parts, as in the case of the scald, their first impression is on the sensitive system alone, or so nearly so, that the difference may be overlooked. Such was the cause of death in the case of the late Mr. HUSKISSON, with the circumstances of which the members of the Society are well acquainted; and hence it is that life is often saved by amputating a limb in which a cause of extreme irritation exists, that caused by the operation being more easily borne than the protracted irritation of a shattered limb, if the accident has not so subdued the strength that the additional irritation of the operation would prove immediately fatal.

To the same head belongs the death from the bite of rabid animals. The hydrophobia is a disease of the sensitive, spreading to the vital, parts of the brain and spinal marrow; and such is the effect of many other poisons.

It is evident that the form of death I am now considering is of the same nature as the preceding, with the exception of the early stage of the latter.

The sedative state of the sensitive organs is of the same nature, whether it has arisen from the excess of the stimulant operation, or from the more direct effect of the agent, when applied in such extent as at once to produce this state. The symptoms produced in the sensitive, and the manner in which they influence the vital system, are the same in both. The same observations, therefore, which apply to the latter stage of the first of these forms, apply, more or less, to the whole progress of that we are considering. In both, what is called death is the final extinction of the sensibility; the termination, as far as relates to our consciousness, of the process which has been going on from the first establishment of the disease. As sleep is the completion of the temporary and limited exhaustion of the excitability which has been going on during the day, death is here the completion of its absolute and final exhaustion, which has been going on during the disease; and it is evident, that as the sensibility decreases, the suffering must become less, and consequently that it is least of all at the moment of what we call death. These observations, however, we shall find do not apply, in the same extent, to the forms of death which still remain to be considered.

THE three forms of death to which the attention has been directed in the preceding part of this paper, namely, that from old age, that from excessive stimulants acting on the sensitive parts of the brain and spinal marrow, and that from agents applied to such extent as to act as sedatives on those parts, agree in an essential respect. The offending cause makes its impression on the organs of the sensitive system, and therefore in all, the sensibility is more or less directly impaired; and although it is only in the first that sleep can be regarded as the immediate cause of what is called death, the cause of injury in the second stage of the second form, and throughout the whole of the third form, producing the sedative effect, and consequently more or less tending to prevent sleep, yet tends, although in a different way, to impair the sensibility; and the termination in all such cases, as I have already had occasion to observe, if no other cause of injury arise in the course of the disease, is a state of nervous apoplexy, in so many cases the prelude of death, which, if not sufficiently violent or sudden, so to impair the powers of circulation as thus immediately to destroy those of the sensitive system, proves fatal

by equally impairing the sensibility and impeding the assimilating processes; and as sleep relieves us from the ordinary stimulants of the day, the insensibility thus induced, relieves us from the sufferings of the disease, which, although it is not, like sleep, preceded by the grateful feelings of repose, is preceded by a gradual diminution of those sufferings.

THE forms of death which remain to be considered differ essentially from the foregoing. It will place in a clearer point of view both what I am about to say of these forms of it, and what has been said of its preceding forms, to consider more minutely than has hitherto been done in this paper, or, as far as I know, in any other discussion on the subject, the nature and relation of the functions of the living animal.

IN the community of functions which constitutes the life of man and all the more perfect animals, the sensitive are the working functions, those by which we perceive and act; the vital, those by which they are maintained. To the former, therefore, belong the immediate wear and tear of intercourse with the external world, and, consequently, the necessity of

accommodating themselves to an infinite variety of circumstances. The vital functions, having but one object, pursue a steady course, from which, in health, they never deviate, except as far as is necessary to accommodate themselves to the necessities of the more eccentric functions of the sensitive system, the well-being of the organs of which depends on them; for they are capable of immediately influencing as well as being influenced by the inanimate agents which exist within our bodies; on the action of which the due structure as well as functions of every part depend. On this principle our food is digested; on the same principle the heart beats, and the secreting and other assimilating organs effect all their chemical changes. Thus the sensitive parts of the brain and spinal marrow are maintained, and thus also are maintained two sets of organs; through one of which, namely, the organs of the external senses with the nerves which convey the impressions made on them, those parts are capable of being influenced by the inanimate agents external to our bodies; and through the other of which, namely, the nerves and muscles of voluntary motion, they are capable of influencing those agents. These two sets of organs, allied by their vital properties to the sensitive parts of the brain and

spinal marrow, and by their capability of being excited by inanimate agents to the world which surrounds us, form the links which connect and enable to conduce to one end the operations of the sensitive organs, namely, the immediate organs of the sensorial powers, and the operations of inanimate nature; two classes of operations which have nothing in common. Let us here pause to consider more particularly the positions stated in this paragraph.

However repugnant it may be to our preconceived opinions, we shall, I think, when the whole of the facts on the subject are carefully weighed, find it impossible to avoid the conclusion, that all the vital functions, and all those functions of the sensitive system by which the sensorial powers influence and are influenced by the external world, are the results of inanimate agents acting on living parts, or living parts on them. Such, as far as I am capable of judging, must be the conclusion, if we compare the results of experiments, an account of which has been laid before the Society, and published in their Transactions *, with observations too simple to require any illustration from experiment.

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* Philosophical Transactions for 1817, 1822, 1827 and 1829, and Experimental Inquiry, Part II. chap. xii.

With regard to the first of these classes, the vital functions, it is evident that the functions of the alimentary canal are excited by the food, of the lungs by the air, and of the heart and blood-vessels by the stimulating contents of the blood.

The blood, as it circulates in the vessels, is justly said to be alive. It possesses properties essentially different from those of inanimate matter; but we know that it is not by its vital properties, which are bestowed on it for other purposes, that it stimulates the heart and vessels, because its stimulating contents, when separated from it, produce the same effects on them. The experiments relating to the evolution of the caloric which supports animal temperature, point out one of the purposes answered by the vital properties of the blood*, and all the experiments relating to secretion and the other assimilating processes, point out the other purposes of its vitality. It possesses vital properties, not for the purpose of acting on other parts, but for that of duly responding to the inanimate agent, which acts on it in all these processes; for that the secreting and

* Experimental Inquiry, Part II. Experiments 80, 81, 82, 83, 84, 85 and 86. See also the last of the papers in the Appendix to this volume.

other assimilating processes depend on the action of an inanimate agent, appears from the experiments which prove that they depend on the nervous influence, which has been shown by direct experiment to be capable of its functions after it has been made to pass through other conductors than the nerves*, and cannot therefore have the properties of a vital power; to say nothing of those experiments by which it has been shown that all its functions may be performed by an agent which operates in inanimate nature†.

