TEMPLE

PRIMERS

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PHYSIOLOGICAL PSYCHOLOGY

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ALDINE HOUSE
J. M. DENT & SONS LTD

1913 · 10—13 · BEDFORD · STREET · LONDON

First Edition, 1905
Reprinted 1908, 1911, 1913

PREFACE

It is now generally recognized that all students of the mind should have some knowledge of the structure and functions of the nervous system. Unfortunately it is not usual, and in many cases it is not possible, for students of psychology to make that thorough study of the nervous system which is desirable, and even those of them who are fortunate in this respect find some difficulty in bringing their physiological and anatomical knowledge into relation with that which they acquire by the study of works on psychology. The writer of this little book has therefore sketched in broad outlines the structure and principles of action of the nervous system and, assuming on the part of his readers some acquaintance with the general principles of psychology, has endeavoured to show how each of these two bodies of doctrine, the physiological and the psychological, supplements the other, deepening our insight into the processes that result in the actions of men and animals, and how the conjunction of the two kinds of research brings before us a number of problems of the deepest interest that remain hidden so long as we confine our attention to one or other of these sciences. These are the problems of the infant science of psycho-physics, the science that investigates the relation of body and soul. The book should therefore not be read alone, but should be studied concurrently with such standard works as Prof. James' *Principles of Psychology* and Prof. Stout's *Manual of Psychology*, and the reader who has made no special study of the nervous system should at least have at hand some such description and figures of the gross anatomy of the nervous system as are to be found in any one of the many excellent text-books of human physiology or anatomy.

The scheme of the nervous system and its functions that the writer has sketched is based upon a careful study of the best authorities; but it is only fair to warn the reader that great differences of opinion upon many fundamental principles still obtain among these authorities. It seemed better to adopt, and apply consistently, a workable scheme of the elementary nervous functions than to confuse the reader by frequent references to these differences of opinion.

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PHYSIOLOGICAL PSYCHOLOGY

INTRODUCTION

Psychology may be best and most comprehensively defined as the positive science of the conduct of living creatures. That is to say, it is the science which attempts to describe and explain the conduct of men and of other living creatures, and is not concerned with questions as to what their conduct ought to be. These questions it leaves to Ethics, the normative science of conduct. In adopting this definition we must understand the word conduct in the widest possible sense as denoting the sum of the activities by which any creature maintains its relations with other creatures and with the world of physical things. Psychology is more commonly defined as the science of mind, or as the science of mental or psychical processes, or of consciousness, or of individual experience. Such definitions are ambiguous, and without further elaboration are not sufficiently comprehensive. They express the aims of a psychologist who relies solely upon introspection, the observation and analysis of his own experience, and who unduly neglects the manifestations of mental life afforded by the conduct of his fellow-creatures. They do not adequately define the task that modern physiological psychology sets before itself. For physiological psychology aims at describing and explaining, as far as possible, all the factors that take part in determining the conduct of all living creatures, and though conduct seems to be in great part determined by our sensations, feelings, desires, emotions and all those other varieties of states or processes of consciousness which introspection discovers and distinguishes, psychology finds itself compelled in an ever-increasing degree to recognize the co-operation in all mental process of factors that are unconscious and so cannot be introspectively observed; and though some of these may be inferred from the nature of the processes revealed by introspection, others can only be inferred from the study of movements and other bodily changes. To define psychology as the science of experience or of consciousness is therefore to exclude the study of these unconscious factors, whereas the definition stated above brings all these within the scope of psychology without excluding the study of any part of experience or element of consciousness, for all experience affects conduct.

A rapid glance at the history of psychological study will help us to understand its present position and aims. Each one of us finds himself an individual centre of experience, shut up within that circle of experience and debarred from immediate knowledge of aught but his own states of consciousness. He is conscious of possessing a body whose parts he can move at will, and he perceives around him a world of objects which in many respects resemble his body, but which differ from it in that he can move or otherwise affect them only indirectly through movements of the parts of his body. And among the objects he perceives are some, the bodies of men, that closely resemble his own in appearance and behaviour Constantly perceiving both his own body and other bodies or things, he finds that he can also remember things previously perceived, can imagine others and can reflect upon the relations between them. And these perceptions and ideas of objects excite in him pleasure and pain, desire and aversion, impulses to act in this way or that in reference to these objects. He finds that he can to some extent control and suppress these impulses or can give them free play, when movements of his limbs or other parts of his body follow. On observing the sequence of these varied experiences he soon discovers amidst their enormous complexity and diversity certain similarities and differences of kind. The common speech that he has learnt without effort or reflection provides him with a rough classification of these different kinds of experiences, he finds that he uses different words to denote the different kinds; and he finds that his fellow-men claim to have experiences similar to his own, which they describe in similar terms and express by similar gestures and movements. He therefore unhesitatingly assumes that they enjoy experiences like his own, perceive the same things, have similar ideas, feel pain and pleasure, and that their conduct is the outcome of a similar play of impulses and restraints. And he notes too that the higher animals, though incapable of speech, behave in many ways like himself and his fellow-men, that their movements seem to show that they too perceive the same objects, suffer pain and pleasure, experience joy and tenderness and rage, and act accordingly. To this extent all intelligent men are, and always have been, psychologists. But from the earliest times there have been men who have sought to gain a deeper understanding of experience and to explain it to others. They have made many guesses, many wild speculations, and many vague hypotheses. But some of them founded the science of psychology by observing carefully their own experiences, analyzing the more complex, defining, classifying and naming the fundamental kinds. This was the descriptive stage of the science, the necessary first stage of every science of observation. It endured for many centuries. The second stage was characterized by the noting of certain orderly sequences, or tendencies to co-existence and sequence, among these kinds of experience, and by the attempt to formulate the laws of these co-existences and sequences. It was attempted to show that all our experience consists of sense-impressions and ideas or faint copies of sense-impressions, and that, while the character and order of our sense-impressions is determined by the action of the things of the physical world upon our sense-organs, the conjunctions and sequences of our ideas can be wholly accounted for by one great law or principle, the law of association of ideas. This stage began to give place to a third stage a little before the middle of last century. At that time the labour of many physiologists, especially of Sir Charles Bell in England, of Flourens in France, and of Johannes Müller and his pupils in Germany, had begun to throw considerable light on the structure and functions of the nervous system. It was shown that, on the one hand, we can only perceive any object if it in some way makes a physical impression upon one or other of the sense-organs, and if the sensory nerves, the nerve-fibres that connect the sense-organ with the central nervous system, are intact; and that, on the other hand, we can move any part of the body only by means of nervous impulses, physical changes conducted from the central nervous system to the muscles by another and entirely distinct set of nerve-fibres, the motor nerves. It was shown, too, that the normal working of the mind depends upon the integrity and normal working of the brain, that to deprive the brain of a full supply of blood, or to give it a severe jar, is to bring all mental process to a stop, to abolish consciousness, and that the destruction of certain parts of the brain always results in the loss of certain faculties or puts an end to certain kinds of experience, whereas the destruction of other parts of the body makes no such radical and definite changes in the character of mental process. It became clear, therefore, that each man's knowledge of the world about him, even his knowledge of the existence of his own body and of the bodies and minds of other men, was gained only through the medium of the sensory nerves and the brain, and that only through the medium of his brain and motor nerves can he exert any, even the smallest, action upon the things about him or make other men aware of his existence; that, in short, we cannot hope to arrive at a complete understanding of the behaviour of men or animals by the methods of introspective psychology alone, but that a thorough understanding of the physiology of the nervous system is a necessary part of the equipment of the psychologist. Hence some of the acutest minds of that time, notably R. H. Lotze and G. T. Fechner, began the attempt to combine the two kinds of research, the physiological and the psychological. Accepting the conclusions of physiologists and anatomists as to the functions and structure of the nervous system on the one hand, and those of the introspective psychologists as to the laws of psychical processes on the other hand, they sought to discover the relations of the two kinds of processes, the nervous and the psychical, and to lay the foundations of physiological psychology, the psychology that strives to render a complete account of the laws that govern conduct.

Since that time introspective psychologists have carried the analysis of mental process to a pitch of refinement greatly surpassing that of the psychologists of the association-school, and in this work they have been greatly aided by the recently-introduced experimental methods, *i. e.* the methods of making introspective observations under conditions accurately controlled and simplified as far as possible.

On the other hand, hundreds of ardent workers, under the stimulus of the ambition fully to explain the behaviour of men and animals, and more or less neglecting the subjective or introspective psychology, have devoted their lives to the elucidation of the structure and functions of the nervous system, and, in spite of very great difficulties, a considerable insight has been obtained. This ardent and successful study of the nervous system, coinciding in time with the rapid and triumphant progress of physical and biological science, has given rise to the prevalence of a very curious opinion as to the true aims of psychological study, an opinion which, if well founded, must completely revolutionize the old ideas as to the aims and methods of psychology, must lead to the supplanting of psychology by the study of the nervous system, and would make the positive science of conduct a branch of physical science. Since this opinion is still widely current we must briefly examine its foundations.

Among the most striking of physiological discoveries are those relating to the reflex actions of the spinal cord. It has been shown that, when the brain of certain animals has been destroyed, while the spinal cord and the trunk and limbs and their nervous connexions with the spinal cord remain intact, the limbs may still be excited by appropriate stimulation of the skin to execute movements that seem to be intelligently directed. Thus, if a drop of weak acid is put on the skin of the trunk of a frog whose brain has been destroyed, the hind-foot that can best reach the spot is raised and drawn across it, as though with the purpose of removing the irritation; and, if that foot is held fast, the other hind-foot makes a similar "attempt." Or if to the skin of the back of a dog in a similar condition an irritation somewhat similar to the bite of a flea is applied, one hind-foot will be raised towards the spot and will execute rapid scratching movements, and, though these movements are not so accurately adjusted as the similar movements of an intact animal, they are yet "aimed" with some precision at the spot irritated.

Now such reflex movements seem to be completely determined by a chain of purely physiological processes. In each case we seem to be able to trace the progress of a wave of physical change, initiated by the stimulus in the sense-organ of the skin, up the sensory nerves into the spinal cord, along certain nervous channels in the cord and out along the motor nerves that pass to the muscles whose contractions bring about the movements. There seems to be no scope for the intervention of mind as a directing agency. The whole process, from beginning to end, seems to be physically determined by the molecular structure of the nerves and by the mode of interconnexion of sensory and motor nerves within the spinal cord, which determines that the excitement transmitted by the sensory nerves shall pass over to this or that group of motor nerves. This conclusion is borne out by the fact that similar reflex movements may be excited in our own bodies while we are in deep sleep or during the complete unconsciousness produced by such drugs as chloroform and ether. The spinal cord, in so far as it is not made up of bundles of nerves passing to and from the brain, has been shown to consist wholly of such complex connexions between sensory and motor nerves constituting nervous mechanisms for the production of reflex movements.[1] And it has been shown also that the structure of the whole brain is essentially similar to that of the spinal cord, that it seems to consist of nervous mechanisms of great complexity serving to transmit nervous impulses, physical excitations, from the sensory nerves to the motor nerves.

This recently-acquired knowledge of the nervous system thus forbids us to accept the view that was for a long time generally entertained, the view that the impulses of the sensory nerves came to an end at some spot or spots in the brain where they stimulate the soul to produce sensations, while the impulses of the motor nerves are initiated in their central ends in the brain by the soul playing upon them as a musician plays on the keys of a piano. We are compelled to believe rather that the nervous processes of the brain are of the type of the reflex processes of the spinal cord, and consist in the transmission of physical impulses through channels of great complexity from the sensory to, or towards, the motor nerves, and to believe also that all psychical processes are accompanied by nervous processes of this character. The conclusion that all psychical process or consciousness is accompanied by neural process is now generally accepted, and may be regarded as well founded. It is expressed as *the law of psycho-neural parallelism.* But many physiologists, not content with this conclusion, have been led by the facts stated above to adopt a view of a more questionable and, indeed, paradoxical character, the view, namely, that if we could completely describe the structure of the nervous system of any man or animal, and had a complete knowledge of the laws of the physical and chemical processes that occur in it, we should be able to account completely for all the conduct of that individual.

This view, which is now held by many psychologists as

[1] Other changes, such as the secretion of tears and saliva, are also produced in this way, but it is allowable to include all these under the term movement.

well as many physiologists,[1] involves the assumption that consciousness, our perceptions, ideas, volitions and feelings, as such, have no influence upon our conduct; that they are caused by the play of nervous processes in the brain, but do not in any way modify or react upon them. Others say that the two kinds of events, the physical events of the brain and the psychical events or processes in consciousness, form two series that run parallel to one another, but never meet or interact. Others, again, say that the physical and the psychical are two modes in which one series of real events appears to us, and that therefore the two series of appearances run parallel to one another. Hence this view in the second and third forms is known as the doctrine or *hypothesis of psycho-physical parallelism*. The rejection of these doctrines implies the acceptance of the old common-sense view that soul and body, or psychical and physical processes, interact or react upon one another, so that psychical processes play a part in determining conduct, and this is known as the *hypothesis of psycho-physical interaction*.

Those who, denying psycho-physical interaction, accept one of the varieties of the doctrine of psycho-physical parallelism or the doctrine of one-sided causation of the psychical by the physical, usually support their position by the two following arguments. First, they assert that the law of conservation of energy, the best-founded generalization of physical science, forbids us to assume interaction, because action of body on soul would imply transformation of physical into psychical energy, and therefore diminution of the sum total of physical energy of the universe, while action of soul on body would involve the reverse of these effects. But to argue thus is to beg the question at issue by assuming that the physical energy of the universe is a closed and finite system of energies. This assumption is an unjustifiable extension of the law of conservation of energy, for the law is merely the generalized statement of the empirically established fact that in every case of

[1] The reader will find a clear and forcible statement of the case for this view in T. H. Huxley's *Essay on Animal Automatism*

transformation of energy in which it has been possible to measure in terms of a common standard the quantities of the transformed and of the formed energies they have been found to be equal or equivalent. Nor is even this strictly true, for in many cases of transformation of physical energy a part of the energy disappears, or becomes latent, though by a convenient fiction it is said to become potential energy; all we know of this so-called potential energy is that it is recoverable and capable of giving rise again to a quantity of energy equal to that which disappeared.

The "interactionist" therefore may deny that the physical system of energies is a closed and finite system, or he may ask: What right have we, while including the potential energies in the system of energies to which the law of conservation is held to apply, to exclude psychical energy from that system? And he may point out that no tenable definition of energy can be given which will exclude psychical energy, if, as he maintains, interaction between physical and psychical energies takes place.

The second stock argument of the "parallelist" is that psycho-physical interaction is impossible, because we cannot conceive or understand how it can take place. This argument clearly implies that we can understand how physical interactions take place. Now in so far as many kinds of physical interaction can be imagined or represented in the mind as consisting in the communication of momentum from particle to particle by impact, it is perhaps fair to claim that we understand them, for we regard them as of a type with which we are familiar; and it is equally true that we cannot understand, in this sense of the word, psycho-physical interaction, because, being absolutely unique, we cannot hope to exhibit it as similar in kind to any more familiar class of interactions. But when we examine our notion of communication of momentum by impact we find that the conception of even this most familiar type of interaction presents great difficulties, that, strictly speaking, we do not understand its intimate nature. Further, there are forms of physical interaction, notably gravitation, the reciprocal attraction of masses at a distance, which cannot be represented in terms of any more intelligible mode of physical interaction. Yet no one on this account denies the reciprocal attractions of the earth and the moon or of the other members of the solar system, and the recent brilliant progress of physical science, since it manifests more clearly than ever before the inadequacy and imperfection of our conceptions of matter and energy and of the nature of physical processes in general, serves to make obvious the absurdity of the deduction of the impossibility of psycho-physical interaction from the proposition that it is inconceivable.

When we are attempting to estimate the weight of this argument we should remember that, although many writers of repute have asserted the impossibility of conceiving psycho-physical interaction and have denied its occurrence on that ground, many thinkers, equally well qualified to form an opinion, have asserted with equal confidence that the action of mind on matter is the only kind of action or causation that we are capable of understanding, and have deduced the impossibility of purely physical interactions from the impossibility of conceiving them. We may fairly set the one body of opinion against the other and conclude that neither argument is valid, that the limits of the possible are not determined by the feebleness of our understandings, and that we must seek to decide the question upon other grounds. While, then, we must admit that psycho-physical interaction cannot be understood in the sense that it cannot be shown to be a special case of a more general type of interaction, we may hope to understand it in the sense that we may hope to formulate its laws and to express the multitude of diverse interactions in a certain number of general formulæ.[1]

The hypothesis of interaction on the other hand is founded

[1] Any reader who still inclines to the hypothesis of psycho-physical parallelism should read the chapter on "Causation," and especially the last section of it, in J. S. Mill's *System of Logic*, and the chapters on "Psycho-physical parallelism" in Prof. James Ward's *Naturalism and Agnosticism*.

upon, and that of parallelism involves a breach of, laws far more certainly established than the law of conservation of energy, namely, the logical laws of causation on which all inductive science is based. One law of causation tells us that, when two processes invariably occur in conjunction in time, no matter how varied the conditions, we must believe them to be causally related. Now our sensations at least are admitted by all to have this relation of invariable concomitance with certain neural processes. Some of those who reject interaction are yet sufficiently logical to admit the necessity of recognizing a causal relation here, and therefore in order to maintain the independence of nervous processes from psychical interference they admit a one-sided action, action of the physical on the psychical without reaction of the psychical on the physical;[1] and they assert that the neural process is in no wise modified in producing its psychical effects, and that it therefore produces exactly the same physical effects as it would if the psychical effects were lacking. But this involves a breach of another law of causation, the law, namely, that the cause must always in some degree pass over into its effects—must in some degree spend itself in producing its effects. All our experience of causation confirms this law, and there is no reason for believing that the causation of psychical effects is an exception to it.

We are then logically compelled to believe that neural processes and psychical processes are causally related according to ascertainable laws, and that the discovery of those laws is the supreme task of physiological psychology. We must therefore recognize that the swing of the pendulum has carried many moderns too far in their reaction against the old introspective and spiritualistic psychology, and that the path of progress lies in the direction pointed out by Lotze, and will be trodden by those who, whatever their metaphysical

[1] This was the view taken by the late Prof. Huxley in the essay referred to on p. 8. In that essay he describes consciousness as an epiphenomenon, and by that word this view is now generally denoted.

views as to the ultimate nature of the world may be, seek to accord due recognition to both the physiological and the psychical factors of our mental life.

We are sometimes told that the introduction of physiological considerations in psychological reasonings is futile, because our knowledge of the nervous system and of the processes that occur in it is so imperfect. It is a sufficient answer to point out that many recent advances in psychology are directly due to physiological observations; for example, our knowledge of the complex processes involved in the use of language has been very greatly increased by the study of lesions of the different parts of the brain concerned in these processes and of the effects of such lesions, and many other examples might be cited. But we may reply in more general terms that the phenomena of sleep, fatigue, and disease, the mental effects of drugs and of injuries to the brain, the slow development and decline of mental power with the development and decay of the nervous system in youth and in old age respectively, cannot be in any sense understood or explained save by reference to the nervous system, and they prove conclusively that our mental life is intimately bound up with, and to a great extent conditioned by, the processes of the nervous system, and therefore cannot be understood without the aid of knowledge of those processes. It is just these features of our mental life of which a thorough understanding is most urgently needed, because it is with these that the educator and the physician are concerned, and it may be confidently predicted that psychology will cease to be regarded as a purely academic study, and will be recognized as providing the only sound theoretical basis for the art of the teacher and the practice of the alienist in proportion as it becomes a truly physiological psychology.

The physiological psychologist must avoid the error, an error into which too many physiologists have fallen, of neglecting or despising the refinements and subtleties of the introspective psychologists. He must admit the primacy of introspective psychology, must recognize that all the objective methods of psychological study presuppose the results of the subjective or introspective method and can only be fruitful in so far as they are based upon an accurate introspective analysis of mental processes. He must recognize, too, that introspective psychology is in a much more advanced condition than neurology, and that his work must principally consist in the application of the results achieved by the former to the elucidation of the problems of the latter science, and must not regard his work as designed to supplant introspective psychology, but merely as its necessary complement. Nevertheless he will not scruple to push his physiological explanations of the conditions of mental processes as far as possible, though admitting the hypothetical and speculative character that, in the present very imperfect state of our knowledge of the nervous system, his explanations necessarily have.

In accordance with these principles the following pages will first describe in general terms the structure of the nervous system and the nature of the nervous processes, and will then attempt to exhibit the correlations, and as far as possible the causal relations, between the nervous functions and the psychical processes as analyzed and described by the introspective psychologists.

CHAPTER I

A Rough Sketch of the Structure and Functions of the Nervous System

THE conduct of a man or animal, in the wide sense in which the word conduct is used in these pages, is the sum of the movements of the parts of his body, and all such movements are effected by the contractions of muscles. By means of such contractions he transports his body from place to place, manipulates the things of the external world, and communicates with his fellow-creatures by gesture, speech, or other signs. Some of these movements, for example, those of speech and gesture, have no immediate relation to the things of the physical world, but others are adjusted, often with marvellous nicety, to produce effects on those things. Movements of the latter kind are guided by impressions made on the sense-organs by the things to which the movements are adjusted. This guidance of the movements by impressions made on the sense-organs is rendered possible by the nerves which connect the sense-organs with the muscles.

The simplest kind of nervous system, possessed by such creatures as the sea-anemone and the jelly-fish, consists of a few nerve-fibres connecting a few very simple sense-organs with a few simply-arranged muscle-fibres, the nerves being more or less intimately connected to form a network or plexus. When any physical change of a kind and intensity capable of stimulating the sense-organ, when, for example, a solid object suddenly comes in contact with one of the sense-organs, a physical or physico-chemical change, which we call the nervous impulse, is transmitted from it along the nerve to one or more of the muscles, and excites in them chemical changes which cause them to contract and so withdraw that part of the body from contact with the object. That is a simple *reflex action* carried out by means of a simple *sensori-motor nervous arc* in response to a stimulus applied to a sense-organ. It is the fundamental type of all nervous action, and it would seem that the nervous system of any one of the higher animals, even of man himself, consists essentially of such sensori-motor arcs conducting nervous impulses from the sense-organs to the muscles.

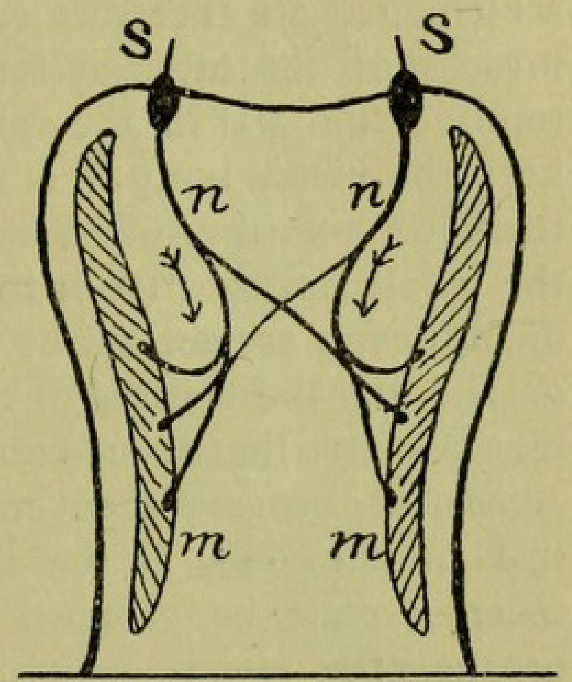

FIG. 1.

Diagram to illustrate a very simple type of nervous system, consisting of a few sensory cells (*s s*) on the surface of the body, each directly connected with a muscle-fibre (*m m*) by a nerve-fibre (*n n*).

The complex nervous systems of the higher animals may be regarded as having been evolved from this very simple type through (1) a great increase in the number and variety of the sense-organs, many of which become highly specialized for the reception of particular kinds of physical stimulus; (2) a corresponding increase in the number of the muscles and in the complexity of their arrangement; (3) a more than corresponding increase in the number and complexity of arrangement of the sensori-motor arcs that connect the muscles with the sense-organs; instead of being simple paths by which the nervous impulses are conducted directly from each sense-organ to some one muscle or group of muscles, the very numerous sensori-motor arcs become connected together in very complex fashions, so that the impulses originating in any one sense-organ may spread through the whole nervous system, or through any part of it, and be transmitted to all or any of the muscles.

In the higher animals and in man we must distinguish two systems of muscles and two corresponding systems of sense-organs. The one system of muscles is attached for the most part to the bones of the skeleton, and the contractions of the muscles of this *skeletal system* produce all those movements of the limbs, trunk, head, and organs of speech by means of which relations with the outer world are maintained. In man these movements are under the control of the will, and the muscles of the skeletal system by whose contractions they are effected are therefore called also voluntary muscles. The muscles of the other system are embedded in the organs of reproduction and in the various organs whose function it is to keep the whole body in a state of vital efficiency, to prepare the food for absorption into the blood, to aërate and purify the blood and to drive it to all parts of the body in just such quantities as are needed by each part. The principal of these organs are the viscera of the thorax and abdomen, and the muscles are therefore known as the muscles of the *visceral system*, or, because their contractions are not under the control of the will, as the involuntary muscles. With these muscles must be grouped the other great system of active organs, the glands which secrete the digestive and other juices and regulate the composition of the blood, for they are controlled by the same system of visceral nerves.

The muscles of the skeletal system are intimately connected by sensori-motor arcs with the sense-organs of the surface of the body which are stimulated by the things of the outer world. The muscles of the visceral system are connected by sensori-motor arcs principally with sense-organs that are embedded in the viscera, and are stimulated by movements, pressures and chemical changes in the viscera; and these arcs constitute a system of nerves that was for long considered to be quite separate from, and independent of, the other larger system, and was known as the sympathetic system. We know now, however, that the two systems of sensori-motor arcs, the skeletal or voluntary and the visceral or involuntary, are intimately connected.

The skeletal muscles are controlled not only by impulses from sense-organs on the surface of the body, but also by impulses initiated in sense-organs that are embedded in the muscles themselves and in the surrounding tissues, the sheaths of the muscles and their tendons and the joint-surfaces of the bones; these sense-organs, which are known as the organs of the "muscular sense," are stimulated by the contractions of the muscles and the movements of the parts resulting from those contractions. The nerves from these sense-organs join the sensori-motor arcs that connect the skeletal muscles with the sense-organs of the surface, and so co-operate with them in determining the sequence and the force of the contractions of these muscles, which are thus under a double sensory control as well as the control of the will.

