THE CAUSATION OF SLEEP

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With respectful Compts

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THE CAUSATION OF SLEEP.

A Physiological Essay.

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PREFACE.

THE following essay is divided into two parts. In the first I submit the views I entertain as to the physiological causes of sleep, without waiting to discuss in detail all those points on which a difference of opinion is likely to be held. This plan enables me to state my argument not only concisely, but more clearly than if I were to digress at every step to controvert the opinions of others when hostile to my own. To the second part are reserved what remarks I have to make on some points which have already been fruitful of controversy. I also take the opportunity here to make one or two objections to current views of the physiology of sleep, and especially to those which have been so ably advocated by Mr Durham.

I have only to add, that this slight contribution to the physiology of the brain is not to be taken for more than it pretends to be. It is not a treatise on the phenomena of sleep. In the writings of Carpenter, Holland, Hamilton, Brodie, Moore, and others, will be found abundant details that bear on its natural history. I confine myself strictly to its causation; and in doing so I, of course, consider it entirely as a physiological question. However imperfect may be my conclusions, I claim for myself honesty of purpose in maintaining them, and in believing that they differ sufficiently from those of other writers to warrant me in submitting them to the attention of physiologists.

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PART I.

FROM whatever point of view we regard the phenomena of sleep, we are soon led to perceive that they can only be adequately considered in connection with questions that bear on the physiology of the brain. In this respect there is a great contrast to the study of many of the phenomena that present themselves during wakefulness. All the higher moods of mind—the various modes in which the activities of thought and will can impress themselves on the consciousness — may be noted, and their nature and relations speculated on, without any reference being made to an apparatus the condition of which can limit and modify their existence or manifestation. The active, healthy mind likes to believe in its own freedom. It is not immediately conscious of those organic conditions which favour or impede its activity, and limit the scope of its operations. But sleep illustrates the tyranny of physical conditions. It is a state, therefore, whose existence is almost ignored by the metaphysician. The feeling of drowsiness may be painfully or pleasantly experienced, but so soon as sleep has fairly asserted its supremacy, the higher consciousness which recognises existence and succession is suspended. Its characteristic phenomena are to be studied, not by self-introspection, but by external observation. If its causation be the object of inquiry, that is to be determined, as in the case of the simplest phenomenon, by an analysis of the agents and forces concerned in its production, and by ascertaining, as far as may be, their usual steps of combination and sequence.

I at once assume the correctness of certain general views in regard to the physiology of the brain. As during the state of alert wakefulness the mind can be readily directed into whatever channel circumstances may require, and the consciousness may in succession be engrossed by impressions on sensory nerves, or by efforts of imagination, or reason, or voluntary motion, so, in the same circumstances, the brain is functionally active; each portion of its mass is ready to respond to its appropriate stimulus, and to take on itself its special duty. Then, as during the continuance of sleep the consciousness of external impressions is obscure or altogether lost, and as the power to perform any intelligent mental act is suspended, so, during the same time, the brain ceases to be able to perform its characteristic functions, and this on account of some physical change in its structure or relations.

What this physical change may be—or at least certain of its elements—is the object of our present inquiry. I leave the metaphysics of sleep entirely out of view. Whether, as Sir William Hamilton and others insist, thinking goes on in the soundest sleep,—or whether, as physiologists are inclined to believe, dreaming or thinking even of the most nebulous sort indicates imperfect sleep, will not be discussed. The questions I intend to keep before myself are:—In what respect do the condition and action of the brain or its relations, during the continuance of sleep, differ from those which are present during wakefulness?—what is the physiological sequence of change from the one state to the other, and on what special change do the more characteristic phenomena of sleep depend?

In entering on such an inquiry we are at once confronted with an extensive series of conditions or factors,—organs, structures, processes, forces,—each taking a part, direct or more remote, in producing the final result. Some of these conditions belong to questions of general physiology, others are strictly special or local. Before the causative sequence of changes can be comprehended or intelligibly expressed, the more important of these must previously have received individual recognition. Of course, I cannot here enter into the whole cyclopædia of subjects involved in the anatomy and physiology of the brain. A selection must be made. I shall have a special position to take up, and in arranging my arguments, or in giving prominence to particular points, I am at liberty to assume the privilege of the special pleader, and to choose such as may appear best fitted to exhibit and support that position. Any other plan would be unsuitable for an essay like the present. The results or conclusions are to be judged, on the one hand, by their harmony with the greatest amount of recognised fact; and, on the other, by the extent to which they afford a satisfactory explanation of special phenomena.

If our knowledge of physiology were perfect, it might be possible to undertake at once a systematic exposition of the various conditions involved, to specify the laws affecting their successive changes, and, by a series of inferences, to arrive inevitably at the last result we are aiming at—the production of sleep. Our knowledge, however, is on many points too general or too uncertain to allow this natural method of procedure to be carried out. We must content ourselves with a less direct mode of reasoning, and certain steps of the process may, in the first instance, appear rather hypothetical. The following is an outline of the argument I intend presently to pursue.

In the first place, proof can be afforded that if the surface of the brain be subjected to pressure the consciousness is so suspended that some of the more characteristic phenomena of sleep are produced. In the second place, we may find a (hypothetical) source of pressure in the venous vessels which, large and tortuous, are spread over the whole surface of the brain. These simply require to become more distended with blood in order to act as compressing agents. Then, to show how this possible source of pressure can be brought into play, I shall have to consider some special circumstances in the physiology of the brain. Unless the latter is to afford an exception to a very general rule, it is to be assumed that during functional activity—that is, during the period of wakefulness—its capillary circulation must be most active, and the expansive tendency of the organ as a whole must be at the greatest. The veins, therefore, must have their calibre reduced to a minimum. But in accordance with another general law the nutritive energies must, by-and-bye, begin to flag. As this occurs so must the forces which keep up an active state of the circulation become languid. In other organs this state is accompanied by collapse or contraction. As the skull is rigid, and as its cavity must be constantly full, any collapse of the brain must be accompanied either by an accumulation of cerebro-spinal fluid in and around it, or by an increased proportion of blood in the veins. I shall endeavour to show how the intra-cranial mechanism is peculiarly adapted to favour the latter occurrence. The pressure of the atmosphere here is directed, not, as in other parts of the body, on the external surface of the vessels, but on their internal surface. Its tendency is to retain the blood within the cranium. The movement of that fluid in the veins of the pia mater goes on, therefore, under opposing physical forces. There is the forward impulse of more blood caused by the action of the heart and the capillary forces; opposed to this is the weight of one atmosphere transmitted through the sinuses of the dura mater; and, as an intermediate resisting force, there is the support on the external surface of the vessels afforded by the structures of the brain. The atmospheric pressure is a tolerably constant quantity; the support outside of the vessels is a varying one. To find what will be the result we have only to apply the law of greatest effect being produced in the direction of least resistance. We have seen that in certain circumstances the capillary forces within the brain become weakened. Simultaneously, and as the result of this, the support to the surface veins is relaxed. When the support is relaxed, the atmospheric pressure must bear with greater effect and distend the veins. Lastly, if distension occurs in the veins, the grey matter is subjected to an altered form of pressure ; it is less from within and more from without. This takes us back to the proposition with which we started. Such pressure from without is incompatible with continued activity of function —psychical phenomena must, for the time, cease to be manifested—sleep is induced. To give more detailed exposition and defence of these views is the object of the present Essay.

In searching for the explanation of any complex process, the natural method, and the simplest, is first of all to explain the more characteristic of its phenomena individually, or single steps of the process. If these individual explanations be correct, the series will naturally fit into one another, and harmonise into one consistent theory. In setting about to accomplish this end, the mind must have free scope at every step to search about for analogies, and especially for any such instance where an adequate or plausible explanation can be given. The same plan may be adopted in theorising about sleep. Therefore, taking simple unconsciousness as a prominent phenomenon, we may consider in what other conditions this is present, and whether its occurrence in these has received a satisfactory explanation.

A state of unconsciousness, more or less deep, is present in all the varieties of coma. This condition differs from sleep in the circumstance that ordinary means are insufficient to bring back a state of alert wakefulness. The psychical phenomena are those of sleep in an exaggerated degree. The breathing and circulation are often oppressed, yet not necessarily; but sensation, intellect and voluntary motion are suspended.

