ticable it may be expressed by keeping the term Sensation for the objective, and Feeling for the subjective aspect. The physiologist therefore will be occupied solely with the neural process in his endeavour to localise the observed functions in their respective organs. The psychologist will be occupied solely with the psychical process in his endeavour to analyse an observed function into its elementary feelings. Each requires the aid of the other; each supplements the other. The convergence is more indispensable than is generally suspected. As Physiology is Anatomy in Action, Psychology is Physiology in Feeling. The anatomical analysis of the organism into its organs is not possible unless guided by the indications of physiological observation: the organs must be seen in action before they can be recognised *as* organs. And these actions themselves must be analysed into their elementary feelings, localised in their respective organs. In vain the scalpel and the microscope will separate the brain into distinguishable parts and constituents; to know the function of this brain, and the significance of its parts, physiological observation is necessary; nor would this, however perfect, suffice; the psychological analysis of Feeling will be necessary to guide physiological analysis in the determination of organs.

I must not be seduced to follow further these considerations, my present purpose being simply to call attention to the existing ambiguities in psychological terms, and the pressing need there is for some convention among men of science which would once for all establish a system of definite symbols; so that for any subsequent writer to speak of sensation when he meant sensation *plus* judgment, would be as reprehensible as to speak of oxygen when he meant carbonic acid.

GEORGE HENRY LEWES.

II.—CENTRAL INNERVATION AND CONSCIOUSNESS.

We are led by anatomical inquiry to conceive of the Central Nervous System, however complex the structure of its different organs, as built up in a very simple and uniform manner out of elementary forms. At all points the system may be resolved, by means of microscopic analysis, into a connected framework of fibres and cells. Its fibres which run in an unbroken course from the peripheral nerves into the central regions are regarded as apparatus which like the nerves proper have transmission as their sole function, whereas the

cells, which are the characteristic elements of the central organs, are understood to be terminal or medial points, in which the action transmitted either originates or undergoes some sort of modification.

Hence there arise two principal problems for physiological investigation: first to trace the course of the paths of transmission, and secondly to determine the changes which the process may undergo through the interpolation of nervous cells. These two inquiries cannot be sharply separated from one another. On the one hand the nervous fibres are not simply conductors, but modify the action which is transmitted through them. In most cases the action as it proceeds appears to gather intensity, as was first shown by E. Pflüger. Sometimes, however, under special circumstances the opposite effect presents itself: the physiological excitation gradually subsides in the course of transmission. On the other hand the central cells appear in many cases to be inserted in a path of conduction solely for the purpose of dividing this path into several branches or of bringing about a considerable change in its direction. In these cases too we may reasonably suppose that the central cells exercise an influence on the course of the action transmitted through them. We can therefore define the first problem in the mechanics of central innervation as the determination of those changes which the interpolation of central cells occasions in the processes conducted along the nervous fibres. Now here we must either be able to assume the processes as known beforehand, or it must be possible in every single case to examine the process of innervation both apart from, and as subjected to, the influence of the interpolation of central cells.

The physical and chemical changes in the nervous fibres which are the ultimate conditions of the physiological process of conduction, are, for the most part, still unknown; and, even in so far as these changes are known, their relation to the physiological action of the nervous fibres is still a matter of doubt. The mechanical theory of nerve-conduction must therefore be based altogether for the present on the observation and measurement of its external physiological effects. Among these muscular contraction is the best external measure of the processes taking place within the nerve. Just as the mechanical theory of heat in its present stage of development is content as a rule to define heat as a mode of motion of which the more exact form is undetermined, but to which we may reason back from the external motor effects of heat, so the theory of nerve-conduction must regard innervation as a motor process in the interior of the nerve, which

arises through definite external motions, the so-called nerve-stimuli, and the strength, course and duration of which may be inferred from the external motion into which it is transformed, namely the contraction of muscle. At the same time such conclusions have an element of uncertainty, since innervation is to be conceived as a complex motor process which must, wherever it is possible, be resolved into its single components. I myself have shown* that it is possible, through the mere analysis of muscular contraction, to resolve the process of innervation in the peripheral nerves into different processes going on side by side and to some extent mutually antagonistic. From this point of view there is opened up at the same time the simplest route to the investigation of those changes which innervation undergoes through the interpolation of central elements. That is to say, this line of investigation will have to set out with the question: "How does the process of nervous excitation (which has to be measured in its external motor effects) when produced by a direct stimulation of a motor nerve differ from the same process when central elements are interposed in the path of conduction?" Here we naturally turn to the Reflex Process as that mode of central innervation which, so far as is known, realises this last condition in the simplest manner. For reflex movement is marked off by this one circumstance from muscular contraction produced through the direct stimulation of a motor nerve.