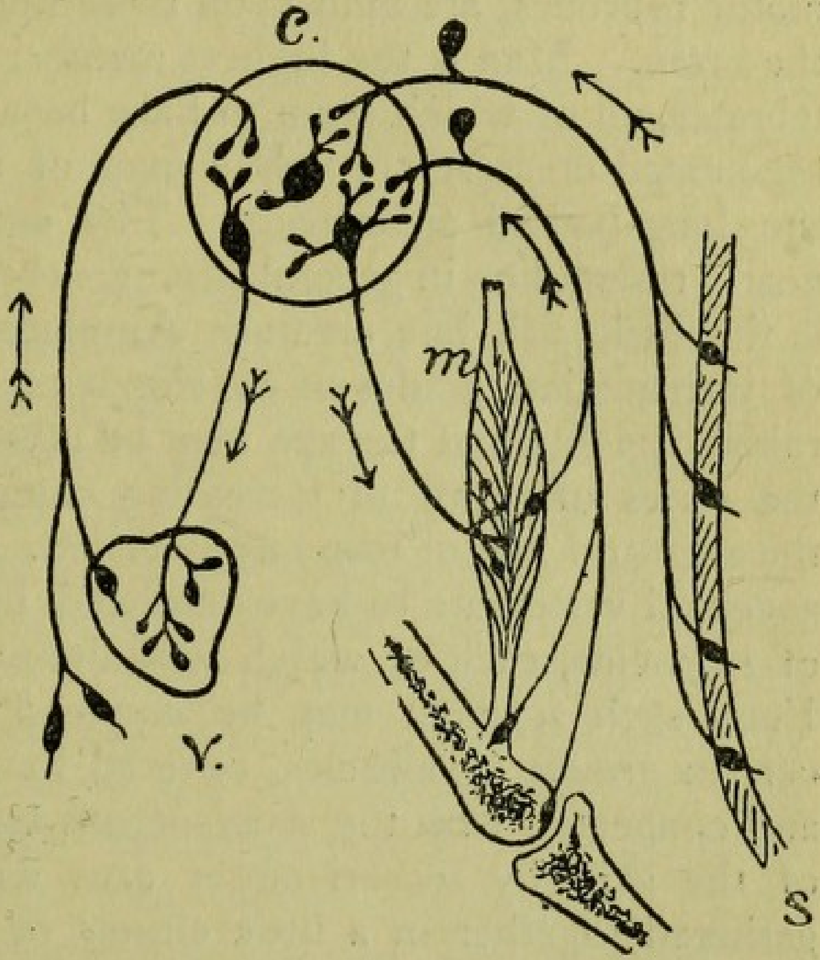

FIG. 2.

Diagram illustrating the functional units, the skeletal and visceral sensori-motor arcs, of each segment of the nervous system of a vertebrate animal. *C* the central nervous system, *m* a skeletal muscle attached to bone, *s* the skin covering it, *v* a muscular viscus. On the right is shown a skeletal arc with double afferent path from sense-organs of the skin and from sense-organs of the "muscular sense" in tendon, joint-surface, and muscle; on the left an arc of the visceral system with afferent path from sense-organs in and about the viscus.

These are the functional units which with their complicated interconnexions constitute the nervous system. They are represented schematically in the diagram Fig. 2.

A sketch of the way in which the nervous system of man seems to have been evolved from a simple form affords the best introduction to an understanding of the plan according to which the functional elements described above are connected together to form the spinal cord and of the plan according to which complex systems of arcs, connecting sensory and motor neurones, are built upon these fundamental arcs to form the brain. Man is the highest member of the family of vertebrates, all of which seem to have been evolved from a simple segmented creature not unlike some of the annnelid worms or the long-bodied arthropods. The existing vertebrate most nearly resembling in general structure the hypothetical ancestor is the little fish-like creature Amphioxus: other vertebrates of intermediate grades of development, the fish, the frog, the rabbit, the dog and the ape may be taken to represent roughly the series of forms of increasing complexity through which the ancestral line of man has ascended. We may conceive the ancestral vertebrate to have consisted like a worm of a series of segments, each of which was almost a complete organism. Each such segment may be supposed to have consisted of certain groups of muscles, covered by a segment of the skin and connected with the sense-organs scattered over that part of the skin by sensori-motor arcs whose middle parts are gathered together in a little cluster or ganglion; and within the ring of muscles of each segment we must imagine a section of the alimentary canal, a large pulsating artery, a kidney and other viscera. The segments are not to be imagined entirely independent of one another, because the alimentary canal is continuous through all of them, their blood-vessels communicate, and the ganglia of neighbouring segments are connected by a longitudinal strand of nerve-fibres. Nevertheless the stimuli affecting the sense-organs of each segment are reflected by simple sensori-motor arcs chiefly to the muscles of the same segment. The animal progresses in the direction of its oral extremity, and the special sense-organs, those of taste and smell, of sight and hearing, become developed about this extremity, since their function is to make the creature aware of the nature of the objects towards which it is moving at any moment. With the development of these special sense-organs in the leading segments the number of sensori-motor arcs in those segments becomes greatly increased, and since the movements of the animal as a whole, *i. e.* the contractions of the muscles of all segments, must be made to work together for retreat from, or advance towards, the things that affect these sense-organs, the nervous connexions of these leading segments with the ganglia of the remaining segments become multiplied. Hence the ganglia of the leading segments become much larger and more complex than the rest; special protection is required by them, and special muscles are needed to move these special sense-organs. Thus the oral extremity containing the rudiments of the brain, the special sense-organs and the mouth, becomes the head. The growing bulk of the brain excludes from the head all visceral organs save the extremity of the alimentary canal leading from the mouth. The regular segmental arrangement of the viscera and of the muscles of the rest of the body becomes disordered by the development of the fore and hind limbs, which require for their varied movements larger and more numerous muscles and more complicated nervous connexions than those of the limbless segments. The stage thus reached is represented by the fishes and the simple amphibians. In the nervous system of man and of all the higher vertebrates we can distinguish the parts which represent the nervous system of the ancestral vertebrate at this stage. They are the spinal cord and basal ganglia of the brain, the latter representing the ganglia of the special sense-organs of the head, the former the chain of ganglia of the body and the longitudinal strand which connects them. These contain, of course, many nerve-fibres which serve to connect them with the later-developed or higher parts of the nervous system, namely, the cerebral hemispheres or great brain; but apart from these, they consist of sensori-motor arcs, small groups of which are connected together to form simple systems of arcs. The conception of a *functional system of arcs* is one of great importance. A system consists of a number of arcs so intimately connected that, when the sensory limb of any one of them is stimulated, the impulse spreads to all the members of the system and excites a group of muscles whose contractions produce an orderly movement of some part or parts of the body or, as it is technically called, a co-ordinated movement. The arcs thus combined in simple systems and constituting the spinal cord and basal ganglia are the foundation on which the rest of the nervous system is built up. They may be called the arcs of the lowest or spinal level.

In the next stage of development branches grow out from the sensory limbs of the arcs of the spinal level of each segment, form various connexions with similar branches and return to the motor limbs of the spinal arcs of the same or other segments. They thus form loops upon the arcs of the spinal level and combine them in systems of greater complexity; by means of these more complex systems more complex conjunctions of sensory impressions co-operate to produce more elaborately co-ordinated movements.

Just as in the primitive vertebrate the middle parts of the arcs of each segment cluster together to form a ganglion in which they are connected with one another by branches, so these loops growing out from the arcs of each segment at a later period of the development are brought together in a single large ganglion which is the rudiment of the cerebrum or great brain, and which appears as an outgrowth from the ganglia of the special sense-organs of the head. These ganglia thus became the basal ganglia of the brain. These loops upon the arcs of the spinal level may be distinguished as arcs of the second or intermediate level. In the vertebrates of an intermediate grade of development such as the rabbit, they constitute almost the whole of the cerebrum.

The third great stage of the evolution of the nervous system is characterized by a great increase of size of the cerebrum, due partly to an increase in the number and complexity of the interconnexions of the arcs of the intermediate level, but chiefly to the development of a great mass of nervous elements which become organized into arcs combining the neural systems formed by the elements of the first and second levels into systems of still greater complexity. These arcs of the third or higher level are related to those of the second level in much the same way as these are related to those of the first or spinal level. In the higher animals, in the dog, and still more in the ape, the arcs of the second level derived from each of the great systems of sense-organs are grouped together in the cerebrum forming the parts known as the sensory areas (see Fig. 3) while the later-developing arcs of the third level are intricately interlaced forming areas, known as the association-areas, surrounding these sensory areas and separating them from one another. In such animals the arcs and systems of arcs of the spinal level are congenitally organized in each individual, *i. e.* the details of their structure and interconnexions are completely determined by heredity and are incapable of modification, save perhaps in a very small degree, in the course of the life-history of the individual. The arcs of the second level and their interconnexions must also be regarded as almost completely organized congenitally. But it is characteristic of those of the higher or third level that their organization, their interconnexions by means of which the simpler neural systems of the first and second levels are combined to form systems of great complexity, is congenitally determined in a very partial degree only, and is principally determined in each individual by the course of its experience. The arcs of the higher level thus constitute the physiological basis or condition of docility, the power of learning by experience.

In the brain of the child the arcs of the first and second levels very early become organized in systems that take form independently of the child's experience; but in addition to these there is present at birth a vast number of nervous elements which become only gradually organized, modifying and combining the congenital systems in extremely complex systems which constitute acquired dispositions to modes of action peculiar to the individual. The number of the elements of this nature is so great that the areas of the cortex of the cerebrum in which they predominate, those which surround

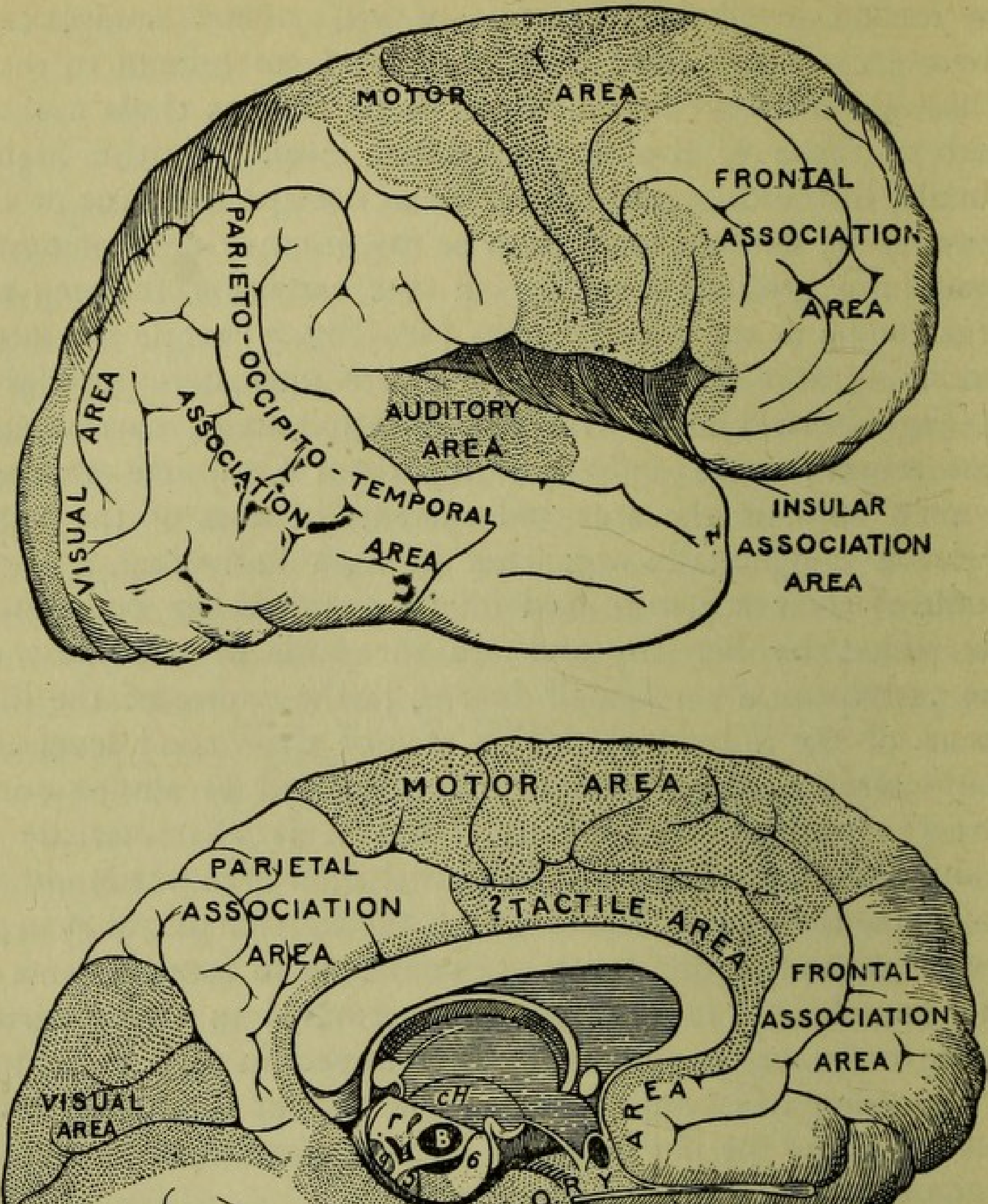

FIG. 3.

Right cerebral hemisphere of man seen from the outer (the upper figure) and from the median side. The sensory areas are dotted. The part marked motor area is the kinæsthetic sensory area. (Flechsig's figure as modified by Schäfer.)

the various sensory areas and are known as the association-areas, are considerably more extensive than the sensory areas, which in the higher animals make up the greater part of the cortex. The greater relative size of the brain of man is chiefly due to the great development of these parts. The very great capacity for learning by experience, rendered possible by this vast mass of nervous elements not congenitally organized, distinguishes the mind of man and raises it immeasurably above that of the highest animals.

This description of the nervous system as consisting of sensori-motor arcs of three principal levels is of course a very much simplified schematic view, and it is probable that future research may enable us to distinguish a hierarchy of levels among the arcs that we have grouped together as constituting the third level. Nevertheless it will form a useful basis for the exposition of nervous functions, and its substantial truth is borne out by three kinds of observation: (1) The comparison of the brains of vertebrates of different levels of development; (2) the order of development of the parts of the human brain, the three levels attaining structural perfection in the order from below upwards; (3) the loss of function in the reverse order under the influence of disease, noxious drugs and general constitutional decay; for the oldest or most primitive parts, having attained the greatest fixity or stability of organization, offer the greatest resistance to destructive influences, while the latest acquired structures are less stably organized and therefore give way most readily under stress of any kind.

Before describing in more detail the functions of these nervous arcs and the parts they play in our mental life, it is necessary to examine more closely the nature of nervous tissue and of the processes that occur in it.

CHAPTER II

The Minute Structure of the Nervous System and the Nature of the Neural Processes

The Neurones.—The nervous system is made up of an immense number of nerve-cells bound together and supported by sheaths and strands of connective tissue and finely branching cells, the neuroglia-cells. Each nerve-cell, or *neurone* as it is now commonly called, is, so far as the maintenance of the vital processes of nutrition and growth are concerned, a self-contained individual, not an independent individual but a member of a very complex society, the cells of the whole body; and its welfare, like that of any member of a highly-civilized community of persons, depends upon the continuance of harmonious co-operation among the members of the society.

The neurones are of various shapes and sizes, but each one consists of a nucleus, which with a certain amount of protoplasm surrounding it constitutes the cell-body,[1] and one or more delicate protoplasmic processes continuous with the cell-body. In many neurones one of these processes is much longer than the rest and is called the axis-cylinder process or *axon.* All the nerve-fibres of the peripheral nerves are axons of neurones. The axon, in most cases, has for its protection a delicate sheath of fatty matter known as the *medulla*, and in

[1] The cell-bodies were formerly spoken of as the nerve-cells or the ganglion-cells, and the false implications which the word nerve-cell has thus acquired justify the use of the word *neurone* to denote the whole cell.

many cases it is of great length, those, for example, which run from the spinal cord to the ends of the toes of a tall man are several feet in length. Some axons give off at short intervals a number of branches or *collaterals*, which connect them with numerous other neurones. The other processes of the body of the neurone are generally shorter and much branched; they are known as *dendrons* because in many cases a single large process of this kind divides, like the stem of a tree, into many branches ending in a great number of twigs.

Those neurones which have long axons have very large cell-bodies, for the cell-body presides over the nutrition of the whole cell. The large cell-bodies of the motor neurones lie in the anterior horns of the central core of grey matter of the spinal cord and in the corresponding parts of the basal ganglia of the brain. Their axons pass out directly in bundles which form the anterior roots of the spinal nerves and corresponding nerves of the head. The cell-bodies of the sensory neurones cluster together in the ganglia of the posterior roots of the nerves, which roots consist of bundles of the axons of these cells. It is thus the peripheral ends of the axons of the sensory neurones which receive the physical impressions of the outer world. All the other neurones, with the exception of a relatively small number belonging to the visceral system of nerves, are wholly confined to the central nervous system, and make up the paths and systems of paths of extreme complexity that connect the sensory with the motor neurones. Some have large bodies and long axons connecting widely separated parts of the central nervous system, as, for example, the pyramidal cells of the cerebral cortex which send down their axons to the various segments of the spinal cord. Others are small and have short axons which are hardly distinguishable from the dendrons.

It has been assumed by some authors that the dendrons always serve to receive the stimulus from other neurones and to conduct impulses towards the cell-body, and that the axon always conducts impulses from the cell-body, but exceptions to this premature generalization are known, and it is mentioned here only that the reader may be warned against accepting it. The neurones which make up the retina and

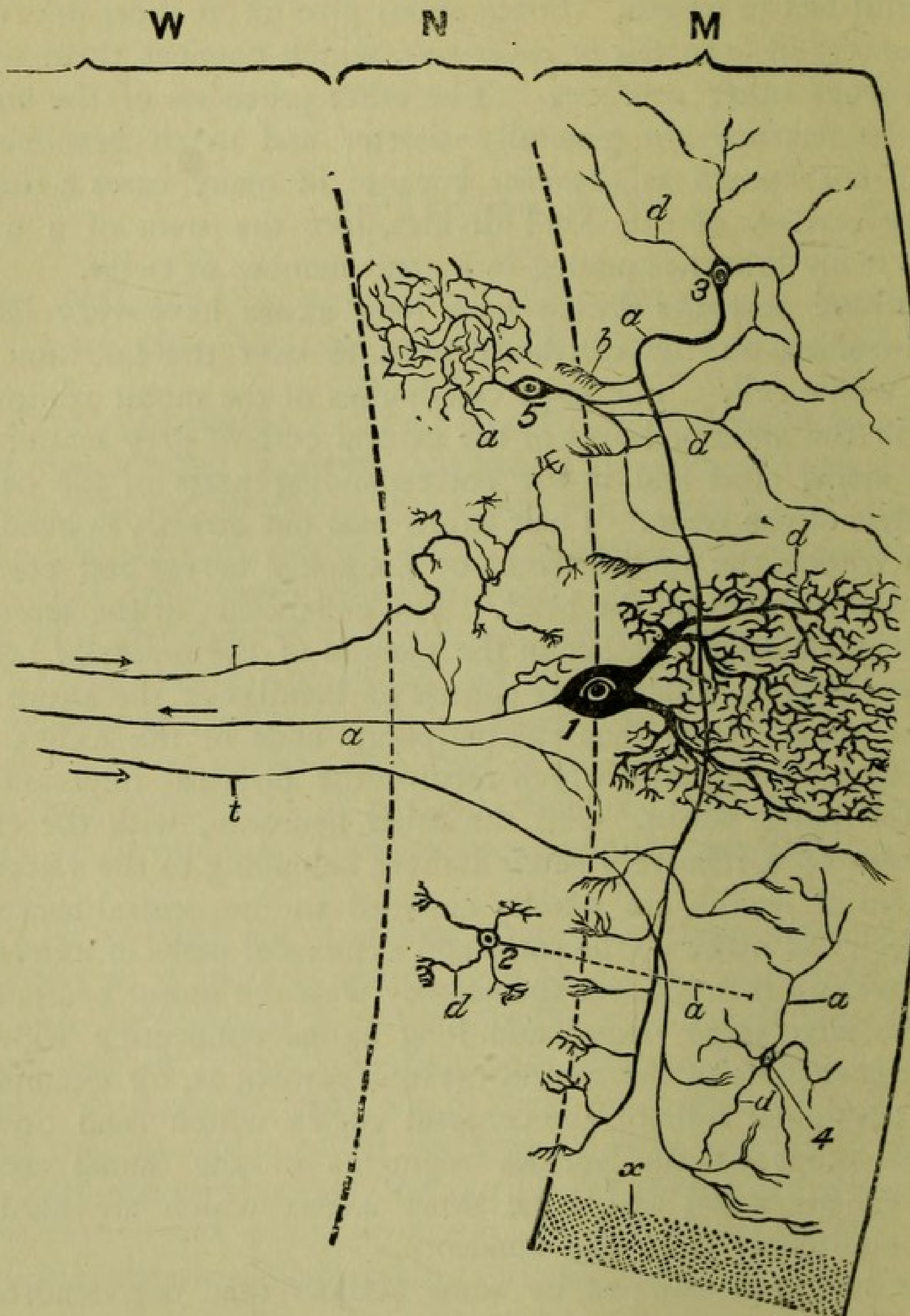

FIG. 4.

Illustrating various types of neurones or nerve-cells. (After Sir M. Foster.) *a a* axons, *d d* dendrons, *b b* terminal twigs that form synapses with the similar branches or the bodies of other cells.

the optic nerves, and those which constitute the olfactory sense-organ are exceptions to the rule that the sensory neurones receive the physical impressions of the outer world upon the peripheral ends of their long axons, for the cell-bodies of those neurones lie in the sense-organs, and are connected with the brain by chains of neurones. These sense-organs are in fact outgrowths from the brain and are, morphologically considered, parts of the brain.

Although the neurone is a vital or trophic unit, it is not the functional unit of the nervous system, for, as we have already seen, the functional unit is a sensori-motor arc through which the nervous impulse is conducted from sense-organ to muscle, and the simplest sensori-motor arc consists, in the higher animals and man, of at least two neurones joined end to end, a sensory or *afferent* and a motor or *efferent* neurone. Even a reflex arc of the spinal cord may consist of a chain of several neurones thus joined end to end, and in the complex arcs of the higher levels the number thus joined in series may be still greater. Besides being joined end to end the neurones of the various arcs are also connected in complex ways by collaterals and by the branches of the drendrons. An understanding of the nature of these junctions of neurones is, as we shall see, of the greatest importance for the physiological psychologist.

The Synapses.—The junctions between neurones are conveniently named *synapses*. The microscopic investigation of the synapses is unfortunately so difficult that, in spite of much labour devoted to it, our knowledge of their structure is still very imperfect. A simple kind of synapse is formed by the division of the end of an axon, or of one of its collaterals, into a number of fine twigs that surround the cell-body of another neurone and terminate in tiny knobs lying close to, or perhaps in contact with, that cell-body. Others are formed by the minute terminal branches of an axon or a collateral becoming intertwined with the branches of a dendron of another neurone or, in some cases, perhaps, with similar fine terminal twigs of the axons or collaterals of another cell. In many cases the terminal twigs of several axons surround one cell-body or are intertwined with the dendrons of a single neurone. It has been generally asserted that there is no continuity of substance between the neurones that are joined at a synapse, and although recent researches seem to show that there is protoplasmic continuity in certain cases, we may confidently believe that in the great majority of synapses there is no simple continuity of substance, but a breach of continuity, or a difference in the nature of the nervous substance, which prevents the passage of the nervous impulse in the form in which it travels along the nerve-fibres, and renders that passage more difficult. This peculiarity of the synapses may be conveniently expressed by saying that each synapse presents a certain resistance to the passage of the impulse. And there is good reason to believe that in many cases the apposed parts of the two neurones are separated by a thin layer of a very highly specialized substance, and that to the presence of this cementing substance is due not only the greater difficulty with which the nervous impulse is transmitted from one neurone to another across the synapse than from part to part of each neurone, but also certain other peculiarities of the transmission of the impulse in the central nervous system.[1]

The Neural Processes.—Each neurone, like every other living cell, is the seat of *metabolic processes* of two kinds, the *katabolic* and the *anabolic*. The katabolic process consists in the partial decomposition of some of the very complex and unstable molecules that are the essential constituents of its substance. By such decomposition some of the chemically stored or potential energy of the molecules is converted into the free energy by means of which the cell discharges its social functions. The anabolic processes consist in the reconstitution of the complex molecules by means of the oxygen and the food-substances that the cell absorbs from the blood. It is the social functions, the part which the

[1] The evidence which points to the existence of such inter-neural substances is presented in a paper in *Brain*, vol. xxiv., entitled "The Seat of the Psycho-Physical Processes."

neurone plays in the economy of the whole organism, with which we are concerned in these pages. So far as we know the social function of the neurone is simply to respond to any stimulus applied to it with a katabolic change that gives rise to a "nervous impulse" and to conduct this "impulse" from part to part throughout the length of its substance. As to the essential nature of this "impulse" we are still ignorant. Some authorities are inclined to regard it as a purely physical change, such as the conduction of heat or electricity in a wire or of a fluid-wave of pressure in a pipe, but it is possible that the conduction of the "impulse" through each part of the neurone involves chemical changes of the same kind as those which initiate it at the spot stimulated. The only kind of change of which we have direct evidence is a change of the electrical state of each part of the neurone as the "impulse" passes through it. When a nerve is stimulated in the middle of its length a wave of electrical change travels in both directions along it from the spot stimulated at a rate of several yards a second, and for this and other reasons we believe that the impulse is conducted through the substance of the neurone equally well in all directions. In the motor neurones the "impulse" commonly takes the form of a rapid succession of such waves of change, but it is probable that in the sensory nerves the "impulse" may consist in a change constantly transmitted from part to part so long as the stimulus is applied.

Since it is still, and probably for a long time to come will be, impossible to define the nature of the "nervous impulse" in physical or chemical terms, and since it is possible that it involves a form or forms of energy with which we have no nearer acquaintance, the best we can do is to describe the processes in the nervous system in general terms, leaving open the question of the exact nature of the forms of energy involved. The following brief sketch of the processes, which is based upon all the established facts and is contradicted by none, affords a useful basis for the exposition of the more complex functions of the nervous system.