The important point in regard to coma to which I wish at present to give prominence, is the fact that, in many instances, the mental state is traceable to a particular alteration in the condition of the brain. Its symptoms may be produced by whatever causes pressure to be directed on the latter organ. I do not need to inquire whether pressure can be proved to exist in all cases of coma. For my present purpose it is sufficient that, in pathology, the experience of both surgeon and physician gives ample evidence to the efficiency of pressure on the brain to suspend the consciousness, and to keep all evidence of mental activity in abeyance. If a portion of bone be depressed in fracture of the skull, if a clot of blood, or a layer of serous fluid be rapidly thrown out on the surface of the nervous structure, the immediate effect is deep and more or less protracted insensibility.

Here then we have got one point in which a direct relationship can be proved to exist between a particular physical condition of the brain and the occurrence of unconsciousness. Doubtless, the coma produced by a clot of blood differs very widely from ordinary sleep. But for the purpose of illustration it is not identity of condition we are to look for. We are simply to consider whether the admitted explanation of a special symptom in the one case can give any clue as to the direction in which to look for a possible explanation of a like phenomenon in the other. It may afford a convenient standpoint until we determine whether any likely path leads from it towards the goal we wish to arrive at. Our next duty, therefore, is to look about for some structure which may possibly act as a pressure-producing agent.

I have already hinted that the venous vessels within the cranium may prove a possible source of pressure. When the dura mater is raised from the brain, the most striking object which presents itself is the mass of dark coloured, tortuous vessels that lie coiled in the meshes of the pia mater. They are supported on the surface of the brain, in close contact with the latter organ, and yet fairly outside of its substance.

Among the many peculiarities of the circulation within the cranium, not the least remarkable is the fact that the circulation of the brain is entirely capillary. Scarcely a single vessel that penetrates its mass can be traced in its course with the scalpel. The arterial vessels divide and subdivide outside the nervous substance, and lose themselves in the fine capillary network of the pia mater. This is a membrane of curious structure, and is most appropriately named. Tender as an organ of protection, it is rich and generous as a source of nourishment. Through its vessels is transmitted all the blood which goes to nourish the brain. When it is gently raised, fine hair-like vessels, so delicate that they break with the slightest traction, are seen to go from its inner surface and to penetrate the brain. Not only, however, do the vessels of the pia mater convey arterial blood, but, like the placenta in fœtal life, they also receive back that of the veins. The latter vessels from the brain join those of the pia mater in a state of capillary minuteness, then coalesce to form larger and larger vessels, until, before they empty themselves into the sinuses of the dura mater, their size is considerable.

In all parts of the body the calibre of the veins is, as a rule, very much greater than that of the arteries which they accompany or correspond to. This is remarkably the case in the circulation of the brain. While the larger arteries are limited in number and widely separated, the veins of noticeable size are scattered over the whole surface of the organ, and lie in fine coils between the convolutions.

In speculating on the veins as a source of pressure, three points are specially to be noted. In the first place, if we take the vessels at any point of fulness, this cannot be over-stepped to the slightest extent without affecting the pressure on the brain. It is at once evident that the dura mater, backed by the hard cranial wall, cannot be in the least affected by the ordinary physiological causes of distension. The only texture that can yield is the nervous structure on which they lie, and yield this must if the fulness of the veins be increased from any cause whatever.

In the second place, the portion of the brain that would be more immediately affected is that part on which the functional capacity of the organ immediately depends. A distinction is usually made between the force-producing and the force-conducting elements of the brain. The production of nervous force lies principally, if not wholly, in the grey or cineritious matter; while the function of the white or fibrous structure is restricted to conducting those influences, physical or psychical, with which the brain is concerned. Physiologists are also at one in believing that the layer of grey matter which covers the cerebral lobes is more immediately related to the performance of intellectual operations. If spread out on an even surface, this layer would cover a body many times larger than the brain itself. To economise space and to concentrate energy, it has been arranged in folds or convolutions. The pia mater is in close contact with the whole of this surface. It not only covers the latter as seen when the dura mater is removed, but it dips to the bottom of every fold, and separates the layers from one another. When the convolutions are gently separated, it is seen to lie like a fine velvety pad between the opposing surfaces. Therefore, whatever physical influence the veins may be capable of exerting must be immediately directed on this layer of grey matter. The slightest alteration in the bulk of their contents must inevitably modify the pressure to which it is naturally subjected.

In the third place, in modifying the pressure on the brain, the veins themselves must be regarded as absolutely passive. Their walls are said to be even more destitute of elastic fibre than the veins in other parts of the body. Any mechanism for altering their volume must be looked for outside of themselves.

The next step of inquiry, therefore, is to consider in what manner the ordinary physiological changes in the brain can affect the circulation of blood in the veins of the pia mater.

This leads us to notice, in the first place, a principle that applies to the circulation in all parts of the body; and, secondly, the operation of this principle in the peculiar physical conditions that are present within the cranium.

The principle to which I refer is embodied in the old aphorism, '*ubi stimulus, ibi affluxus.*' As it is the object of the circulation to convey material of stimulus and repair to the various organs, and to remove waste, and as the need for such material differs very greatly according as the organ is quiescent or functionally active, some mechanism might appear to be necessary for so regulating the supply of blood to individual parts, that this shall be made to correspond to the demand. And we find this to be the case. For example, when the mammary secretion is being established, the afflux of blood to the gland becomes several times larger than when its function was dormant. When the mucous membrane of the stomach is stimulated and the secretion of gastric juice begins, the surface becomes intensely injected with rapidly moving blood. In short, wherever growth, and especially where the transformations that accompany functional activity go on with greater activity than usual, there is an increased determination of blood towards and through that part.

It is not necessary for me to explain the mechanism by which this is accomplished. Whether an attraction at the capillaries is the immediate and by itself efficient cause, or whether, in addition, a nervous influence acting on the feeding vessels must assist to determine the afflux of blood, and so to stimulate those changes which go to create the attraction, I need not decide. I have only to insist that there is a necessary relation between the one phenomenon and the other. The physical changes which accompany combustion are sufficiently analogous to afford us an apt illustration. When combustion in a furnace is languid, the draught of air through it is weak, or artificial means may be necessary to sustain it. But if the [chemical actions be brisk, so also is the current of air. This is drawn with some degree of force from one direction, and it is more or less rapidly urged onwards in another. Other things being equal, the strength of attraction, or the velocity of the current, will be in proportion to the amount or rapidity of the act of combustion. So, in nutrition, the greater the amount or rapidity of change in the organic molecules, the more strongly is blood attracted to the part, and the more quickly does it circulate through the capillaries.

When this occurs in a cluster of vessels, an obvious result must be an increase in the absolute amount of blood in the part, and, therefore, an increase of bulk in the whole texture or organ. More rapidly moving blood must necessarily press more strongly against the walls of the vessels, and the amount of dilatation may be limited only by the capacity of the tubes or the support which these receive on their external surface.

I have mentioned that within the cranium this principle operates in peculiar circumstances. To one of these peculiarities, and to some results that immediately depend upon it, we have now to give attention.

The cavity of the cranium differs from the other great cavities of the body in having its amount of space rigidly fixed. In the chest and abdomen changes are constantly occurring in the bulk of their contents, and their elastic or pliable walls are enabled at once to adapt themselves to every such change. But the firm bony structure of the cranium cannot be altered without physical violence. The bulk of its contents must therefore continue absolutely the same—that is to say, within such periods of time as the ordinary growth of the bone shall not materially affect its size.

A curious result of this fixed capacity on the part of the cranial cavity is that the quantity of blood within its vessels at any moment must be wonderfully uniform. I do not say it must remain absolutely the same—indeed it is probable that material changes do occur. But the amount of change that can take place in a limited period of time must be extremely small, and can only occur along with a reverse change, to a corresponding extent, in one or other of the remaining contents of the cranial cavity. We may conveniently consider these contents to be constituted by the brain tissue, the blood, and the cerebro-spinal fluid. The fibrous structures may be left out of view, as a lengthened period is necessary to affect their bulk. It is obvious, then, that no change can occur in the quantity of any one of these without that of the others being at the same time affected. For example, if the solid nervous structure be increased, the fluids must be diminished; if the blood be augmented while the solid structures remain unchanged, there must be decrease in the cerebro-spinal fluid—if any two of them remain unaltered, the third must also continue unaltered during the same period.

So long, then, as the brain substance and the serous extra-vascular fluid continue unchanged, the absolute volume of blood in the intra-cranial vessels must remain the same.