We have to thank Helmholtz† for the first numerically exact observations which have been made in this direction. These, however, are concerned exclusively with the average interval of time after which the reflex movement occurs, it being proved that the process of excitation undergoes a considerable retardation in its transmission through central elements. Next we must reckon the observations which Pflüger‡ has collected relating to the laws of conduction of reflex nervous action and which point to a varying disposition of the central substance with respect to the conduction of excitations according to the direction in which they arrive and depart. These last researches have so far however yielded only qualitative results. Finally it is to be mentioned that more recently the attention of several observers, Setschenow§ being the first,

* *Untersuchungen zur Mechanik der Nerven und Nervencentren*, Abth. I. Erlangen, 1871.

† Pflüger's *Archiv für Anatomie und Physiologie*, 1850, 1852.

‡ *Die Sensorischen Functionen des Rückenmarks*, Berlin, 1853.

§ Setschenow, *Ueber die Hemmungsmechanismen für die Reflexthätigkeit des Frosches*, Berlin, 1863; Sotsch. u. Paschatin, *Neue Versuche am Hirn u. Rückenmark des Frosches*, Berlin, 1865; Sotsch. *Ueber elektrische u. chemische Reizung der sensibeln Rückenmarksnerven*, Graz, 1868.

has been directed to the peculiar phenomenon that different reflex excitations exercise in certain circumstances a mutually inhibitory influence, and that similar inhibitory influences can issue from the stimulation of the higher central structures. Several of these researches have been published since the conclusion of my own investigations of which I am about to offer a short summary. I shall indicate at the proper places the points in which my results do or do not coincide with those of other observers, while describing the course which my own researches have taken. As regards technical materials and methods I shall in these pages, where I am seeking to interest psychologists and philosophers in the general conclusions to be drawn from my labours, content myself with naming what is essential to the understanding of the results, reserving the rest for a more elaborate publication which will address itself to the narrower circle of physiological experts.

The investigation begins (I.) with the *simple reflex excitation of the spinal column*, the various forms of which under their respective normal conditions we will seek to determine. Among the different forms of reflex conduction the simplest is (1) the *unilateral* variety, in which the excitation is passed on from a posterior root to the anterior root belonging to it. Next to this is (2) *transverse* conduction, in which the excitation of a sensory root of the one side is transmitted to motor roots of the other side given off at the same height. The most complicated form is (3) that of *longitudinal* conduction which takes place along the axis of the spinal column from higher to lower nerve roots or conversely, and which again may be either unilateral or transverse. With these inquiries into the conduction of reflex processes we shall need to connect another question (4) that of the *influence of the spinal ganglia on reflex excitation*.

In the second place (II.) we will inquire into the subject of *reflex excitability and its changes under different conditions*; and more particularly (1) the influences of *preceding stimulations*, (2) the effects of *temperature*, and (3) certain *toxic* effects which alter the reaction of the spinal column to reflex stimuli.

A third subject of inquiry (III.) will be the influence which is exerted on the reflex process by the *simultaneous excitation of other nerves or nerve-centres*. Here our attention will have to be directed (1) to the interference of stimulations acting simultaneously upon different parts of the *spinal column*, and (2) to the effect which the *higher nerve-centres* and their stimulation produce on the reflex process in the spinal column.

Only after we have thus examined the subject from different sides shall we be able (IV.) to discuss the *essential qualities of the reflex process and the nature of central innervation generally*. Finally (V.) we may consider the psychological bearings of the inquiry, and seek to understand in general the *relation between central innervation and consciousness*.*

I.

According to Pflüger the general law of conduction of reflex action is as follows: first of all with moderate stimulation reflex contraction appears only on the side on which the stimulation takes place; with increasing stimulation the muscles lying symmetrically on the other side are also thrown into a state of contraction; later on this state of contraction extends upwards and downwards till at last all motor nerves which spring from the spinal column and the medulla oblongata are simultaneously excited. This law however supplies only a qualitative expression for the variations in intensity of the stimuli required for unilateral, transverse and general reflex excitation. Nor is any account given of the precise course of the reflex excitation, and more particularly of the various degrees of intensity with which the stimulation travels in different directions within the central organ. To supply this deficiency it is necessary to substitute a quantitative investigation. We must obtain an exact record of the series of changes making up the reflex contractions, and this is best secured by the following device. The reflex contraction under examination is compared with a second contraction effected in the same group of muscles through another stimulation applied at exactly the same moment of time. This other contraction may either be produced by a direct stimulation of the motor nerve or be itself a reflex contraction. The direct form is employed in the investigation of simple unilateral reflex action. In order to secure as far as possible similar conditions for the phenomena to be compared, we select in both cases such an intensity of the stimulus as will make the amounts of contraction (represented graphically by height of curve) equal. In this way the difference of intensity in the stimuli supplies a measure for the difference between the reflex and the direct excitability. In the investigation of transverse reflex conduction and of longitudinal conduction in the spinal column we commonly use for comparison not direct contraction but simple unilateral reflex contraction; for in these cases we are concerned with relatively great retardations and inhibitions in the transmission of the excitation through the spinal cord. It should be added that