Every part of each neurone is irritable, *i.e.* is capable of responding to a stimulus with a katabolic change which initiates a "nervous impulse." This katabolic change results in the conversion of chemical potential energy into free nervous energy, just as the decomposition of such a substance as nitro-glycerine results in the liberation of energy from the chemical potential form. But the process of liberation of energy in the neurone differs from processes of a similar kind that occur outside living tissues in one very important respect, namely, the quantity of energy liberated in the neurone varies with the intensity of the stimulus, a feeble stimulus produces a small quantity of chemical change and the liberation of a small quantity of energy, and a strong stimulus produces a correspondingly large quantity of change and liberates a large quantity of energy. The energy so set free seems to behave like other forms of free energy, *e.g.* heat and electrical energy, in that it tends to flow from any place of high potential to places of lower potential along conducting substances. The part of the neurone stimulated becomes a place of high potential and therefore the freed energy tends to flow along the neurone, which is for it a conducting substance, just as the electrical energy liberated in the cell of a chemical battery tends to flow along any wire or other conducting substance leading from the cell. Whether the freed energy flowing through the neurone excites in each part, as it reaches it, a chemical change resulting in the liberation of more energy, we do not know.

We have seen that the simplest kind of sensori-motor arc consists of a sensory and a motor neurone whose central ends are joined in a synapse within the spinal cord. When the peripheral end of such a sensory neurone is stimulated by any physical impression made on the sense-organ, the energy, which is thereby liberated in it, escapes across the synapse to the motor neurone and acting upon it as a stimulus to katabolic change causes the liberation in it of more energy. Thus augmented the freed energy flows down the axon of the motor neurone and escapes into the muscle with which it is connected, exciting in it too katabolic changes and the liberation of energy in the form of heat and molar motion. And the quantity of these changes, too, is proportional to the intensity of the stimulus, *i.e.* to the quantity of energy transmitted by the nervous arc, or, as it is more commonly put, to the intensity of the conduction-process in it. The study of the process of conduction of the "nervous impulse" through simple sensori-motor arcs enables us to draw certain conclusions as to the way in which the synapse affects the process.

The resistance presented by the synapse to the passage of the "impulse," the flow of freed energy from neurone to neurone, is revealed by the following facts: (1) a feeble stimulus may be just strong enough to excite the sensory neurone, but the excitation may fail to overcome the resistance of the synapse and to spread to the motor neurone and muscle; (2) if stimuli of this strength are applied to the sensory neurone in quick succession, the energy liberated in it by the successive stimuli accumulates until the resistance of the synapse is overcome and a reflex movement is produced; (3) the impulse is delayed at the synapse, a certain time is required for the overcoming of its resistance, and the delay is briefer, *i.e.* the resistance is more rapidly overcome, the more intense is the stimulus; (4) the application of a continued stimulus, such as a chemical irritant, to the sensory neurone results in a rapid succession of impulses in the motor nerve; the energy continuously liberated in the sensory neurone seems to be discharged across the synapse intermittently, just as the electrical energy generated by the friction of an electrical machine is discharged intermittently from pole to pole of the machine, causing a rapid series of sparks; (5) the transmission of the impulse in the reverse of the normal or habitual direction, *i.e.* in the direction from motor to sensory neurone, seems to be very difficult or impossible; the synapses appear, in fact, to act, in all the lower parts of the nervous system at least, as valves rendering conduction from the efferent or motor to the afferent or sensory side of the nervous system very difficult; hence the fact that nervous energy tends to flow always towards the motor neurones and the muscles, a fact expressed by the current phrase, "the law of forward conduction." Other characters of the synapses may be inferred from more general considerations: (6) the process of transmission of energy across the synapses is one that readily exhibits fatigue from which recovery is very rapid; the fatigue manifests itself as a temporary increase of resistance; this liability to fatigue is an indication that the process involves chemical changes; (7) the synapse is readily affected by changes in the composition of the blood, especially by the presence in it of certain drugs and of waste products of nervous and muscular activity which cause an increase of its resistance; (8) the resistance of the synapse, besides being liable to be increased by fatigue and changes in the composition of the blood, varies from moment to moment with the state of the neurones between which it forms a junction, being diminished when they are excited and charged with free energy, increasing again when they return to rest; (9) the process of transmission of energy across the synapse leaves its resistance to the passage of the impulse in that direction permanently lowered in some degree, so that the more frequently the discharge of energy has taken place the more readily will it take place in the future. This permanent lowering of resistance, or increase of permeability, of synapses seems to be the essential condition of the formation of neural habits, and is therefore an effect of the highest importance.

If the conclusions just stated are well founded the part played in the nervous system by the synapses is supremely important, for it is the various degrees of resistance of the innumerable synapses, variable by the several influences enumerated above, that guide the course of the excitation-process initiated in any sensory neurone, as it spreads from neurone to neurone through the maze of the nervous system, and determine its issue by this or that group of motor neurones to this or that group of muscle fibres. For, as was said in Chapter I. (p. 20), the sensori-motor arcs, even those of the spinal level, are not commonly simple and isolated from one another, but are combined to form neural systems of various degrees of complexity. And no one system is completely isolated from the rest, for if the nervous system is in a state of abnormal excitability, a stimulus applied to any small group of sensory neurones may initiate an excitement which spreads throughout a very large part of the nervous system and throws almost all the muscles of the body into contraction. But when the nervous system is in a normal condition, the excitation-process resulting from a stimulus of moderate strength applied to a sensory neurone, or group of sensory neurones, spreads through a limited system of arcs and excites a co-ordinated contraction of one group of muscles only. The neural system was defined as a group of sensori-motor arcs so connected that when any one part of it is excited through a sensory neurone the excitement tends to spread to the rest of them. We now see that such a system consists of neurones connected together by synapses of low resistance, and we can understand how simple systems, consisting of a few neurones united by synapses of the lowest degree of resistance, may be connected together by synapses of rather higher resistance to form more complex systems, and these again by synapses of still higher resistance to form still more complex, compound systems. We can understand, too, that since the resistances of the synapses are liable to temporary variations from various causes, the effects produced in the nervous system by a stimulus of given character and intensity applied to any group of sensory neurones may be very different on successive occasions.

CHAPTER III

The Reflex Processes of the Spinal Level

Having in the two foregoing chapters surveyed the broad outlines of the structure of the nervous system, and acquired some notions of the nature of its structural elements and their functions, we must now consider in more detail the processes that occur in each of the three great levels that we have broadly distinguished, and must attempt to exhibit their relations to the psychical processes that accompany them and to the movements that result from them.

We may assume that in the primitive ancestral vertebrate each sensory neurone is connected with some one motor neurone (or small group of motor neurones) of the same segment in a more intimate fashion than with any others, thus constituting a simple reflex arc through which the energy liberated in the sensory neurone most readily discharges itself into efferent nerves. But in the higher vertebrates the simplicity of this primitive arrangement has given place to more complicated systematic connexions, especially in the case of the sensori-motor arcs of the skeletal system, which we will consider before noting some special features of those of the visceral system. Most of the movements that serve any useful purpose can only be effected by the co-operation of a number of muscles, hence the motor neurones through which such a group of muscles is thrown into contraction have become connected together, largely by means of central neurones, to form corresponding groups or systems of which no one member can be excited without the others. The sensory neurones are connected with these *motor systems;* those of similar function and of the same region of the body are in the main connected with the same motor system, so that when stimulated successively they give rise to similar movements, and when stimulated simultaneously they re-enforce one another. A motor system may thus be excited through any one of a number of sensory neurones, and in some cases the latter may belong to widely-separated regions of the body.

On the other hand, a sensory neurone may be connected with a considerable number of motor systems. Thus, the axon of many a sensory neurone, entering the spinal cord by one of the posterior nerve-roots, extends to the upper end of the cord and gives off, in each segment, a collateral which enters the grey matter to make connection with some motor system. It has been shown also that some sensory neurones are connected by long central neurones with motor systems of distant parts of the cord. Stimulation of a sensory neurone which is thus connected with a number of motor systems commonly leads to excitement, not of all these systems but of only one of them at any one time, and the energy of the sensory neurone discharges into this or that one in a manner determined by a number of factors that vary from moment to moment. Of these factors the most important are *fatigue of the synapses*, *facilitation* and *inhibition*. The first has been mentioned above, the other two we must consider a little more closely.

The simplest example of ***facilitation*** is the re-enforcement of the excitement of one motor system, produced by the stimulation of one sensory neurone, by the simultaneous stimulation of another which is connected with the same motor system. In such a case the second sensory neurone, discharging its freed energy into the same motor system as the former, augments the excitation, so that two such stimuli, which individually are too feeble to give rise to a reflex movement, may do so when simultaneously applied. A similar result may be produced if they are applied, not simultaneously, but at an interval of a few seconds. This seems to be due to the persistence in some degree of the state of excitement induced by the former stimulus, the energy liberated in the neurones of the motor system seems to escape from them not all at once, even if muscular contraction is produced, but gradually, so that a residual charge remains for some few seconds, rendering a second discharge into the motor system more effective. And excitement of a system, however induced, seems always to persist in this way, facilitating for some few seconds a fresh excitation, unless it is so violent or long continued as to produce fatigue. One of the most important examples of facilitation is that exerted by the sensory neurones of the "muscular sense." These are constantly stimulated in some degree by the long-continued partial contractions or tonic contractions of the muscles which they themselves largely determine, for, as we have seen, these sensory neurones of each region join in the spinal level the sensori-motor arcs, or systems of arcs, which innervate the muscles of that region, thus constituting systems of circular self-maintaining activity known as the motor-circuits (see Fig. 2). In this way the motor systems of the spinal level are continually maintained in a state of partial excitement, a tonic excitement which *facilitates* the action upon them of the cerebral hemispheres, and of the sensory neurones of the surface of the body.

Inhibition is the reverse of facilitation: it consists in the partial or complete prevention of the spread of the excitement from a sensory neurone to a motor system, and seems always to be the result of the simultaneous excitement of some other motor system. A relation of reciprocal inhibition obtains in many, perhaps all, cases between any two motor systems that innervate two antagonistic groups of muscles, such as the flexors and the extensors of the elbow or knee-joint, or the muscles which turn the eyes to the left and to the right respectively. Let us call two such antagonistic motor systems *m a* and *m b* respectively. If, while one of such a pair of systems *m a* is excited through a sensory neurone *s a* in a moderate degree, so that the one group of muscles is maintained in a state of partial contraction, a feeble stimulus is applied to a sensory neurone *s b* that opens directly to the other motor system *m b*, that stimulus fails to excite this system *m b* as it would do in the absence of the excitement of *m a*, and the muscles innervated by *m b* remain unaffected, *m b* is "inhibited" by the effects of the stimulus to *s a*. But if a strong stimulus is applied to *s b* the discharge of *s a* into *m a* is prevented, and the excitement of *m a* and of the group of muscles innervated by *m a* ceases, or, in technical phrase, is inhibited. As to the way in which such inhibition is effected there is no hypothesis generally accepted by physiologists. But there are many strong reasons for believing that it is the result of the diversion of the stream of energy, liberated in the sensory neurone or groop of neurones *s a*, into the channels of the system *m b*, these being rendered paths of lower resistance than those of *m a* through their intense excitement by way of *s b*. If this be the case, the energy diverted or drained from *s a* to *m b* must augment the excitement of *m b* and of the muscles innervated by this system, there must be a vicarious usage in *m b* of the energy liberated in *s a* and destined, as it were, for the excitement of *m a*. One good reason for accepting this *hypothesis of inhibition by drainage* is that, while it is not incompatible with any established facts of nervous process in the spinal levels, similar inhibitory processes, involving the vicarious usage of nervous energy on a great scale, play a great part in the higher levels of the nervous system, and these processes, as we shall see in a later chapter, are inexplicable by any other hypothesis of the nature of the inhibitory process that has been suggested.

The variability of the reflex actions of the cord is largely due to one important class of inhibitions, namely those exerted by the cerebral hemispheres. The reflex processes of the cord seem to be habitually inhibited to a great extent by the activity of the cerebral hemispheres, for they are usually rendered brisker and are more readily elicited when the cerebrum is separated from the cord. Now it was said above that the arcs of the higher levels which constitute the cerebral hemispheres, combine the simple systems of the spinal level in more complex systems, and to this the inhibitory action of the hemispheres may be due; for while, in the absence of the hemispheres, the several systems of the cord are relatively independent and complete mechanisms, in the intact state of the nervous system they are but parts of more complicated mechanisms, and the energy liberated in sensory neurones therefore diffuses itself through these more complex systems instead of throwing into action the relatively simple and isolated mechanisms of the spinal level.

Although the systems of the spinal level are relatively isolated from one another, they are yet indirectly connected, their relative isolation, their demarcation, being effected by the presence in the paths by which they are connected of synapses of relatively high resistance. Hence when a stimulus to a sensory area, that excites one motor system and provokes a reflex contraction of one muscle group, is rendered more intense, the result is, not that the one muscle group is thrown into more violent contraction, but that the excitement spreads across the synapses of higher resistance to other motor systems and throws into contraction other groups of muscles, those that have the closest functional relations to the first group. It is, in fact, impossible to evoke a maximal contraction of any muscle group by way of the simple reflex process. For the production of such contraction it is necessary that nervous energy liberated in great masses of neurones of the brain shall be converged into the motor channels of the spinal level.

It was mentioned on p. 16 that the viscera generally are supplied with both afferent and efferent nerves that form reflex arcs of the spinal level. As the viscera have undergone in the course of evolution many changes of form and many changes of position in the body, their gross anatomy and relative positions being of secondary importance to that of the skeleton and its systems of muscles, the visceral nervous arcs are of less regular form and arrangement than those of the skeletal system. A considerable number of the neurones of which they are composed lie wholly outside the central nervous system, their cell-bodies being clustered in a number of irregularly-arranged ganglia. Yet, probably, in every case the complete sensori-motor arc traverses the spinal cord, and is there connected with others of both the visceral and the skeletal systems. Among the most important of the visceral arcs are those which control the respiratory movements, the beat of the heart, the calibre of the small arteries of all parts of the body, the movements of the intestines and the secretions of the digestive and other glands. As in the case of the reflex arcs of the skeletal system, these sensori-motor arcs connect together for the most part structures of the same region of the body that are functionally related, and this primitive arrangement has suffered fewer alterations in their case than in the case of the arcs of the skeletal system; thus we find that the sensory or afferent neurones of the lungs are most intimately connected in the spinal cord with the motor neurones that innervate the respiratory muscles, those of the heart with the motor neurones of the heart, those of the surface of the peritoneum, the delicate membrane that sheaths the intestines, with the motor neurones of the muscular walls of the intestines, while the motor neurones of the small arteries of each part of the body are most intimately connected with sensory neurones of the skin and other structures of the same part.

The spinal sensori-motor arcs of the visceral system differ in two important respects from those of the skeletal system. In the first place, the former constitute simple systems that are more stably organized and less subject to those variable influences, notably fatigue, facilitation, and inhibition, which so frequently affect the latter, and the reflex effects of the stimulation of the afferent limbs of these arcs are therefore more constant in character; nevertheless the intensity of these effects is readily affected by changes in other parts of the nervous system, and is apt to share in any general exaltation of the excitement of the whole system. Secondly, some of the efferent neurones of these systems seem to be exclusively inhibitory in function, *i.e.* they carry impulses which on arriving in the peripheral organ, gland or muscle, depress its activity. Whether the conduction-process in these neurones is of a different nature to that of other neurones we do not certainly know; but there is some evidence to show that it is not, and in that case the inhibition, which is produced by their action upon the glands and muscles, must be due to some peculiarity of those tissues, or, perhaps, to the mode in which the neurones are connected with them.

The following interesting question has been much discussed. *Do the processes in the arcs of the spinal level directly affect consciousness?* Some authors have assumed that even when the brain has been destroyed the reflex processes of the spinal cord are accompanied by some obscure and lowly form of psychical process, and others go even further and assume that, even in the intact animal or man, the activity of each of the various reflex mechanisms of the spinal cord is accompanied by some psychical process that remains independent of the general consciousness which accompanies the processes of the brain.

It is impossible from the nature of the case, to obtain direct evidence upon this point. What little indirect evidence we have supports the view, indicated by certain general considerations and now accepted by most authors, that the reflex processes of the spinal level in man and the higher animals do not affect consciousness, though it must be admitted that this cannot be maintained with equal confidence in respect to the processes of the cord of frogs and other such lowly vertebrates. The only objective evidence, on which we can rely in endeavouring to form an opinion on this question, is obtained by noting whether a given action of an animal, evoked by particular circumstances, exhibits on repetition on successive occasions any evidence of increased nicety of adaptation to the circumstances. Only where such adaptation appears do we seem justified in concluding that consciousness accompanied the process; that is to say, modification of the mode of reaction seems to be in every case *learning by experience* in the proper sense of the word. When this test is applied to the reflex actions of the cord we discover no evidence of increased nicety of adaptation of such actions in individuals, and hence conclude that consciousness does not accompany the production of these reflex actions.

Conversely, the purely reflex actions are uncontrollable by the will, *i. e.* those nervous processes which do not affect consciousness cannot be affected by consciousness. Combining the two propositions we may say, when consciousness accompanies the neural process growth or persistent change of the neural disposition, constituting retention of the effects of experience, results, and when there is no consciousness no such growth results. That is, the two processes consciousness and modification of the neural disposition stand in the relation of antecedent and invariable consequence, the relation commonly called a causal relation. Further consideration of this relation must be postponed to a later chapter.

The foregoing brief account of the nature and functions of the arcs of the spinal level is largely based upon the study of the reflex processes of the spinal cord of animals whose brains have been destroyed or severed from the cord. The study of such reflex processes in man is extremely difficult, because his highly-developed cerebral hemispheres normally exert a powerful inhibitory action upon the reflex processes of the spinal level. It is held by some that in man the habitual control of the motor mechanisms of the spinal level by impulses from the cerebral hemispheres has led to the dissolution of those intimate and orderly connexions between the sensory neurones and those mechanisms by which the pure reflexes of the animals are carried out. But some pure reflexes are readily evoked in man, and it is probable that their seeming paucity is due to the strong control exerted by the very highly-developed cerebrum. However that may be, it is certain that the motor mechanisms for the production of co-ordinated movements exist in the spinal level of the nervous system of man as of the animals, and that it is by playing upon them that the impulses descending from the brain excite and control contractions of the muscles.

CHAPTER IV

The Sensori-motor Arcs of the Intermediate Level

The afferent or sensory paths, besides taking part in the formation of the reflex arcs of the spinal level, are prolonged upwards to the cerebral hemispheres. Thus many of the axons of the posterior root of each of the spinal nerves, after giving off collaterals to the grey matter of the various segments of the cord, make junctions at the upper part of the cord with other long neurones which, crossing the median line, pass up through the basal ganglia and the central white core of the cerebrum to reach the cortex of the cerebral hemisphere. Each cerebral hemisphere is thus connected by afferent paths with the sense-organs of all parts of the opposite side of the body. And the nerves of the special senses are similarly connected with the cortex. Thus the fibres of the optic nerves contribute to the formation of reflex arcs of the first level by junctions, in the basal ganglia of the brain, with the motor systems that innervate the muscles of the eyeballs, and in the same region make junctions with neurones whose axons pass up from the basal ganglia to the occipital cortex, constituting the principal fibres of that part of the central white matter of the cerebral hemisphere known as the optic radiation.

In this way the sensory neurones of all parts of the body are connected with the cerebral cortex, and those of each of the principal senses are connected with a certain region of the cortex of each hemisphere. These parts of the cortex, known as the sensory areas, are indicated in the Fig. 3 (p. 22) by dotting. We see there the *visual area* at the posterior or occipital pole of the hemisphere, the *auditory area* in the temporal lobe, the *tactile* and *olfactory areas* on the mesial surface above and below the great commissures by which the two hemispheres are connected with each other and with the spinal level, and lastly, the area of the "muscular sense" or *kinæsthetic sense*, marked "motor area" in the figure, occupying all the middle part of the cortex on both the mesial and lateral surfaces of the hemisphere. The remaining senses, taste, temperature, pain, and the visceral or organic senses are possibly represented by similar areas that have not yet been defined, or it is possible that the cortical neurones most directly connected with those sense-organs are intermingled with those of the sensory areas indicated. But however that may be, we may assume with some confidence that the sensory neurones of these senses are connected with elements in the cortex in much the same manner as those of the other senses whose cortical areas are roughly defined in the diagram.

When the fibres, by which the various sensory paths are thus continued to the cerebrum, enter the layer of grey matter which constitutes the cortex, we can no longer trace their connexions anatomically in the dense tangle of neurones which are the principal constituents of this grey matter. But we know that from these sensory areas fibres pass down to join the various motor mechanisms of the spinal level. Thus from the visual area fibres carry impulses to the motor mechanisms of the eye-muscles in the basal ganglia, and in the kinæsthetic area are the cell-bodies of large neurones, known from their shape as the pyramidal cells, whose axons pass down to join directly the motor mechanisms of all parts of the spinal level. And from physiological data we can conclude that the afferent neurones, which enter each of the sensory areas, are connected by shorter or longer chains of small neurones in the grey matter of the area with the efferent neurones of the same area which pass down to join the motor systems; we are able to infer also that in the main the afferent neurones of any one sensory field or region of the body are most intimately connected, in the sensory areas of the cortex, with the efferent neurones that make connexions with the motor systems of the same region, the motor systems that have the most intimate functional relations to that sensory field. This connexion is best established in the case of vision and of the kinæsthetic sense; thus, the afferent paths from one side of the retina are connected, in the visual area of the cortex, with the efferent neurones that play upon the motor system which causes the eyeball to rotate in such a way as to bring the centre of the retina, the spot of acutest vision towards that side; and any afferent neurone of the kinæsthetic sense is connected most intimately with the efferent neurones which play, through a motor system in the spinal level, upon the muscles whose contractions stimulate, through sensory neurones, that afferent neurone (see Fig. 5). Thus these sensori-motor arcs of the intermediate level constitute systems of long loops upon the sensori-motor arcs of the spinal level.[1] If such a loop formed merely a more roundabout path between a sensory neurone and the motor system with which it is connected in the spinal level, it would be difficult to see any reason for its existence. But we may assume that these loops effect connexions of the sensory neurone with a greater number of motor elements which are thus combined by them in larger systems; for example, while the reflex arcs of the spinal level leading from the retinæ effect contractions of the muscles in and about the eyeballs, the corresponding arcs of the intermediate level seem to serve to combine the contractions of the muscles of the eyeballs with such contractions of the muscles of the head and neck as aid in the direction of the eyes towards objects in the visual field.

Anatomically, then, these arcs of the intermediate level

[1] The upper and lower arcs leading from organs of the "muscular sense" and returning to the muscles of the same part are conveniently spoken of as the upper and lower motor circuits.

differ from those of the spinal level (1) in that they consist of longer chains of neurones, the middle parts of the chains

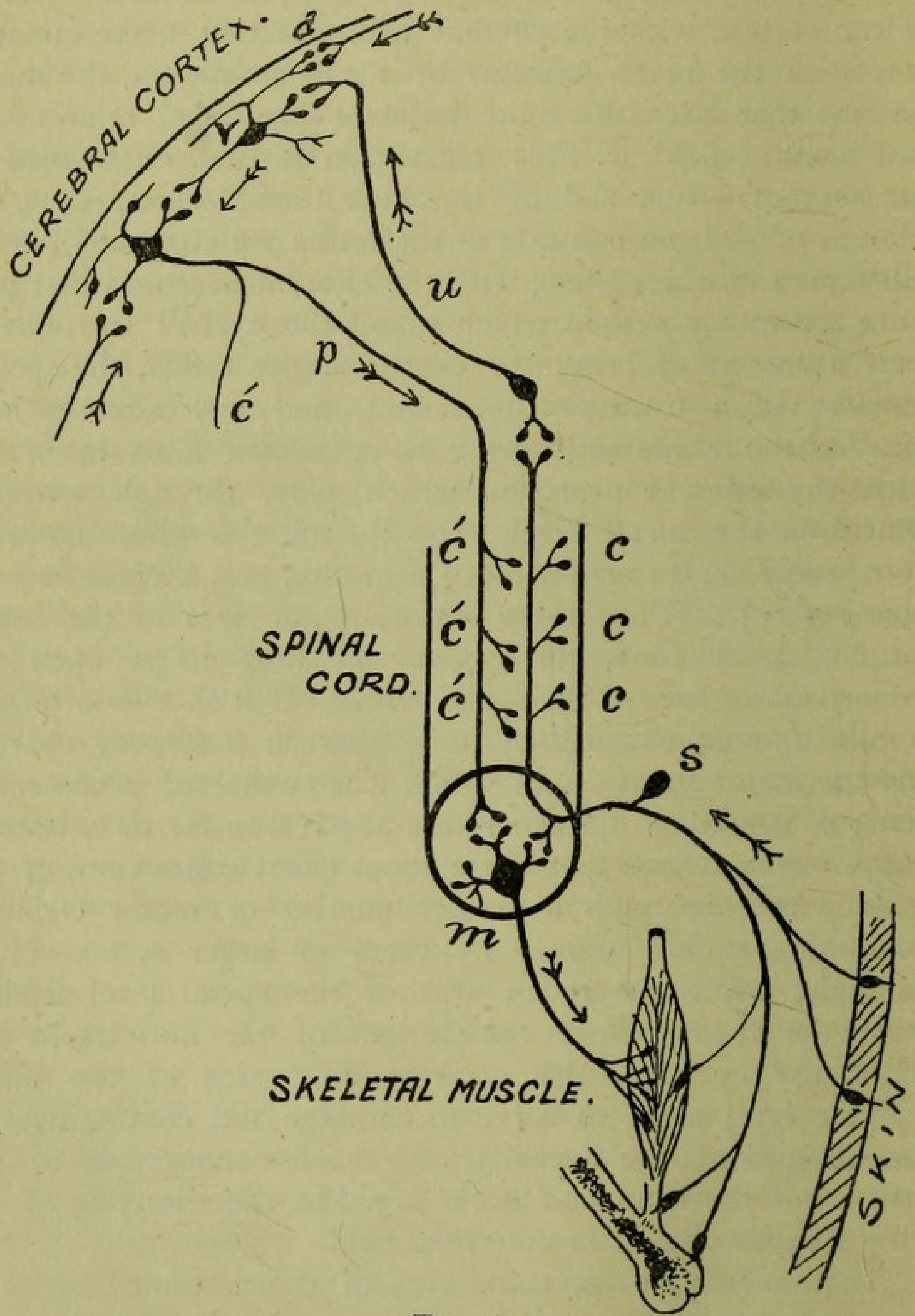

FIG. 5.