In regard to the nervous structure, we find time to be a necessary element in producing any change on its bulk. Of course, it is certain that during active exercise the destructive predominate over the constructive operations, and as this goes on some compensation must be made by one or both of the fluids being augmented; still, time is necessary for this. Nutrition and waste are, on the whole, so nicely balanced that an immediate decrease of bulk can hardly occur. Nor does it appear that the cerebro-spinal fluid can become suddenly altered in quantity. It cannot be raised from the spinal canal without some other fluid taking its place there. Its function is to afford equalised support to the more solid structures, and its quantity will remain uniform until some disturbing influence interferes with the balance of support. According as this is lessened or increased will it readily be transuded from or absorbed into the blood vessels.

We may assume, then, that in short periods of time very little alteration can take place in the total amount of blood circulating in the vessels within the cranium. This does not interfere, however, with endless changes in the local distribution of blood within the cavity itself. For example, the anterior lobes of the brain, or any one of the encephalic ganglia, may receive at one time more, and at another time less blood. But it may be positively affirmed that if any particular set of vessels be made to receive more blood, it can only be by draining the vessels of some other part of the cranial cavity.

In the eye of science scarcely any change can be said to be more wonderful than another. The magnitude or unexpectedness of results may in some cases be more impressive than in others, but everywhere the mystery of immediate causation remains equally inscrutable. Yet, if the feeling of wonder be permitted in any case, it may well be indulged in when contemplating the change from sleep to wakefulness. The world of consciousness is quickened anew: intelligence takes the place of chaos; and reason and will, from being spell-bound, become potent for infinite good or for infinite mischief.

To this immense psychical change the brain is intimately correlated. Its special function as a part of the animal economy is called into active exercise; its structures are raised to a state of tension, and they are ready to respond to stimuli from without or from within.

Among the conditions which accompany this state of tension, one of the most necessary, unless the brain is to prove an exception to a general biological law, is an increased circulation through its vessels. Its capillaries will be flushed with rapidly moving blood; pressure from within is thus augmented, and, unless mechanical obstacles prevent, its absolute bulk as an organ must be increased.

That there is this decided tendency to expansion is well known to the surgeon. In those cases where a part of the cranial wall has been lost as the result of injury, and the behaviour of the brain can to some extent be noticed, this fact has been constantly observed. During sleep the brain appears to retire or sink; but immediately on the patient awaking, it expands. The exposed part rises into the opening in the bone, or even protrudes beyond it.

But how can this expansion of the brain take place while the cranial walls remain entire. I have just been insisting not only that the cubic bulk of contents cannot be altered, but that even the amount of blood must be extremely uniform. It is certain that no physiological force can immediately distend the skull. How, then, can any room be gained for the brain to expand?

There appear to be two possible ways in which it may be done. In the first place, the cerebro-spinal fluid may to some extent be dislodged; or, secondly, room may be got simply by the balance of the encephalic circulation being altered. I believe the latter is the principal, if not the only, method by which the brain gains room, and a glance at the relative position of parts may enable us to see how.

It has already been noticed that the circulation of the brain is mainly capillary, but that masses of large veins lie coiled on its surface and between the convolutions. Now it must be on these veins that pressure from within the brain must be first directed when there is any tendency in this organ to expand. When the cerebral lobes are roused, the greatest activity is at their circumference, or in the layer of gray matter. It must be in this surface, therefore, that the vascular erythism must be greatest. The veins lying upon, yet fairly outside of the brain, must be the first point on which pressure will be directed, and, unless the active brain requires these as well as the arterial vessels to be distended to their full extent, they must necessarily be compressed and their calibre be reduced.

On the other hand, in the healthy brain, and especially in young individuals, the amount of extra-vascular serum is very small,—it lies in limited spaces at the base of the cranium or in the ventricles, and the force necessary to dislodge it from these can only be produced by the reaction of the brain circumference against the inner surface of the dura mater; —that is to say, it would be only a surplus force continued after the veins have been reduced to a minimum extent of compression. Then, as the vertebral canal is already full, and as its capacity is as fixed as that of the cranium, it can receive nothing from the latter unless some other fluid is dislodged from its own cavity. The veins here must be reduced in calibre, and thus a round-about process would be required to accomplish what may be done directly. These points, however, will be better understood when they are looked at from another point of view, which we shall immediately have occasion to do. In the meantime, I only wish it to be assumed as a possibility, that the capillary circulation of the brain can be increased by the amount of blood in the surface veins being to a corresponding extent diminished.

If the proposition be admitted, that during activity the brain is more vascular, and that, to permit this increased vascularity, space is gained at the expense of a proportion of blood in the veins, the converse proposition—that when its function is in abeyance the brain has less blood in its vessels, and that the veins of the pia mater are fuller—becomes, of course, self-evident. For producing the latter condition, however, there is an interesting mechanism provided, and it may assist to establish the correctness of our views, if its nature be pointed out, and its mode of operation to some extent explained.

Here, again, I have to request attention, first, to a general principle, viz., that in the muscular and nervous systems exercise of function involves destruction of tissue, and that rest is necessary for thorough repair,—and, secondly, to the operation of this principle under peculiar physical conditions.

All the animal textures which are capable of manifesting vital phenomena are the subjects of ceaseless change. Their integral particles are being constantly renewed,—yet, by a delicate balance of operations, the same composition is still preserved to the texture. In the muscular and nervous tissues this process goes on with a regular flow and ebb. In the active discharge of function the changes of nutrition are not merely more rapid. The disintegrating predominate greatly over the reparative elements of the process. Repair fails, for the time, to compensate for the waste. As this goes on it gives rise to a positive change of composition in the tissue, and the latter, in consequence, responds less readily or less strongly to its ordinary stimulus. A period of repose is necessary, during which constructive changes are allowed to predominate. Then, with its standard composition restored, it again recovers its tension and irritability.

The local circulation sympathises with these nutritive changes. In accordance with the principle we had previously been considering, the vascularity is much greater in the hurried interchange which accompanies exercise of function, than it is in the quieter process of simple growth or repair.

I have said that the general principle now under consideration operates in the brain under peculiar physical conditions. I allude here to the relation which the cranial contents have to the pressure of the atmosphere, and which depends on the close unyielding structure of the cranial walls.

That the atmospheric pressure, so constant and universal, should be made subservient to the attainment of ends in the animal economy, is what might be expected. Bearing on the general surface of the body, its influence can readily be communicated through the soft textures. Of this fact we have a familiar illustration in the operation of cupping. When an exhausted glass is placed over any flat surface of the body, that surface is at once forced to some extent into the vacuum. It rises tense and rounded like the section of an orange, and, if punctures have previously been made in the skin, the blood flows freely from these. The weight of the atmosphere, bearing on the surface outside of the rim of the glass, presses the fluids in the direction of least resistance,—that is, towards the vacuum.

The contents of the cranium must, apparently, be removed from the direct action of this force. Let us suppose a fac-simile of the cranium and vertebral column to be made of glass. If its cavity be filled with water, and the cranial end raised (as in the ordinary experiment with a jar in the pneumatic trough), of course every drop would at once be run off. The air, entering at the optic and other foramina, would very speedily displace the heavier fluid. But let all the precautions be attended to that we find present in nature. Let the eye-sockets be plugged with a closely fitting incompressible ball, and every fissure be carefully guarded with layers of fibrous texture. If the same experiment be now repeated not a single drop of the water would be dislodged by gravitation. The only way in which direct pressure may possibly be transmitted to the interior of the cranium will be through the eye sockets; but as even this method is not probable—and, at any rate, as any change so effected must be infinitesimal in amount, it may be practically assumed that all the contents of the cavity are removed from the direct influence of the atmospheric pressure.

All the more important, however, must be the indirect influence conveyed by means of the circulation. As pressure applied to a fluid is transmitted equally in all directions, then any force acting, for example, at the jugular veins, will be transmitted to every part of the cranial cavity. In this way, an equilibrium of pressure can at all times be preserved between the internal and external surfaces of the cranium. It need hardly be said that the jugular veins lie conveniently exposed to whatever influence the weight of the atmosphere may be likely to communicate. Its tendency must be to retain the blood within the encephalic vessels. Before that fluid can leave the sinuses of the dura mater, it must be urged onwards by a force from behind. In ordinary circumstanees, the sources of this force are, in the first place, the action of the heart on the general circulation ; and, secondly, the forces created at the capillaries in the nutrition of the brain itself. We have already had occasion to notice the latter, which is, perhaps, the more important of the two sources. But without the combined operation of both not a drop of blood can leave the cranial cavity, however favourably the head may be placed in regard to the influence of gravitation.