With regard to those functions by which the intercourse of the sensitive parts of the brain and spinal marrow with the external world is maintained, it is evident that the organs of the external senses are excited by inanimate agents external to our bodies, and that the muscles of voluntary motion are capable of influencing those agents; and we know that the impressions made on the external senses are propagated, and the muscles of voluntary motion excited, by the nerves, whose powers, as appears from the

* Philosophical Transactions for 1822, 1829, and 1833, and Experimental Inquiry, Part II. Chap. XII.

† Ibid.

experiments just referred to, depend on an inanimate agent.

While the results of these experiments remain undisputed, if we assert that the nervous influence is a vital power, we must allow that such a power may exist in a mechanism wholly different from that to which it belongs in the living animal, and that all the functions of a living power may be performed by an agent which operates in inanimate nature; positions, which I believe no man, acquainted with the laws of the living animal, will be hardy enough to maintain.

Such, then, it would appear, is the nature of our frame. The sensitive parts of the brain and spinal marrow which are at once the immediate organs of enjoyment, the end of our being, and the source of those powers on which our intercourse with the external world depends, are maintained by a set of organs, the functions of which are excited by certain agents which belong to inanimate nature, and operate by other sets of organs which are capable of influencing, and being influenced by, every object around us, the functions of which are also excited by an agent of the same description. And these

inferences are in no slight degree strengthened by another and distinct set of experiments, to which I referred in an early part of this paper, namely, those relating to the order in which the functions cease in the act of dying; for the whole of the phenomena traced by these experiments, as will more clearly appear from what I shall have occasion to say a little lower, tend to the same conclusions. Why do the nervous and muscular survive the sensorial functions? Why are the failing powers of life maintained in the organs of the two former classes of functions, after all trace of them is lost in the last class?

To the same conclusions, also, I cannot help thinking the following very simple train of reasoning might, without the aid of experiment, have led us. Although a single fact is often sufficient to establish the truth, when it is once arrived at, we almost always find others ready to give it their aid.

The phenomena of the three classes of functions above enumerated, namely, those by which our bodies are maintained, those by which the sensorial organs are influenced by the external world, and those by which they influence it, appear themselves sufficient to evince that the agents employed in their

production partake of the nature of that world. Were not this the case, is it possible that the analogy between them and its phenomena could be such as we find it? Can we conceive a stronger analogy than the phenomena of inanimate nature bear to the propagation of an impulse along a nerve? Do not a thousand inanimate agents excite the muscular fibre in precisely the same way as the nervous influence does*? and it would be difficult to believe that the agent which operates in the formation of the secreted fluids from the blood, and the other assimilating processes, is of a nature essentially different from that which effects similar changes in the laboratory of the chemist, even if the facts to which I have had occasion to refer had not been experimentally ascertained; but these facts, bearing more directly on the question, necessarily make a stronger impression.

Let us for a moment glance at those phenomena in which we are assured that no inanimate agent interferes. It is evident that the organs to which impressions made on the nerves are conveyed, must be those organs from which the nerves in question

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* The first of my papers in the Philosophical Transactions for 1833.

originate and derive their power. The sensitive nerves must communicate the impressions made on them to the sensitive parts of the brain and spinal marrow. It therefore follows that the sensorial functions, consequent on impressions made on the nerves of the sensitive system, are the effects of the influence of the nerves on those parts of these organs. What are the results of this action of one vital part on another? Can we see any analogy between the phenomena of inanimate nature and pleasure or pain, the excitement of the feelings, or of the powers of reflection?

We thus readily perceive why the sensorial functions are the first which cease in dying. The stimulating parts of the blood are still present to excite the vessels, and the nervous influence, as appears from direct experiments above referred to, is still present to support the functions of the assimilating organs; but the sensorial functions, being the results of vital parts acting on each other, as the vital powers fail, the powers of the parts acted on, and those which act upon them failing together, these functions necessarily cease. Here there is no inanimate agent present, as in the case of the nervous and mus-

cular functions, to excite the languid powers of life*.

It is evident that in such a system as I have been describing, there are two principles, either of which may determine the decay of all the sensitive functions. These, the functions by which the intercourse with the external world is maintained, may become incapable of their work, or those functions which maintain them, of their office. In the only natural death, that of old age, we have seen both these principles of decay in operation. The sensitive functions are gradually dimmed, and the vital functions gradually become less active.

Life, without much violence done to language, has been called a forced state. It consists of excitable

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* It is observed in my Inquiry into the Laws of the Vital Functions, that in the most sudden death arising from causes which instantly destroy the powers of the nervous system, all the vital powers are at once destroyed; but this is only to be understood comparatively. The time in such cases required for their destruction is short; but in all the instances I have witnessed, the same succession, however rapid, could be observed. It was still evident that the muscular and nervous survived the sensorial functions. After these functions had ceased slight flutterings of the heart and fleeting contractions of the muscles of voluntary motion could still be observed.

parts called into action by suitable stimulants. These stimulants, it appears from what has been said, are all of an inanimate nature, for although the sensorial can only be excited through the nervous system, the action of the former, it is evident, equally, though not so immediately, depends on the agents which excite the latter. Hence the harmony which exists between the living powers of the animal body and the powers of inanimate nature. There is nothing in common in the nature of these powers; but the organs of the former, being composed of the same materials with the world which surrounds us, can be excited by no means but the agents which operate in that world; and on what principle could we expect any other result?

These organs themselves are a part of inanimate nature. Deprived of their vital powers, they may still, as far as we see, be perfect in all their parts. On what their vital powers depend, we know not. In the study of these powers, and the relation they bear to the other powers of nature, we must be satisfied to take the facts as we find them. And what other knowledge have we of the inanimate powers themselves? Do we know more of the nature of gravitation or electricity than of life? It is the properties,

not the essences, of things which are the objects of our senses. Our nature must be changed before the latter can be made a subject of inquiry. Life is a certain train of phenomena, depending on the peculiar state of its organs produced by the action of the same agents, which operate in other parts of nature, on the material organs of our frame. We may arrange these phenomena in the way that best assists the memory, and best shows their relation to each other and the other phenomena of nature; but no task can be more hopeless than the attempt to proceed one step further, either with respect to the living powers or any other principle of action. Such an attempt is beyond not merely the limits, but the nature of our minds. It is the blind attempting a knowledge of colours.