* The first three sections that follow in smaller type are given in abstract only, and the author is not responsible for them in their present form. Sections IV. and V., as well as the Introduction, are translated *in extenso*.—ED.

the research in its main parts depends on the use of the pendulum-myograph, which gives the means of recording contractions that follow very closely on one another. The subject of experiment is always a frog, and the stimulus is an electric (generally induction) current.

(1.) *Unilateral Reflex Excitation*: Simple unilateral reflex excitation lends itself more especially to the investigation of the general features of the reflex process and of the changes which this undergoes under different conditions. Overlooking for the present all changes of reflex excitability, we have here to consider how the strength of the stimulation affects the commencement and the course of the reflex process.

The reflex contraction differs under all circumstances from the second contraction (produced by direct stimulation of the motor nerve) in two respects: it commences *later* and it is of *longer duration*. The first difference depends on the intensity of the stimuli which is known to affect the period of "latent excitation" (viz. that in which the muscle is apparently still at rest). Thus the reflex process is greatly retarded relatively to the other when the direct stimulus is strong and the reflex stimulus weak, and slightly retarded when the direct stimulus is weak and the reflex stimulus strong. In this latter case the difference may become infinitesimal so that both contractions apparently commence at the same instant, though the reflex contraction never *precedes* the other. As a rule even the strongest reflex excitation will undergo as compared with the weakest direct excitation a certain delay, though the quantity may be too small for determination by our chronometric instruments. On the whole, too, the latent period of the reflex process varies with the alteration of the strength of the stimulus far more than the latent period of the direct contraction. Very powerful stimuli usually bring about tetanic reflex processes, but at the same time even the weakest reflex processes have a considerably longer duration than direct contractions.

As soon as the two contractions are of approximately equal height, the difference of the latent periods constantly amounts to a very considerable quantity, more especially if we remain below the maximum of contraction. Only when we do so can we be at all certain that equality in the contractions means also equality in the excitations. Now with equal intensity of the excitations the velocity of transmission in the nerve remains unaltered. Hence it is only in the case specified, in which there is either an equal amount of contraction below the maximum or a bare attainment of the maximum, that we can be certain that the difference of the latent stimulations signifies the period required for the transmission of the stimulation inside the grey substance, or, as it may be called, the *reflex period*.

In order, then, to determine the absolute magnitude of the reflex period and of its variations with varying intensity of the stimulation, we need a careful graduation of the stimuli so as to secure in every single experiment perfect equality between the direct and reflex con-

tractions. In a normal condition of excitability of the spinal column this end must be attained by making in every instance the reflex stimulus stronger than the direct stimulus of the nerve. Now in all thoroughly successful experiments there shows itself a *diminution of the reflex period with an increase in the amount of the two contractions*. For example, whereas the height of the contractions rose from 1.5 to 4 millim., the reflex period fell from 0.027 to 0.015 sec. At the same time when the animal is in a normal condition the reflex period generally fluctuates within these two limits of time upwards and downwards. It seldom rises above 0.030 sec. except the excitability is in itself an abnormal one or is altered through poisons and other influences.

These differences between reflex and direct contraction correspond perfectly to the differences that are observable between two contractions effected through applications of a stimulus at points unequally removed from the muscle. In this case, too, the contraction produced by the more distant stimulus constantly manifests a retarded commencement and an increased duration, only it must be added that in the case of reflex contraction both differences are considerably increased. Thus we see that the influence exercised on the progress of the stimulation by the interpolation of the central grey substance is equivalent to the effect of a very long tract of nerve.

Finally, both these properties of reflex contraction—retarded commencement and increased duration—are closely related to one another. The greater the delay in the commencement of a reflex contraction the larger, as a rule, the increase in its duration. Accordingly reflex processes whose commencement is very greatly retarded have always in addition a tetanic character. On the other hand the converse is not always true: it is possible for reflex contractions to become tetanic without on this account commencing any later than in ordinary cases. It should be noted here that even the normal reflex process owing to its long duration stands on the boundary between contraction and tetanus. Now this tetanic character of reflex contraction may increase without the reflex conduction being retarded. On the other hand where the transmission of the excitation within the grey substance occupies an unusually long period, the duration of the excitation also is always more or less increased.