Restricting our attention for one moment to the blood in the veins of the pia mater, we find it acted on by two antagonistic forces. On the one hand, there is the active *vis a tergo* —the combined operation of the heart's action and the capillary forces—urging onwards by the impulse of more blood ; and, on the other, there is the passive resistance of the atmospheric pressure. Between these two a constantly operating force is exerted on the walls of the vessels, the natural tendency of which must be to dilate the latter. So long as the support which they receive on their external surface continues perfectly uniform, the flow of blood will be even. If that support be increased, as we have seen it may possibly be in certain circumstances, the veins will be compressed and contain less blood. And now we may see how, if the support be lessened, physical conditions are present to retard the flow of blood and to distend the vessels. The atmospheric pressure becomes an active force, not from its amount being increased, but from a resisting force becoming weakened.

Considering how numerous, and how large and tortuous are the veins of the pia mater, it is extremely improbable that they are at any time distended to their full extent. Lying packed between opposing surfaces, a more or less flattened or compressed state is likely to be present. If the external support which they receive be lessened, their distension becomes a physical necessity. Here, as everywhere, force applied to a fluid produces most effect in the direction of least resistance. The walls of the vessels are perfectly passive, or almost so, and the flow of blood, acted on, as we have seen, by opposing forces, is unintermitting. Only with absolutely uniform support can the calibre of the vessels continue to be the same. The more that support is weakened the greater must be their distension. If need be, they will become enlarged and knotted, like varicose veins in any other part of the body.

We are now in a position to discuss the question which was started in the early part of this essay. Assuming that the characteristic phenomena of sleep can be caused by any change that would involve pressure to the surface of the brain, and observing that the venous vessels of the pia mater are fitted to produce pressure exactly at the required locality, it was asked whether any physiological conditions could be brought into play to cause such distension. I have now to answer the question in the affirmative, and, at the risk of repeating much that has already been said, I shall proceed to state in their order the successive steps of my argument.

The brain, as the organ of mind, can be no exception to the general organic law, that the active evolution of force can only occur with immediate loss to the instrument. I make no attempt to determine in what precise physical condition the nutrition of the brain becomes altered. Before details in this respect can be safely predicated, the chemist and histologist must enlighten us further as to the immediate sources of nervous energy. It is certain, however, that the cellular elements become so disposed that active evolution of force is less easy; that they have less powerful attraction for the oxygen of arterial blood, and that the infinitely subtle vibrations of the molecules begin to remit. This lessened molecular activity is the first step in the series of changes which culminates in the production of sleep.

The next link in the chain of causation, and one which springs naturally and inevitably from the first, is a change in the capillary circulation of the brain. Here, as in other organs, nutrition and the circulation act and react energetically on one another. In a texture of such delicate organisation, vitality cannot long be maintained without fresh currents of blood, and without the subtle attractions and repulsions between the latter and the tissue molecules the currents of blood cannot be sustained. When rapid change and combustion are going on the local movement of the blood is only remotely dependent on the heart's action. The fluid flushes the capillaries with an active expansive effect, and the immediate result is a positive increase of volume in the organ. But if the activity among the molecules subsides, the circulation becomes quieter. Its excitement stood in the relation of effect to the other excitement as cause, and as the latter abates so must the other. With the absence of the actively distending force, the vessels will more readily become emptied of blood, either from the natural elasticity of their own walls, assisted, it may be, by the operation of ganglionic nerves, or by pressure externally from any direction.

As the brain occupies a close rigid cavity, which must be constantly full, it cannot retire from the inner surface of the cranial wall without some other material taking its place. We may be certain that "nature's horror of a vacuum" is here absolute. A special mechanism, therefore, is provided for lessening or contracting the circulation of the brain. The veins are so disposed on its surface, and the blood within them is so related, through the internal jugulars, to the pressure of the atmosphere that they can readily become distended, or rather they must necessarily become distended and more filled with blood, when the support they receive is diminished. If the brain retires to the slightest extent, an equivalent of space is simultaneously taken up by the flow of blood through them being retarded. Or, to put this view in another way, if the natural distending impulse of the brain, caused by its active circulation, is diminished, then the brain mass is compelled to retire and to have its capillary circulation lessened, because the unremitting distending force in the veins is now allowed to bear with greater effect.

A change thus occurs in the encephalic circulation. The mass of blood remains the same, but its balance, as between the brain tissue and the veins which lie outside of its substance, is altered. The absolute amount of internal pressure also continues the same, but its direction as regards the brain itself is modified. It is less from within and more on the surface of the organ; that is to say, the layer of grey matter, on which functional capacity more immediately depends, is subjected to a compressing force.

With this altered direction of pressure the continued exercise of function is incompatible. As an unsympathetic touch is sufficient to check the vibrations of a bell or glass, and abruptly to put a stop to the musical tone, so when the grey layer is subjected to pressure on its surface, the infinitely subtle vibrations or active molecular changes in its tissue are checked. As the special function of the brain depended on these, that ceases to be exercised,—the cerebrum fails to be the medium through which mental phenomena can be presented, — sensation, thought, and voluntary motion are suspended;—in a word, sleep is induced.

In the causation of sleep there is thus a combination or succession of conditions. The first is a modified nutrition in the nervous texture; the last is pressure on the surface of the brain by an increase in the proportion of blood there. The connecting link between these two is a weakened capillary circulation through the brain itself. All these conditions, I would insist, are necessary to complete our idea as to the physiological causes of sleep. We could easily suppose, indeed, that if the first and second alone were fulfilled, the brain would not be in a fit state to subserve mental manifestations. A little reflection, however, may convince us that if sleep depended on such a condition, resulting simply from the natural changes occasioned by the exercise of function, it would be attended by serious inconvenience.

A true theory of sleep must be consistent, not only with the facts of unconsciousness, but also with those of wakefulness. If this were a treatise on all the aspects of sleep that can interest the physiologist, attention would have to be given to the fact that it is not always immediately after sleep when the mind is clearest and most active. With many invalids especially, the early part of the day is the period of greatest languor; and at the time of evening when sleep should be thought of, the mind is at its brightest. Many students also find that it is after the evening lamp has been lit when they have their thoughts most completely under command,—when ideas and their relations are clearest, and the attention can be kept most continuously in one channel. The evening, too, is the season selected by fashion for occasions of festivity or enjoyment. These facts show that the brain has in itself a power of adjustment and of bringing forward reserves of energy. If our theme were less restricted, it would be necessary to speculate on the causes of this, and especially to consider how internal pressure or support can be modified. My object in alluding to them here is to insist, that if the induction of sleep depended simply and entirely on a change in the nutrition of the brain, mental action should become more difficult as the day advanced. Then, as the brain is a composite organ, some parts of its mass would become exhausted while others were perfectly fresh, — activity would thus oscillate from one part to another, —our lives would be a constant dream,—the power to concentrate the will and continuously to keep one object in view could not be sustained.

Although the brain is a composite organ, just as the faculties of the mind are very varied, yet, as the unity of mind is one of the fundamental axioms of the metaphysician, so the brain in its operation must be regarded as a virtual unit. As such it is active in wakefulness; and in this state the rigid casing of bone is to the brain what the metal tube is to the rifle; it prevents diffusion, and, therefore, waste of energy; it conditions the vividness of ideas and the continuity of thought. As a unit, also, the brain must go to rest in sleep.

Whether it has been fatigued in purely mental work, or in exercising the muscles, or whether there may be simply a want of sufficient stimulus and interest, the immediate physiological result is the same. To accomplish this, some factor other than merely modified nutrition is necessary, and that we have in the uniform and accommodating application of hydrodynamic pressure to the surface.

In healthy sleep this pressure is correlated, on the one hand, to the state of the mind, and, on the other, to that of the nutritive forces. It is capable of infinitesimal gradation, and it will oscillate with the varying conditions of mental activity. It is permissive and mild, or it is imperative and irresistible, according to circumstances. With an increase of stimulus to the brain—some stronger impression from without, or some more vivid idea from within, —or from some fresh adjustment in the brain itself, the pressure is overcome and the mind is speedily alert; or if exertion has been long-continued, and fatigue great, the relaxed condition of the brain is more decided, and the symptoms may approach those of coma.

Confirmatory evidence in support of these views may be got in various directions. I am unwilling to load this part of my essay with details, and shall content myself with briefly considering how the brain circulation is likely to be affected in syncope, in asphyxia, and in retarded venous circulation. We may find that with very varying causes the physiological result is still the same.