When we say we understand any of the phenomena of nature, we only mean that we are able to class them with other similar phenomena. We say that we know why a stone falls to the ground, because we class its fall with the other phenomena of gravitation. With regard to the phenomena of animal life, we at once see the limit of our inquiries, because it is self-evident that these phenomena exist no where but in the living animal, and consequently

that there is no more general principle to which they can be referred, a position so evident that it is difficult to understand how it could ever have been overlooked.

It is customary to speak of life as a subject of peculiar mystery. But if what has just been said be correct, we have precisely the same means of acquaintance with it as with the other powers of nature. Its phenomena are as open to observation and experiment as the phenomena of any of these powers; and we possess no information respecting any of them but such as is derived from those sources. The greater appearance of mystery arises, not from the greater obscurity of the nature of life, but from its phenomena bearing less analogy to those of the other powers of nature than these bear to each other; in consequence of which the former are less familiar objects of contemplation. Simple as such observations are, they cannot be regarded as superfluous, when we see them overlooked by such writers as Hartley, Hunter, and others of almost equal name.

We cannot be surprised that the inanimate agents, which are incapable of any change that unfits them for their office, should at length effect a permanent change in the vital parts on which they operate, of

all parts of nature the most changeable. Hence the death of old age.

The sensorial functions we have seen fail first, because their organs are removed from the immediate action of the inanimate agents which still excite the organs to which they are directly applied; but for the same reason, it is in the latter, the organs of the nervous and muscular systems, that the decay begins. Their powers are gradually impaired by the operation of the inanimate agents which excite them, and the sensorial powers, as appears from all the phenomena of our decay, only fail in consequence of their failure; but as a certain vigour is necessary to render the latter capable of maintaining the sensorial functions, these necessarily cease before the total extinction of those of which maintain them.

IN the forms of violent death which have been considered, the offending cause makes its impression on the organs of the sensitive, in those which remain to be considered on the organs of the vital, system.

IT is evident from what has been said of the nature and relations of the functions of the living animal, that there is one class of the causes of death which is necessarily confined to the vital organs. On them,

we have seen, the inanimate agents, on the operation of which life depends, make their impressions. Those which impress the organs of the sensitive system excite only the functions by which our intercourse with the external world is maintained, and consequently may cease to operate without at all endangering life. But the withdrawal of the agents which excite the vital organs as certainly proves fatal as the loss of power in these organs themselves.

The operation of such causes is too simple to require any comment. It is evident that the want of food must destroy the digestive and other assimilating functions, that of air the functions of the lungs, and the loss of blood, to a certain extent, those of the heart and blood-vessels.

THE other causes, which belong to the forms of death I am now to consider, operate in a manner analogous to the offending causes which make their impression on the organs of the sensitive system; for although the vital organs are not subject to the same species of exhaustion with those of the sensitive system*, like them they may be debilitated either

* See the paper *On the Nature of Sleep.*

by the excess of the stimulant, or the more direct, effect of the agent, according to the degree in which it is applied. The excitement of fever terminates in debility of the heart and blood-vessels, or where the cause is more powerful, as we see in the worst forms of typhus, it may directly impair their powers; and similar observations apply to the effects of the offending cause on all the other vital organs. Although such are uniformly its effects on the parts on which it operates, its effects on the system in general, in consequence of the sympathies of our frame, admit of greater variety. These also may be divided into two classes.

In considering the second of the forms of death in which the impression of the offending cause is confined to the organs of the sensitive system, it appeared that when it is both violent and sudden, it immediately, in consequence of the sympathy of the sensitive and vital parts of the brain and spinal marrow, and the influence of the latter on the heart and blood-vessels, destroys the circulation*; whereas, when less powerful, it proves fatal, not only more

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* Philosophical Transactions for 1815, and Experimental Inquiry, Part II. chap. ii.

slowly, but also in a different way. A similar observation applies to the causes of death which make their impression on the vital organs; for the circumstance of their being more or less violent and sudden, or making their impression on an organ more or less immediately essential to life, not only renders their effects more or less sudden, but essentially influences their nature.

When the cause affects an organ immediately essential to life, and is of such power as at once to destroy its function, death, depending wholly on the loss of that function, may be instantaneous; but when the cause operates less rapidly, or affects organs less immediately essential to life, death is not only more protracted, but the various causes of continued irritation which attend derangement of the vital, influencing the state of the sensitive system, it often arises as much from the impression made indirectly on the organs of this system, as on those to which the cause is applied, and sometimes more so. Thus, any cause which suddenly destroys the function of the heart or lungs, at once proves fatal, and the cause of death is simply the loss of a function immediately essential to life; but a loss of function in the intestines produces, not immediate

death, but a series of causes of irritation, which exhaust the powers of the sensitive system, and death arises as much from this cause as from loss of function in the seat of the injury. Thus a blow on the stomach may instantly prove fatal by the impression it makes on the vital parts of the brain and spinal marrow without producing any other cause of derangement*; but the inflammation of that organ, by the torture it occasions, often exhausts the powers of the sensitive system, before the inflammation has time to run the course that would prove fatal by its effects on the stomach itself.

We observe the same thing in a more remarkable degree where the organ is still less immediately essential to life, and the disease consequently is more protracted. It is in this way that stone in the bladder proves fatal. If such local mischief do not occur as disturbs the usual course of the disease, life terminates in the same way as from torture, only more slowly as the suffering is less severe and continued, that is, in a morbid debility of the powers of the sensitive system, more or less, according to circumstances, affecting the vital parts of the brain and

* Philosophical Transactions for 1829.

spinal marrow, and the last symptoms, as in cases where the cause of the disease makes its first impression on the sensitive organs, are those of nervous apoplexy.

In this way death from causes of injury, making their impression on the vital organs, often approaches very nearly to the nature of the other forms of death which have been considered; and in almost all instances, with the exception of the most sudden, this is more or less the case; and consequently many of the observations made respecting the other forms of death, apply to the form I am now considering, particularly those relating to the gradual diminution of sensibility and perversion of taste which so generally precede, and more or less reconcile us to death.