Diagram to illustrate the relation of sensori-motor arcs of the first and second levels. *m* represents a group of motor of similar functions being brought together in the various sensory areas of the cortex, (2) in that their interconnexions are more complex. Physiologically they differ (1) in being of less fixed or stable organization, and therefore more readily affected by those influences which, as we have seen, modify the activities of the arcs of the spinal level, notably changes in the state of the blood, fatigue, facilitation, and inhibition; this lower degree of stability is well brought out by the effects of anæsthetic drugs, such as chloroform, which in all probability produce their effects by increasing the resistance of the synapses; when a certain quantity of such a drug has been introduced to the blood the functions of the arcs of the second level are abolished, while those of the first level are not abolished until a larger dose has been given; (2) the activities of the arcs of the second level are more readily controlled by the will, and more easily modified, especially more easily inhibited, by processes simultaneously excited in other parts of the nervous system; for example, the contraction of the pupil, which is brought about by arcs of the first level when light falls upon the retina, cannot be prevented by an effort of the will, nor is it prevented by impressions simultaneously made upon other sense-organs, but the reflex movement of the head, which aids in directing the eyes upon a bright object, can be prevented or inhibited by the will or by impressions made on any other sense—impressions that

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neurones or motor system innervating a group of skeletal muscles, *s* the sensory neurones of the "muscular" or kinæsthetic sense stimulated by the contractions of the muscles, *u* the upper part of the afferent path to the kinæsthetic area of the cerebral cortex, *p* one or more large neurones of the pyramidal tract forming the descending limb of the loop or arc of the second level, *v* a chain of cortical neurones connecting *u* and *p*, *a* an association-path through which *v* may be centrally excited, *c* and *c'* colaterals of *s* and *p*. All relations are simplified in the diagram. For the sake of simplicity the afferent path from the sense-organs of the skin is represented as joining that from the sense-organs of the "muscular-sense" before entering the spinal cord; in reality the two paths converge only at the motor neurone *m* as in Fig. 2.

more powerfully attract the attention ; (3) the passage of "nervous impulses" through these arcs has definite psychical effects, namely those affections of consciousness which we call sensations. Hence the reflex movements that are excited by way of these arcs are known as *sensation-reflexes*. Examples of such sensation-reflexes are the cough provoked by irritation of the sense-organs in the mucous membrane of the throat, the blinking of the eyes on the rapid approach of any object, the turning of the eyes and head towards any bright flash of light or of the face towards the source of any sudden loud noise. It is probable that many stimuli, which might evoke pure reflexes of the spinal level if the cerebrum were destroyed leaving the rest of the nervous system intact, normally excite sensation-reflexes, the reflex processes of the spinal level being either inhibited by the higher levels or modified and complicated by the activity of the arcs of the intermediate level. Some processes, which normally are pure reflexes of the spinal level so long as the conditions are of a routine character, become sensation-reflexes as soon as the stimuli that excite them assume other than the most usual characters, especially if they become much more intense than usual ; for example, the reflex processes that maintain the respiratory movements seem to be pure reflexes of the spinal level, so long as there is no need for an exceptionally rapid supply of air ; but when, owing to imperfection of the quality of the blood or failure of the heart to pump it at the proper rate through the blood-vessels, an unusually rapid renewal of the air in the lungs becomes necessary, the sensory neurones which bring the afferent impulses from the lungs are more intensely excited, their excitement spreads through the arcs of the second level, and the respiratory movements become sensation-reflexes. Of the reflex processes by which the viscera are controlled some, like the respiratory movements, are capable of becoming sensation-reflexes, *e.g.* swallowing, coughing, and those which control the bladder and the lower end of the bowel, and these, like the respiratory movements, can be voluntarily controlled in some measure ; others, such as those by which the beat of the heart, the calibre of the small arteries, the movements of the stomach and the secretions of the various glands are regulated, are not thus capable of becoming sensation-reflexes, and are beyond the control of the will.

At every moment very many different stimuli are playing upon my sense-organs. Variously coloured rays of light are entering the eyes, waves of sound fall upon the ears, the skin receives stimuli from the clothes and all other objects in contact with the body, the contractions of skeletal muscles excite the nerves of the "muscular sense," and many of the sensory nerves of the visceral system are almost constantly stimulated. Some of these stimuli excite only pure reflexes like those just mentioned, but most of them excite sensations and sensation-reflexes. Of all the objects that thus excite sensation my attention is given to only one at any moment, only one of them is at that moment an *object* for me in the psychological sense of the word, and if I am absorbed in thought my attention is given to none of them. Nevertheless all these sensations, excited by objects to which no attention is paid, are present to consciousness in an obscure manner, they constitute a field of undiscriminated or marginal sensations and are the principal constituents of the rich and massive though vague background of consciousness on which the object of attention at any moment stands out as the most prominent feature of the state of consciousness. Thus, as I write, while my attention is at any moment wholly given to my train of ideas and their expression in writing, my eyes receive rays of light from a large number of objects, my ears receive various impressions of sound, my clothes and chair press upon the sense-organs of my skin, the maintenance of my posture and the movements of my hand excite kinæsthetic sensations, my teeth hold a pipe the weight of which stimulates the nerves of teeth and lips, while the smoke from it stimulates the sense-organs of the interior of my mouth and nose. All these excite sensations, and though I am not distinctly aware of all these sensations, and perhaps could not afterwards recall any of them in memory, they are obscurely present to consciousness, as I should vividly realize if any group of them were suddenly abolished. Are then all these sensory stimuli exciting also sensation-reflexes? It would seem that most of them are, while some perhaps are not, the reflexes that might be excited by the latter being inhibited by the processes of other parts of the brain. The stimuli due to the weight of my pipe excite sensation-reflexes by which the contraction of my jaw-muscles is maintained, those falling on the skin and on the nerves of the "muscular sense" excite sensation-reflexes by which my posture is maintained, many of those falling on the retinæ aid in guiding the movements of eyes and hands, though the most important part of this guidance of the skilled movements of the hand is no doubt effected by processes more complex and known as the secondarily automatic processes, which we shall have to study later. These stimuli therefore excite not only sensations, but also sensation-reflexes that are essential to the maintenance of my activity in writing.

The Sensations.—We never experience any sensation as a simple state of consciousness. A sensation is in every case only a part or an element of the complex consciousness of any moment; nevertheless by directing our attention to a sensation we can single it out from the mass of other sensations and can make it the most prominent feature of consciousness. When we thus introspectively examine our various sensations, we find that some seem to be complex in the sense that we seem to be able, by a further effort of attention, to abstract one element or quality from the whole, and perhaps, repeating this process, by successive efforts to analyze the sensation and discover in it, or rather to bring out of it, a number of distinguishable qualities that at first had remained undiscriminated. Thus in choosing a coloured wall-paper or a cloth, we may say of two similar patterns, "I prefer this one because it has a warm tone, or a tinge of green, which is lacking to the other." So, on hearing a note struck upon the piano or other stringed instrument, we may by an effort of attention single out in turn each of the overtones of the fundamental, making each in turn the object of attention, and so analyze and show to be complex that impression of sound which, if no such effort is made, remains a simple sensory experience. Some sensations resist all our efforts to analyze them in this way; we cannot, for example, discover in the pure note of a tuning-fork any multiplicity of qualities as we can in the clang of a vibrating string, and in the sensation excited by the pure ray of the red end of the spectrum we cannot distinguish more than one quality of colour as we can in the colour of an orange or of a purple robe. Such sensations we therefore incline to regard as simple qualities, and those which we can analyze by an effort of attention we regard as complex or in some sense compounded of the simpler qualities that we discover in them. But we know that while some sensations can be analyzed by every one without special training or practice, as, for example, the taste of lemonade or the sensation excited by contact of a cold, hard object with the skin of the finger-tip, others, like the musical clang, can be analyzed by most of us after a little practice, but not at all by those who have no "musical ear," and others again only by those who have special aptitude and training, as, for example, certain odours or flavours which the wine- or tea-taster, the gourmet or the chemist alone can analyze. We are therefore led to suspect that some of the sensations which no one succeeds in analyzing are yet compound, in the sense that a person of exceptional and specially trained powers might succeed in analyzing them. Hence we are driven to seek the aid of some other criterion than the purely psychological one in forming an opinion as to the simplicity or complexity of any given quality of sensation. Such aid is given by the consideration of the physical nature of the stimuli that excite our sensations and of the neural processes that they initiate when they fall upon the sense-organs. Such consideration shows that most of the qualities of sensation that can be readily analyzed are excited by stimuli that are complex in character, and that, when the different physical elements of such a complex stimulus are applied separately to the sense-organ, the resulting qualities of sensation are those qualities which we can discover in the compound sensation by selective attention. Thus the taste of lemonade is excited by a mixture of chemical substances, sugar and an organic acid, and if these are applied in turn to the tongue we experience sweetness and acidity, sensations of the qualities that we discover by analysis in the taste of lemonade. Just so the clang is excited by a complex vibration of a string transmitted to the ear by the air, and if vibrations of the rate of each of the regularly recurring partial vibrations are led to the ear separately and successively, we experience in turn each of the qualities of sensation that we discover by analysis in the clang.

Again, in the case of many of the analyzable sensation-qualities there is evidence that the different elements of the complex physical stimulus excite different sensory neurones, and that the complex sensation cannot be excited by the stimulation of a single sensory neurone; thus, for example, in the case of lemonade, the sugar stimulates one set of sense-organs in the tongue, the acid another set, and the application of lemonade to one set only excites, not the taste of lemonade, but of acidity or sweetness only; and in the case of the clang it is highly probable that the various partial vibrations affect different sensory neurones in the internal ear. When we find that the psychological analysis of a sensation is thus confirmed by the discovery that the physical and physiological conditions of the sensation are complex in the same degree, we are justified in regarding it as a resultant of the fusion of the multiple effects of the complex stimulus.

On the other hand, when we find that a sensation-quality which we cannot analyze is excited by a physically simple stimulus, and can be excited by that stimulus acting upon a single sensory neurone, as seems to be the case when cold or heat is applied to a single cold- or heat-spot in the skin, we seem justified in concluding that such a sensation is by nature simple, and that it would remain unanalyzable no matter how highly developed our power of discrimination might become.

Such a sensation we call a psychical element, and the analyzable sensations we call *fusions*, psychical compounds or complexes of such elements.[1] Although it is not possible to say of some sensation-qualities whether they are elementary or compound, we may conclude that all varieties belong to one or other of these two classes. Among the most important of the tasks of the physiological psychologist is the determination of the number and character of these psychical elements, the exhibition of all other sensations as fusions of two, three or more of these elementary qualities, and the discovery of the nature of the neural process that is the physiological condition or excitant of each of them.

A first and most important step towards the solution of these problems was made by the great German physiologist, Johannes Müller, when, in the early part of the last century, he propounded the *doctrine of the specific energies of sensory nerves*. The essence of this doctrine, as interpreted in the light of modern knowledge, is the proposition that by the stimulation of each sensory nerve-fibre or neurone only one quality of sensation can normally be excited, so that, though some sensory neurones may be stimulated by a variety of physical influences, the quality of sensation resulting is always the same in the case of each neurone, and is therefore determined, not by the character of the physical stimulus, but by the character of the nervous tissue which the stimulus throws into activity.

The principal evidence on which this doctrine is based is afforded by those instances in which it has been found possible to excite a sense-organ (or a sensory nerve) by stimuli other than its *adequate stimulus*, *i.e.* the kind of stimulus which normally excites it and for the reception of which it is especially adapted. In every case in which it has been possible to stimulate any sensory nerve- or sense-organ in this way, it has been found that the resulting sensation is of the quality which normally results from the stimulation of that nerve- or sense-organ by its adequate stimulus. Among the most striking

[1] The nature of the fusion we must discuss later (p. 75).

instances are the following:—Pressure upon the eyeball stimulates the retina mechanically and evokes visual sensation, in the form of ill-defined patches, corresponding to the area stimulated if the pressure is localized,[1] or filling the field with irregular specks if applied as a blow that stimulates the whole retina and causes the subject to "see stars."

Section of the optic nerve in patients not anæsthetized has been reported by them to cause a 'bright flash of light.' By passing a galvanic current through the eyeballs, between an electrode placed upon the closed lids and one upon some other part of the head or body, visual sensations are excited which vary in quality with the direction of the current. Sensations of taste may be excited by applying mechanical or electrical stimuli to the surface of the tongue, and according as this or that part is stimulated the sensation is of the quality which is normally excited through the kind of sense-organ that predominates in the part. Sensations of smell may be excited by electrical stimulation of the mucous membrane that lines the cavity of the nose. Stimulation of each of the four kinds of sensitive spots found in the skin (see p. 63) excites only the one kind of sensation, no matter what be the nature of the stimulus, the most striking instance being afforded by the stimulation of 'cold spots,' by heat, when sensation of cold results. Further weighty evidence in support of the doctrine of the specific energies of sensory nerves, is the fact that the Young-Helmholtz theory of the visual processes (when modified in the light of modern knowledge) and Helmholtz's theory of the auditory processes, in spite of all the attempts that have been made to supplant them, give us by far the most satisfactory explanations of these processes;

[1] The reader should verify this statement by closing the eyes, turning them as far as possible to the left side, shielding them from the light and then pressing firmly with the tip of the little finger upon the outer angle of the right eyelid. He will then find that his visual field seems to be filled with fairly bright light, including a number of brighter points that come and go irregularly. These are known as phosphenes.

and these theories are based upon the assumption of the truth of this doctrine.

Now it is one of the most indisputable of the logical laws of causation that unlike effects have unlike causes, and we are therefore compelled to assume that the nervous process which is the immediate exciting cause of each quality of sensation is different to that which excites any other quality of sensation; and we cannot suppose that the difference consists merely in a difference of locality of the process within the head. We must believe that it is a difference which could, if we knew more about it, be expressed in physical or chemical terms. We must believe, in fact, that each of the primary or elementary qualities of sensation is excited by a nervous process of peculiar or specific character, and that the stimulation of any sense-organ gives rise to one or more such specific processes according as the resulting sensation is elementary or compound. Nervous processes that are immediately correlated with psychical processes, or, as we may say, in accordance with the view of the relations of soul and body defined in the introductory chapter, nervous processes that act directly upon the soul and are acted upon by it, are conveniently spoken of as *psycho-physical processes*. Hence the specific processes we are considering are the psycho-physical processes that excite the sensations. The question now arises—Where do these specific psycho-physical processes occur? The answer seems to be that they occur in the sensory areas of the cortex of the brain; for so long as any sensory area is intact the corresponding qualities of sensation may be experienced, and even though the sense-organ be destroyed or the sensory nerves severed the sensations may still be experienced in the form of hallucinations; and, on the other hand, if one of the sensory areas is destroyed by disease or a wound, the corresponding sensations are never experienced again though the sense-organ and the sensory nerves remain intact, and their disappearance from the consciousness of the individual is so complete that he is not even aware of the nature of his loss, it is with him as though he had never experienced this kind of sensation.

Hence we conclude that the specific nervous processes occur in those parts of the neural arcs of the intermediate level which lie in the sensory areas of the cortex. There remains the question—Is the specific character of each of these kinds of psycho-physical processes in the cerebral cortex due to the constitution of the nervous substances in which it occurs? Or is it due to the constitution of the sense-organs or of the sensory nerves or neurones, each part of the cortical nervous substance being capable of becoming the seat of an indefinitely great variety of processes excited by different kinds of specific changes transmitted by the afferent neurones from the sense-organs?

The latter view is maintained by high authorities, notably by Prof. Wundt, and less explicitly by Prof. Hering, but there are three good reasons for rejecting it and for accepting the former alternative. First, if we assume that the specific quality of each kind of psycho-physical process is determined by the constitution of the nervous substance of the sense-organ or afferent neurones, it would be necessary to assume also that the processes throughout the chain of afferent neurones are psycho-physical processes directly affecting consciousness, and this assumption would be untenable, for, as we have already seen, the loss of the sense-organ does not render impossible the recurrence, in the form of hallucination, of the quality of sensation which normally follows its stimulation, while loss of the cortical structures alone does prevent the recurrence of the corresponding qualities of sensation. Secondly, we have many reasons for believing that the constitution and the conduction-processes of all sensory nerves are similar in kind, that they present no specific differences and are in fact not specifically different from those of the motor nerves.

Thirdly, we find, perhaps, the strongest reason for believing that the specific character of each kind of psycho-physical process is due to the constitution of the cortical substance in which it occurs, in the empirical evidence of localization of cerebral functions and in the fact that physiological psychology is compelled to assume such strict localization of elementary functions[1] as the basis of any attempt to explain the part played by the brain in mental process. This last argument is of great importance, though its weight is perhaps not commonly appreciated by physiologists. Explanatory psychology is based upon the principle of *association*, although in the reaction against the excessive claims made for the principle of "association of ideas" it is now the fashion in many quarters to belittle the importance of association. Now association is a physiological principle. It is not ideas that become associated with one another but the functional elements and groups of elements of the brain. The function of the cerebrum is the retention of effects of experience and the modification of future action and experience through these retained effects. And we can only conceive these retained effects which modify the course of future mental process, as consisting in the association of nervous elements to form functional groups, the connexion of them in such a way that the members of each group tend always to be simultaneously active.[2] Now it is clear that if the neural elements of the cortex were of indifferent function, if each were capable of becoming the seat of any one of the varieties of psychophysical process, merely taking up like a telephone-plate different forms of vibration impressed upon sensory neurones by physical stimuli and transmitted by them to the brain, the systematic association of such neural elements in functional groups would in no wise explain the recurrence of psychical elements in the groupings previously determined by sense-impressions. The re-excitement of such a group of neural elements might be accompanied on one occasion by one

[1] During any moment of waking life many neural elements of different specific functions must be simultaneously active and these may be widely distributed in different parts of the cerebral cortex, hence the localization of elementary functions does not imply localization of faculties as assumed on most inadequate grounds by the phrenologists.

[2] The reader will be able to follow this argument more easily after reading the chapters on mental retention

psychical state, and on others by quite different psychical states. On the other hand, if we assume that the specific characters of sensory processes are due to the specific constitutions of neural elements localized in the cortex of the brain, elements that are capable of becoming associated together when excited simultaneously or in immediate succession, we have a physiological conception which enables us to understand, however vaguely and imperfectly, the processes of memory and association on which our mental life is founded.

We have then three great principles, the principle of "the specific energies of sensory nerves," the principle of strict localization of cerebral functions, and the principle of association, each of them arrived at independently of the others and each founded upon a great mass of empirical evidence. Together they constitute the indispensable basis of physiological psychology. Each implies the other two and is only rendered intelligible and serviceable as an explanatory principle by the acceptance of the others; if we do not accept them, the complex structure of the brain and of the sense-organs, as the material basis by the aid of which psychical processes are brought into systematic correspondence with the objects and processes of the outer world, remains an unintelligible mystery; as Prof. Münsterberg acutely remarks, it would be impossible to see why a single sensory neurone should not constitute the sense-organ by which we appreciate the complex of sounds given out by an orchestra and why the neural basis of the psychical functions should not be a single cell. And these three principles can only be combined to afford us this indispensable basis, when we attribute "the specific energies" of sensory nervous processes to the specific and invariable constitution of structural elements of the cerebral cortex that are capable of becoming associated together when thrown into simultaneous action.

We must now attempt to define still more accurately these structural elements, whose highly specialized constitution determines in them, whenever they are excited, the occurrence of the psycho-physical processes. Since there is no evidence that nerve-fibres, whether axons or dendrons, have any specialized functions except that of the conduction of the nervous impulse, and since what evidence we have tends to show that the conduction-process is of the same nature in all fibres, it has been usual to assume that the cell-bodies of neurones of the cerebral cortex are the seats of the psycho-physical processes, and that conclusion seemed inevitable so long as the nervous system was regarded as a continuous network of fibres and cells. But recent research, having shown that the cell-junctions or synapses are highly important structures that determine many of the peculiarities of the neural processes within the central nervous system, suggests that these may be the seats of the highly specialized nervous substances in which the psycho-physical processes occur. And there is much to be said in favour of this view. We may note a few of the more important considerations. In the first place, we have no positive evidence that the cell-bodies of neurones have any specialized functions beyond the presiding over the nutrition and growth of the cells and conducting the nervous impulse in the same way as the axons and dendrons. Secondly, the fibres and cell-bodies seem to be extremely resistant to fatigue, whereas there is much evidence that the synaptic processes are very readily fatigued, and very highly specialized metabolic processes, such as the psycho-physical processes seem to be, are just such as we should expect to be readily fatiguable. Thirdly, there is, as we have seen, reason to believe that the transmission of the impulse across synapses is a discontinuous process, a rapid series of discharges, and there is evidence that the psycho-physical processes also are of this nature. Fourthly, a more speculative argument may be adduced, as follows :—If mind or consciousness plays a part in guiding the evolution of the nervous system, whether in the individual or in the race, it must be largely through influencing the organization of neural elements in functional groups or systems, and this process seems to consist in the establishment of cell-junctions or synapses and in the perfection of those junctions. And this is borne out by the fact that it is only while such organization is proceeding that the neural processes are accompanied by psychical processes; while the organization of a system of elements is imperfect, its excitement is accompanied by psychical processes which became progressively less vivid as the organization proceeds; in other words, while the synapses are of high resistance, the transmission of the nervous impulses across them is constantly coincident in time with, and hence presumably causally related with, psychical processes, and is no longer so related when their resistance has been diminished to a certain degree. Hence the psychical process that accompanies the transmission of the excitation through a system of neural elements would seem to be one of the necessary conditions of the overcoming of the resistance of the synapses.

A rough simile may make this conception clearer. We may liken the flow of nervous energy through a system of cortical neurones to an electric current, flowing through a system of incandescent lamps and their connecting wires. The filaments of the lamps are the places of high resistance, the synapses, and the heat, which is generated during the passage of the current through them, may be likened to the psychical effects that accompany the passage of the nervous current through the synapses. Now let us suppose the filaments of the lamps to be carbon filaments in an atmosphere of hydro-carbon gas. At each passage of the current through the filaments the heat will cause a deposit of carbon on them, thickening them and so diminishing their resistance. Then, as by each passage of the current the resistance of the filaments is diminished, the amount of heat generated in them on the next passage of the current will be less, until they cease to present any appreciable resistance and no appreciable heat is generated. Perhaps the simile would be closer if we likened the psychical effects not to the heat but rather to the light generated by all the lamps, the heat of each filament being likened to an unknown form of energy that plays a part in the transmission of the impulse across each synapse.

This conception of the functions of the synapses is, however, speculative, and we are not warranted in regarding it as established. What we have to accept as a well-established view is that some part or parts of the sensori-motor arcs of the intermediate level, where they traverse the cerebral cortex, are of a highly peculiar constitution, such that the process of transmission of the "nervous impulse" assumes in them a very special or specific character, that this highly specialized nervous substance is not of one character in all cases, but exhibits a certain number of varieties which give rise to a corresponding number of kinds of psycho-physical processes, each of which excites one of the elementary qualities of sensation.

The Elementary Qualities of Sensation.—We must now briefly review the sensations and attempt to discover the primary or elementary qualities in the case of each of the senses. The preceding paragraphs will have familiarized the reader with the conceptions of simple and complex qualities of sensation. The simple qualities of sensation are the ultimate differences of kind. Qualities differ more or less widely from one another, thus red is unlike blue, but not so unlike it as is sweetness or cold or the note of a tuning-fork, and in general the sensations of each of the senses are less unlike one another than they are unlike those of other senses; they have various degrees of affinity which are immediately experienced and recognized and cannot be further explained in the present rudimentary state of our knowledge, though it is possible that at some future date they may be correlated with degrees of difference of the psycho-physical processes.

Each quality of sensation has certain variable attributes. Every quality of sensation may be experienced in different degrees of *intensity*, some like touch or pressure having few degrees or a small range of intensity only, others like the visual and the auditory sensations having great range of intensity; and the series of intensities of any quality of sensation is always a continuous one without breaks or jumps. When, for example, a railway engine rushes by you whistling continuously, you experience a certain quality of auditory sensation that passes continuously from a very high intensity to very low intensity, until the sound, as we say, dies away in the distance. The intensity, like the quality of the sensation, cannot be affected by any voluntary effort, it is wholly determined by the nature of the stimulus and the state of the sense-organ and nervous apparatus.[1]

All sensations have also *duration*, they always endure for a longer or shorter period of time which is commonly rather greater than the duration of the stimulus that excites them. Some qualities of sensation have a third variable attribute, namely *extensity*, i.e. they seem to occupy space or to have a peculiarity which we can only describe in terms of space; sensations of sight and touch have this attribute in the most marked degree, and it is a disputed question, which the reader should attempt to answer by introspection, whether any sensations are altogether without it.

It is usual to distinguish higher and lower senses, the higher, like vision and hearing, being those that have a great variety of qualities and high cognitive value (*i. e.* are the sources of much information as to the properties of the things of the external world by which they are excited), the lower, like the temperature sense, being those that have small variety of qualities and are of low cognitive value. The higher senses are also regarded as being higher in the evolutionary sense. We seem justified in believing that all the qualities of sensation have been slowly differentiated, in the course of evolution of the animal kingdom, from some primitive obscure quality of sensation, more closely allied, perhaps, to touch or pressure sensation than to any of the sensations of the more specialized senses. The process of this differentiation presents a fascinating problem that science has as yet hardly begun to consider.

There is good reason to think that many parts of the body

[1] This statement is perhaps too absolute. It is possible to maintain that the intensity of a sensation may be slightly increased by an effort of attention.

are supplied with sensory nerves the stimulation of which gives rise to sensations hardly, or not at all, differentiated from this primitive quality; they are spoken of as the nerves of *common sensibility*. We cannot voluntarily direct our attention to these sensations, and so cannot single them out; they remain always undiscriminated in the confused obscure background of consciousness, unless the nerves be subject to exceptionally violent stimulation through inflammation or injury to organs, when the sensations become painful. They contribute largely to determine our sense of general wellbeing or discomfort.

The ***organic sensations*** are but slightly differentiated from those of common sensibility. They are the indefinite sensations excited by stimulation of sense-organs in the viscera. So long as all is well with the viscera these sensations are feeble and do not attract attention, but when the visceral functions are in any way disturbed or accelerated we become aware of them as the sensations of hunger and thirst, of fullness, of nausea, of colic, of palpitation, of "breathlessness," of flushing, of fullness of the organs of evacuation and so forth.