There is no more certain or speedy means of inducing sleep, or the appearances of sleep, than compression of the internal carotids. "It is sometimes difficult to catch the vessels accurately, but once fairly under the fingers the effect is immediate and decided. There is felt a soft humming in the ears, a sense of tingling steals over the body, and, in a few seconds complete unconsciousness and insensibility supervene, and continue so long as the pressure is maintained. On its removal, there is confusion of thought, with return of the tingling sensation, and in a few seconds consciousness is restored."*

It is easy to see how the encephalic circulation must be affected in sudden and complete stoppage of the arterial supply. As not

* Fleming—Brit. and For. Med. Chirurg. Rev., April 1855.

more blood can enter the cranial cavity than is allowed to flow out of it by the venous sinuses, let the action of the heart be ever so strong, so not more can leave the sinuses than is simultaneously being admitted by the arteries. If the supply by the latter, therefore, be completely checked, so must be the exit by the former. But at the instant of the failure of arterial supply, the capillaries of the brain itself were full. These vessels have their own inherent forces, which continue to transmit onwards the blood within them. As not a drop of it leaves the cranial cavity, it can only accumulate in the veins, and thus cause the brain to be compressed.

If the supply of blood be simply diminished —if from hœmorrhage or from emotional effect on the heart's action, less blood is sent to the brain than is consistent with its activity, the same altered balance occurs, although not so abruptly nor so completely. At the moment of failure the capillaries are filled with a certain volume of blood, and are transmitting it onwards with a certain distending impulse. The result is that, in the first moments, more blood is transmitted into the veins than is being discharged from the cranial cavity. It thus becomes impossible for the balance of the circulation to retain its *status quo*. With the absence of the impulse or support in the brain itself, the surface veins become speedily distended, with the result, again, of producing pressure on the brain and complete unconsciousness.

In the insensibility that results from asphyxia, the sequence of change differs from that of ordinary sleep in the circumstance that the first step is an altered state of the blood, rather than a change in the molecules of the structure. The union of oxygen with the elements of the tissue is the most absolute of all the conditions of nervous action. If carbonic acid, therefore, accumulates in the blood, or if oxygen is replaced by some subtle agent like chloroform, the interchange or attraction between the blood and the tissue is suspended, or is less active. From this point the sequence of physiological change is the same as in ordinary sleep. With less active interchange the capillary circulation becomes languid, and it therefore presents a less potent resistance to the tendency which the atmospheric pressure has to retard the circulation in the veins and to cause the latter to become distended.

Of mechanical causes interfering with the return of blood from the head, the most interesting illustration is exposure to intense cold. As is well known, the effect of this is to produce a strong tendency to somnolence, and, if indulged in, the sleep very speedily deepens into coma of a dangerous character. Here the atmospheric pressure is fortified by the constringent effect of the cold. This drives the blood from the surface, and causes congestion of the internal organs. Within the head the capillary forces are unable to cope with the difficulty of expelling blood from the sinuses of the dura mater. Congestion of the veins is the inevitable result. They become gorged to their full extent, and so great is the strain on the vessels, that within a few hours effusion of serum occurs to a considerable amount.

Lastly, I submit the confirmatory evidence afforded by the appearance of the retina during sleep. This was determined by Dr Hughlings Jackson with the ophthalmoscope, and his observations have been confirmed by others.

He found "the optic disc to be then whiter, the arteries smaller, the veins somewhat larger, and the neighbouring part of the retina more anœmic than in the waking state."* In the details of a case of trance, where the unconsciousness was profound and protracted, the following is the description of the condition of the retina as given by Dr Jamieson:—"There was a marked contrast in size between the retinal veins and arteries. Compared with their appearance after the attack had quite passed away, the veins were larger and the arteries smaller, and at the time this was especially distinct, the veins standing boldly out against the white back-ground afforded by the disc and orange-coloured choroid, while the arteries were fine and hairlike."†

As the circulation of the retina belongs to the same system of vessels as that of the brain—the blood from the veins, for example, being emptied into the cavernous sinus, and therefore being subject to the same conditions of atmospheric pressure—these facts as to its appearance during sleep afford important evi-

* Carpenter's Physiology, 7th edit., p. 649.

† Edinburgh Medical Journal, July 1871.

dence in support of the views I have imperfectly submitted in regard to the circulation of the brain itself during the same period.

PART II.

DR BURROWS ON "DISORDERS OF THE CEREBRAL CIRCULATION."

In the preceding part of this essay I have assumed as correct the views of the encephalic circulation advanced by Monro (*secundus*), and supported by Abercrombie, Kellie, and others. As expressed by Dr Kellie, these views were to the effect that "it does not appear very conceivable how any portion of the circulating fluid can ever be withdrawn from within the cranium without its place being simultaneously occupied by some equivalent, or how anything new or exuberant can be intruded without an equivalent displacement."*

These views are considered erroneous by eminent authorities of the present day. "They

* Transactions of the Medico-Chirurgical Society of Edinburgh, vol. i., p. 102.

have been completely overthrown by Dr George Burrows," says Sir Thomas Watson.* "By this refutation," he adds, "of a prevalent error, not unlikely to warp or mislead our practice in some cerebral disorders, Dr Burrows has done the science of medicine an essential service." It becomes very necessary, therefore, to examine the grounds on which this opinion rests, for, of course, its correctness would seriously vitiate the whole of the reasoning founded on an opposite assumption.

I shall not be expected here to review the volume of Dr Burrows, nor to enter into any detail of his experiments. I shall confine myself to his conclusions, which, as far as possible, I shall give in his own words.

On turning, then, to the interesting work of Dr Burrows, I find that, notwithstanding his own assertions to the contrary, his views really do not differ materially from those of the three authors mentioned above, and that his experiments do not disturb by one hair's-breadth the position they took up. The following are the

* Lectures on the Principles and Practice of Physic, 5th edit., p. 322.

conclusions which Dr. Burrows himself was led to adopt.

"Those who have maintained this doctrine of the constant quantity of blood within the cranium have not, I believe, taken into due consideration that large proportion of the contents of the cranium which consists of extra-vascular serum. We know that in health the quantity which exists in the ventricles, membranes, and substance of the brain is considerable. Regarding this serum as an important element of the contents of the cranium, I admit, that the whole contents of the cranium, that is, the brain, the blood, and this serum together, must be at all times nearly a constant quantity."*

Now, abundant evidence may be given to prove that Monro, Abercrombie, and Kellie, never dreamed of entertaining any other opinion; except, perhaps, that they would have insisted that in health the proportion of extra-vascular serum is small, rather than considerable. Thus, even in the quotation given by Dr. Burrows to shew the views of Monro, the latter expresses himself to the effect that the quantity of blood within the cranium must be the same at all times, "*those cases only excepted in which water or other matter is effused*

* On Disorders of the Cerebral Circulation, pp. 32, 33.

or secreted from the blood vessels; for in these cases a quantity of blood equal in bulk to the effused matter will be pressed out of the cranium." In his first essay on the subject Dr. Abercrombie says :—"upon the principles of hydraulics, it seems probable, that the vessels of the brain must always contain a considerable quantity of blood, even when the other parts of the system are much exhausted of it. This results from the peculiar situation of the brain,—its confinement in an uninterrupted cavity of bone, in which it is closely shut up from atmospheric pressure. In such a cavity, the blood probably cannot be diminished below a certain quantity, *except something entered to supply its place*, and in the language of the old philosophy, 'to prevent a vacuum.'"*

To make this matter perfectly clear, however, I shall ask the reader carefully to compare the two following extracts. The first is from Dr. Burrows, giving his summary of Dr. Kellie's observations, and the second is from Dr Kellie's own essay.

"The summary of these observations," says Dr.

* Edin. Med. and Surg. Journal.—Nov. 1818.