I have already had occasion to observe, that even in some protracted cases there is little of this tendency. This, of course, is most apt to happen where the sensitive system is least affected, and therefore where the cause of injury makes its impression on vital organs of little sensibility,—on the lungs, for example, organs of peculiarly dull feeling,—a wise provision, for the air is so variously impregnated, and in so many ways which it is impossible to guard against, that, were their sensibility acute, we should

be exposed to constant causes of irritation. It is probably from its being so little so that, of all our organs, their sensibility is least apt to be increased by disease, the common effect of continued irritation. Those who have been troubled with carious teeth know how sensible the gums, parts of comparatively dull feeling, often become in disease. Even the most severe inflammation of the lungs may exist without pain, although the difficulty of breathing, cough and fever, which attend it, sometimes exhaust the feelings as much as pain. In its more chronic forms, however, it is often but little distressing even in these ways; and I have seen a few cases of pulmonary consumption, in which the sensibility and relish of life continued so entire, long after the patient was sensible of his approaching end, as to produce a state of mind peculiarly distressing, differing but little from that of those who look forward to what is called a violent death. This, however, is rare. In all serious and particularly tedious illness there is generally sufficient bodily suffering and perversion of taste, more or less, to blunt the sensibility, and in some measure to wean the patient from the love of life; and we generally find the grief and agitation on the part of the relatives, and on that of the

patient, a degree of indifference and composure, which those who have only experienced the feelings of healthful vigour are at a loss to comprehend. Even the dread of death at length prepares us for it. The feelings of the criminal who is hanged on the instant are those of horror; of him who has languished in prison, of resignation.

But of whatever kind and degree the previous suffering may be, and by whatever cause produced, the last act of dying, in the common sense of the word, is still but the extinction of the sensibility, and consequently the termination of all suffering; and, as might from its nature have been foretold, so calm in general is this last act, that the most anxious observer often finds it impossible to ascertain the moment at which it takes place.

The circumstance which has given rise to our notions respecting the sufferings of our last moments is, that in certain diseases there is a convulsive action of the muscles at the time at which the sensibility is extinguished. But these are not acts of volition. The laws of our nature tell us that they are not the effects of suffering; and we never see in the patient any indication that he suffers. They are of the same nature with the convulsive motions of the epileptic,

of which he is wholly unconscious. Were they indications of a struggle of feeling, necessarily connected with the last act of dying, as has been supposed, they would be a constant symptom; whereas they only occur under certain circumstances of the constitution or the disease. One of the least painful of violent deaths is that from loss of blood; yet here this struggle very uniformly attends the last act of dying, according to the common acceptation of the term; and it is evident that here the sensibility, in consequence of the failure of circulation, is almost extinguished before this involuntary action of the muscles takes place*.

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* It may appear at first view that our condition would have been improved had we not been endowed with the sensibility which often renders disease so great an evil; but in the same proportion as our ease would have thus been consulted, our danger would have been increased. It is by the quick sensibility of our frame that we are warned of a thousand dangers, and enabled to guard against them. Such is the imperfection of our present state, that we enjoy few advantages which have not occasionally their accompanying evils. But there is no instance but that of sleep, which is rather an imperfection than a positive evil, in which the evil necessarily exists: and thus we have reason to believe that the sum of enjoyment is the greatest of which that state admits. The species is protected at the expense of the individual.

It is generally supposed that the struggle of the criminal after the drop falls is the measure of his sufferings. The most vigorous necessarily suffer most, because in them the sensibility is with most difficulty extinguished; but it is not uniformly in them that this struggle is greatest. We have reason to believe that it is little, if at all, connected with the feelings of the sufferer. All such convulsive motions are of the same nature with what is called *subsultus tendinum*, so apt to occur in fever, even while the sensibility is little, if at all, impaired, but which gives no uneasiness but what arises from the motions of the limbs it occasions.

The causes of disease under various circumstances must act more or less interruptedly. In some cases their operation wholly ceases, and is renewed at intervals, causing the disease to intermit. There is a principle in the animal body on which the cure of all diseases depends, termed by writers the *vis medicatrix*, in consequence of which the more immediate effects of the offending cause are followed by others which tend to counteract them. If the surface of the bowels, for example, be irritated, a more copious secretion of their fluids and an increase of the peristaltic motion are excited, by which the irritation is

relieved and the cause of injury expelled; and although there are few cases in which the operation of this power is so simple as in this instance, in all diseases its effects may more or less be observed, and a great part of the object of medical treatment, as far as the nature of the disease is understood, is to assist and regulate its operations*. We find even in those diseases which are of the most continued form, partly from its operation and partly from the cause of the disease acting more or less interruptedly, more or less evident remissions. Hence, and from a thousand accidental circumstances which influence the course of disease, and many of which it is impossible to trace, we find in diseases of contin-

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* Here, as in other instances, that imperfection of our present state, which we have reason to believe inseparable from it, appears. Nature, for example, relieves inflammation sometimes by exciting discharges from the inflamed part, sometimes by the process of suppuration; but she still employs the same means, although the effusion or suppuration by which the inflammation is relieved, from the nature or situation of the part affected, generally proves fatal. Such is the case in croup, the disease termed internal water of the head, inflammation of many vital organs, &c. In these cases it is the object of the physician to cure the inflammation by artificial means before it has time to run to such terminations. In other instances as, in some external inflammations, his object is to promote these operations of the *vis medicatrix*, as the least injurious way of removing the disease.

uance, that at one time the stimulant, at another the sedative, effect prevails. Thus the sufferer appears at one time to be sinking, and at another to revive, without our always being able to trace the cause of such variations. All this the complicated nature of the animal body, and the various ways in which it may be influenced, would lead us to expect. We might also be led to expect that it would sometimes happen that when the excitability is nearly exhausted, such a cause of excitement might under certain circumstances occur as would suddenly exhaust that which still remains, and thus, by causing a sudden but temporary revival, prove the prelude to death. Hence what is termed a lightening before death, on which so many superstitions have been founded. This is seldom strongly marked. That it occasionally is so, we have sufficient evidence, and that it should be so, is perfectly consistent with the laws of the animal economy; but it will appear from what has been said, that, like the convulsive motions I have been considering, it has no essential connexion with the act of dying, and is not the consequence, but the cause, of its immediate approach.

Before I proceed to the last part of the subject, namely, the order in which the nervous and muscular

functions cease, on which a very few remarks will be sufficient, I shall shortly recapitulate the leading features of the different forms of death, without recurring to the other parts of the subject, which are too numerous to admit of recapitulation; and make such additional observations as the recapitulation suggests.

WE have seen that the forms of death,—for, as I have already had occasion to observe, the whole operation of the causes of decay in strict language constitutes the act of dying—may be arranged under five heads.