(2.) *Transverse Conduction*: In investigating this variety of reflex conduction we proceed according to the same principle as before with the single difference that the second contraction is produced through unilateral reflex, and not direct motor, excitation. It may be observed that stronger stimuli are requisite for the production of transverse and longitudinal than for that of unilateral reflex processes. If we choose for the two reflex processes to be compared stimuli of equal intensity, the two contractions will differ in the fact that the one arising through transverse excitation (a) commences later, (b) is smaller in amount, and (c) has a longer duration. If however the transverse reflex process is very weak, the latter difference disappears owing to the fact that weak contractions

commonly have a shorter duration. The retardation of the transverse reflex excitation in relation to the unilateral, fluctuates in general between 0.006 and 0.012 sec. Since however the transverse excitation is also the weaker, and weak excitations are always conducted more slowly in the nerve, this period cannot wholly be referred to the retardation produced by the grey substance. In order to isolate this element of retardation as far as possible, it is necessary to examine rather those reflex excitations in which the two stimuli are of different intensity and are so graduated that the amounts of the resulting contractions are equal, while at the same time (for reasons already given) they lie below the maximum limit of contraction. In experiments arranged in this way, the retardation reaches only from 0.004 to 0.006 sec. It will thus be seen that the retardation of transverse reflex excitation corresponds to from one-fourth to one-fifth of the unilateral reflex period as formerly determined. This retardation too is greatest in the case of feeble excitations, and diminishes with their intensity.

(3.) *Longitudinal Conduction*: In investigating this variety of reflex process, we compare the reflex contractions produced by stimulating two unilateral sensory nerves as far apart as possible in the column, as for example the nerves of a fore and hind leg of a frog (the brachialis and the ischiadicus). In this case the usual difference in the two contractions is the same as in that of unilateral and of transverse reflex excitation: the reflex process produced in the hind leg by stimulation of the higher nerve commences later and for the most part requires stronger stimuli. Nevertheless the amount of the difference is here subject to greater fluctuations than in the previous cases. Now it is very considerable, now it assumes a minimal and in rare instances even a negative value, the upper reflex process commencing somewhat earlier than the lower. Very probably these deviations proceed from the unequally rapid degeneration of the nerves or of the different regions of the spinal column.

(4.) *Influence of the Spinal Ganglia on Reflex Conduction*: It is found that the nerve roots are more excitable than the nerves below the spinal ganglia, much stronger stimuli being required in order to effect a reflex contraction through the latter. Further experiments show conclusively that the single condition of this difference consists in the interpolation of the spinal ganglia.

II.

(1.) *Influence of preceding Stimulations*: Every reflex excitation which does not last too long leaves behind it for a certain period a heightened reflex excitability. This is equally true whether the modifying and the testing stimuli act on the same fibres or whether they are applied to different fibres and even to such as enter the spinal column on different sides. This shows that the effect is not due to any modification of the sensory fibres. It can also be demonstrated that it does not depend on any change in the motor

fibres, for these are found to be at the time in a state of exhaustion. Thus the same reflex stimulus which exhausts the peripheral nerves increases the excitability of the central substance of the spinal column. The increase, however, gives place afterwards to a state of exhaustion, the interval depending on the animal's energy at the time. Further, even in the case of the peripheral nerves, stimulation is followed by a stage of increased excitability, only that here it disappears very rapidly and gives place to exhaustion. Thus the central substance differs from the peripheral fibres only in the mode of progress and duration of these changes.

(2.) *Influence of Temperature*: A considerable lowering of the bodily temperature produces if not unduly prolonged (a) an increase of reflex excitability, and (b) a retardation of the reflex processes, as manifested both in a later commencement and in a longer duration. These results correspond to those obtained by subjecting the peripheral nerves to the influence of low temperature. Shivering, it may be remarked, is but one manifestation of the increase of reflex excitability by cold.

(3.) *Toxic Effects*: The results of poisoning on the reflex process are found to be as follows: (a) Increase of reflex excitability (being greater and more lasting, the higher the animal's vitality), (b) gradual transition from reflex contraction to a condition of reflex tetanus (which occurs the more quickly the lower the animal's vitality), (c) increase of the reflex period, by which the ordinary duration is occasionally multiplied tenfold.

III.