Burrows, "is thus stated: that though we cannot entirely or nearly empty the vessels of the brain, as we can the vessels of the other parts of the body, it is yet possible, by profuse hœmorrhage, to drain it of a sensible portion of its red blood. If, instead of bleeding *usque ad mortem*, we were to bleed animals more sparingly but repeatedly, there is no doubt that we should succeed in draining the brain of a much larger quantity of red blood, although serous effusion would be increased." *

The following are Dr. Kellie's own words:—

"The summary of these observations, in so far as they apply to our present subject of inquiry, may be thus stated,—that though we cannot, by any means of general depletion, entirely or nearly empty the vascular system of the brain, as we can the vessels of the other parts of the body, it is yet possible, by profuse hœmorrhage, to drain it of a sensible portion of its red blood; *that the place of this spoliation seems to be supplied both by extra- and intra-vascular serum, and that watery effusion within the head is a pretty constant concomitant or consequence of great sanguineous depletion.*

"If, instead of bleeding, as in our examples, *usque ad mortem*, we were to bleed animals more sparingly and repeatedly, I have no doubt that we should succeed in draining the brain of a much larger quantity of its red blood; but in such experiments *we should, I think,*

* Op. Cit. p. 11.

find a larger effusion of serum, and be satisfied that many vessels, destined to circulate red blood, were filled with serum only, and even the larger trunks with a very thin and diluted blood." *

These extracts, I believe, require no comment. They tell their own tale, first, in regard to what the views of Kellie and the others really were on this question of constant quantity within the cranium; and also, as to the unfair representation of these views as given by Dr. Burrows. As the above description or explanation applies exactly to those cases where Dr. Burrows found an anœmic state of the brain produced, so subsidence of red corpuscles, displacing the serous part of the blood, accounts sufficiently for the appearances of congestion in the others. In fact, Dr. Kellie has answered, by anticipation, every objection which his critic has advanced.

In another part of his essay Dr Burrows proceeds as follows:—

"Does the anatomical structure of the human cranium warrant the opinion that it is a complete sphere, capable of removing its contents from the in-

* Op. Cit. p. 116.

fluence of atmospheric pressure? I think not. The numerous fissures and foramina for the transmission of vessels and nerves through the bones of the cranium appear to me to do away with the idea of the cranium being a perfect sphere, like a glass globe, to which it has been compared by some writers. If there were not always an equilibrium of pressure on the parts within and without the cranium, very serious consequences would arise at the various foramina of the skull. Are, then, the contents of the cranium removed from the influence of the atmospheric pressure? I think not, from other considerations. Atmospheric pressure is undoubtedly exerted on the blood in the vessels entering the cranium. This pressure, by a well ascertained law in hydrostatics, must be transmitted in all directions through the fluid blood, and hence to the blood and other contents of the cranium." *

If Dr Burrows, instead of making indefinite statements and queries, had pointed out a single foramen or fissure through which, in the natural state of the parts, it were possible for the atmospheric pressure directly to affect the interior of the cranium, he might have had some foundation for an argument, but in the face of direct denials, and apparent proof of the contrary opinion, he has none. As to the serious consequences that should arise at the

* Op. Cit., p. 35.

various foramina, "if there were not always an equilibrium of pressure on the parts within and without the cranium," he answers himself in the next sentence, where he shews that there is a constant communication between the pressure outside and the organs within the skull through a fluid medium. It must therefore be on this medium, on the circulation, that any disturbance of equilibrium would tell at once. Why any special disaster should occur at the foramina, I cannot conceive. The fibrous adhesions and coverings would first have to give way.

In reading the latter remarks quoted above from Dr Burrows, the inference might fairly be made that previous writers had overlooked the fact that the weight of the atmosphere can affect the interior of the cranium through the blood-vessels. But Monro, Kellie, and Abercrombie, all specially mention the fact. Dr Burrows himself, at a different part of his volume, gives the following quotation from Dr Abercrombie:—"The cranium," says the latter author, "is a complete sphere of bone, which is exactly filled by its contents, the brain, and by which the brain is closely shut up from atmospheric pressure, and from all other influences from without, *except what is communicated through the blood-vessels which enter it.*" Dr Kellie says:—"the brain is defended from the weight and pressure of the atmosphere,—a force constantly acting on every part of the system,—a force therefore which *must be constantly operating to maintain the plenitude of the vascular system within the head.*"

In regard to the expansive tendency which is occasioned in the brain by the movement of blood in its vessels, Dr Burrows remarks, that "the force which is impressed on the cerebral substance through the momentum of blood in the cranial vessels, is derived partly from the contractible power of the left ventricle of the heart, and partly from the reflux of the venous blood during expiration." * He makes no allusion to what may be considered the most important of all the forces affecting "the momentum of blood;" viz., that acting at the capillaries, and immediately caused by the more or less active molecular changes in the brain itself. The "reflux of venous blood,"

* P. 43.

if not impossible while the cranium is entire, must be infinitesimally small.

In the early part of his essay Dr Burrows says, "I am more strongly induced to give an abstract of these (Dr Kellie's) experiments, because I suspect that most writers on the subject, subsequent to Dr Abercrombie's publication, have been satisfied with his allusions to the experiments of Dr Kellie, and that few have taken the trouble to analyse the original account of them." I have only to express a hope that any physiologist taking an interest in the subject of the encephalic circulation, may not be satisfied with the account of Dr Kellie's views and experiments as given by Dr Burrows. The more closely the essay on "Some Reflections on the Pathology of the Brain" is studied, the more must we admire the clear, common-sense views of the author, and the cautious method of inference which he manifests at every step of his argument.*

* As the volume in which Dr Kellie's paper appeared is a scarce one, might the New Sydenham Society not be induced to reprint the essay in some volume of selected monographs?

Mr Durham on "the Physiology of Sleep."

The views presented in the first part of this essay are what I have held for some years, and I have given public expression to them on two occasions.* Since then several communications have been published on the physiology of sleep. The most important of these is that by Mr Arthur E. Durham, in Guy's Hospital Reports for 1860. In this essay, the author gives the results of some experiments on animals to determine the condition of the brain during sleep. Similar experiments have been made by Dr William A. Hammond, of New York. The conclusion arrived at by both of these authors is, that during the continuance of sleep the whole mass of blood within the cranium is diminished. The following is Mr Durham's account of "one or two of the most successful" of his "numerous experiments and observations:"—

"A dog having been thoroughly chloroformed, a

* Edin. Med. and Surg. Journal, Oct., 1854. Essays in Medical Science. (On the Encephalic Circulation and its Relation to the Physiology of the Brain), 1859.

portion of bone about as large as a shilling was removed from the parietal region of the skull by means of the trephine, and the subjacent dura mater partially cut away. The portion of brain thus exposed, seemed inclined to rise into the opening through the bone. The larger veins over the surface were somewhat distended, and the smaller vessels of the pia mater seemed full of dark-coloured blood; no manifest difference in colour between the arteries and veins could be perceived. The longer the administration of chloroform was continued, the more distended did the veins become. As the effects of the chloroform passed off, the animal sunk into a comparatively natural and healthy sleep. Corresponding changes took place in the brain; its surface became pale, and sunk down rather below the level of the bone; the veins were no longer distended; a few small vessels, containing blood of an arterial hue, could be distinctly seen ; and many which had before appeared congested, and full of dark blood, could scarcely be distinguished. After a time the animal was roused ; a blush seemed to start over the surface of the brain, which again rose into the opening through the bone. As the animal was more and more excited, the pia mater became more and more injected, and the brain substance more and more turgid with blood ; the surface was of a bright red colour, innumerable vessels, unseen while sleep continued, were now everywhere visible, and the blood seemed to be coursing through them very rapidly; the veins, like the arteries and capillaries, were full and distended, but their difference of colour, as well as their size, rendered them clearly distinguishable. After a short time the animal was fed, and again allowed to sink into repose ; the blood-vessels gradually resumed their former dimensions and appearance, and the surface of the brain became pale as before. The animal slept in a perfectly natural manner. The contrast between the appearances of the brain during its period of functional activity, and during its state of repose or sleep was most remarkable." *

In another experiment he "replaced the portions of bone removed by accurately fitting watch glasses, and rendered the junction of their edges with the bone air-tight, by means of inspissated Canada balsam. The different appearances of the brain could be satisfactorily observed through the glasses, and were found to correspond as nearly as possible with the above description."

On these interesting experiments I may be allowed to make one or two remarks. In the first place, the extent of pia mater exposed by removing a piece of bone the size of a shilling, and "partially" cutting away the dura mater, is comparatively small. Indeed, were the whole surface of the brain exposed, the greater part of the pia mater would be

* Guy's Hospital Reports, 1860, pp. 153, 154.

out of sight, so much of it lies between the opposing surfaces of the convolutions. Still, it must be admitted that from positive facts observed at one point, we may infer with great probability as to the condition of the whole membrane.

In the second place, the facts immediately observed on the dura mater being cut away, appear strongly to confirm the views I have advocated in the first part of this essay. The circulation of the pia mater is venous, and the brain tissue is comparatively bloodless; that is to say, the balance of the circulation is proved to be altered.