1. The only natural death, that from old age, where all the powers of life, in consequence of the operation of the agents which excite their organs, gradually decline, and death is only the last sleep, characterised by no peculiarity, in which these powers, partly from their own decay, and partly from the lessened sensibility increasing the difficulty of restoring the sensitive system, become incapable of this office, in consequence of which the individual awakes no more; for it is to be recollected that it is not in the commencement, but in the progress of the last sleep that what we call death takes place. In its

commencement we have seen, the sleeper may always be roused by stronger stimulants than those which preceded it.

All the other forms of death, it appears from what has been said, may be regarded as more or less violent, some adventitious cause disturbing the natural process. They were divided into two classes, in the one the offending cause makes its impression on the sensitive, in the other, on the vital organs. The former were divided into those cases in which the debility which precedes the total loss of sensibility arises from the excess of the stimulant operation of the offending cause, and those in which it is the direct effect of that cause; the latter into those cases in which the vital powers fail in consequence of their organs being deprived of the stimulants which excite them, and those in which the offending cause makes its impression on these organs themselves, the power of which, analogous to the operation of the offending cause on the sensitive organs, is destroyed, either by the excess of its stimulant, or its more directly debilitating operation, according to the nature or degree of that cause. Thus are induced,

2. The death which in its nature most nearly resembles the death of old age, that from excessive

exhaustion of the sensitive system, from the operation of stimulants of greater power than this system can bear, notwithstanding the intervals of such imperfect repose as their continued operation admits of, without the supervention of disease; which, not being capable of relief from the continued action of the vital parts of the brain and spinal marrow, by sympathy spreads to them, the affection of each system increasing that of the other, till all the powers of the sensitive system are destroyed.

3. The death in which disease of the sensitive system arises, not from causes over exciting, but directly debilitating it; the debility they produce, being of the same nature with that from excessive excitement, and running the same course as in the second stage of the preceding form.

4. The death which arises from the privation of the natural stimulants of the organs of life; and lastly,

5. That which arises from diseased states of those organs, analogous to the states produced in the organs of the sensitive system by the causes which make their impression on them.

IF the foregoing include all the modes of decay,

the physiological nature of death, in its various forms, is referable to very simple principles. In the natural decay, the excitability of the organs of both the sensitive and vital systems is gradually impaired by stimulants, which, whether existing within our bodies or making their impression from without, belong to inanimate nature; for it is by the impression of such stimulants alone that the functions of life are maintained. In the different kinds of violent death, with the exception of the death which arises from a failure of the natural stimulants of the vital organs, which is comparatively rare and extremely simple in its nature, we find the excitability of one or both of these systems, or some parts of one or both of them, capable of influencing all the others, more quickly destroyed by the continued operation of causes which either stimulate beyond the limits of health, or applied beyond the limits of their stimulant operation, destroy the powers of life, either by directly destroying the powers of the sensitive system or depriving it of those powers by which it is maintained. All these causes, it is evident, tend to the same effect, the extinction of the sensibility, which constitutes death according to the common acceptation of the term, the immediate

cause of which, therefore, exists in the sensitive parts of the brain and spinal marrow.

Thus it appears that, in every instance,—for it will be found, I believe, that there is no case of death which may not be referred to one of the foregoing heads,—what is called death and the loss of sensibility are one and the same, and therefore that the last act of dying can in no instance be an act of suffering; and this we have seen confirmed by direct observation, as far as the observation of the bystander can confirm it; to which may be added the experience of the sufferer himself, because those who, from submersion or other similar causes, have passed that portion of the act of dying where suffering can alone take place, and who have, as above explained, been in the common sense of the word dead, and in consequence of the degree of vigour still remaining in the vital organs restored by inflating the lungs, declare that they had been sensible of no suffering but such as arises from a less degree of the same cause which in them had wholly extinguished sensibility: an observation well illustrated by the circumstance, that those who are restored by artificial respiration, and could not have

returned to life without this aid, and those whose breathing, not having been long enough suspended wholly to destroy the sensibility, and who consequently, although to all appearance equally insensible, in a short time after the cause is removed, breathe spontaneously, give precisely the same account of their sufferings.

In those in whom the sensibility has been extinguished by submersion, it is in the first part of the process by which they recover, not in the last part of that by which they lose it, that they suffer, which it is not difficult to explain.

In the latter the sensibility is almost lost before it is wholly so. The apoplectic who has still feeling enough to breathe, who may still be roused to remove the extreme cause of suffering which the want of a supply of air in the lungs occasions, may be insensible to all other causes of exeitement; for, in proportion to the immediate importance of that supply, is the feeling which impels us to obtain it. We have instances of the hand being voluntarily held in the fire; but none, of the breathing voluntarily stopped till the lungs were injured. The circumstance of the breathing, independently of artificial means, being finally lost, is a proof that

the sensibility is wholly extinguished; and as its extinction in such a case must be more or less gradual, the capability of acute suffering, it is evident, must be lost some time before the period at which the want of air in the lungs cannot even be felt.

In the act of recovery, on the other hand, the sensibility necessarily begins to revive before the vital organs perfectly recover their functions after so severe a shock. The sensitive, on its revival, thus finds the vital system still more or less in a state of disease, to which the former, as its powers increase, is every moment becoming more sensible; for while the powers of both remain, all derangement of the vital is felt by the sensitive system; a wise provision, by which we are warned to guard against causes of danger confined to the former.

IT will readily occur from what has been said, to those whom I have the honour to address, that under certain circumstances more than one of the preceding forms of death may concur. The first indeed, the death of old age, may be regarded as so far a combination of more than one of the other forms, that the cause makes its impression on both

the sensitive and vital systems; but its effects on both, as appears from all that has been said, are essentially different from those of disease.

In certain cases the cause of disease makes its impression on both systems, and then more than one of the last four forms concur. This I have already had occasion to point out necessarily happens from mechanical injury of considerable portions either of the brain or spinal marrow. When both systems are directly impressed by the cause of the disease, which is comparatively rare, it produces, as follows from what has been said, a combination of the third and fifth, or second and fifth forms, according as its effects are more or less sudden and severe.

SUCH in different cases is the varied course of our decay previous to the moment at which the sensibility is extinguished, emphatically called that of death, because it completes the decay of the sensorial powers, and leaves us only those which we possess in common with the vegetable world; for the vegetable, like the animal, can convey its juices, form its secreted fluids, and in some instances move its limbs, if proper stimulants be applied; an additional argument, it might be shown, if any were

required, for all such functions being the effects of inanimate agents acting on living parts.