(1.) *Interference of Reflex Stimuli*: By this is meant the simultaneous action of stimuli on different fibres springing from the spinal cord. The reflex process which occurs when a given sensory fibre is stimulated alone, is compared with that which ensues when the same fibre is stimulated during a permanent stimulation of another sensory fibre. The two fibres stimulated may be unilateral and of equal height, or bilateral, or of different height. In the first case there results in the majority of instances an increase of reflex excitation, though an inhibition may take place instead if the interfering stimulus is very weak or the vitality of the animal very high. Also in the other two cases we meet with both an increase and a diminution of reflex excitation, only that here the inhibitory effect is the more frequent. In all cases after the animal's energy has been exhausted, the effect of inhibition gives place to a more or less considerable mutual augmentation of the reflex processes. If we compare these results with those obtained by compounding different stimuli in the same peripheral nervous fibre, it becomes apparent that the augmentation of the reflex process by the interfering stimulus must be ascribed in part at least to the superposition of the molecular vibrations in the peripheral nerves. It is quite otherwise with the inhibitory effects, which differ *in toto* from those which present themselves as transitory phenomena in the peripheral

nerves. Consequently we must refer those effects of inhibition to the activity of the central substance. At the same time it must be borne in mind that the phenomenon of inhibition is not a specific property of the central organ but only presents itself here in a more striking form, in respect of amount and duration, than in the peripheral nerves.

(2.) *Influence of the Higher Nervous Centres:* Setschenow first observed that the stimulation of certain regions of the brain leads to a diminution of reflex excitability, and he inferred that these regions are special inhibitory organs. But as the difficulties of localising these central stimulations are so great, it is better to overlook any conclusions respecting the influence of particular parts of the brain on reflex excitation and to concentrate attention on certain general relations which seem to be discoverable in these observations.

It is found that, so long as the stimulation of the central parts leads to no visible external effect, its influence on a simultaneous reflex process is very uncertain, but, when manifestations of pain occur, this influence never fails to reveal itself. It shows itself either as an intensification or as an inhibition of the reflex process. The former occurs when the emotional movements engage the same muscles as are acted on in the reflex process, and consequently is the result of a summation of excitations. When the same muscles are not involved in the movements of pain, the effect on the reflex process is an inhibitory one.

Here then we have to do with a class of phenomena analogous to those of interference between the stimulations of different spinal sensory nerves. In the stimulation of the higher central regions, also, the intensification of the reflex process only presents itself when the stimulus acts on sensory nerve-fibres. Hence it may be inferred that in this latter case, no less than in the former, the augmentation of the reflex process results from a summation of stimulations. On the other hand we must suppose that whenever the conditions of such a summation do not exist, the excitation of any area of grey substance in which sensory nerves terminate (be they those of the spinal column or of the brain) has an inhibitory influence on the excitation of other and similar areas. This view should throw light on the well-known phenomenon that the reflex excitability of the spinal column increases when the brain is removed. So long as the brain is intact, there goes on, simultaneously with the stimulation of the spinal column as a reflex organ, a stimulation of those collections of grey substance in the brain in which the sensory fibres terminate. Now we have found in general that simultaneous stimulation of central regions in which centripetal fibres terminate has an inhibitory influence, provided the two reflex excitations do not become compounded in the same motor fibres. Thus one and the same peripheral stimulation, by producing excitations in different parts of the centres, may occasion an effect of inhibition.

IV.

We have found that excitations which have been conducted to the central substance can undergo in this region two opposite kinds of transformation. They can be either *inhibited* or *intensified*, and both changes are favoured by the circumstance that the central substance is already in a state of excitation. Hence there arises the question under what conditions the inhibition and the augmented excitation proceed from the interference of stimuli. This question immediately conducts us to another, namely, whether the two transformations proceed from different parts of the central substance. With respect to inhibition within the spinal column there are two regions in either of which we may suppose the inhibitory process to take place. Either the interfering stimulus may be conducted further in the posterior column, and so intersect the principal excitation immediately after its entrance into the grey substance, or, since according to the universal law of reflex conduction it enters the anterior cornua, it may effect the inhibition in a path which connects the motor central regions, that is to say, through central fibres lying between different portions of the anterior cornua. In a similar way we may conceive the inhibition which proceeds from the higher central regions, either as a process which is confined to the region where the sensory nerves end, or as one which passes out from motor centres in the brain to the points of origin of the motor spinal nerves. In the latter case the inhibitory process would be conducted by the same route as motor excitation. In support of this conclusion the fact might be quoted that the Will too is able to suppress movements. On the other hand, it should be observed that inhibition through the will may possibly be conducted by quite other paths than the voluntary excitation of the muscles. We may conceive the inhibitory operation of the will also as an *indirect* one, which is first of all directed to the region of the sensory nerve-terminations, and only produces the actual inhibition when setting out from these. There is, indeed, nothing unreasonable in the hypothesis that the will is capable of operating on sensory regions, since we constantly observe such an effect in the voluntary control of images of fancy and of memory. There is one observation which positively supports the view that inhibition is always a process which takes place between sensory central tracts, namely, the connection of the inhibition which proceeds from the higher central organs with the feeling of pain. To this must be added as a yet more decisive negative instance the