The objection immediately presents itself, that the comatose condition induced by chloroform is not sleep. That is at once granted. The degree of unconsciousness is much greater, and the physical changes in the brain are likely to be more decided. But the immediate physiological conditions are perfectly analogous. In ordinary sleep there is a flagging interchange between the blood and the tissue, in consequence of the latter having a lessened attraction for the oxygen of the former: the effect of chloroform is to check the interchange by displacing the oxygen itself to a greater or less extent. The absence of sufficient reaction between the blood and the tissue molecules being the reason, in both cases, why the capillary circulation becomes weakened, the ultimate result — an altered balance of the circulation—less blood within the solid structures, and a greater volume in the veins—must be the same in both. Any difference will be one of degree; just as in different sleepers, or in the same individual at different times, we have also great differences. In light, easily broken sleep the venous distension may be very slight, while in those who sleep heavily and snore loudly it is likely to be greater.

But, says Mr Durham, when the effects of the chloroform go off, and sleep becomes natural, all the vessels seen become contracted and almost emptied of blood. Here, we may be allowed to remember, that the experiment now becomes vitiated by the circumstance that the phenomena observed occur after the pia mater has been exposed to the air. Is it at all probable that the most vascular membrane in the body—the texture, therefore, where the animal temperature is likely to be highest—can be abruptly exposed without physical effects speedily following? If the capillary oozing from a cut muscle is at once checked by such exposure, is the fine capillary net-work of the pia mater to undergo no change? In the experiment where "watch glasses" are made to replace the bone, Mr Durham does not mention whether the glass was placed in close contact with the membrane. Any quantity of air under it would prevent the brain from being enclosed in a perfectly resisting case. The experiment, indeed, to be satisfactory, will be one of no ordinary difficulty, and, from the extreme delicacy of the pia mater and its vessels, a slight flaw may afford most misleading results.

Even at this point, therefore, I should be disposed to ask a verdict of "not proven" on the issue submitted by Mr Durham, viz., that the veins of the pia mater, as well as the arterial and capillary vessels of the cerebral tissue, have less blood in them during sleep than during wakefulness. But a serious, if not insuperable objection remains to be urged.

Facts, no doubt, are "stubborn things," but a common-sense inference from the comprehension of correlated facts is also stubborn. Such an inference is the one by Monro, that the quantity of blood within the cranium cannot be reduced unless an equivalent volume of some other material is simultaneously introduced. Now, if the whole intra-cranial system of vessels be so thoroughly drained, there must be a large vacant space unless something else is made to fill it. We become curious, therefore, to learn how Mr Durham meets this difficulty.

Dr Hammond never once alludes to the possibility of such an objection being raised. In watching the exposed brain as sleep was coming on, he found that "its volume slowly decreased; many of its smaller blood-vessels became invisible, and finally it was so much contracted that its surface, pale and apparently deprived of blood, *was far below the level of the cranial wall*;"* and assuming it to be "sufficiently established" that "sleep is directly caused by the circulation of a less quantity of blood though the cerebral tissues than traverses them while we are awake," he

* On Wakefulness, p. 30.

passes on as if there was no further difficulty in the way.

The following is the manner in which it is disposed of by Mr Durham :—

"It is obvious enough, that the total contents of the cranium must be a constant quantity. Now, the variations I have described in the amount of blood in the encephalic vessels are accompanied by corresponding variations in the amount of cerebro-spinal fluid in the ventricles of the brain and in the subarachnoid spaces. That this is not only possible, but true, may be easily proved by experiment, and by observation in cases of fractured base of the skull, in which accident has prepared the experiment for us.

"The rapidity with which the cerebro-spinal fluid can be absorbed and produced, is established by the original investigations of Magendie, confirmed and extended by those of Hilton, Ecker, and other physiologists; the correctness of whose conclusions may readily be tested by the repetition of their experiments. It is evident from the anatomy of the parts that, as the encephalic vessels become distended, the fluid can easily pass from the ventricles to the base of the brain, and from the subarachnoid spaces within the cranium into that of the spinal canal. When, on the other hand, the amount of blood in the vessels undergoes diminution, the pressure of the atmosphere on the surface of the body (transmitted by the soft tissues) causes the re-ascent of an equivalent amount of cerebro-spinal fluid. The force thus exerted seems to have been overlooked by those who have been at a loss to account for the rise of the fluid from the vertebral canal.

"Again, when the distension of the blood-vessels is lessened, the pressure to which they are subject is also lessened to a corresponding extent, and thus the effusion of fresh serous fluid is promoted." *

In regard to the statement that "the fluid can easily pass from the ventricles to the base of the brain," it may be mentioned that this is denied by eminent anatomists. Dr Todd, for example, has the following observations on this point:—"Does the internal fluid communicate with the subarachnoid space? Majendie affirms that a communication takes place by means of an opening which is situated at the inferior extremity of the fourth ventricle. I have not been able to satisfy myself of the existence of such an opening. . . . My own opinion is, that this orifice does not exist naturally, but that it is produced by the violence to which the brain is subject in its removal, or in the manipulations necessary for demonstrating it. It appears to me that the fourth ventricle is closed in the same way

* Op. Cit. pp. 157, 158.

as the inferior horn of the lateral ventricles, namely, by the reflection of its proper membrane from its floor on to the adjacent pia mater."* Such a statement, from so accurate an observer, should convince us that the passage of fluid from the subarachnoid space into the ventricle must at least be slow. Dr Todd believes it can only occur by a process of endosmose.

But supposing the communication to be as free as Mr Durham could desire, we are still at a loss to know what becomes of so much fluid. How is it that after death the quantity found is usually very small indeed? Let it be remembered that the brain, in proportion to its size, receives more blood than any other organ of the body—that, indeed, it is computed that one-fifth of the entire mass of blood is sent to the intra-cranial vessels. Then, judging from the description of appearances, as given by Mr Durham and Dr Hammond, and assuming that the whole brain is equally affected, it would surely be a moderate calculation to say that one-half of the blood

* Cyclopædia of Anatomy and Physiology, vol. iii., pp. 640, 641.

must be drained from its vessels during sleep. Therefore, a space equivalent to one-tenth—or, to give a large margin, say one-twentieth—of the whole blood in the body must be taken up with serous fluid. Now, what becomes of it all? Why does it not begin to well out profusely whenever the membranes of the brain are punctured? In most cases the quantity is so small that its presence is easily overlooked. In young subjects very little is found, even when it is looked for. In hypertrophy of the brain there may not be a drop of extra-vascular serum, yet we are told that "there is nothing special in the cerebral symptoms which could lead us to the diagnosis of this particular form of malady."* A true theory of sleep must, of course, apply to all classes of cases, but, if Mr Durham's physiology be correct, the subjects of brain hypertrophy should be absolutely sleepless.

Again, if the quantity of serous fluid be increased at the base of the brain, the latter must be pushed upwards. Now, if this happens to even a moderate extent, the nerves in that locality must always be seriously

* System of Medicine, vol. ii., p. 484.

stretched when sleep supervenes. Thus, instead of being a means "to protect the larger vessels and nerves situate there from the unequal pressure of neighbouring parts," it would become a constant source of positive danger. This circumstance alone should show that there are serious fallacies in Mr Durham's argument.

Nor is he at all happy in his explanation of the mechanism by which the fluid can be raised from the spinal canal. "When, on the other hand, the amount of blood in the vessels undergoes diminution, the pressure of the atmosphere on the surface of the body (transmitted by the soft tissues) causes the reascent of an equivalent amount of cerebro-spinal fluid." On reading this sentence we are certainly brought to a stand-still. We in vain try to recollect what are the "soft tissues" through which the atmospheric pressure can bear on the serous fluid within the spinal canal. We had supposed that the latter cavity was as much removed from the direct effects of external pressure as are the contents of the cranium. Our first impulse, therefore, is to say that the ascent of cerebro-spinal fluid, by aid of the atmospheric pressure, is simply a physical impossibility.

It would certainly have been satisfactory if Mr Durham had stated with more detail the mechanism he here insists on. The cavity of the vertebral canal is one of fixed capacity, and it cannot be altered by atmospheric pressure. Its contained serous fluid can be raised to the cavity of the cranium only by its absolute quantity being increased, or by some immediate engorgement of the spinal veins. In the case of the encephalic veins, we are able to trace how, through the "soft tissues" of the neck, the jugular veins may be subjected to the influence of atmospheric or any other pressure: how, according to a simple law in hydrostatics, the force so occasioned must be communicated through the sinuses of the dura mater to the blood flowing in the veins of the pia mater; and I have ventured to infer, that if vascular pressure within the brain itself be lessened, distension to a greater or less extent in these veins becomes a *physical necessity.* But I can see neither necessity nor probability for the opinion that lessened vascular pressure within the cranium should cause engorgement of the spinal veins. Are the lumbar, or intercostal, or any of the other venous channels by which blood is returned from the canal, more directly exposed to the pressure of the atmosphere than the internal jugular? Would artificial pressure from without assist in the least degree to raise a single drop of either venous or serous fluid from the spinal canal into the cranium? I cannot believe it. Until Mr Durham, therefore, shall point out with some detail the mechanism by which the atmospheric pressure can cause the ascent of fluid, I shall insist that such ascent, if not a physical impossibility, is, to say the least, a physiological improbability.