After the removal of the sensorial functions, none remain to us but such as are maintained by the immediate action of those agents. Our bodies are hastening to be mingled with the matter of inanimate nature. They retain only those powers which immediately depend on its agents, and these are rapidly failing, because, for reasons which have been pointed out at length*, the due application of those agents in the more perfect animals cannot long survive the loss of the sensorial powers.

The power of organising the elements of inanimate nature belongs, and some have supposed exclusively, to the vegetable world; but as we see plants, the mushroom tribe, possessed of no organising power, and therefore, like animals, nourished only by matter already organised, some of the lower species of animals, on the other hand, seem to possess this power. Thus, it would appear that there is a class of animals and of plants in which the animal and vegetable, in this essential respect, exchange their

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* The first paper in this volume from the Philosophical Transactions for 1829; and Experimental Inquiry, Part II., chap. xi.

natures. As the animal becomes imperfect, and approaches the nature of the vegetable, the sensorial powers dwindle, and the lowest animals appear to extract their nutriment from air and water, which, being generally diffused, are at hand, and consequently obtained without any sensible effort on the part of the animal. His life, therefore, although not independent of the external world, is, like that of the vegetable, independent of any act of volition. As we rise in the scale of animals, the sensorial powers increase, and, in the same proportion, become more essential to existence. From those animals which obtain food without any act of volition, we come to those who can only obtain it by such an act, but who still without any act of this kind obtain the influence of the air, yet more immediately necessary to their existence. We arrive at length at the most perfect class, which can neither obtain food nor air, except by an act of the sensorium. In them the sensorial power is as necessary for the inhalation of air, as the ingestion of food. When sensation ceases, they as certainly cease to breathe as they cease to eat. Thus it is that in this class of animals the due application of the inanimate agents on which life

depends, cannot long survive the loss of the sensorial functions.

AS we have been enabled, by the aid of the experiments referred to in the foregoing paper, to trace the steps by which the sensibility in the various forms of death is extinguished, that is, of our decay up to that moment which has for very evident reasons obtained the name of death, by the same means we may with more ease trace the steps by which the remaining powers of life are extinguished.

AS the powers of life fail, we have seen, the first functions which cease are those which wholly depend on these powers. The others, being the results of inanimate agents acting on vital parts, continue as long as those agents are supplied, for the purpose of exciting their organs. The first of these powers which fails is evidently the power of the capillary vessels, because their function continues as long as any blood can be supplied to them from the larger arteries. The circumstance of the action of the capillaries only ceasing when the larger arteries are

empty affords a proof that the assimilating processes, without which their power would fail, are still more or less in a state of activity. These processes, we have seen, are immediately dependent on the vital parts of the brain and spinal marrow. The due mechanism of every part, it appears from direct experiment, depends on the action on the blood of the agent they supply. When the capillaries can no longer supply the blood on which it acts, it is evident that the functions of this agent must cease, and consequently that those parts of the brain and spinal marrow by which it is supplied, being thus deranged, their powers must cease also*.

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* In the first of any of the more perfect animals, unless the nervous influence be supplied from without, the rudiments of the organs which supply it and those of the sanguiferous system must have been simultaneous creations, because neither is capable of producing the other, the functions of each being inseparable from those of the other. But we have seen that it is a necessary inference from direct experiment, that while the vital principle is unimpaired, the powers of circulation, provided the blood be duly exposed to the influence of the air, are, with the aid of voltaic electricity, capable of all the assimilating functions. No other powers are required for the maintenance and growth of the animal body.

We have reason to believe that the vital parts of the brain and spinal marrow may, like the lungs, be inactive in the fœtal state, some other means in this state being employed to supply an agent, which after birth can only be supplied by them. Well-

These are the last of the powers of life which fail, and thus the body of the more perfect animal is left subject to the laws of inanimate matter. The first functions which cease are those of the sensitive parts of the brain and spinal marrow; the last, those of the vital parts of these organs.

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grown fœtuses, perfect in all their other parts, have been born without either brain or spinal marrow. The growth of such fœtuses must depend on the same causes as the growth of other monstrous productions in the uterus, namely, as far as relates to the brain and spinal marrow, on the powers of the mother alone, how applied it is impossible for us to say.

APPENDIX.

THE following pages are added because they show how much certain positions, in the preceding papers, have been misunderstood by some who pretend to judge of such subjects, and tend farther to illustrate those positions.

From the Medical Gazette for March 15, 1834.

IT would perhaps have been as well if Dr. Prout had not, in his Bridgewater Treatise, again brought on the carpet the subject of a late discussion. As, however, he has chosen to do so in his usual style, in the following passage; I feel myself called upon to make a few observations on this his second attempt to explain the process of digestion. I may observe, in passing, that it does not exactly appear why, in

this Treatise, he should have encroached on the department of another gentleman, so eminently qualified for the task, appointed to treat the physiological part of the subject, and thus given to his work the incongruous title "*Chemistry, Meteorology, and the Function of Digestion.*"

In page 512, he observes—

"We dwell on this point the more, because, from deficient recollection of what electricity is, and what are the living powers acting through the nervous system of animals, it has been maintained, nay, has even been endeavoured to be experimentally proved, that these nervous powers are identical with the powers of electricity. It is impossible to imagine a greater fallacy. Admitting that electricity, properly directed, could change the proximate elements of the food into those of chyle, can we imagine this principle to vary spontaneously its mode of operation, so as to produce the same chyle from every sort of aliment*—that electricity is an intelligent agency,

* So confused are Dr. Prout's ideas on the subject, that he does not perceive that it is in the formation of the gastric juice that voltaic electricity performs the function of the nervous influence in the living stomach. The conversion of the food depends on the operation of the gastric juice itself. Neither the nervous influence, nor voltaic electricity act on the food.

acting with a certain object? Besides, if the nervous agency be identical with electricity, how different must be its functions in different nerves; in one nerve, for example, digesting and assimilating the food; in another, conveying sight; in a third, conveying sound, in the brain itself shall we say actually thinking! As to the experiments on which it has been attempted to rear this untenable opinion, they prove nothing whatever, and are easily explained on other principles." But here, according to Dr. Prout's usual method, he considers the assertion sufficient, and adds, "Such explanation would be foreign to our present object, were we to introduce it here."