In the skin are sense-organs of four special senses, each mediating one well-marked quality of the ***cutaneous sensations***. These are the senses of touch, contact or light pressure, of heat, of cold, and of pain or smarting. It is not clear that any of these senses mediates more than a single quality of sensation, though it seems hardly correct to describe the sensations evoked by a warm body and a hot body respectively as differing only in intensity. It is but a few years since it was discovered that the peripheral organs of these four senses are confined to small spots scattered over the skin, and that by the application of the appropriate stimulus to each kind of spot the corresponding sensation can be evoked in relative purity, while other spots are insensible to that form of stimulus. The reader should study these sensations in the following way:—Let him touch gently a hair on the back of his hand. This will excite pressure-sensation, for the roots of the hairs are surrounded by the minute sense-organs of the pressure-sense. Then let him choose a small area of skin devoid of hair, say the palm of the left hand, and prod it gently with the end of a moderately fine hair, working over it systematically. He will find, if the hair used is of appropriate length and rigidity, that some spots readily yield pressure-sensation, while others are insensitive to this gentle stimulus. Let him mark these spots with an aniline pencil. Then let him take a blunt metal point (or a blunt pencil-point will serve the purpose), and work over the same area, drawing the point in close-set parallel lines across the surface. He will find a number of spots which, when touched, give distinct sensation of cold, all other parts giving no such sensation. Working over the area again in similar fashion with the blunt metal point warmed to about 45° C., he will find a third set of spots from which alone sensation of heat is evoked. Lastly, let him take a short horse-hair, mount it in the split end of a match-stick, cut it across obliquely half-an-inch from the handle, and then prod over the same area of skin. He will find that smarting or pain-sensation is evoked at a fourth set of points and not elsewhere. He should try also to evoke paradoxical sensation of cold by applying the metal point warmed to 45° or 50° C. to the cold spots previously found.

The cutaneous sensations ordinarily experienced are compounds of these elementary qualities, usually two at least being simultaneously evoked, and in our touch experiences the cutaneous sensations are commonly compounded with kinæsthetic sensations. The fusion of these sensation-qualities is never very intimate, the compounds can generally be easily analyzed. The perception of wetness, for example, involves usually a fusion of sensations of pressure and of cold, but the fusion is of low degree, we can easily direct our attention to either of the elementary qualities.

The ***kinæsthetic sensations*** are those by means of which we appreciate the position and movements of the parts of the body, especially of the limbs. They may be vividly experienced by setting hard all the muscles of the right arm in a half-bent position, when strain sensations will be localized in the muscles themselves and in and about the elbow-joint. These are excited by the stimulation of sense-organs in the muscles, in their tendons, and in the tissue lining the smooth surfaces of the joint. Those from the muscles and tendons chiefly serve to make us aware of the degree of force exerted by the muscles, while those from the joints make us aware of the position and of the range and direction of movements of the parts. If the reader is inclined to doubt the importance of these sensations, let him cause his arm to be moved gently by some other person into a position of rest while his eyes and ears are closed, and then let him ask himself how it comes about that he can accurately describe the position of the limb and can bring it from that position directly into any other desired position. In sufferers from some diseases these sensations are impaired, in others they are lacking; in the former case the movements of the patient are uncertain and irregular, in the latter the patient remains unaware of the positions into which his limbs may be carried, so long as his eyes are closed.

All these kinæsthetic sensations are of similar qualities; they are of very great importance in perception, especially the perception of spatial relations; but we seldom have occasion to pay attention to them, they commonly fuse with sensations of other qualities, visual, pressure, temperature sensations and so forth, and aid us in localizing those sensations or the objects that excite them.

Sensations of taste and smell occupy an intermediate position in the scale of differentiation. We enjoy only four specific qualities of taste-sensation, namely, sweet, bitter, sour and salt, each mediated by separate sense-organs differently distributed over the surface of the tongue, *e.g.* those for bitter sensations are most abundant at the back of the upper surface of the tongue, those for sweet sensation about the tip. When the different sense-organs are simultaneously stimulated they yield complexes of sensation readily analyzable, as in the case of lemonade mentioned above. In the case of smell we are on difficult ground, because hitherto it has not been found possible to distinguish by either the psychological or the physiological test any qualities that seem to be elementary. This is no doubt due, in part at least, to the fact that we cannot apply stimuli to the sense-organs in the olfactory mucous membrane individually, but only to the whole surface at once. Nevertheless, there is some evidence that some of the olfactory sensations are less complex than others into whose composition they seem to enter, and we can roughly classify the qualities in about eleven classes, the members of each of which are similar in quality. In certain pathological states one or more of these classes of sensation is defective or lacking. These facts, and the analogy of the other senses, justify us in supposing that all our olfactory sensations are fusions of a few elementary qualities.

The ***visual sensations*** are a highly specialized and differentiated group. We must recognize that in the retina we have mingled together two different kinds of visual sense-organs, namely, the rods and the cones. These minute bodies, the ends of sensory neurones, are packed closely side by side in a single layer, the sensitive layer of the retina. When light falls upon them it excites chemical changes, just as it does in the photographer's film or plate, and the substances resulting from these changes act as chemical stimuli upon the sensory neurones. The cones alone are present in the small central region of clearest vision, the *fovea centralis*, the area on which falls the image of any object directly looked at. This is surrounded by a zone in which rods and cones are intermingled, and the peripheral region is made up of rods with but very few cones.

The function of the rods is to enable us to see in light so dim that it cannot stimulate the cones. We may regard the rods as representing a primitive form of visual sense-organ from which the cones have become differentiated and specialized. In ordinary daylight our visual sensations are excited through the cones only, for the rods are kept in a state of exhaustion by so bright light. But when the eyes have been shielded from bright light for some minutes the rods regain their sensitivity. Hence on entering a dimly-lit room, or on going out of doors from a brightly-lit room on a moonless but starlit night, we can at first see little or nothing, for the cones are insensitive to so dim a light, and the rods are exhausted. After a few minutes, the rods having regained their sensitivity, we can see the outlines of objects and differences of light and shade, but no colours, for the rods mediate only one quality of sensation, a slightly bluish grey of small range of intensity. If then one looks at a small object, such as one of the dimmer stars, it will be found to become invisible as the eye is turned directly upon it, for its image then falls upon the central region of the retina in which no rods are present. Since the rods mediate a single elementary sensation-quality, no matter what be the kind of light falling upon them, and since they are sensitive to light too dim to affect the cones, the solar spectrum, when made of very low intensity, appears no longer as a band of colours, but as a band of dim grey light a little shortened at the red end. The shortening at the red end is due to the fact that, while the rods are sensitive to rays of all other parts of the spectrum, they are insensitive to the red rays or rays of greatest wave-length. It has recently been shown, too, that the rods respond to stimulation less rapidly than the cones, so that the sensations resulting from the stimulation of them appear in consciousness an appreciable interval after those due to simultaneous stimulation of the cones. These facts have only recently been established, and since they are very instructive and important the reader should make the following simple experiment which will serve to illustrate some of them. Let him paste a small piece of green paper (about ¼ inch square) on a red surface—say the red cover of a book—and then in dull lamplight, or by the light of a single candle near at hand, hold the surface at arm's length. He will find that when he looks directly at the green spot it appears as a very dull green, but that when he looks at a spot on the surface an inch or two distant from it, it appears considerably brighter, but hardly at all green, *i.e.* it will be a greenish grey, the fusion of the achromatic or grey sensation of the rods and of the dull green of the cones. Then, while still directing his gaze a little to one side of the green spot, let him cause the surface to oscillate gently but rapidly from side to side. At each movement he will see a grey cover (as it were) slip off the dark green spot, so that the grey and the green patches (due to the rods and the cones respectively), which are coincident while the surface is at rest, oscillate relatively to one another. The appearance suggests that the grey spot is supported above the green spot by a delicate spring, for at each movement it lags behind the green spot, which seems to slip out from beneath it, and regains its position upon the green spot a moment later. It is the more sluggish reaction of the rods that causes this lagging of the grey spot, and which enables us to analyze in this simple mechanical fashion the fusion of green and grey sensations due to the cones and rods respectively.

The stimulation of the cones evokes all the many qualities of colour as well as white or achromatic sensation. We have therefore to recognize the remarkable fact that achromatic sensations may be excited by two different kinds of physiological process. When we look at the solar spectrum we have all the qualities of colour, with the exception of the purples, spread out in a band. In this long series there is a very large number of distinguishable qualities of sensation, and all neighbouring qualities pass into one another by insensible gradations. This fact suggests that the whole series is given by fusions of a smaller number of elementary qualities in various proportions, and there are many other considerations which confirm this suggestion and have led to the general acceptance of it. But as to how many elementary qualities we must assume and which they are, differences of opinion still obtain.

If we apply the psychological test and attempt to analyze by selective attention the different colour-qualities, we find that some are readily analyzable. Purple, for example, clearly contains a blue and a red element, orange a red and a yellow element, peacock or Prussian blue a green and a blue element. In others we cannot thus discover two constituents. It is generally admitted that crimson red, a certain green, and an ultramarine blue cannot be analyzed, that they seem simple and elementary qualities. Yellow is also declared to be unanalyzable by some authors, and claimed as an elementary quality; but this is open to question. If we arrange pure red, green, and blue in a linear series, we can perceive no natural affinities which would lead us to place them in any one order rather than another, but if we add yellow to the series it claims a place between red and green rather than between red and blue or blue and green. The conclusion thus indicated by the psychological test, namely, that red, green, and blue are the only elementary colour-qualities, is borne out by other facts. If we take three rays from any three widely-separated parts of the spectrum we can, by mixing them in various proportions and throwing the mixed ray into the eye, excite colour-sensations of every quality; but if the three rays chosen are red, green and blue, the other qualities excited by the various mixtures of these three rays are of greater purity, saturation or richness than if any other three rays are chosen. By mixing red and green rays in various proportions we can excite the series of qualities which in the spectral series are intermediate between red and green, namely, scarlets, oranges, yellows and yellow-greens; by mixing red and blue rays we obtain the series of violets and purples, and by mixing green and blue rays we obtain the series of blue-greens.

If to a ray, mixed of any two of these three kinds in equal proportions or intensities, we add a ray of the third kind of low intensity, the quality of the sensation excited is not changed but merely becomes less rich or saturated; if, for example, a feeble red ray is added to a mixture of blue and green rays of equal intensities, the blue-green quality of the sensation is not altered, but the blue-green becomes less rich:

and if then the intensity of the third ray is increased step by step the quality of the sensation remains the same, but at each step becomes less rich or paler until, when the third ray is of intensity equal to that of the other two, the colour is no longer distinguishable, and we have achromatic or white sensation.

These results of mixture of rays of different wave-lengths suggested to the great physicist, Thomas Young, the hypothesis that in the retina are nerve-fibres of three kinds, stimulation of which evokes red, green, and blue qualities of sensation respectively, and that all other qualities of visual sensation, including white, are fusions of these three elementary qualities or of two of them. And this hypothesis, supplemented by the recognition of the part played by the rods and in other ways, enables us to explain satisfactorily all the many curious facts of visual sensation.

It must be added that in recent years many physiologists have adopted a different hypothesis, that proposed by Prof. Hering of Leipzig. Neglecting the facts which show that we cannot always analyze our compound sensations, they deduce from the unanalyzable character of white and from the asserted unanalyzable character of yellow the simplicity of those qualities; and they assert that when we look at a black surface surrounded by white we experience a positive sensation of blackness, not a mere gap in the field of visual sensation. They therefore assume six elementary qualities of visual sensation, red, green, blue, yellow, black, and white. Prof. Hering's theory of the visual processes setting out from this position offers explanations of many of the facts of visual sensation, though, in the opinion of the present writer, there are insuperable objections to it. We cannot here follow up the issue between these rival hypotheses, though the subject is one that fascinates the mind when once a grasp of it has been attained. The important point for us to note is that nearly all are agreed that a few only of the qualities of visual sensation are elementary, four (red, green, blue, and the grey rod-sensation) according to the modern form of Young's theory, six according to Prof. Hering's, and that all the many others are fusions of these few in different proportions. This conclusion is strongly supported by the study of cases of colour-blindness, most of which, those of partial colour-blindness, seem to be due to the defect of one or other of the elementary qualities, while the rare cases of total colour-blindness, or at least one variety of them—those in which the retina has a blind spot corresponding to the central rodless region of the normal eye—seem to be due to complete defect of the functions of the cones.

We have then to believe that in the visual area of the cortex are psycho-physical substances of four kinds taking part in the constitution of the sensori-motor arcs of that area, and that excitement of each of these gives rise to a specific psycho-physical process and to one of the four elementary qualities of visual sensation, red, green, or blue, or the achromatic sensation-quality mediated by the rods.

Auditory sensations are excited when vibrations of the air are communicated to the delicate mechanism of the internal ear, vibrating structures that stimulate mechanically the ends of the sensory neurones that lie in contact with them. We experience a very large variety of qualities of auditory sensation. Some of them are readily analyzable by an effort of attention and we find that these are excited in every case by complex physical vibrations. Those on the other hand that are excited by simple regular vibrations of the air defy analysis and are called pure tones; all the qualities excited by simple vibrations form the single series that we call the tone-scale. At the one end of this scale are the deepest tones excited by vibrations striking the ear at the rate of about sixteen a second, at the other end are the tones of very high pitch excited by vibrations of the rate of about 30,000 a second. Between these extremes is a very large number (about 12,000 in the case of a person of trained musical ear) of distinguishable qualities or pure tones, each of which is of just perceptibly higher pitch than its predecessor in the series.

Is each of these many thousand distinguishable pure tones an elementary quality of sensation excited by a corresponding specific psycho-physical process?

We have good reasons for answering this question in the negative, for believing that the number of elementary qualities is much smaller than the number of distinguishable pure tones, and that all the pure tones are fusions of two or more of an unknown number of elementary qualities. They may be stated as follows:—(1) The analogy of the other senses, in which, as we have seen, the elementary qualities are few, renders improbable the asumption of a very large number in the case of hearing. (2) We know that it is impossible for some ears to analyze complex tones or clangs which are easily analyzed by others, and that even a well-trained ear may find difficulty in analyzing the complex formed of a tone and its octave or first overtone. (3) Pure tones are not merely more or less different in pitch; some that are of very different pitches have nevertheless a great resemblance; this resemblance obtains in the highest degree between a fundamental tone and its overtones, the tones excited by vibrations whose rates are exact multiples of the rate of that which excites the fundamental. The first overtone or octave of any tone differs from it, as regards pitch, more than any of the intermediate tones of the scale and yet is, in another indefinable fashion, more like it, so much like it that even a trained ear may mistake a tone for its first overtone. This fact suggests that each pure tone is a fusion of at least two elementary qualities, one of which is common to it and all its upper and lower octaves, another which is peculiar to it and determines or constitutes its pitch. (4) If each distinguishable tone were an elementary quality we should expect to find that when the air is made to vibrate at a steadily increasing rate, as when a violinist runs his finger up the bowed string or the length of a whistle-pipe is regularly diminished while its note is sounded, the pitch would rise by a series of steps from one elementary quality to another; but this is not the case, the transition is perfectly smooth and continuous. A concrete example will make this point clearer:—if two elementary qualities are excited by 196 and 200 vibrations per second respectively and are just perceptibly different in pitch, then the tone excited by 198 vibrations per second should be identical in quality with either 196 or 200, it should be of one or other of these elementary qualities. But we know that it is identical with neither, for it is distinguishable from 194 from which 196 is not distinguishable, and it is distinguishable from 202 from which 200 is not distinguishable. The rise in pitch seems in fact to be perfectly continuous and the differences of pitch infinite in number; such continuous variation of quality indicates that, as in the case of the continuous changes of quality of the colour-scale, the change is due to a continuous change in the proportion of two or more constituents of a complex.

We are therefore driven to believe that the so-called simple tones are not elementary qualities but complexes, and we have no certain guidance as to the number of elementary qualities by the fusions of which all the tones are produced. It has been suggested that there are only two such qualities, a highest and a lowest, and that all others are fusions of these two in different proportions. It is very improbable that their number is so small, yet by analogy from the other senses we are led to expect that they are few relatively to the total number of distinguishable qualities. Perhaps the most satisfactory view, if the physical mechanism of the internal ear can be shown to admit of its adoption, is that all the elementary qualities are contained in a single octave, which might be likened to the complete colour-series, and that the differences of pitch that distinguish the same qualities in different octaves are not properly differences of quality, depending upon specific differences of the psycho-physical processes, but are rather of the same order as differences of extensity or voluminousness in the case of visual, tactual or temperature sensation, and are due to differences in the number of sensory neurones excited, the deep pitch (the voluminous) being due to simultaneous stimulation of many neurones, high pitch to stimulation of few.

The list of classes of sensation must be completed by the addition of the sensations excited by stimulation of the nerves of the semicircular canals and of the utricle and saccule. These are minute organs embedded in the bone of the skull close to the internal ear, with which they are probably nearly related developmentally. They are named collectively the *vestibular apparatus*. They consist of little chambers containing liquid, and the movements of the liquid, which occur when the head is moved in any direction, seem to stimulate the sense-organs. The resulting sensations are, like the organic sensations, very obscure, and only attract attention when the organs are stimulated with unusual violence or in an unusual manner, as when we turn rapidly round and round, or are carried rapidly in a vertical direction, as in a lift, or when our motion in a horizontal direction undergoes sudden acceleration, as sometimes in a railway train; we then become aware of those sensations which characterize the state of giddiness. There is much evidence that obscure, undiscriminated sensations excited through these organs play an important part in our appreciation of the position and the movements of the head and of the whole body. The impulses initiated in these sensory nerves are chiefly transmitted to the cerebellum. Hitherto no mention has been made of the cerebellum, and the few remarks that have to be made may be introduced here. The cerebellum is the mass of nervous tissue that lies beneath the posterior pole of the cerebrum, attached by thick bundles of nerve-fibres to the basal ganglia. We remain very ignorant as regards its functions. It is commonly regarded as having no immediate relation to the psychical functions, and if that is the case the psycho-physical processes that excite the sensations mentioned just now must be assumed to occur in the cerebral cortex.

The afferent paths of the "muscular sense" have been described as passing up to the Rolandic, "motor," or kinæsthetic area of the cortex, and that is true of many of them; but others, perhaps of the nature of branches from each of the direct paths to the cerebral cortex, pass to the cerebellum, and there become interwoven with the afferent paths from the vestibular apparatus. In the cerebellum the "impulses" derived from these two sources become co-ordinated and return to the motor mechanisms of the spinal level, effecting especially those extensive and delicate co-ordinations of the contractions of muscles of the trunk and limbs by which the equilibrium of the body is constantly maintained during waking life. And it is probable that the cerebellum thus plays both directly upon the motor mechanisms of the cord and indirectly, by means of connexions with the systems of arcs of the second level in the cerebral cortex.

Having reviewed the classes of sensations we may now attempt to make a rough estimate of the number of specific kinds of psycho-physical processes and of the corresponding number of elementary qualities of sensation, as follows :—

Number of elementary qualities of sensation excited through—

Sense-organs in the skin . . .	4.
,, of the "muscular sense" .	1. (?)
,, ,, taste	4.
,, ,, smell	11. (?)
,, ,, vision	4.
,, ,, hearing—probably not more than 50 at the most.	

To these must be added a small number not accurately defined, excited through sense-organs of the viscera and through the vestibular apparatus.

We may conclude therefore that the number of elementary qualities of sensation is not large, probably not more than 100, possibly considerably smaller. Each of these may be excited in various grades of intensity, the number of distinguishable grades being small in some cases, large in others.

Psychical Fusion.—The immense variety of our sensory experience is due to the complex fusions of these elementary qualities in different proportions, the degrees of intimacy of fusion varying from such low degrees as we find in the case of the qualities of taste-sensations or of the cutaneous sensations, to so high a degree that the fusion defies our best efforts to analyze it.

At any moment of waking life the state of one's consciousness in so far as it is sensational, and every state of consciousness is very largely sensational, is due to a multitude of stimuli playing upon the sense-organs within and on the surface of the body, and exciting, indirectly through the sensory nerves, a number of different specific psycho-physical processes in the sensori-motor arcs of the various sensory areas of the cerebral cortex. Each of these excites an elementary quality of sensation of greater or less intensity, and all these are fused with various degrees of intimacy to form the complex sensory background of consciousness in which, by successive efforts of attention, we can discriminate different qualities. The fusion of the elementary qualities is thus a purely psychical fusion and does not imply a fusion of the nervous processes that excite the elementary qualities.

This view of the relation of the sensory processes to consciousness is that which has been adopted more or less explicitly by some of those who have taken the most comprehensive view of the nervous functions and whose philosophical competence demands our respect, notably by Fechner, Helmholtz, Lotze and Wundt, but it is not yet accepted by all physiologists and psychologists.

It has always been recognized that any state of consciousness of an individual, however complex it may be, is yet in a sense a unitary whole and not a mere agglomeration of the parts or features which we distinguish in it by introspective analysis. It has been obvious, too, that such a unitary psychical whole is frequently conditioned by impressions simultaneously made on different sense-organs and by the "impulses" transmitted from the latter to the brain by different sensory nerves. It has seemed, and still seems to many thinkers, necessary to assume that the different sensory nervous processes, which thus co-operate in determining the unitary state of consciousness, must themselves become fused to a unitary physical or physiological process in some part of the substance of the nervous system, and that the unitary state of consciousness is thus the psychical correlate of a unitary physical or neural process. Hence they have sought for a *sensorium commune*, some central nervous substance to which the various sensory nerves shall communicate their specific modes of activity (commonly conceived by these authors as forms of molecular vibration), so producing in that central substance a unitary physical process, a complex form of vibration, the resultant of all the specific kinds of processes in the sensory paths simultaneously active. Many different parts of the brain have been in turn regarded as this hypothetical central organ, but the progress of our knowledge of the structure and functions of the nervous system has proved that no such organ is to be found. Some authors have therefore fallen back on the view that each kind of specific sensory process radiates itself through all parts of the brain, or that, at least, it radiates itself through the parts simultaneously excited by other sensory processes, so that the substance of each part so excited is thrown into a form of activity which is the resultant of the specific activities of the several sensory tracts. Although, when presented in this form, the doctrine that physiological fusion underlies all psychical fusion cannot be refuted so easily as when it is based on the assumption of a *sensorium commune*, we have sufficiently good grounds for rejecting it. In the first place, it is inconsistent with those three well-founded principles which, as we have seen (p. 58), form the indispensable basis of physiological psychology, and which are summed up in the doctrine of the determination of elementary qualities of sensation by the specific character of certain nervous elements, the psycho-physical substances, localized in different regions of the brain and capable of becoming associated together for simultaneous functioning. Secondly, recent research furnishes evidence amounting almost to complete disproof of the doctrine of physiological fusion underlying psychical fusions in just those relatively simple cases to which the doctrine has been most confidently and plausibly applied, *e.g.* the fusions of the effects of similar stimuli simultaneously applied to similar or corresponding parts of the retinæ of the two eyes.

If, then, the attempt to find a physiological basis of the fusion of effects of simultaneous sensory stimuli has broken down, we have to recognize that in sense-perception the psychical state is the unitary resultant of a multiplicity of locally-separate and qualitatively-unlike nervous processes, and that the fusion is a purely psychical fusion obeying laws that are purely psychical laws and have no equivalents in the physiological sphere. How, then, are we to conceive this psychical fusion? Two courses are open to us. We may assume that each psycho-physical process excites a corresponding sensation-element, and that these psychical elements then coalesce to constitute the complex sensation. This view has been, and still is, widely accepted. But there seem to be insuperable objections to it. If we assume that psychical elements come into existence in this way, we may not assume that they can by coalescing one with another become other than they are. Two chemical elements may, on becoming mingled together, form a compound which appears to us as a different substance, because when thus combined they may produce effects on our sense-organs, and on other substances, different to any that either alone can produce. But in the case of the hypothetical psychical elements the essence and whole being of the elements is their appearance. We cannot legitimately conceive that by coalescing two such beings can disappear and be replaced by a third being different to both. We are compelled to admit, or so it seems to the writer as to many others, that the so-called psychical elements are not independent entities, but are partial affections of a single substance or being; and since, as we have seen, this is not any part of the brain, is not a material substance, but differs from all material substance in that, while it is unitary, it is yet present, or can act or be acted upon, at many points in space simultaneously (namely the various parts of the brain in which psycho-physical processes are at any moment occurring), we must regard it as an immaterial substance or being.

And this being, thus necessarily postulated as the ground of the unity of individual consciousness, we may call the *soul* of the individual.

The phrase, fusion of elementary qualities of sensation, which we have hitherto used, is therefore in strictness illegitimate, but it is so difficult to describe the facts of our mental life in terms to which no exception can be taken, that we seem justified in continuing to use this very convenient phraseology, if we do not allow it to lead us into error. And if we clearly realize that psychical elements are not entities, separate existents, but merely conceptions that we form by abstraction from the complexity of concrete states of consciousness and by the direction of attention in turn to the several features that we can discriminate, we may conveniently describe all states of consciousness as fusions or syntheses of elements, just as we have described the compound qualities of sensation as fusions of the elementary qualities of sensation.

The Feeling-tone of Sensation.—When a physical impression is made upon any sense-organ, the sensation that it excites is commonly in some degree pleasing or displeasing, exciting or soothing. These effects are now generally classed as feelings, the word being used in a much stricter sense than was usual some years ago. The psychology and the physiology of the feelings are still in a rudimentary state, and there is no agreement as to how the relation of the feelings to the sensations is to be conceived, nor as to how many fundamental forms of feeling are to be distinguished. But all are agreed that pleasantness and unpleasantness are the most important varieties, and, leaving on one side the disputed questions as to the number of kinds of feeling and the way in which their relations to the sensations are best conceived, we may describe pleasantness and unpleasantness as the two most important forms of the *feeling-tone of sensations*, and attempt to define their conditions. Feeling-tone, as the word implies, is in some way dependent upon the sensations. Nevertheless, the feeling-tone is in a certain degree independent of sensation-quality; for one quality of sensation may be at one time pleasant, at another unpleasant, and at a third have no appreciable feeling-tone. Pleasant and unpleasant feeling-tone are antagonistic and tend to neutralize one another, so that a sensation cannot have both kinds of tone.

Most sensation-qualities are pleasant when of low intensity, and become unpleasant when their intensity is increased beyond a certain point, which we may call the indifference-point. The position of the indifference-point in the scale of intensities varies from time to time for each quality of sensation, and is very different for the different qualities, and is different for different individuals; in the scale of intensities of sweet sensation, for example, it lies very high for most persons, save shortly after a surfeit of sweet things, when the indifference point is brought down very low in the scale; and in the scale of intensities of bitter sensation it lies very low for most persons, though here still greater individual differences are found.

The different classes of sensation have feeling-tone in very different degrees. The more specialized sensations, whose cognitive value is high, have comparatively feeble feeling-tone; visual sensations even when very intense are hardly so unpleasant as a nauseous odour, nor is a pure rich colour sensation so pleasing to most persons as a delicious odour. The organic sensations, excited by changes taking place in the viscera, have the most intense feeling-tone, and these sensations are generally so vague that the feeling-tone predominates over the sensations. When many sensations, which individually have marked feeling-tone, are simultaneously excited, we cannot introspectively distinguish the feeling-tone of each sensation, the whole complex of sensation produces a resultant feeling, the sensations, to use a crude simile, pool their feelings; hence, when many organic sensations are simultaneously excited, a massive state of feeling results. The feeling excited by an impression made on one of the higher senses is often due in part to reflex changes produced in the viscera, which in turn excite organic sensations with well-marked feeling-tone.