following fact. When different stimulations interfere with one another in motor fibres, an increase in the excitation is always observable. A similar augmentation also manifestly takes place when the same motor central point is set in a state of excitation by different fibres. Hence it is plain that sensory stimuli which are unilateral and act at the same height—that is, which operate most directly on the same motor centres—most easily cause an increased reflex excitation. Accordingly, it is without doubt the simplest supposition, and one which is most consonant with the facts, to refer the phenomenon of interference which occurs with two simultaneous sensory stimulations to a double reciprocal action—(a) to one taking place between the stimulated sensory central points by means of central fibres running between these, and attended with the external effect of *Inhibition*; and (b) to one taking place between motor central points, to which the sensory stimulation is transferred through a reflex process, by means of motor central fibres connecting these points, and attended with the external effect of a *Summation of excitations*. The influence of the will on reflex processes may be regarded as a case of this double action. For the will can either occasion an excitation of the same muscles which lie in the path of the direct reflex conduction, and so intensify the reflex movement, or react on the sensory central parts which produce simultaneously with the reflex process a feeling of pain, and thus inhibit the reflex process. In this way we arrive at a general understanding of the double consequence of an interfering sensory stimulation, namely, as a result of its double mode of conduction; that is to say, (a) of the transference to other sensory central parts, including those that enter into the reflex-path immediately under investigation, and (b) of the transference to centres of movement, among which again may be included those that are concerned in the reflex process.

Thus we arrive necessarily at the conception that the form of Interference depends on the mode of connection of the central structures. There must be fibrous connections of the cells which in a special manner conduct inhibitory effects, and these are according to all appearances the connections of the sensory cells. On the other hand there must be fibrous connections which subserve a summation of excitations, and these are plainly the connections of the motor cells. Since, however, the general laws of the physiology of nerves render improbable the supposition of a specific difference of the conducting fibres, we are left to seek the proper ground of the special form of inhibitory effect in the different *mode of termination* of the fibres within the central ganglion-cells. We must

assume on the one hand that the sensory fibres terminate in the sensory cells in such a way as to favour not only the extinction of the stimulation, but also the inhibition of other stimulations conducted to the same cells; on the other hand that the same fibres terminate in the motor cells in such a way as to promote a diffusion of the excitation, and as a consequence of this an augmentation of other excitations conducted to the same central structures.

It is obvious how we may connect this difference of the central cells with their physiological function. The sensory cells have, as we know, for their special function to receive stimuli, and to transform them into sensations; on the other hand the motor cells are those central points from which the external work done by the organism originally proceeds. We may further co-ordinate these conclusions with the conceptions derived from the general chemical statics of the organism. Recent biology teaches that the animal organism is not, as was formerly supposed, merely a seat of combustion, that is to say, of the formation of chemical compounds, or of the transformation of unstable into stable combinations, but that in it, as in plants, there takes place as well a process of decomposition, that is, transformation of stable into unstable and relatively complex combinations. More especially the nerve substance appears to be a seat of such decomposition, for some of the materials of nerve (as Lecithin) are more complex and more unstable combinations than the albuminous and fatty substances which the animal body absorbs in its nutriment. Now all external work, like the evolution of heat or muscular contraction, depends on a process of combustion, that is on the formation of stable compounds. Conversely, a process of decomposition cannot take place without a disappearance of external work. But, as a rule, external work is liberated in the motor central tracts and disappears in the sensory cells. This contrast, however, does not hold good as a universal law. For example, reflected sensation is a phenomenon which, without doubt, involves a diffusion of excitation among sensory central parts: on the other hand the fact that the stimulation of a motor fibre never passes beyond its original cell in a centripetal direction may be best explained as a result of inhibition which possibly has its basis in the particular form of termination of the motor fibres within the anterior cornua. In this way we reach the conclusion that in every ganglion-cell there take place simultaneously processes of combustion, resulting in external work, and processes of decomposition in which external work disappears. In the sensory cells, however, the process of decomposition pre-