The facts ascertained by the experiments Dr. Prout here refers to, are—1, that the nervous influence is capable of passing through other conductors than the nerves, it having been shown that it is more or less capable of its functions after having passed through a space of not less than a quarter of an inch between the divided ends of the nerves which convey it; 2, that when the stomach is deprived of any considerable part of its nervous power, whether that supplied by the brain or spinal marrow, it is no longer capable of secreting the

gastric juice; 3, that when the lungs are in like manner in either way so deprived, they in a few hours not only become incapable of their functions, but their structure, being more evident than that of the stomach, in many parts is sensibly and wholly changed; and, lastly, that if under such circumstances voltaic electricity of a certain power be sent through the stomach and lungs by the lower portions of the divided nerves, as soon as the division of the nerves is made, and the upper portion displaced, the secretion of gastric juice, and the function as well as structure of the lungs, continue as perfect as when their nervous influence is entire.

It is a pity that Dr. Prout did not give his explanation; because, as he does not call in question the results of the experiments, the reader, I think, must have some curiosity to know how he makes the application of the observation just quoted—namely, "that they prove nothing whatever, and can easily be explained on other principles" than that of galvanism performing the functions of the nervous influence.

I think it will be admitted, after due consideration, that it would be difficult to find a passage in any treatise, which betrays a greater want of know-

ledge, and consequent confusion of ideas, respecting the subject it treats of, than that just quoted from Dr. Prout's publication. He here not only confounds together the sensorial and nervous powers, but both with the vital principle; and ascribes to those he censures the confusion which exists only in his own mind. By whom has it been asserted that any of the sensorial functions can be performed by voltaic electricity, or that it can maintain any of the nervous functions when the vital principle is extinct? I beg to refer to papers published in the Philosophical Transactions of 1829 and 1833, for my opinions on this subject; which Dr. Prout has either not seen or not understood, for I cannot suppose that he intentionally misrepresents them.

IN some instances, Dr. Prout has so modified his opinions, since the publication of his lectures, that certain passages in his present Treatise directly contradict the corresponding passages in them. In others he maintains, and endeavours to enforce, some of the most exceptionable of his former positions.

Thus, for example, in his lectures he observes, "In France, most substances are exposed, through the medium of oil or butter, to a temperature of at

least 600°, by the operation of frying, or some analogous process. They are then introduced into a macerating vessel, with a little water, and kept for several hours at a temperature far below the boiling point, not perhaps higher than 180°; and by these united processes, properly conducted, the most refractory articles, whether of animal or vegetable origin, are reduced more or less to a state of pulp, and *admirably adapted for the farther action of the stomach.*" In his present Treatise he observes (p. 509, speaking of French cookery), "In one respect, indeed, that of reducing to a state of pulp those refractory substances which we have before mentioned, the culinary processes of our neighbours are much superior to ours; but in nearly every other respect, and most of all in the use of pure sugar *or pure oil, their cookery is eminently injurious to all persons who have weak digestion.*" I had suggested to him, that the frying with butter, or oil, notoriously renders food indigestible. Other similar instances might be adduced, particularly relating to what he calls the organisation of the food.

What does Dr. Prout mean by different degrees of organisation? matter is either organised or unorganised. With what he says on this subject no

distinct idea can be associated, either in his own mind or that of his reader. It only contributes, with other inaccuracies, to the confusion which all who peruse either his Lectures or his Treatise must perceive.

But in the majority of instances we still find him straining to make the phenomena suit his preconceived opinions. Thus he still maintains that the reduction of food to a state of pulp renders it more digestible, although every common dyspeptic can tell him that the lean part of a mutton-chop, moderately done, is more digestible than any stew he could prepare for him; and, in p. 507, he ranks alcohol among the things of most difficult assimilation, although it is well known that is not only easy of assimilation itself, but for the time, perhaps, more than any thing else, assists in enabling the digestive organs to assimilate other things. He confounds the injurious effects of the habitual use of alcohol, which depend on the hurtful excitement it occasions, with a supposed difficulty in its assimilation. If Dr. Prout's opinions had not shut his mind against the simplest evidence, he would have perceived that, of all solids, the unreduced muscular fibre, and of all liquids, diluted alcohol, are the most easy of assimi-

lation. It is notorious that the latter can often be assimilated by stomachs which can assimilate neither wine nor beer, which he would persuade us is of so much more easy assimilation. The other properties of either animal food or alcohol are questions of a wholly different nature. We should neither recommend alcohol in diseased liver, nor a slice of mutton to a man labouring under fever; but it is certainly, neither in the one case nor the other, because they are difficult of assimilation.

Dr. Prout's theory is, unfortunately, as much in opposition to simple matter of fact, in what he says of sugar, as of alcohol; for every dyspeptic knows, that the purest crystallised sugar is more easy of assimilation than either soft sugar or molasses.

His present view of the digestive process is radically defective, in the same way as that given in his lectures. It is to the chemical part of this process alone that his attention is directed, the cause of many of his inaccuracies. His only attempt is to determine the effects of the secreted fluids on the food. On the manner in which the organs which secrete these fluids, and consequently the fluids themselves, are influenced by the different kinds of food, and other causes; and on the powers by which their due appli-

cation to the food is regulated; powers no less essential to the process of digestion than the chemical properties of these fluids themselves, and the derangement of any one of which, as we see in certain states of disease, deranges every part of that process, he is altogether silent; and consequently respecting the various circumstances which have been determined respecting these essential and most characteristic parts of the digestive process, by some of which design is more simply, and consequently more impressively displayed, than in the nature of things can be done by any of the chemical parts of the process. Where can design be more strikingly displayed than in the manner in which the gastric juice, with the exception of that part of it which is secreted previous to the meal, and when there is little else in the stomach, is so applied to the food, that every particular particle of food, however copious the meal, is equally exposed to that juice at the moment of its secretion; and, therefore, before it can be diluted, and thus its powers impaired by the other contents of the stomach, and with an accuracy which sets at defiance all the art of the most careful manipulator; and yet the means employed for a purpose apparently so difficult of attainment, are equally simple and effective. Since

as far as we may judge from the whole of the circumstances, Dr. Prout appears to have volunteered the appropriation of this part of the subject, he should have been particularly careful to fulfil in it the intention of the testator. He observes, that unfortunately cooks are seldom chemists—a circumstance, on the present occasion, less to be regretted than that chemists are seldom physiologists.

From the Medical Gazette for April 5, 1834.

On the Uses of the Gastric Juice, and the Substitution of Voltaic Electricity for the Nervous Influence.

HAVING been led, in reply to a passage in Dr. Prout's Bridgewater Treatise, to the subjects which form the title of the present communication, I beg to make a few additional observations respecting them.

I mentioned, as a prominent instance of the adaptation of means to their end, so strikingly displayed in many of the functions of the living animal, the manner in which the muscular power of the stomach is employed in the application of the gastric juice to the food.