These are the chief points that seem to demand consideration when we attempt to discover the nature of the physiological conditions of the feelings. That the feelings are physiologically conditioned we cannot doubt, when we reflect how greatly modified they are by changes of the state of the nervous system induced by fatigue and rest, by drugs and by disease. Yet we remain in the deepest ignorance of these conditions. It has been suggested, and indeed confidently asserted by some authors, that the essential condition of pleasant feeling is a predominance of the anabolic or constructive processes, and that of unpleasant feeling a predominance of the katabolic processes; but these authors fail to tell us in what tissues they suppose these metabolic processes to occur, and there are so many patent exceptions to the statement that it may be put aside as groundless. A better-founded generalization, made by Herbert Spencer, is that the things that are noxious to us commonly excite unpleasant sensations, those that are beneficial pleasant sensations. Still better founded is the generalization that pleasant feeling determines appetition, a tendency to seek the continuance of the pleasant sensations, and that unpleasant feeling determines aversion or a tendency to withdraw from the objects that excite unpleasant sensations. This relation we must consider later (p. 157).

It is improbable that there exists in the brain any special organ or physiological substrate of the feelings. The feeling-tone of sensation is probably determined by some peculiarity of the psycho-physical processes that excite the sensations themselves. But it is a tenable view that while the sensation-qualities are excited by processes in highly-specialized nervous substances in certain regions of the cerebral cortex only, the processes in all nervous substance, even that of the spinal cord and the peripheral nerves, directly co-operate in determining the state of feeling. Whatever be the truth as to the distribution of the nervous substances in which the neural correlate of the feelings runs its course, we may define the most general conditions of pleasant feeling as the normal activities of the parts of the nervous system at a moderate intensity, and those of unpleasant feeling as abnormal activities, especially processes of abnormally-high intensity.

After-sensations or After-images.—When a stimulus ceases to act upon a sense-organ, the sensation that it has excited usually persists for some little time longer—in some cases for a small fraction of a second, in others for many seconds,—owing to the continuance in the sense-organ of the process induced in it by the stimulus. Such after-sensations (more commonly, though less properly, called after-images) are most vivid and persistent in the case of visual sensation. Visual after-images may be readily observed by any one, after a little practice in directing his attention to them, by gazing steadily for a few seconds at any bright object, such as the flame of a lamp or the incandescent film of an electric lamp, and then closing and covering his eyes. A more satisfactory method is to sit opposite a small window, or a window of which all but a small part is covered, and, after sitting with closed eyes for a few minutes, to gaze steadily for ten or twenty or more seconds at a patch of bright white cloud framed by the window. On closing the eyes and covering the lids with a dark cloth the observer will continue to see the bright patch of light with the dark bars of the window upon it, and, if the light received by the eyes was sufficiently bright, the white after-image will be followed by a succession of brilliant colours in which the three primary colour-qualities predominate in turn. Such after-sensations are in all probability due to the continued stimulation of the sensory neurones of the retina by the substances liberated in the cones by the action of the light upon them. After-sensations are of no great psychological importance, the study of them is of interest chiefly as a means of gaining an insight into the physiological visual processes. They must not be confused with the primary memory-image which we must now consider.

Memory-images.—After glancing attentively at any familiar object most persons can recall its appearance with almost complete faithfulness at any moment during the next few seconds. This recalled image cannot be kept continuously in the focus of attention, though it can be recalled again and again; but after about half a minute the recalled image is apt to appear more vague, uncertain and lacking in detail the greater the lapse of time since the impression was made. Such a representation of an object is an idea of the object, and the peculiarly distinct representation, that is possible for a short time after the perception of the object, is distinguished as the primary memory-image. The representation differs from the percept in being less intense, less constant, and in attracting the attention less forcibly. But it resembles it closely in that we can distinguish in it by introspective analysis qualities of sensation resembling those we can distinguish in the sensory presentation. The qualities that we thus discover in the representation we speak of as sensory images or simply as images, reserving the name sensation for those we discover in the actual sense-presentation. The image resembles the sensation of which it is the representation or reproduction in every respect save that it lacks the vividness of the sensation. This is not a mere lack of intensity, as is stated or implied by many authors, for the least intense sensation has this peculiar vividness while the image of the most intense sensation lacks it entirely. This sensory vividness is one of the fundamental characters of experience and cannot be psychologically described or explained, but we may hope to discover its physiological conditions.

In the experience of some persons, images of all kinds of sensation appear readily and are faithful copies of the sensations. But most persons experience images of one or other of the classes of sensation more readily than other kinds, visual imagery being most commonly the predominant kind. Some persons are incapable of calling up, even by a voluntary effort, any distinct visual images while waking and yet enjoy visual imagery in their dreams, and it is probable that every one who has enjoyed the use of all his sense-organs during the first years of childhood is capable under favourable conditions of experiencing sensory imagery of every kind. If a person has never experienced one or other kind of sensation owing to imperfection of the corresponding sense-organs, or loses the use of one of his senses at an early age, if for example he is born blind or loses his eyesight before his third year, he becomes incapable of experiencing the corresponding imagery. But if a person has enjoyed normal vision for the first few years of his life, he usually continues to be able to call up visual images even though the eyes be completely destroyed or removed by surgical operation. Images therefore do not involve the activity of the sense-organs or sensory neurones. But if one of the sensory areas of the brain is destroyed, the subject becomes incapable of experiencing, not only the sensations normally excited by the processes of that area, but also the corresponding images. Hence we conclude that the images of each class of sensations are excited by psycho-physical processes occurring in the same areas of the cortex as those which excite the corresponding sensations. The further question remains—Is the psycho-physical process that excites an image due to the excitation of the same nervous elements, the same psycho-physical substances, whose excitement gives rise to the sensations? Or to put the question in the more usual form, Are the seats of the sensation and the corresponding image identical or separate? If, as we have seen reason to believe, the specific character of each psycho-physical process is due to the specific constitution of the substance in which it occurs, we cannot suppose the seats of the two processes to be completely identical; for we have to believe that the psycho-physical process in the one substance differs only in intensity on different occasions, and that differences of intensity determine only differences of intensity of the sensations, whereas the image differs from the sensation otherwise than in intensity, namely in the lack of sensory vividness. On the other hand we have good reasons for believing that the image results from the excitement of the same sensori-motor arc as the corresponding sensation. In the first place, their motor tendencies are the same, the cortical excitement in both cases issues from the cortex by the same efferent paths. Secondly, the image stands for, and plays in mental process the same part as, the sensation, and the facts of retention, reproduction and association are intelligible in their physiological aspect only on the assumption of identity, or partial identity, of the seats of the psycho-physical processes that excite the sensation and the corresponding image. For, as we shall see in a later chapter, the fundamental fact underlying those effects is that the excitement of two sensations simultaneously or in immediate succession results in a tendency for their images to recur in consciousness simultaneously or in immediate succession, because the two nervous tracts whose excitement gives rise to the two images have become associated together. But if these tracts are not active at the time of the excitement of the two sensations simultaneously or in immediate succession, it is impossible to conceive how the excitement of those other tracts can bring about this association.

A satisfactory solution of this difficulty is suggested when we reflect that the nervous arc, whose excitement by afferent impulses from the sense-organ gives rise to the sensation, consists probably in every case of a chain of several cortical neurones, and that the excitement of the image is due to spread of excitement to this chain from other regions of the cerebral cortex; we may suppose that when the whole arc, the complete chain of neurones, is excited by impulses from below impinging on its sensory end, sensation results, and that when the arc is excited by impulses coming from other regions of the cortex and impinging on its middle part and therefore, in accordance with the law of forward conduction, exciting only the efferent or distal part of the arc, the image results. This seems to be the only intelligible view of the physiological relations of sensations and images, and its acceptance enables us to offer satisfactory solutions of two much-discussed problems, which we must briefly consider in separate paragraphs. Before passing on to these let us briefly note that images have feeling-tone which differs from that of the corresponding sensations, if at all, in intensity only. There is no difference between the feeling-tone of sensations and that of images corresponding to the sensory vividness that distinguishes the sensations.

Hallucinations and Recurrent Sensations.—An *hallucination* is a presentation that has sensory vividness, although no such object as is presented in consciousness is at the time affecting the sense-organs. Probably most sane persons experience hallucinations occasionally, but they are important and frequent symptoms of mental disease. *Recurrent sensations* are hallucinations of which we can trace the cause in the repeated sensory presentation of the hallucinatory object; a tune or the sound of running water repeatedly heard during the day, or objects studied all day long under the microscope are apt to be represented in the evening, especially as one falls asleep, with sensory vividness. This we may suppose to be due to an irritable weakness of the over-worked sensori-motor arcs in the sensory cortex; if, for example, it is some visual impression that has engaged our attention all day long, we may suppose that the sensory paths of the cortex, that have been principally active, remain so irritable that any impulses excited in the optic nerve by slight impressions on the retina, instead of discharging wholly by paths of the spinal level or being confined to their appropriate paths in the sensory cortex, are diverted to these abnormally irritable paths and so excite the recurrent sensations.

Hallucinations are explicable in a similar fashion. It is known that in many cases of hallucination there is chronic irritation of a sense-organ; in cases of auditory hallucination, for example, it has sometimes been found that there is disease of the ear leading to continual irritation of the sensory neurones. We may suppose that disease induces an irritable weakness of a certain system of paths in one of the sensory areas of the cortex, so rendering them paths of abnormally low resistance, and that any impulses passing up from the corresponding sense-organ, and possibly also from other sense-organs, are therefore liable to be diverted to them from their normal paths, so re-exciting the chains of cortical neurones in their whole length, and producing a representation of sensory vividness. This view is in harmony with the fact that an hallucination may sometimes be shown to be a distortion and amplification of an actual sense-impression by hallucinatory sensations; for in such cases we may suppose that the 'impulses' initiated in the sense-organ, besides traversing the normal sensory paths of the cortex, spread also to those affected with irritable weakness.

The Feelings of Innervation.—It has been and still is a keenly-disputed question whether we have '*feelings of innervation*.' Bain and many other authors have maintained that the current of nervous energy, passing out from the Rolandic or so-called "motor" area of the cortex to the motor mechanisms of the spinal level, gives rise to peculiar affections of consciousness which play in mental process a part similar to that of the sensations, making us aware of the character and intensity of the 'impulses' going out to the motor mechanisms, and therefore, so long as those mechanisms and the muscles are in a normal condition, making us aware of the character and the force of the movements in the moment before they actually take place. Such affections of consciousness are generally implied by the phrase 'feelings of innervation.' Recently several authors, notably Prof. James, have severely criticized this view, and have asserted that we have no feelings of innervation, that we become aware of our movements only through the kinæsthetic images which may precede them and the kinæsthetic sensations that are excited by them, and that the anticipatory image of the sensorial consequences of a movement is the immediate and necessary psychic antecedent of a consciously-performed movement. This view is now generally accepted, even by Prof. Wundt, by whom the phrase feeling of innervation was introduced, for although Wundt retains the phrase feelings or sensations of innervation, he identifies them with the images of kinæsthetic sensations. Figure 5 (p. 46) will help us to understand the physiology of the process, and make clear the advantages of the view of the relation of images to sensations proposed above. As we see indicated in that figure, the contraction of a group of muscles excites a group of sense-organs in the muscles, in their tendons and sheaths, and in the surfaces of the joints moved. From these sense-organs of the "muscular sense" impulses pass up the sensory neurones, and when they reach the cord two paths are open to them, one, a direct reflex path of the spinal level, leading them back to just those muscles whose contractions initiated them (thus constituting the motor circuit of the spinal level) ; the other passing up to the Rolandic or kinæsthetic area of the cerebral cortex, traversing the cortex as a chain of neurones, and returning by the large neurones of the pyramidal tract to just the same motor mechanisms of the spinal level and the same muscles, those whose contractions initiated the impulses; thus constituting the upper motor circuit of the second level. Wundt, in discussing this question, suggests that in the production of voluntary movements the pyramidal neurone *p* (being excited from other regions of the cortex) propagates its excitement in two directions, on the one hand sending the innervation current to the motor neurones of the spinal level *m*, on the other hand sending a current backwards to the neurones *v* (which he regards as constituting the "sensory centre"), and so exciting kinæsthetic images of the movement at the same moment that the movement is being produced by the contractions of the muscles. There are several serious objections to this view. First, it assumes that the psycho-physical processes of the sensation and of the image have identical seats, and differ only in intensity; but, as we have seen, sensory vividness is not to be identified with intensity, as is implied by this suggestion. Secondly, it involves a breach of the law of forward conduction. Thirdly, and this is the most serious objection, it renders quite unintelligible the part played by the kinæsthetic images and the neural processes underlying them. As Prof. James has clearly shown, we normally produce a movement by calling up the idea of the movement, the kinæsthetic images of the sensations that will be excited by the movement, and, if we do not attribute any causal efficacy to the images, we must at least regard the neural processes that excite those images as the immediate causal antecedent of the innervation current that passes down the neurones of the pyramidal tract. But Wundt's scheme makes of these processes meaningless bye-products of the innervation current, for it represents both the kinæsthetic images and their neural processes as following upon the outflow of the innervation current, and not as preceding but as coinciding in time with the production of the movement.

If we accept the view of the relation of images to sensations stated above, we shall regard the kinæsthetic sensations, arising from the contraction of the muscle-group, as excited by psycho-physical processes occurring in the chain of elements *v*, that connects *u* the afferent with *p* the efferent neurone of the motor circuit of the second or sensory level, whether those processes are confined to the substance of the synapses of the chain of neurones, of their cell-bodies, or of the whole chain. And we shall assume that, when the idea of a movement is followed by the movement, the process consists in the excitement of the chain *v*, not through *u*, but through some association-path *a*, joining *v* at some point between its junctions with *u* and *p*; the impulses thus initiated in *v* then, in accordance with the law of forward conduction, discharge themselves through the chain *v* towards and into *p*, exciting in so doing the kinæsthetic images of the movement that is to be produced.

CHAPTER V

The Arcs of the Third, or Higher Level

It was stated above that the arcs of the third level are in the main related to the arcs of the second or, as we may now call it, the sensory level in the same manner as the latter are related to the arcs of the spinal level, *i. e.* they serve to co-ordinate the activities of different systems of arcs of the second level, by combining those systems in larger systems, whose excitement leads to movements of a still higher degree of co-ordination adapted to still more complex situations. The neurones of which they are composed are the principal elements of the large association-areas (see Fig. 3) that surround the sensory areas.

We may distinguish among these arcs two principal kinds:—(1) those that connect the arcs of the Rolandic or kinæsthetic area with other arcs of the second level in the other sensory areas of the cerebral hemisphere. They converge upon the Rolandic area from all the other sensory areas, and the impulses that they bring find their efferent path to the motor mechanisms of the spinal level in the neurones that form the descending limbs of the upper motor circuits, namely the large neurones of the pyramidal tract. Fig. 5 may be used again to illustrate this point. The paths converging from other sensory areas must be supposed to open into the chains of neurones represented by *v* or to be directly connected with *p*. The large neurones *p*, whose cell-bodies are the large "pyramidal cells" of this region of the cortex, send down their axons to form direct connexions with the motor systems of all parts of the spinal level. Hence this system of pyramidal neurones, with the cortical paths converging upon it from all parts of the cortex has been aptly likened by Prof. James to a funnel, the mouth and conical body of the funnel being represented by the converging cortical paths, its neck by the Rolandic cortex, and its stem, through which the outflow takes place, by the neurones of the pyramidal tract. Since the Rolandic cortex and pyramidal tract thus constitute the principal efferent channels for all the higher-level arcs, the degree of their development in vertebrates of the various classes corresponds closely with that of the arcs of the higher level. Thus, while in man both are very largely developed, in the higher apes they are relatively much smaller than in man, and in such animals as the dog they are small, in the rabbit hardly distinguishable, and in the lower vertebrates are lacking.

(2) A second important class of higher-level arcs consists of arcs that connect with one another the various sensory areas of each hemisphere other than the kinæsthetic area. We have to remember also that the transversely-running fibres of the *corpus callosum* connect each part of one cerebral hemisphere with the corresponding part, as well as with other parts, of the other hemisphere.

The superior function of the arcs of these association-areas is indicated in an interesting way by the fact, clearly demonstrated by Prof. Flechsig, that the neurones of which they are composed attain structural perfection in each individual at a much later age than those of other parts of the nervous system. While the latter are fully developed at birth, most of the former are not perfected until a later age, some not until adult life is reached.

Of the functions of these higher-level arcs and of their arrangement in organized systems we can speak only in the most general terms. Since they make up a large part of the cortex they must be of great complexity, and, as was said above, it is not improbable that, as our insight into the structure of the cerebrum deepens, we shall discover that these higher-level arcs are arranged in a hierarchy of levels, the relation of the higher to the lower being in each case similar to that of the arcs of the second to those of the spinal level.

One very difficult question may be raised at once: Do the activities of these higher-level arcs contribute to consciousness psychical elements similar to, or of a kind different from, those contributed by the arcs of the sensory areas? We do not certainly know. It is, however, sound procedure to assume that they do not, so long as we can point to no definite evidence of such additional psychical elements. And it is a defensible view, and perhaps the best working assumption at present, that the sensations and the corresponding images with their accompanying feelings are the only psychical elements, and that all states of consciousness are syntheses, either fusions or spatial and temporal colligations, of these elements. If this is the true view, the activities of these higher-level arcs have no immediate psychical correlates, no parts of them are psycho-physical processes, and they serve merely to bring about in the most delicate and marvellous fashion the co-ordination, orderly co-operation and sequence, of the activities of the arcs of the sensory level that do contribute psychical elements, combining those arcs in systems of greater complexity, and especially uniting into one system sub-systems of the different sensory areas, combining, for example, systems of the visual and auditory and kinæsthetic areas to form the complex systems, by means of which, in reading aloud, visual, auditory and kinæsthetic impressions co-operate in the guidance of the movements of the organs of speech.

Perception.—The higher-level arcs are primarily concerned with perceptual processes. When my attention is drawn to any one of the many objects that at any moment are affecting my sense-organs, I am said to perceive that object, while all the impressions made by other objects excite only sensations that fall in the field of inattention; these other objects may be said to be "sensed" merely and not perceived. The object of attention, the perceived object, occupies the focus of consciousness, the sensations excited by it are synthesized to a higher kind of unity that stands out upon the background of consciousness in which all the other sensations are obscurely present; the latter are therefore conveniently described as marginal sensations. While the impressions made by the unperceived objects do, as we have seen, affect conduct, in that they co-operate in the maintenance of posture and the guidance of routine movements, the impressions made by the perceived object play the leading part in guiding movements, they determine the special purposive movements to which all the rest are but subsidiary.

The psychical synthesis that we call perception involves, not only the sensations excited by the object of attention, but also images of sensations previously experienced, and the proportion of imagery to sensation is very different in different perceptions. If I look up at the full moon and perceive it merely as a disc of silvery light in a certain position, visual sensations predominate in that percept; but if, as my eye receives the rays of light, certain faint markings on the surface of the moon vividly suggest a face looking down upon me, revivals of previous sensory impressions predominate in the percept over the actual sensations.

One sensory impression may suggest in this way different objects, may lead me to perceive in turn several objects. Consider Fig. 6. On looking at the figure you may perceive merely a geometrical arrangement of straight lines on a flat surface. But, in spite of the fact that the lines are purposely drawn without perspective, the figure commonly suggests, and is perceived as, a flight of steps looked at obliquely from above; and it may be perceived also, especially if the suggestion is received verbally, as a flight of steps looked at obliquely from below. It is obvious that the optical impression made, and the sensations excited by the figure, remain unchanged, while the perception changes from the one form to the other. In each case the perception is a synthesis of the one group of sensations with certain obscurely-revived images, and the images thus synthesized are different in each case. When I seem to see the steps from above, the sensations are synthesized with one group of kinæsthetic images, when I see them from below, with a different group. In the former case the excitement of certain paths of the visual area of the cortex spreads through a certain system of higher-level paths, organized by previous experiences of steps seen from above, to the kinæsthetic area, and excites there a certain group of kinæsthetic images; in the latter case it spreads through a different organized system of higher-level paths, and excites a different group of kinæsthetic images. If these higher-level paths connecting the visual and kinæsthetic areas were destroyed by disease, the visual impression would excite the same visual sensations, but the excitation-process would

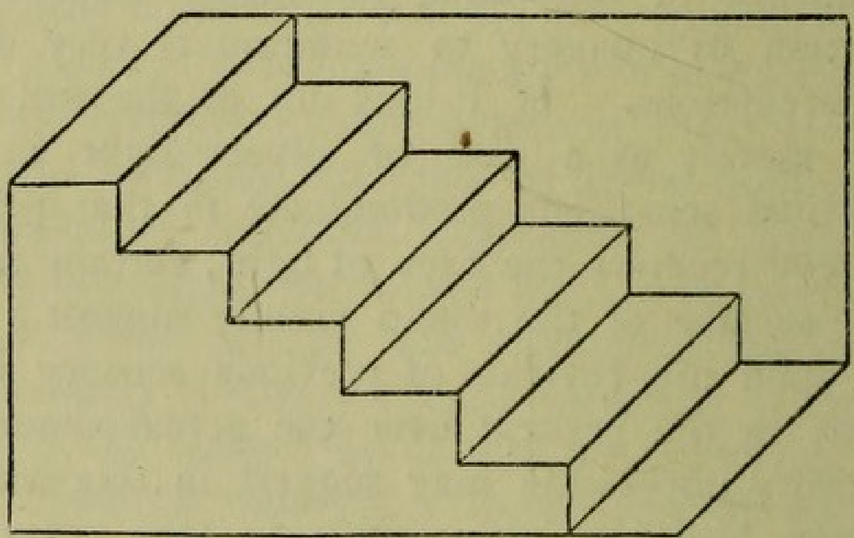

Fig. 6.

remain confined to the visual area, the kinæsthetic images would not be revived, and the impression would have no meaning. Cases of this kind occur and are described as cases of psychical blindness.

Perception seems to involve in every case a synthesis of sensations and images of different senses, and the synthesis results in an establishment of relations of some kind among the sensations. Perhaps the most important kind of relation thus established is the spatial relation, and we may consider now how physiological psychology attempts to throw light upon our perception of spatial relations. It is generally agreed that some form of the doctrine of local signs, first proposed by Lotze, is a necessary hypothesis, though there obtains still much diversity of opinion as to the nature of local signs, and as to how far the hypothesis is capable of explaining spatial perception.

We must begin by stating the most general law of psychical fusion, namely, that all simultaneously excited sensations tend to fuse and to fuse more completely to an unanalyzable whole the more alike they are in quality. The fact that visual sensations of similar quality, simultaneously excited by stimulation of different parts of the retina, do not fuse but remain separate, spatially colligated instead of fused, is an exception to this rule, and this is the first point that the hypothesis of local signs undertakes to explain. It will help us to realize the need for the explanation, if we reflect that in all cases, save those in which spatial colligation occurs, sensations of similar quality fuse completely, while those of unlike quality fuse also in a less intimate degree. Consider a few examples:—visual sensations of similar quality excited by stimulation of symmetrically situated or approximately corresponding parts of the two retinæ fuse completely (for they have identical local signs), and so also auditory sensations of similar quality excited through the two ears; pressure sensations excited by stimulation of closely adjacent parts of the skin fuse completely, and so also sensations of heat and cold, and of taste and smell; almost all the organic sensations habitually fuse in an unanalyzable mass. Of sensations of unlike quality, the auditory illustrate the law of fusion most clearly, the degree of intimacy of fusion being proportional to the degree of their similarity. Fusions of unlike qualities we can analyze in proportion as we are habitually concerned to distinguish the elements.

The theory of local signs sets out, then, by assuming that each sensation, spatially distinguishable from other sensations of similar quality, is so distinguishable only in virtue of some mark peculiar to itself, or at least peculiar to all sensations evoked by stimuli applied to the same sensory area. Place two small discs of white paper six inches apart on a dark ground evenly illuminated, and from a distance of one yard direct the right eye to a point midway between them. Each disc excites a small group of sensory neurones in the retina, from each of which impulses are propagated through arcs of the visual cortex, exciting in them similar psycho-physical processes, and the two resulting sensations are exactly similar in quality, intensity and extensity. If there were excited no other neural processes that affect consciousness, the two sensations would fuse to a single sensation, just as they do when two similar processes are excited by stimulating corresponding parts of the two retinæ, for consciousness would be affected by both processes in an identically similar manner, and there would be no ground for that peculiar difference of the two affections which we call a difference of locality; for we cannot suppose that a mere difference in locality of the two psycho-physical processes in the brain can determine the consciousness of difference of locality of the two objects. Hence, the spatial separateness of the two sensations implies that each neural process is complicated by an additional factor which is different in the two cases and which contributes to consciousness a specific element intimately combined with the visual sensation and serving to hold apart the two sensations and to give them difference of locality. This specific element is the *local sign.*

What then is the nature of the neural process that gives rise to the local sign? It must be a process that is distinct from the process which excites the sensation-quality, for all qualities of sensation excited from the same spot of the retina have the same local sign; and for each of the many parts of the retina, whose stimulation gives rise to spatially distinguishable sensations, it must be specific or peculiar; and not only must these processes be specifically different for each such spot, they must also be systematically related one to another, those excited from adjacent spots must be more alike than those from widely separated spots, for the sensations excited from these separate spots are not merely kept apart in consciousness, they are spatially separated in proportion to the distance apart on the retina of the spots stimulated. The local signs, in fact, form a system of marks of accurately graded affinities.

Now we know that an optical image, when it is thrown upon any peripheral part of the retina, excites a reflex tendency for the eyeball to rotate upon its centre in such a way as to bring the centre of the retina, the fovea or spot of acutest vision, to the position of the optical image. And Lotze suggested that the neural process which, in the absence of counteracting tendencies, brings about this reflex movement, is the neural correlate of the local sign.