dominates; in the motor cells the formation of stable combinations. In the former, therefore, we observe a disappearance of external work, and, whenever the function of the cells is raised through external stimuli, an inhibitory effect on the work done by other central structures standing in close connection therewith. In the motor cells, on the contrary, we see work produced, and every stimulus which is conducted to these by the appropriate paths adds to the amount of this external work. We thus find in these mechanical properties a basis provided for the two functions of the central nervous system, of chief importance for psychology, without needing to have recourse to the old doctrine of the *specific energy* of the central parts, a doctrine which equally contradicts the facts of the physics of nerve and those of anatomy. These two fundamental functions of the nervous system are, first, the reception of external impressions and the transformation of the same into a latent condition in sensation, and, secondly, the conversion of stored-up into external work in the reflex and voluntary movements.

V.

According to the older modes of conception, Consciousness is a domain of phenomena into which the validity of general laws of nature does not extend. Thus the voluntary actions of man are withdrawn from the causal connection of external nature just because they spring out of psychological motives. In entertaining this view writers have become involved in a contradiction with a postulate supplied by that most general law of nature on which we have been constantly obliged to take our stand in the foregoing investigations, namely, the principle of Conservation of Energy. If this principle lays claim to a universal validity, we cannot withdraw from it those movements which we are conscious of only as psychologically caused. Assuming that the principle has in reality the universal validity ascribed to it by natural science, there present themselves in connection with the whole domain of the psychophysical vital actions of man two problems for scientific investigation. In the first place these phenomena must be referred to their *psychological* causes, in the second place we must determine the external causal connection out of which they arise as *physiological* processes.

We must, no doubt, bear in mind that the principle of the Conservation of Energy has to do only with motor forces, and that consequently the movements which proceed from psychological causes are subject to this principle only so far as they

are *external*. The internal or psychological causation of our mental states cannot be touched directly by a law which only has reference to masses and their reciprocal action. Thus it would be futile to seek to apply this law to the synthesis of compound perceptions out of simple sensations, or to the association of ideas, or to the determination of the will, that is to say, to the principal instances of psychological causation. At the same time, as soon as these internal mental states lead to external movements, these latter fall under this principle. Hence arises the important psychological postulate, *that the internal causation of our mental states, and the external causation of our movements can never conflict with one another*. Every movement which has an internal cause (e.g. in conscious motives) necessarily has an external cause as well. It is certain that Leibniz had a lively appreciation of the necessity of such a connection when he put forward his doctrine of a Pre-established Harmony. But since he was entangled in the old metaphysical prejudice which split up man into two different beings, a material and a spiritual, he was only able to conceive this connection as a constant miracle. It is precisely this unavoidable corollary of Dualism which makes the hypothesis scientifically impossible.

The postulate that external and internal causality can never conflict in their results leads to two further demands of wide scientific consequence as soon as we admit that the connection of the physiological and the psychological mechanism is only conceivable from the point of view of Monism. In the first place the internal causation must be just as stable and invariable as the external; in the second place we must be able to show for every member of the internal causal chain a corresponding member of the external causal chain, namely, the physiological processes of innervation. It may happen that in certain stages of our investigations only the one or the other side of the event is open to observation; but a real solution of the problem is in every case attained only when we succeed in exhibiting both series of phenomena in their mutual penetration. In point of fact the whole of recent psychology is pervaded with a disposition to satisfy this postulate, and every step which it takes in this direction transforms the bare postulate into the actual proof of a complete parallelism between the internal and the external phenomenon.

In this manner the formation of complex perceptions out of simple sensations presents itself on one side as an operation of psychological synthesis, in which there is manifested a general property of our consciousness, namely, the tendency to fuse simultaneous sensations, and to arrange related sensations

according to their intensity and strength. The same processes, however, are seen to repose on a connection between impressions of sense and movements, which connection has its basis entirely in the physiological properties of the organs of sense and of their nervous centres.