I may now add, that such are the principles on which the supply of this juice depends, that the quantity supplied must always, in a healthy stomach, be proportioned to the demand for it, there being neither defect nor redundancy; and that its uses well illustrate the observation, that although in human endeavours many attempts often fail to effect one purpose, in the works of God, each arrangement not only

> "———— can its end produce,
> But serves to second to some other use."

The gastric juice is not only the immediate instrument by which that part of the digestive process which belongs to the stomach is effected, but (as has been proved experimentally) is the means of informing us both of the want of food, when a fresh supply is necessary, and, if we listen to its dictates, of the quantity required. Nor is this all, for its secretion being influenced by all those causes which would render a supply of food injurious, instead of beneficial, it fails, and with it the appetite, when the other processes of assimilation being suspended, the chyle prepared in the stomach would only prove a source of irritation; nay, the appetite, excited by the gastric juice, is so modified, as, under certain circumstances.

even to point out to us the kind of food at the time required, giving us, at one time, a high relish for the stronger kinds of food, and at another for the more cooling and less nutritious kinds; and it would be well if the dictates of the physician could with the same certainty be relied on.

If we can trace such proofs of design in the formation of, and the circumstances relating to, one secreted fluid, what conception can we form of the wisdom and power which would be displayed in all the functions of the living animal, so complicated, and yet so correctly adapted to their ends, if we had knowledge sufficient to trace all the workings of its Maker!

In endeavouring to elucidate the nature of the nervous influence, the first step was evidently to ascertain its functions, to distinguish its functions from those of the sensorial power, with which, in many instances, they are so intimately blended. For this purpose an extensive set of experiments was made, a detailed account of which the reader will find in my Experimental Inquiry into the Laws of the Vital Functions. It appears from these experiments that, besides the excitement of the muscles of

voluntary motion, universally acknowledged to be a function of the nervous influence, its functions are, the occasional excitement of the muscles of involuntary motion; the act of forming from the blood the various secreted fluids; that of supporting all the other assimilating processes by which the healthy structure of every part is maintained; and that of causing an evolution of caloric from the blood, for the purpose of preserving the due temperature of the animal body.

Having determined the functions of the nervous influence, we are prepared to ascertain whether there be any other power capable of all these functions, if made to operate under the same circumstances, that is, applied in the same way to the same parts, and while the vital principle is unimpaired.

Voltaic electricity, it had been found, is capable of exciting the muscles of involuntary as well as those of voluntary motion. And it appears, from the experiments referred to in my former paper, that it is not only capable of forming the secreted fluids from the blood, when applied in the same way, and under the same circumstances as the nervous influence, but of maintaining all the other functions on which the healthy stricture depends; and in both

instances, as far as we can see, as perfectly as the nervous influence itself.

These points having been ascertained, it only remained to determine, whether it is capable of causing an evolution of caloric from the blood. The determination of this point thus became an important object, because, if it be determined in the affirmative, voltaic electricity is proved to be capable of all the functions of the nervous influence. It appears to be so determined by experiments related in the Twelfth Chapter of the Second Part of my Inquiry into the Laws of the Vital Functions.

A circumstance occurred in the course of these experiments, which strikingly illustrates some of the statements in my former paper.

It is evident, that in determining the question before us, arterial blood must be employed; venous blood having already undergone the operation of the nervous influence, is no longer capable of any of the functions maintained by this influence, till its vital properties are renewed by the changes effected in the lungs. Arterial blood from a rabbit was received into a cup, placed in water of the temperature of 98°, namely, that of the animal, and the bulb of a very

sensible thermometer, and the wires from the opposite ends of a powerful galvanic trough—the wires being placed on each side of the bulb—were immersed in the blood, which had been in the cup about two minutes before the apparatus was adjusted. But although the appearance and consistency of the blood was greatly changed by the effects of the electricity there was no evolution of caloric; the thermometer even fell faster than that in another cup, the arrangement and contents of which were the same, with the exception of the galvanic wires. The experiment was then repeated in the following manner:—The cups being arranged as in the preceding experiment, and, in one, the galvanic wires placed as before, the same artery in two rabbits of the same temperature (98°) was then opened, and the blood allowed to flow into the cups; a thermometer, raised to 98°, being put into each of the cups at the moment the blood began to flow into them. One minute after the blood began to flow into the cup without the wires, the thermometer stood at 97°; in a quarter of a minute more—that is, a minute and a quarter after the blood had begun to flow into the cup—at 96°; and so on gradually falling; for it is to be observed, that although the cups were raised to 98°, the air in

them was ten degrees lower. One minute after the blood began to flow into the cup with the wires, the thermometer stood at 100°; in half a minute more at 102°; in half a minute more at 100°; and in half a minute more at 99°, in another half minute at 98°—that is, three minutes and a half after the blood had begun to flow into the cup. After this the thermometer continued gradually to fall. In this experiment the evolution of caloric, under the influence of voltaic electricity, had been such as to raise the temperature of the blood four degrees. In repeating the experiment on the blood of a rabbit, whose temperature was only 96°, the galvanised blood rose three degrees. It was possible that the great difference of result observed when the blood had stood two minutes in the cup, before the introduction of the galvanic wires, and when it was allowed to flow from the vessel upon the wires, although no change in its appearance had taken place, might arise from some elastic fluid having escaped previously to the introduction of the wires in the former instance. It was ascertained, however, by an experiment detailed in the chapter just referred to, that no elastic fluid is disengaged from arterial blood under such circumstances. From the whole of the circumstances,

it would appear that voltaic electricity fails to cause an evolution of caloric from blood which has been extravasated even for two minutes, for the same reason that it fails to excite the muscular fibre of an animal which has lain dead for a certain length of time; the difference of the length of time required in the two cases, only proving that the vital principle is sooner extinguished in the blood than in the muscular fibre. As we might have foreseen, it is here, as in all other instances, only where the vital principle remains that voltaic electricity can perform any of the functions of the nervous influence. On what principle could it be expected to perform those functions, unless in all respects made to operate under the same circumstances under which the nervous influence itself operates. It is not without surprise that we see so obvious a position overlooked.

It is evident that if voltaic electricity in the preceding experiments, operate on the same principle as the nervous influence, it should occasion no evolution of caloric from venous blood, which has already undergone the operation of that influence. On repeatedly exposing venous blood to the influence of

the wires, while it flowed from the vessels, no caloric was disengaged, the temperature of the blood being uniformly the same, whether the wires were employed or not.

THE END.

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