Mr Durham proceeds: "again, when the distension of the blood vessels is lessened the pressure to which they are subject is also lessened to a corresponding extent, and thus the effusion of fresh serous fluid is promoted." Now, in what circumstances do we actually find an accumulation of serous fluid within the head? Is it not in those cases in which we may with confidencc predicate increased pressure within the vessels, or diminished support outside of them? For example, it occurs in inflammatory diseases,—is there lessened pressure in these? Could lessened pressure cause the sutures of the cranial bones to be opened up after they have been fairly knit? Effusion is also found in the coma that has been brought on by exposure to intense cold,—is there not decidedly increased pressure here? It is, further, to be seen in old age, when the cerebral tissue has become atrophied, and where, in consequence, we may suppose the external support of the vessels has become weakened.

Mr Durham lays great stress on the fact, and he repeatedly alludes to it, that in fracture at the base of the skull, "the cerebro-spinal fluid does not flow at all, or flows very slowly, from the ear during sleep, but begins to flow afresh as the patient wakes up. This fact," he says, "affords striking confirmation of the hypothesis advanced in the present paper." It appears to me that the fact tells just as decidedly in the opposite direction. If the atmospheric pressure causes the spinal fluid to well up into the cranium during sleep. why should it just at that particular period cease to flow from the ear? If it came with a sudden spurt on the patient waking up, and then as suddenly ceased, the drift of the argument could be understood ; but if it goes on during the period of wakefulness, it simply shows that the flaw in the uniform support which the vessels usually receive on their external surface, permits direct effusion to occur more abundantly when the increased vascular pressure which accompanies functional activity has set in.

Mr Durham's further speculations on the physiology of sleep are of great interest. I do not require, however, to enter on the consideration of these. I have wished to restrict myself to those points on which our views are hopelessly antagonistic, and I now leave it for others to determine on which side the greater amount of probability may lie.

MR CHARLES H. MOORE "ON GOING TO SLEEP."

The little volume by Mr Moore is a remarkably pleasing and instructive work. His detailed observations on the phenomena of sleep, and on the requirements of a theory of its mechanism, are very ingenious and interesting. His own views, intended apparently as a complement to those of Mr Durham, ascribe an important office to the ganglionic nerves in inducing sleep. These are supposed to act on the arterial vessels, causing their contraction, and so lessening the circulation of the brain to an extent incompatible with activity of function.

"The mechanism of sleep is no mere weariness of the brain itself, no chemical process for clearing its texture, no voluntary suspension or gradual causeless subsidence of its activity; it acts with power, putting the functions of the brain into compulsory abeyance, and depriving the subsidiary organs of their sense.*

"Compulsion like this is clearly not exercised by the parts which sleep and wake, but by a separate mechanism. . . . Now the functional repose of the brain would be secured by a sufficient but not an excessive reduction of its arterial circulation.† . . . It may be taken without question that the reduction of the quantity of arterial blood in the brain is effected by contraction of the arteries themselves.‡

"If now it be considered reasonable to conclude that the contraction of the arteries conveying blood to the brain is the immediate cause of sleep, the question may next be entertained under what control this contraction takes place. Assuredly that power is not left with the brain itself.§ . . . The cause of the con-

* "On Going to Sleep," p. 15.
† Op. Cit p. 16. ‡ P. 20. § P. 24.

traction of the arteries is not far to seek; since it cannot be cerebral, it must be ganglionic. The brain does not send nerves to its own arteries. They are supplied from the sympathetic system. Around the carotids is a large number of them, proceeding from the first great ganglion in the neck. The vertebrals receive their endowment in less abundance, and chiefly from the second and third cervical ganglia.* . . . If ganglia can produce contraction of the blood-vessels of a gland with the effect of arresting its secretion, they may by the same means interrupt the activity of even so mighty an organ as the brain." †

"Wakefulness opens the arteries, superseding the influence of the ganglion over them. . . . The first power, that of the brain, overwhelms the less, which is that of the ganglion. Let the first moderate, the influence of the second rises. It is not necessary to conceive this latter as more than an automatic action—a resumption by the ganglion of its natural energy—which is forthwith expended upon the muscle with which it is connected. Be the brain, therefore, weary, or bewildered out of its attention, or soothed by a monotonous sound, or simply unoccupied, straightway the ganglia, set free for separate action, usurp supremacy, not over the brain, but over the arteries. The exact proportion of activity between the brain and the cervical ganglia, which is requisite for setting the latter free, is a matter of degree only, and is from the nature of the case undefinable and possibly variable.

* Pp. 24, 25. † P. 26.

. . . At any moment when the attention of the brain is unconcentrated, instantly the ganglia become uncontrolled and primary nervous centres, and reduce the size of the arteries." *

We need not be long detained with any criticism of these views. Of course, I shall not be expected to agree with the author when he says, "it may be taken without question that the reduction of the quantity of arterial blood in the brain is effected by contraction of the arteries themselves." As I have already pointed out, the exit of blood from the cranium takes place under the opposing pressure of one atmosphere. This opposition has effect backwards through the sinuses of the dura mater to the minute venous radicles of the pia mater. It tends to prevent more blood from entering these by the capillaries, and it reacts against the internal surface of the veins through their whole extent. To accomplish the movement and exit of blood, therefore, active internal forces are necessary. The action of the heart affords the primary condition of a supply of arterial blood; the molecular affinities between the blood and the

* Pp. 30, 31.

tissue constitute, more immediately, a direct, active, antagonistic force. Let the rapid and powerful affinities that accompany activity of function be weakened, either from exhaustion on the part of the tissue, or from a less stimulating quality of blood being supplied, and an altered balance of the circulation becomes inevitable, although the arterial vessels were to continue as dilated as before. This argument, however, has already been stated oftener than once, and its details need not be repeated here.

Still I am by no means inclined to question that the ganglionic nerves may have an important influence in favouring the contraction or dilatation of the arterial vessels. But before that influence can be made the foundation for a theory of sleep, we would require to have much fuller information as to its mode of operation, and its analogous action in other organs, especially in those whose function is periodic. When the stomach is quiescent, would it be considered a philosophical explanation to say that the secretion of gastric juice is suspended on account of the positive energy of the ganglionic nerves being exerted to keep the gastric arteries contracted? Is it not rather the case that, in the circumstances alluded to, these nerves are also considered to be quiescent? Or when the secretion of milk begins, is it sufficient to say that the inhibitory action of the sympathetic system on the vessels of the mammary gland has been overcome? If great difficulties stand in the way of such explanations being received in these instances, it is not likely that Mr Moore's theory of the causation of sleep can be accepted without considerable qualification.

But let us suppose that this view is, nevertheless, correct, and that the action of the ganglionic nerves to produce contraction of the cerebral arteries is an essential condition of sleep being induced. Such an admission would still give only a limited view of its causation. In illustration, we may recall the circumstance that Dr Lyon Playfair regarded sleep to be constituted by a diminished combustion of the cerebral tissue. Now, no one denies that, during its continuance, the affinities between the oxygen and the molecules of nervous substance are less powerfully exercised than in wakefulness, but I am not aware that any physiologist is satisfied that this knowledge is sufficient to account for all the phenomena, or to explain the mechanism of sleep. It is an important fact among the necessary factors, but not a solution of the problem. It ignores the mass of anatomical and physiological detail which surrounds the question, and really shirks the difficulties instead of surmounting them. So, if the action of the ganglionic nerves was proved to be as absolute as Mr Moore believes, it would still be only one item among the essential conditions. By itself it would be insufficient to cover all the phenomena involved. An altered balance or the circulation would still be imperative, and would more completely fulfil what Mr Moore insists to be necessary:—"Compulsion, not exercised by the parts which sleep and wake, but by a separate mechanism." Indeed it may be safely asserted that no theory which leaves out of view the physical surroundings of the brain, and the self-evident deductions from these as to the peculiarities of its circulation, is likely to give more than a limited and unsatisfactory explanation of the more important workings of the brain, whether in the sleeping or in the waking state.