Such a process meets the requirements, for the movement of rotation, that must be executed in order to bring the fovea into the position of any other spot of the retina, is a specific movement, as regards direction and extent. Thus, in the case of the two discs of white paper considered above, the one excites a tendency for the eye to rotate through a certain angle towards the right hand, the other a tendency for it to rotate through an equal angle towards the left, and any other spot of light in the field of view projects its image upon a corresponding spot of the retina and excites a tendency to a movement of extent and direction peculiar to itself, and does so no matter what may be the quality of the sensation that it excites. Lotze did not define more nearly the nature of the neural process, and other authors who have adopted his theory of local signs have suggested different views of its nature. We may attempt to give greater definiteness to Lotze's theory as follows—The process by which the axis of the eye is turned towards the optical image is probably a pure reflex of the spinal level, for the reflex tendency is present in the first hours after birth, and in the animals it is not abolished by the destruction of the cerebrum; this process therefore cannot be regarded as the neural correlate of the local sign. But when such a movement of the eye is made, a certain complex of kinæsthetic sensations is excited. The eyeball rotates in a close-fitting socket. The arrangement closely resembles the ball-and-socket joints at the shoulder and hip, and it has been experimentally proved that the kinæsthetic sensations from these joints enable us to appreciate with great delicacy the direction and range of movement and the position of the limb. Hence we may assume that the turning of the eyeball in its socket to any position excites the sense-organs of the socket and surrounding parts in such a way as to evoke a certain complex of kinæsthetic sensations that is peculiar to each position, and that this complex of kinæsthetic sensations is the primary form of the local sign. We seldom pay attention to the kinæsthetic sensations from our limbs, they habitually enter consciousness as undiscriminated elements determining awareness of position of the parts of the body, and the kinæsthetic sensations of the eyeballs are no exception to this rule; hence the difficulty of discriminating these sensations by an effort of introspective analysis. All through the life of the individual and the lives of many generations of individuals, the stimulation of any one spot of the retina has, then, frequently caused by a pure reflex process the turning of the eyeballs to a certain position and has so excited indirectly a certain complex of kinæsthetic sensations. These kinæsthetic sensations are excited by psycho-physical processes in certain arcs of the kinæsthetic area of the cerebral cortex, while the visual sensations that they accompany are excited by processes in arcs of the visual cortex. In accordance with the principle of association that we have to study later, the two groups of nervous elements become associated together, a path of low resistance is formed leading from the arcs of the visual cortex and joining those of the kinæsthetic area. Hence, whenever the former are excited, impulses spread through this association-path, an arc of the higher level, and re-exciting the kinæsthetic arcs revive the images of the complex of kinæsthetic sensations; and this will occur even though the reflex movement of the eye is prevented. A complex of kinæsthetic images is therefore evoked by a stimulus falling on any spot of the retina, a complex peculiar to that spot, and this complex is synthesized with the visual sensation and constitutes its local sign.

Some such account as is here briefly indicated seems to be the utmost that physiological psychology can do at the present time towards explaining our perception of spatial relations. The imagination staggers before the complexity of the neural processes demanded by such a scheme for the explanation of so simple a perception as the shape of a circle or triangle. But when in binocular vision we perceive the relative distances of the parts of a complex object and its absolute distance from the eye as well as its general shape, the complexity of neural processes that we must postulate as underlying the complex conjunction of local signs, becomes very much greater. This, however, does not constitute a valid objection to the theory. There are other more serious difficulties. No doubt the reader will realize some of them vividly enough, but the scope of this book forbids discussion of them.

Let us now apply the same principles to a rather more complex case of perception, the case of estimating by the eye the size, shape, distance and weight of such an object as a tumbler standing within reach of the hand. The rays reflected from the object excite certain groups of sensory neurones in the two retinæ; impulses are propagated from them, which by a reflex process cause the two eyes to be turned upon the tumbler and to be converged to just such a degree that the two images of it fall on corresponding areas at the centres of the two retinæ; at the same time by a reflex process the lenses of both eyes are rendered convex to just such a degree as serves to bring the rays of light from the tumbler to an accurate focus on each retina; all these adjustments of the eyes excite corresponding kinæsthetic sensations, which as local signs make us aware of the position and shape of the object. The synthesis of visual sensations with the kinæsthetic sensations and images of ocular positions and adjustments must in a young child constitute the perceptual processes, but in the adult the perception is more complex. The child during its early years continually grasps after near objects seen, and gradually acquires the power of grasping the object accurately and at once. In this way the visual experience is repeatedly enriched by the kinæsthetic and other sensations resulting from the grasping of objects, and an association becomes established between each particular visual-kinæsthetic impression and the particular kinæsthetic complex resulting from the grasping movements, *i.e.* in physiological terms, the one system, consisting of arcs in the visual and kinæsthetic cortex united by arcs of the higher level, become associated, or connected by a path of low resistance, with a system in the "arm-area" of the kinæsthetic contex, so that impulses tend to spread from the one system to the other; hence the sight of the object prompts to just such movements as are required for grasping and lifting it, and revives the kinæsthetic imagery of the movements. All these images are synthesized in the percept and supplement the spatial determination of the object by the visual processes, they make us more accurately aware of its distance and size and shape, and also imply its weight, hardness, and all those properties which the hand discovers on grasping the object.

The sensations and images that are synthesized in perception are always of two or more senses, as in the case considered above of perception of spatial relations by the eye.

The process of reinstatement of images of other senses by an impression made upon one sense is known to psychologists as *complication*, and the word may be usefully applied also to the underlying neural process.

Let us now consider an instance of perception in which the complicating images are more vividly present to consciousness, one which will illustrate also the part played by the higher-level arcs connecting sensory areas other than the kinæsthetic area. Imagine yourself seated reading in a quiet London lodging on a Sunday afternoon. A man comes slowly down the street crying out repeatedly one word. At first the auditory sensations excited by his voice mingle with the obscure field of marginal sensations, your attention being wholly given to your book. Then for one reason or another, it may be because the sound becomes louder on nearer approach of the crier, the auditory impression attracts your attention from your book to itself, and you perceive the word muffins, probably repeating it to yourself. If you had no experience of muffins or had never heard them called by this name, your perception would involve only the auditory sensations and kinæsthetic images of the movements of the organ of speech,—the excitement of the auditory area would spread only to the kinæsthetic area in which the organs of speech are represented, that known as Broca's area. But if you have frequently enjoyed the eating of muffins your percept may be much richer, images of the visual appearance of muffins, of their taste and smell and flabby greasiness in the mouth, may rise at once to consciousness, complicating the auditory impression. If that happens, it is because impulses have shot across from the auditory area by higher-level paths to the visual, olfactory, gustatory and tactile areas, exciting in them just such groups of arcs as have been previously excited by the impressions made on these several senses by muffins on previous occasions. And if you should happen to be hungry and gluttonously fond of these delicacies, the excitement in each of these sensori-motor arcs may be so intense as to produce the same motor effects as would be produced by the muffins if they acted upon each of these senses; you sniff the air and munch your lips, your mouth waters, and your eyes turn and converge upon the spot of the table on which your fancy depicts the desired object, while the combined feeling-tone of all the processes constitutes a pleasure well-nigh as keen as the actual eating would yield.

This example will serve to illustrate also the nature of the idea or representation of an object and its relation to the percept. In this percept the complicating imagery preponderates over the sensations, but so long as actual sensations co-operate in the process we call it perception. As the sound dies away and with it the auditory sensations, the imagery may remain present to consciousness as before, some one kind of imagery, if you are a visualizer the visual imagery, becoming most prominent and replacing the auditory sensations as the central feature of the state of consciousness. The synthesis of these elements we call a representation or idea of the object. Such an idea, the product of the reproductive imagination, the lowest form of ideational activity, is thus a synthesis of images of sense, and its relation to the percept is like that of the image to the sensation. The percept of any thing in one particular aspect and the corresponding idea of the thing have similar physiological correlates, the conduction of impulses through the same system of sensori-motor arcs, the principal difference being that, in the case of the percept, at least one of the sub-systems of arcs in one of the sensory areas of the cortex is excited directly through a sense-organ and the afferent path from it to the cortex, while in the case of the idea all parts are excited indirectly through association-paths that connect them with other parts of the cortex.

Hence the idea stands for and has the same psychological relations and functions as the percept of which it is a reproduction, and the following statements apply to both equally because they express the principles of action of the neural disposition which is the physiological basis of both.

The object of perception or imagination at any moment is a single object only in the psychological sense. It is true that several objects in the ordinary sense of the word, *e.g.* the five fingers of my hand, may be combined in a single percept or idea, but only by being thus combined as parts of one object. Therefore of all the many physical things simultaneously affecting my senses, one only or one complex of things is the object of attention, and as one thing becomes the object of attention the thing perceived in the previous moment ceases to be the object of attention; as any object comes to the focus of consciouness it drives out and excludes from the focus all other objects. The most striking instances of such exclusion of impressions from the focus of consciousness, owing to concentration of attention upon other objects, are afforded by the case of soldiers who, in the excitement and effort of battle, fail to notice that they are wounded; the intense concentration of attention upon the movements of the enemy and their own actions prevents the violent sense-impressions made by sword or bullet from attracting attention to themselves. But similar though less striking effects of concentration of attention upon any object are frequent in the experience of every one. There can be no doubt that we must find a physiological expression for this singleness of the object of attention and for the power of one object to banish all others from the focus of consciousness. Translated into physiological terms it means that only one of the perceptual systems of cortical paths, consisting of two or more sub-systems in sensory areas united by higher-level paths, can be active at any one moment, that the spread of the nervous excitement through one such system somehow brings about the cessation of activity in the system active at the previous moment and prevents the activity of other systems, *i.e.* the activity of any one such system inhibits that of all other systems. Hence we need not seek for inhibitory centres in the cerebrum, as many authors have done; each perceptual system of arcs, each system involving higher-level arcs, is an inhibitory centre for every other, the activity of each system brings about as a collateral effect the inhibition of all others.

We have seen that a relation of this sort obtains between certain of the relatively isolated motor systems of the spinal level, notably between those that innervate antagonistic muscle-groups, such as the flexors and extensors of the elbow-joint. And we saw that, though we do not certainly know how this inhibition is brought about, it may be conceived as a drainage of the free nervous energy from the inhibited to the inhibiting system, owing to the latter becoming for the moment the path of least resistance. There is evidence that similar inhibitory effects are exerted by the activity of any one group of arcs of a sensory area of the cortex upon the other arcs of the same area, especially in the case of the visual area. All the phenomena of light- and colour-contrast seem to be due to such inhibitions, and the very intense contrast-effects produced by a smoothly-graded zone of transition between the contrasting areas, seem to be explicable by this hypothesis only.

Hence this view of inhibition as drainage, which so long as we consider the spinal level only seems but a speculative suggestion, becomes a well-founded hypothesis when we consider the processes of inhibition in the arcs of the second level. And when we consider the evidences of inhibition in the higher levels, the inhibition exerted by the activity of each higher-level system on all other similar systems, the hypothesis receives further support, because we can conceive no other way in which this antagonistic relation between the activities of all the multitudinous higher-level tracts can be brought about. But the most weighty evidence in support of this view is afforded by the consideration of the processes of association which we have to consider in a later chapter (p. 132).

The importance of this reciprocal inhibition, which confines the attention to a single object only at any one moment, is obvious. In a purely contemplative being, a god whose sole function was to lie beside his nectar watching the whirligig of time and hearing the music of the spheres, we should regard such narrowness and singleness of the focus of consciousness as a serious limitation of capacity, but for us, whose function it is to react upon our environment by means of our muscular system, it is of prime importance; for, as we have seen, the object of attention determines the trend of bodily activity; and if we were capable of attending to two or more objects at once, the parts of our muscular system would frequently be impelled to incompatible modes of activity, that co-ordination of the muscular actions of the whole body, in virtue of which the contractions of the muscles of all parts co-operate towards the achievement of one end, would be impossible.

We may now summarize those characteristics of the nervous process excited by the object of perception which distinguish it from the processes excited by sensory impressions that fail to attract the attention:—(1) The excitement of the sensory nerves is propagated, not merely through arcs of the corresponding sensory area of the cortex evoking sensations, but also through some organized system of arcs of the higher level to other sensory areas evoking images, and leading to a complex co-ordinated outflow of motor-impulses. (2) The contractions of the muscles, especially those by which the sense-organ concerned is adjusted for the better reception of the impression, *e.g.* in the case of a visual impression, the intrinsic and extrinsic muscles of the eyeballs, excite the nerves of the "muscular sense," and impulses, passing up these nerves to those arcs of the kinæsthetic area which constitute a part of the total system excited, re-enforce the excitement of the system, and so tend to maintain the object in the focus of consciousness; this is a process of facilitation comparable to that facilitation of the reflex processes of the spinal level, which, as we have seen (p. 37), is effected by the branches which the afferent neurones of the "muscular sense" send to join the motor mechanism of the cord, and by which the tone of those mechanisms is principally maintained. This is the motor element in the process of sensory attention to which some authors have attached so great importance. (3) The excitement of one perceptual system thrown into activity inhibits the activity of all others, because it becomes the path of lowest resistance for the discharge of energy from the sensory to the efferent side of the whole cerebral system; and the activity of the dominant system is thus augmented by the energy that it drains to itself from other parts.

We have now developed the conception of neural systems far more complex than the simple systems of the spinal level which we first considered, yet of essentially similar nature. The perceptual neural system is a complex of sensori-motor arcs of all three levels, and comprises arcs in two or more of the sensory areas of the cortex, and all these arcs are so intimately connected that excitement, initiated in any one of them, tends always to spread throughout the system. We have to regard the brain of the adult as consisting of a great number of such systems and sub-systems of neurones, organized with various degrees of completeness and stability and interconnected with various degrees of intimacy. Some of the perceptual systems are congenitally organized, while others are built up by the course of the individual's experience. The statement that systems are congenitally organized does not necessarily imply that they are present fully developed at birth, but rather that they have an inherited tendency to develop along certain lines. The mental life of most of the animals must be regarded as almost purely perceptual and determined almost completely by congenitally organized perceptual systems. Man, too, has such congenitally organized systems, but he differs from the animals in that his long education greatly modifies his congenital systems and develops many new systems peculiar to each individual.

When the newly-hatched chick pecks accurately at any small grain upon the ground near it, seizes it in its beak and swallows it, that is only possible because its nervous system contains a system of sensori-motor arcs which is thrown into activity by the impression made on the retina by the small grain, and which then produces the accurately co-ordinated contractions of the muscles by which the movements are effected. Consider a less simple case. Let us take that of a young squirrel burying a nut for the first time, an action that has been observed in a young squirrel brought up in captivity on the first occasion of its receiving nuts. The nut is held in the mouth while a hole is rapidly scratched with the fore-feet, the ears are then pricked, apparently in the endeavour to catch any sounds of possible robbers, and the nut is pressed into the hole and covered up. Here is a train of perceptual activities carried out by a complex congenital perceptual system; the sense-impressions made by the nut initiate the process, and each further stage of activity is guided and maintained by the new impressions, brought by the previous stages, throwing into activity successively the sub-systems of which the total complex system is made up.

Such *congenital perceptual systems* we call *instincts*, and the actions evoked when the appropriate objects excite such systems we call instinctive actions. Man has many instincts, but most of them mature slowly, and his capacity for learning by experience, *i. e.* for modifying the congenital systems and developing new ones, is so great that the manifestations of their activity are commonly overlaid and more or less obscured by acquired modes of action. Nevertheless, they form the determining groundwork of his nature and are apt to rough-hew the forms of his activities, shape them how he may in detail. Consider the tremendous part played in human life, even in the most highly civilized societies, by the instinct of reproduction. Consider how the pursuing or hunting instinct may determine the main outlines of the life of a man in whom it is strong and who is in a position to follow his natural inclinations. Almost all the activities and interests of a keen sportsman are derived from this one instinct. Just as the smell of certain wild animals will irresistibly attract the attention of a dog to the exclusion of all other objects, and will excite it to a characteristic train of actions, so the sight of a scurrying rabbit will irresistibly attract the attention of the normal boy and provoke him to a wild pursuit. In the dog the particular kind of odour excites certain congenital systems and so attracts the animal's attention and determines it to certain forms of action, and in the boy the visual impression produces a similar effect.

CHAPTER VI

Emotions

The possession of congenital nervous dispositions renders possible the perception of certain classes of things without previous experience of similar things, and determines their possessor to act in reference to these things in a manner more or less roughly adapted to promote his own welfare or that of his species. Such inherited perceptual dispositions are instincts. The only effects of the excitement of instincts that we can observe in the animals are those bodily movements which we call instinctive actions. But when such a disposition is excited in ourselves by an appropriate object, we not only perceive the object and experience an impulse to a certain kind of action, but we experience also what we call an emotion, or emotional state of consciousness, *i. e.* the background of consciousness, on which our percepts and ideas stand out as the most prominent features, and which is ordinarily dim and vague, becomes more prominent and takes on a characteristic quality in the case of each of the primary instincts. In ourselves the bodily movements characteristic of each instinct, instead of having free play as in the case of the animals, are frequently suppressed or modified by the retained effects of previous experience and by the will. Hence of the two results of excitement of instincts in ourselves, we commonly attach more importance to the peculiar state of consciousness than to the bodily movements, whereas in the case of the animals the resulting bodily activities are alone open to our observation. So it has come about that in the past psychologists have commonly treated of the instinctive actions of animals and of the emotions of man, failing to realize that instinctive actions and emotions are but two different manifestations of the one process, the objective and the subjective effects of the excitement of inherited perceptual dispositions.

The relations of the more subtle, secondary or derived emotions to instinctive modes of action are often obscure but, as Mr. Shand has pointed out, even these emotions can only be successfully analyzed and classified by reference to the kinds of bodily activity, or tendencies to bodily activity, by which they are commonly attended. Consider how a skilful actor can by mere gestures and facial play depict even the more subtle emotions. And in the case of the primary and more intense emotions the relation of each one to an instinctive train of actions is clear. Thus, the excitement of the instinct of flight results in the emotion of fear and in the movements of flight or at least the impulse to such movements; so the excitement of the instinct forcibly to break down all external opposition to the free play of natural impulses results in the attitudes and movements of combat and in the emotion of anger; the instinctive cherishing and protecting of offspring is accompanied by tender emotion, and the instinctive play of the reproductive impulses is attended by sexual passion.

For the effective exercise of each kind of instinctive activity there are needed certain adjustments of the activities of the visceral organs, and these adjustments, like the bodily movements, result immediately from the excitement of the instinct; the excitement of the disposition issues, not only in a co-ordinated stream of impulses along the motor nerves of skeletal muscles, but also in a like stream of impulses in the efferent nerves that govern the activities of the viscera. Such adjustments may be regarded as "serviceable associated habits" of the instinctive actions. Since the group of visceral adjustments accompanying each kind of instinctive action is peculiar to that kind, and since these adjustments cannot be voluntarily controlled or prevented, whereas the bodily instinctive movements can be, and often are, controlled and modified by the will, we rightly regard the effects of these adjustments as the most reliable symptoms of the emotions.

Let us consider the visceral adjustments that result from the excitement of one of the primary instincts, namely the instinct of flight. For effective flight the muscles of the limbs need to receive the greatest possible supply of well-aërated blood; and this can only be secured by an increased force and frequency of the heart-beat, by increased frequency of the respiratory movements of the chest-walls and diaphragm, and by contractions of the small arteries of all the organs that do not immediately aid in flight, driving the blood from all these organs to the muscles of the limbs, especially from the skin and various glands which in their normal state contain large quantities of blood. Hence we find that excitement of the instinct of flight gives rise to violent action of the heart, to hurried breathing, to pallor and coldness of the skin, to dryness of the mouth and throat, and to those other disturbances of the digestive functions which result from the checking of the blood-supply to the salivary glands and other organs of digestion.

So constant are these visceral effects and so little are they under the control of the will, that the dryness of the mouth has been regarded among some peoples as the most reliable symptom of fear, and the man accused of crime is made to try to eat dry rice, when if, owing to lack of saliva, he is unable to moisten and swallow it he stands convicted of fear, presumptive evidence of guilt.

The excitement of each primary instinct results, then, in such a characteristic group of visceral adjustments, which we regard as symptomatic of the corresponding emotion. But beside these specific symptoms, there are others which are common to all intense emotions and are the result of an excitement diffused throughout the central nervous system. This diffused excitement is indirectly produced by the excitement of the instinct in the following way:—The contractions of the skeletal muscles, and still more the changes in the viscera, that follow directly upon the excitement of the instinct, excite in turn the sensory nerves of those organs, so that a stream of nervous impulses is sent back to the spinal cord and brain along all these nerves, and each impulse arriving in the central nervous system liberates a certain quantity of nervous energy that tends to diffuse itself to some extent throughout the system, augmenting that flow of energy which is constantly taking place from the afferent to the efferent or motor side. Hence the nervous system becomes surcharged with free nervous energy that tends to escape along all efferent channels. If this excitement is very intense it may produce general convulsions, and so, destroying all co-ordination of movement, defeat the "ends" of the instinct. But when this general excitement is less intense, it manifests itself in some incöordination of voluntary movements, in the tense and trembling state of many muscles, in ejaculations, cries or screams, in weeping or laughter or both alternately, in sweating, in dilation of the pupil and general visceral disturbance. So long as this general excitement is not too intense it renders instinctive action more effective, because it determines the outflow of a greater volume of nervous energy to the muscles. Hence under the strong excitement of an instinct, or, as we more commonly say, under the influence of strong emotion, our muscular system may execute more forcible contractions than any we can voluntarily produce in the absence of such excitement.

Let us now turn to the consideration of the subjective aspect, that peculiar state of the background of consciousness which we call the state of emotion. The focus of consciousness is occupied by the object that excites the instinct, or by perceptions or ideas connected with it, and these appear on a background of peculiar character and intensity. Part of this intensity seems to be due to a general feeling of excitement corresponding to the diffused excitement of the nervous system, and therefore, like this, common to all states of instinctive excitement. Of this feeling we can say nothing further than that, like pleasure and pain, it seems to be one of the primary forms of feeling and has for its correlate or antagonist the feeling of relaxation or depression. Beside this feeling of excitement we can discover, by introspective analysis of each emotion, the organic sensations, due to the stimulation of sensory nerves by the visceral adjustments, and the kinæsthetic sensations of tension and strain caused by the strong action of the various muscles. Thus in the emotion of fear we can note by introspection the sensations caused by the forcible beating of the heart, and by the hurried respiratory movements, the coldness and "creepiness" of the skin, the dryness of the mouth and throat, and vague but unpleasant sensations in the abdomen. All the organic sensations have marked feeling-tone, and they, together with these other secondarily aroused sensations, are certainly important elements of the total state of consciousness; and since the visceral adjustments and the corresponding organic sensations, aroused by the excitement of each of the primary instincts, constitute a characteristic group, they contribute to determine the peculiar quality of the corresponding emotion.

The question now arises—Does the emotional state of consciousness contain other psychical elements than those above described? Is each primary emotion merely the synthesis of such a characteristic complex of elements, or does it contain beside these a specific constituent of a quite different nature? Of course the emotion is not merely the sum of the elements; just as the perception is more than, and other than, the mere sum of the sensations and images of which it is the synthesis, so the emotion is more than and other than the mere sum of these elements. But is it not the sum of these elements in the sense that if they were taken away the emotion would be destroyed, and would not the subtraction of the organic sensations in particular destroy all that is characteristic of each kind of emotion? Does it not resolve, on introspective analysis, into these elements without remainder?

Prof. James has boldly answered these questions in the affirmative, and has supported his position with many forcible arguments, and has thereby given a mighty shock to the psychological world, which in the main stoutly refuses to accept this conclusion. But those, who thus refuse to accept the organic sensations as the essentials of emotion, find it very difficult to produce any positive evidence in support of their view. Certain ingenious experiments made by Prof. Sherrington have been held to afford such evidence. Prof. Sherrington found that it was possible to operate upon a dog in such a way as to render it impossible for visceral changes to send nervous impulses to the brain, and yet to maintain the animal in a fair state of health, and he observed that a dog in this condition exhibited most of the symptoms of emotion when appropriate means were taken to excite its instincts. These facts, however, do not warrant the conclusion that normal emotional states are possible along with complete visceral anæsthia, for Prof. Sherrington did not observe the emotion of the dogs, a feat quite impossible from the nature of the case; he observed only the bodily effects that normally result from the excitement of an instinct. If Prof. James' theory be true, that is just what we should expect to observe in such cases, although, if we accept that theory, we must believe that the dogs felt no emotion; for the interruption of the sensory paths by which the organic sensations are normally excited should not interfere with the primary expression of the excitement of the instinct, which should therefore appear in these dogs as in normal animals, and as, in fact, it did.

Prof. James has summarized his view in the statement that "the bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur *is* the emotion." This and similar passages would seem to warrant the statement that, according to Prof. James, no emotions could be experienced if the inflow of sensory impulses from the viscera were in any way prevented, and his doctrine is commonly represented in this way. But to make that statement would perhaps be going beyond the position assumed by him. He would admit that the nervous elements in the brain, whose excitement by these impulses from the viscera gives rise to organic sensations, may be centrally excited and that, as in the case of other sensory brain-elements, the central excitation may give rise to images of visceral sensation.

Now we shall see later that it seems to be a general law of brain-action that any given elements, repeatedly excited together or in immediate succession, become so connected that on the re-excitement of some of them, the excitement spreads at once to the others. If a certain kind of sensory impression has repeatedly excited a given emotion, the excitement of the brain-elements concerned in the process of perception must have been on each occasion immediately succeeded by that of the elements excited through the visceral changes, and, in accordance with the law just stated, the two groups or systems of elements must have become connected together, so that perception of the object on any future occasion will immediately give rise to the group of images, or revived organic sensations, with their accompanying feeling-tone, even though the inflow of impulses from the viscera should be in any way prevented; hence, even though the theory be substantially true, emotions may be experienced in the absence of nervous impulses from the viscera, and this may well have been the case in Prof. Sherrington's dogs mentioned above, and in certain cases of visceral anæsthesia in human beings, who seemed to experience emotions in spite of apparent insensibility of the viscera.

If the theory is modified by the recognition of the possibility of emotions depending upon revived or reproduced organic sensations, without the intervention of actual visceral changes, it would seem to cover all the facts. But if we accept the theory in this modified form we can no longer accept Prof. James' statements in their literal sense. He writes, *e.g.*, "Common-sense says, we lose our fortune, are sorry and weep; we meet a bear, are frightened and run; we are insulted by a rival, are angry and strike. The hypothesis here to be defended says that this order of sequence is incorrect, that the one mental state is not immediately induced by the other, that the bodily manifestations must first be interposed between, and that the more rational statement is that we feel sorry because we cry, angry because we strike, afraid because we tremble, and not that we cry, strike, or tremble, because we are sorry, angry, or fearful, as the case may be. Without the bodily states following on the perception, the latter would be purely cognitive in form, pale, colourless, destitute of emotional warmth."