A similar example of the regular concomitance of psychological and physiological processes is afforded by mental association, which again forms the foundation of a host of complicated psychological operations. As is well known, the psychologist distinguishes four so-called Laws of Association. According to the first *similar* mental states attach themselves to one another; according to the second *contrasting* states of consciousness sometimes enter into connection; according to the third presentations awake one another which stand in a *spatial* relation one to another; according to the fourth mental states which follow one another in *time* tend to re-enter consciousness in succession. Upon a closer consideration of these laws it becomes apparent that they can be simplified by subsuming each pair under *one* law. Similarity and Contrast may both be regarded as a principle of the *internal* connection of mental states. In this way the apparent opposition between the two disappears. The connection through Contrast just as much produces a *completion* of the first mental state by means of the second as the connection through similarity. But the fact that under certain circumstances contrasting states are able to supplement one another is to be explained by the other fact, that every presentation or idea is accompanied by a *feeling* of greater or less intensity. Now it is a peculiarity of feeling to move between extremes; consequently a feeling readily reproduces its contrast, more especially as our consciousness does not admit of monotonously continuous feelings, but can only preserve its elasticity through a certain change of feelings. In fact it is evident upon closer examination, that all cases of change of presentations which can be brought under the principle of contrast are characterised by the accompaniment of lively feelings. Thus, for example, hunger, fatigue &c. are disagreeable feelings, and as a consequence easily call up presentations which are accompanied with opposite feelings. In opposition to the law of the internal connection of mental states, Co-existence and Succession may be conceived as a principle of *external* connection. For space and time are the two external forms in which all our presentations move, and in which, therefore, they must also be connected.

But as on the one side the processes of association may be thus derived from the nature of our mental states and from the psychological forms of space and time to which they are sub-

jected, so on the other side they can be regarded as necessarily conditioned by the laws of central innervation. It is a fundamental law of the central functions that an excitation follows a definite path the more easily the more frequently it has already traversed the same, and that different excitations combine so much the more readily the oftener they have already been connected. The phenomena of concomitant movement (*Mitbewegungen*) as well as the facts of physiological exercise and habit everywhere afford us confirmations of these truths. In this sense we may say: association is nothing more than the internal psychological image of a similar process which presents itself externally in concomitant movement. Just as in this last it is sometimes a group of muscles lying near the group directly set in motion, for example, in the movements of the third with the second or middle finger, at other times a group of muscles which has often acted in a common function, as for example in the customary movements of the arms during walking, so we find associated sometimes those presentations which have a certain affinity and whose excitations correspond to similar regions of the brain, sometimes those which are connected through space and time and whose excitations therefore have spread simultaneously or successively over different regions of the brain. In the phenomenon of increase of excitability through previous stimulation, as described in an earlier part of this paper, we have before us, so to speak, the most elementary form of this whole chain of phenomena. Indeed, it is to be expected that with every presentation called up through an external impression of sense an eddy of associations would be excited in us, were not the processes of inhibition in the central substance an effective means of limiting the diffusion of the excitations. In the rush of ideas which characterises insanity, it looks as if the brain were in a condition of unchecked excitation similar to that which is produced in the spinal column by certain toxic operations, this state being always followed, as we have seen, by a rapid exhaustion of nervous energy.

There is indeed one department of man's vital actions in which only fragments both of the internal and of the external causation are accessible to observation, and this is the highest manifestation of life—the sphere of conscious voluntary actions. Psychological causation presents itself here in the form of motives of volition. But of these motives only a few are present to consciousness, owing to its limited nature. Even in the most favourable instance all the motives cannot be accessible to our reflection, because only a part of these are acquired by us ourselves, the remainder resting on the innate

and inherited properties of our consciousness. The general direction which these properties give to our volitions is named our *character*. In the fact that we recognise voluntary action as the immediate outcome of our character, consists our free-will. This, even when regarded from the psychological side, is by no means a contradiction of causality, but rather is that special form of psychological causation which manifests itself in our conscious actions. We are responsible for our actions because character is the object of moral judgment; but we form our conclusions respecting the character from the voluntary actions.

Action, however, is only one side of the manifestation of will. Parallel to this there is the influence of the will on the current of our thoughts. Here the will follows associations as its immediate determinants, though here too no less than in actions it is guided by the whole nature of consciousness, as depending on original dispositions and past experience. It is the will that first brings about *ordered thought*, which is an internal measure of character, just as action is an external. Moreover the voluntary control of our ideas reacts powerfully on our voluntary conduct, for the motives of the latter are, it is obvious, present to consciousness in the form of representations.

Indeed, not only the psychological but also the physiological causation of our voluntary actions is in its precise nature inaccessible to direct proof. As in dealing with the former we are obliged to content ourselves with understanding single threads of the causal process under the form of motives, so in considering the latter we have to satisfy ourselves with the conclusion that in the nature of the nervous centres we have a means of conceiving in general a causal connection of physiological processes separated through immeasurably long intervals. On the one side the central substance is clearly a mighty reservoir of potential energy, and on the other side it shows itself in an extraordinary measure disposed to undergo continual change through processes taking place in it, and thereby to accumulate dispositions for future processes of excitation. Thus here too we are led to that conception which is the highest metaphysical outcome of psychology in our day, namely, that man has the two attributes of natural object and spiritual being not in any juxtaposition but as wholly involved with one another—as different sides of the one and indivisible human existence.

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