We may, then, while recognizing the truth implied by Prof. James' theory, yet maintain that common-sense puts the sequence in the right order, and that the rise of the emotion may precede the bodily changes and may occur in their absence. The causal question, Does the emotion cause, or play any part in determining, the character of the bodily changes? remains as a special case of the great unsolved problem of interaction of psychical and physical processes. We can only give this answer,—If we may believe that the synthesis of sensations, images and feelings, which constitutes perception, modifies in any way the course or intensity of the nervous currents in the sensori-motor arcs that are the physical bases of those psychical elements, the seats of the corresponding psycho-physical processes, then we may believe that that special kind of perception in which the synthesis includes a large proportion of organic images and sensations and feelings, and which we call emotional perception, constitutes no exception in this respect, and that, in fact, its influence upon the course of nervous process, and so upon conduct, is greater than, not less than, that of unemotional perception.

Physiological considerations throw light upon one or two other facts of the emotional life. In psychological language it is said that the emotion, once excited, tends to maintain itself until exhaustion ensues, or until it has achieved its object. We have seen already how the bodily changes increase the general excitement of the nervous system by sending back to it streams of impulses along many sensory nerves. And we have seen in an earlier chapter how the kinæsthetic impulses tend to return by what are called the motor circuits to just those muscles whose contractions excite them, so tending to maintain the muscular activity that gives them birth. It would seem that an arrangement much like that of the motor circuits obtains in the case of the afferent and efferent nerves of the visceral organs, so that, like the contractions of skeletal muscles, the changes in these organs also tend to maintain themselves by a circular nervous process. Hence the fear and the bodily symptoms of fear, provoked by a sudden and momentary impression, persist for some little time, though the harmless character of the disturbing incident is at once realized. Hence the sudden anger dies slowly away, though its cause be removed, and is apt to vent itself upon the unoffending. Hence the tears and lamentations may continue to flow though the cause of grief no longer exist. This slow passing away of the emotional state is of course best displayed by children, as by the child who continues to sob in his mother's arms though he has realized that the terrifying face or the growling wild beast was only his elder brother in disguise.

The above physiological considerations explain, too, why an emotional perception is apt to leave a deeper and more lasting impression than others. The surcharge of nervous energy, generated in the manner described above, raises the intensity of all the nervous processes to a high pitch, so that those traces, which they leave behind them and which are the physical conditions of memory, are deeper and more permanent traces. In this state of high general excitement and abundant free energy we may see also a suggestion of a physiological explanation of the fact that when our instincts and emotions are excited in a moderate degree our attention is keener, our flow of ideas more rapid, and our voluntary movements more vigorous. It may be said, in fact, that the activity of our brains is dependent upon a stream of energy from below, that the processes of our bodily organs constantly send up to the central nervous system streams of nervous energy, now fuller now more feeble, and that without these streams of energy, those poured in from the organs of special sense would hardly suffice to maintain the nervous system in a working condition, and would certainly be insufficient to maintain it in a condition of vigorous and high activity. Hence the intimate dependence of our mental health upon the health of our bodily organs and the mental enfeeblement that may result from their enfeebled state in disease or in old age. It is undoubtedly true that, as Dr. Maudsley has said, "It is not for the most part that brains wear out in old age, many times they would go on longer if they were properly fed with energy from below, but the organic functions decay and fail; it is their failure which causes desire to wane and the grasshopper to be a burden; they are the source of life's energy and relish, and in their integrity and vigour lies the secret of a fresh and active old age. To live for ever, having got rid of the flesh with its appetites and lusts, would be to have a vapid and joyless immortality, the one long bootless desire of which would be an impossible suicide."

> "Ay me! Ay me! with what another heart
> In days far-off, and with what other eyes
> I used to watch—if I be he that watched—
> The lucid outline forming round thee; saw
> The dim curls kindle into sunny rings:
> Changed with thy mystic change, and felt my blood
> Glow with the glow that slowly crimsoned all
> Thy presence . "

CHAPTER VII

Mental Retention

THE conduct of such an animal as a dog or cat in its natural state is throughout life principally instinctive, consisting of trains of perceptual activities, the expressions of the working of the congenitally organized dispositions that make up almost the whole of its nervous system. Its conduct becomes but little modified by its experience. And the lower we go in the animal scale, the less evidence is there of modification of conduct in accordance with the past experience of the individual animal. Man, on the other hand, is greatly superior to the animals in this respect, he has a great capacity for learning, for acquiring new modes of behaviour in various circumstances through experience of the effects of similar circumstances and of his previous reactions to them. Such modification of conduct in accordance with past experience is only rendered possible by the retention in some way of effects of that experience. And we have now to study the way in which the brain plays its part in mental retention.

So long as psychologists worked almost exclusively by the introspective method, they paid attention only to the evidences of retention revealed by introspection. Of these the most striking, and therefore the first to be observed, was the fact that an object previously perceived can be mentally represented, that we can recall ideas of objects previously presented to the senses. A second fact of fundamental importance, observed by introspection, was that the perception, or the re-presentation or idea, of one object is apt to be immediately followed by the idea of some other object, the perception of which at some previous time had immediately followed that of the former object. These facts were expressed by saying that the mind retains ideas of the objects it perceives, and that the ideas of objects perceived in immediate succession or temporal contiguity, or in certain other relations, become associated together, so that one tends to recall or reproduce another.

But we have no evidence that ideas themselves persist in the mind. So far as we can discover by introspection, when one ceases to perceive an object and occupies oneself with other perceptions or thoughts, that object ceases to be present to consciousness, the presentation ceases to have any psychical existence, although after a longer or shorter interval we may be able to recall again and again an idea of the object which is in a sense a revival or, as it has been called, a faint copy of the percept. On the other hand we have overwhelmingly strong reasons for believing that the process of perception produces an alteration in some part of the substance of the brain, a new arrangement or disposition of nervous matter, and that the persistence of this nervous disposition is an essential condition of the possibility of the re-presentation of the perceived object, of the recall of an idea of the object. If the ideas themselves do not continue to exist in the interval between perception and re-presentation, then those links, which we call the associations of ideas and which are the essential conditions of the reproduction of ideas of objects in an order determined by the order of their perception, cannot be links between ideas but must be links between the nervous dispositions that are the necessary conditions of the revival of ideas, and must themselves be nervous dispositions. We may still speak of ideas being stored in the mind and being associated together, just as we may still say of a man that he carries the image of his beloved in his heart, but the two expressions have the same sort of validity only. They are picturesque survivals from the age of ignorance. When therefore we speak of the reproduction of one idea by another in virtue of an association established between them, we are using the convenient terminology of an earlier stage of science and must remember that the actual processes denoted are quite other than those the words seem to imply.

Not very long ago psychologists who sought a physiological basis for mental retention were content to assume that the persistent nervous change, which is the essential condition of the revival of an idea, was some change in what they called a "ganglion-cell," meaning thereby the nucleus-containing body of a nerve-cell. And an association was conceived as a nervous channel connecting two such "ganglion-cells," such that, when one of them is excited, an "impulse" travels along this path to the other and, on reaching it, causes it to give out its idea as a bell gives out its note when struck. This conception was in fact suggested by Hume, one of the first to treat of the association of ideas, and it still finds a place in some text-books. But this way of representing the physiology of retention is very unsatisfactory. The principal objections to it may be stated as follows:—(1) It is impossible to conceive how the perception of an object should produce in a cell-body any kind of change which could constitute the condition of re-presentation of the object. To attribute processes of so great complexity to individual cells is merely to substitute for the brain, about whose structure and functions we have some small amount of knowledge, the cell-body whose structure and functions we cannot hope to understand in the same detailed fashion; it is to resign ourselves to the impossibility of finding a physiological explanation of mental retention without having made any serious effort to find one. (2) This conception did not help us to understand how retention plays its part in modifying conduct; for if, as was supposed, the perception of an object produces such a change in a "ganglion-cell" that whenever the cell is re-excited an idea of the object results, there is no intelligible connexion between that result and the modification of conduct by the effects of the previous experience. This conception was, in short, arrived at by simply translating the imperfect results of a purely introspective psychology into the terms lying nearest to hand in a very imperfect physiology. (3) The conception was based upon, and tended to confirm, the great errors of the associationist psychology, namely the assumption that ideas are discrete entities, faint but faithful copies of impressions stamped upon the passively receptive mind by the objects of the physical world, and that thought consists merely in the reproduction or reinstatement of these faint copies singly or in clusters.

Modern psychology insists upon the truth that each of us can only perceive and mentally retain that which previous experience has prepared him to perceive. If you are confronted with an object of a kind new to you, you can at first perceive and remember only those features which it has in common with objects already familiar to you; other features you must learn to discriminate by fixing your attention upon them successively, before you can apprehend them as parts of the whole. Perception and mental retention of any object imply therefore the possession by the perceiving individual of some kind of systematic organization elaborated by the course of previous experience from the rudiments of mental structure that he inherits; and that which is retained is always only some further development, by accretion or internal differentiation, of a pre-existing complex disposition systematically related to other similar dispositions. The child enters upon life with certain congenital dispositions, and his education consists in the gradual further development of these dispositions and of systematic connexions between them. And his powers of perception and retention develop with the development of these dispositions. Consider how gradually by oft-repeated efforts of perception the child acquires the power of perceiving, distinguishing and retaining the forms of printed letters.

The educated adult has at his service an enormous number of dispositions, and all his further perceptions involve the co-operation of these systems gradually built up in the course of his education. We are apt to suppose that the mind receives and retains any sensory impression as a clean sheet of blotting-paper receives the print of the written characters or a smooth waxen surface the impress of a seal. If that were the case any physiological explanation of retention, other than the "ganglion-cell hypothesis" (which is no explanation) would be impossible. But the process of perception and retention of an impression may be likened more truly to the application of a seal to a waxen surface on which a countless number of impressions have previously been made; each new impression finds its way into the marks previously made by similar seals and deepens and alters them a little, and, if no such congruent marks have been previously impressed, the novel form of seal fails to leave any recognizable trace. The new impression is only rendered possible by the co-operation of the accumulated effects of previous impressions. Adhering to the simile we may say that when the new seal, the object of present perception, fits accurately into marks already made, we call the process *assimilation;* when it does not perfectly fit to the old marks, but effects some change in them, we call the process *apperception*. The marks, of course, are the dispositions elaborated from the simpler congenital dispositions in the course of education, and the modification of any mark by a new impression is the modification of a disposition that is effected in the process of perception, and the persistence of this modification constitutes retention.

The realization of these truths renders impossible the acceptance of the doctrine of the retention of ideas stored in the mind whether as unconscious ideas, or sub-conscious presentations, or depositions of some inconceivable kind in "ganglion-cells." In spite of the convincing evidence that the retained effects of mental process, by which future mental process is modified, are more or less permanent structural changes induced in the nervous system, some authors still prefer to present their psychology without reference to the physiological factors of mental process. They therefore describe those dispositions which are inherited in simple rudimentary forms embodying the experience of the race, which are gradually elaborated, differentiated, multiplied and systematically interconnected by the experience of the individual, which principally determine the course of future mental process, and which in disease and old age undergo dissolution and decay,—they describe these dispositions, which constitute the structural framework of our minds, as unconscious psychical dispositions. If the fictitious character of this hypothesis is frankly admitted it may legitimately be used to facilitate the exposition of mental process, and for this purpose it is greatly superior to the conception of ideas enduring in an unconscious or sub-conscious state and stored in some receptacle which, without further definition, we call the mind. But if this phrase is held to be other than a convenient fiction it becomes an hypothesis of questionable legitimacy, for it is an hypothesis that can never be directly subjected to the test of verification, and which postulates a kind of existent of which we have and can have no experience and of whose nature it is exceedingly difficult to form any conception. It may be said that J. S. Mill pronounced the ether of the physicists to be an illegitimate hypothesis on similar grounds, and that it has nevertheless proved exceedingly fruitful and therefore is justified. The principal difference between the two cases is that in the latter case no kind of existent otherwise known could be invoked for the explanation of the phenomena observed, whereas in postulating psychical dispositions for the explanation of mental retention and growth we should be preferring as a principle of explanation an unknown, hypothetical and inexplicable kind of existent to one well-known and one of which we have very good reason to believe that it plays an important part in the production of the effects to be explained. It would be as though we should insist on explaining the conduction of sound by an hypothesis of ethereal vibrations, in spite of all the evidence that sound is conducted by matter. For what knowledge we have of the structure of the nervous system, and of the principles of its growth and activities, shows them to be just such as lend themselves readily to the explanation of mental process as introspectively observed and as manifested in the conduct of men and animals. So long as we erroneously regard the mind as capable of passively receiving and retaining a mental copy of any object that affects the sense-organs in all its complex detail, it may well seem impossible to suggest any structural change in the brain by which such retention can be conditioned ; but when we adopt the truer view that perception and retention are conditioned by complex pre-existing dispositions, the marvel of mental retention is diminished, though not abolished, and we can form a vague conception of the nature of the nervous changes in which it consists. Without, then, presuming to reject unreservedly the conception of psychical dispositions, we must recognize that the principles of sound method compel us to regard the dispositions, whose structure embodies the retained effects of past experience, as neural systems such as we have studied in the foregoing chapters.

We provisionally assume therefore that all retention, all the facts covered by the words re-presentation and association in their widest sense, may be regarded as conditioned by the persistence and further organization of such neural systems, by their consolidation or by their further growth through the incorporation of other neural elements or minor systems of elements and by the acquirement of new connexions with other systems. These processes are essentially similar, they all consist in the association of neural elements or groups of elements, in the formation between them of paths of low resistance by which the "nervous impulse" passes readily from one to the other. The master-key to the understanding of mental retention must therefore be, according to this view, a satisfactory conception of the process of association of neural elements.

Neural Association is of two varieties, simultaneous and successive. Simultaneous association consists in the establishment of such connexions between neural elements that they tend to be simultaneously active, successive association in the establishment of such connexions between groups or systems of neural elements that they tend to become active in immediate succession. The former may be regarded as differing from the latter only in the greater intimacy of the connexion established, for elements successively associated may by further repetition of the associating process become simultaneously associated. Both forms of association imply the formation of a path or paths of low resistance between the associated elements or systems of elements.

In an earlier chapter (p. 33) we saw that we have good reason to believe that the passage of the "impulse" through a chain of neurones leaves that chain more or less permanently altered, in such a way that its resistance to the passage of the impulse is in some degree diminished, so that a feebler excitement of the neurone at one end of the chain will thereafter be able to propagate itself throughout the whole. We saw also that the synapses or junctions of neurones are the principal seats of the resistance offered to the passage of the impulse throughout any chain of neurones and that therefore this lowered resistance is probably due, in chief part at least, to a change in the molecular constitution of the synapses. However this may be, we must regard this law of the diminution of resistance by the passage of the impulse as a fundamental law of neural association. It is commonly called the *law of neural habit*. We must therefore agree with Professors James and Royce and other high authorities when they assert that the law of neural habit is the foundation of all mental growth, for, as Prof. James puts it, "all the materials of our thought (and we may add, all acquirement of skill in movement) are due to the way in which one elementary process of the cerebral hemispheres tends to excite whatever other elementary process it may have excited at some former time." But when Prof. James goes beyond this and asserts that "there is no other elementary causal law of association than the law of neural habit" we must refuse to accept the dictum. For there is another elementary causal law of association at least equally important with the law of neural habit, without the operation of which the latter would never have an opportunity to play its part in forming neural associations.

This law may be stated thus:—When the excitement of one neural system *a* is immediately followed by the excitement of another system *b*, the free nervous energy of the former system *a* tends to discharge itself by some path into the other system *b*. This might be called, for reasons we shall consider presently, the *law of the attraction of the impulse*. If, when *a* and *b* are first excited in immediate succession, such a discharge from *a* to *b* takes place, then, in accordance with the law of neural habit, the path by which the discharge takes place will become a path of lowered resistance, and whenever *a* is re-excited in any way there will be a tendency for the excitement to spread through this path to *b*. But until the impulse has once found its way from *a* to *b* the law of neural habit can effect nothing. Given the first passage of the impulse from *a* to *b*, the law of neural habit explains the tendency to recurrence of the process. But how is the path first found? The problem—How does the impulse first find its way from *a* to *b*? is a crucial problem for physiological psychology. If we can find a satisfactory solution of this problem, this solution in conjunction with the law of neural habit will enable us to explain the fundamentally important process of neural association by temporal contiguity. If no solution can be found, physiological psychology is bankrupt. This difficulty has been ignored by most of those who rightly insist on the importance of the law of neural habit; but it has not escaped the acute mind of Prof. James, who in spite of the dictum to which we took exception on p. 125, has suggested what seems to be the true solution of the problem. He has, however, presented the suggestion so modestly that the reader may fail to notice the importance of it, and the writer confesses that for fully half-an-hour he has enjoyed the delusion that he had himself discovered the solution.

Before considering this hypothesis, let us first realize the difficulty more vividly by the aid of a concrete example of a process of very frequent occurrence in the growing mind of a child. A child sees an object of a kind that he has never seen before, say a schooner-rigged ship, and while he looks at it, his father says, "That is a schooner." When the child again sees a similar ship the name at once recurs to him, the auditory impression has become associated with the visual impression. The visual impression excited a system of neurones principally of the visual area in the occipital lobe of the cerebral cortex, the auditory impression excited a system of neurones in the auditory area of the temporal lobe, and the reproduction of the word by the visual impression, on the second occasion on which the ship is seen, implies that a path of low resistance has been formed between the two systems. On the first occasion "impulses" must have found their way by some path from the visual system to the auditory system in accordance with the law of the attraction of the impulse, and that path, in accordance with the law of neural habit, has become a path of low resistance, and each time the process is repeated the path becomes more firmly established. How then did the "impulse" find the path from the system in the visual cortex to that in the auditory cortex on the first occasion of the conjunction of the two impressions? Why did it follow just this track among all the thousandfold paths presented by the jungle of higher-level neurones, any one of which, under other circumstances, it might have followed? For we must remember that the visual impression might have become associated with any other impression that might have followed immediately upon it, with the words brig or barque or cutter, with the sound of the waves, or the smell of seaweed, with the sting of salt spray on the skin or the taste of it upon the lips, or with the vision of blue water flecked with waves.

We may legitimately assume that all parts of the cerebral hemispheres are connected together in such a way that, under favourable conditions, the excitement of any sensory neurone may spread to any part, just as in the strychnine-poisoned animal the excitement of a sensory neurone may spread through all parts of the spinal cord. But even if we suppose the excitement of the system in the visual cortex to radiate itself through all the millions of neurones of the cortex, we are no nearer an explanation of the fact that, on re-excitement of the system, impulses tend to spread to just one other system through just one path, for according to the law of neural habit they should simply radiate once more with greater ease throughout all parts. If we could assume the existence of an undifferentiated matrix embedding all the neurones, capable of conducting impulses in all directions, and of becoming organized along lines of maximum conduction, the problem would perhaps be easier of solution. But we can find no warrant for such an assumption in the known structure of the brain. The only anatomical basis we have to work upon in forming an hypothesis consists of the millions of branching neurones and their synapses (as described in Chapter II.) forming the association-areas of the cerebral hemispheres. Of these many are already organized to form higher-level paths, others remain relatively independent. The younger the brain the larger the proportion of unorganized neurones, the older the brain the larger the proportion already organized and the smaller the capacity for acquirement of new organizations, for further learning. Through this maze of millions of possible paths the "nervous impulse" finds its way from *a* to *b* when they are excited in immediate succession, no matter how widely separated the two systems may be, nor what their previous history.

How then is the current directed from *a* to *b*? By what marvellous agency is the path selected? Here is one point where the physiological psychologist who believes in psychophysical interaction might feel disposed to invoke a directive power of psychical energy or of "mind," working in some way that we cannot at all conceive. But that is a last resort to which we may not betake ourselves until we have made every effort to find a purely physiological explanation. Let us therefore look at the facts a little more closely. Prof. James formulates the law of neural association through temporal contiguity as follows:—"When two elementary brain-processes have been active together or in immediate succession, one of them on reoccurring tends to propagate its excitement into the other." We may question whether this statement is too sweeping and goes beyond the facts. If by elementary brain-process is meant any process of the adult brain more simple and elementary than the excitement of a perceptual system involving arcs of the higher level, it would seem that it is so. For at any moment of waking life a large number of elementary brain-processes are commonly active together, namely, all those simultaneously excited by impressions made on our sense-organs which, although they evoke marginal sensations, do not attract attention. The diverse marginal sensations of any moment seem to become associated together in no appreciable degree, or in a very slight degree only. If while your attention continues to be concentrated on this page a series of sounds falls on your ear, say a series of words, they excite only marginal sensations, and if a little later you are asked to repeat what was said, you will be unable to recall the words, and even if the first one be given you it will fail to reproduce the others. There may be some feeble and evanescent association established between such impressions, but effective durable associations are only formed between the objects to which attention is given in successive moments. The passage of the attention from the one object to the other seems to be the essential condition of the formation of an effective association, especially between objects presented to different senses, as between the ship seen and its name heard.

The following simple experiment will illustrate many of the facts of primary importance in this connexion. Let the reader glance for half a second at the irregular group of dots of Figure 7, and then close his eyes. He will probably be unable to reproduce the group in memory or to say how many dots are there.[1] If he looks again he will find that he cannot take in the relative positions of all the dots at a single glance, in a single act of attention, *i. e.* he cannot combine them all in a single perception. But he will be able to combine four dots in this way, and if he imagines the

[1] If the reader has exceptionally good powers of visualization he may retain a "primary memory image" of the whole group so vivid that he can count the dots and note their position.

whole group divided into four groups of four dots by vertical and horizontal lines crossing at the centre, he can by four successive acts of attention perceive the relations of the dots of each group to one another, each group falling into the field of inattention, becoming merely marginal sensations, as the attention is turned to another group. By turning

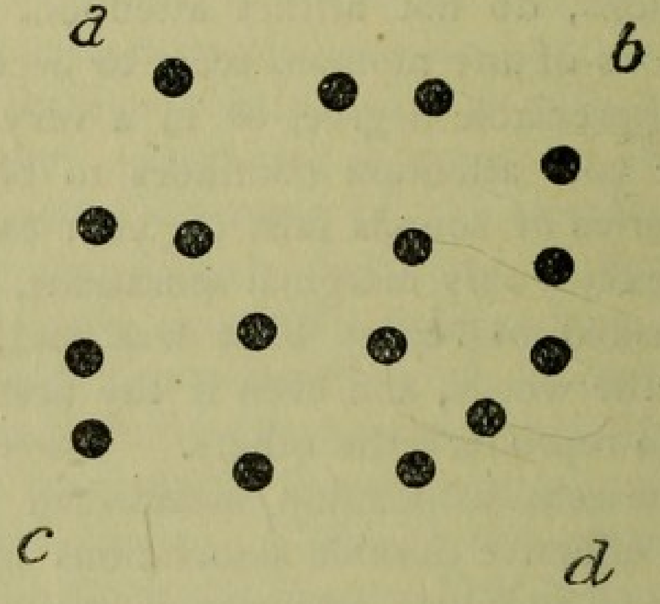

FIG. 7.

his attention from *a* to *b* and from *b* to *a*, he will become able to combine *a* and *b* in one group; in the same way he, can learn to combine *c* and *d* in one group, and to reproduce the groups *a b* and *c d* in imagination. Then by turning his attention from *a b* to *c d* and from *c d* to *a b* he will become able to combine all the dots in a single perception, and then by an effort, or perhaps not until after further turnings of the attention to and fro from group to group, he will be able to form a visual representation of the whole group.

This simple experiment is very instructive in several respects. It illustrates how very limited is the power most of us have of re-presenting, or calling up a memory-image of, an unfamiliar object, and that the mere co-existence of the visual impressions does not establish any appreciable association between them; it may lead us to doubt the accuracy of the psychology of the popular novelist who describes how all the details of the scene he depicts were photographed upon the hero's brain in a single flash. But the point of special interest for our present discussion is that the perception of the relations is only rendered possible by a process of building up an apperceptive system, that the combination of the dots in a single percept or idea only becomes possible as we establish associations between the groups, successive associations which by further strengthening we convert into simultaneous associations, and that this establishment of associations is effected by turning the attention from group to group. Just in the same way, in the case of the child learning the name of the ship, as in other cases also, the association between the visual and the auditory impression is only formed by the turning of the attention from the one to the other. Now the turning of the attention to the second impression *b* involves its withdrawal from the first *a* ; *a* ceases to be perceived and falls back into the field of marginal sensations. Putting this into physiological terms our account is as follows. While *a* is perceived the impulses which it initiates in the retina spread, not only through arcs of the visual cortex exciting visual sensations, but also through some systems of arcs of the higher level. When *b* attracts attention and is perceived, the impulses initiated in the sense-organ by *b*, which, while *a* was perceived, were confined to arcs of the sensory area and excited only marginal sensations, spread through some higher-level system of arcs, and the coming into activity of this system of higher-level arcs inhibits the activity of the higher-level system excited by *a*. Let us call the two higher-level systems α and β respectively. How then does the coming into activity of β inhibit α? In an earlier chapter we have provisionally adopted the hypothesis that inhibition is effected by drainage of energy from the inhibited to the inhibiting tract, through the inhibiting tract becoming the path of lower resistance. Applying this hypothesis to the case in hand, we may suppose that β, either owing to voluntary direction of the attention to *b*, or by reason of the intensity of the impression *b* or for some other reason, coming into activity drains to itself the free energy in process of transmission through α, causes the impulses to discharge from α into β through some chain of neurones intervening between α and β, instead of continuing to discharge in the forward direction towards the kinæsthetic area of the cortex, the neck of the funnel (see p. 91). Since attention to any one impression always involves its withdrawal from any other, we must suppose that systems of arcs of the higher levels are more freely inter-connected than those of the spinal level, (where, as we have seen, this tendency to reciprocal inhibition obtains only between certain pairs or small groups of systems) so that the free discharge of any one system in the forward direction drains any other higher-level system. During waking life all the neurones of the brain are kept in a state of tone, *i.e.* partially charged with free energy, by the continued slow metabolism of their substance. We may liken these systems of neurones to india-rubber tubes arranged vertically and freely connected by many transversely running tubes. They are all closed at their lower ends by spring-valves, and all are partially distended with water at a certain pressure insufficient to open the valves. This low pressure throughout the system represents the tone of the neurones. If then the pressure in one tube *a* is suddenly increased by injecting into it at its upper end an additional quantity of water, a wave of pressure will travel down the tube, throw open the valve at its lower end, and water will flow down and out of the tube. If in the next moment while this flow is taking place and the pressure is not yet equalized in the system, a similar sudden increase of pressure is caused in any one of the other tubes *b*, throwing freely open its valve, currents will set towards this tube through all the transverse tubes in virtue of the tension or tonus of the whole system, but the main flow will be through those transverse tubes which form the most direct path between *a* and *b*, and this current, relieving the tension in *a*, will result in its spring-valve closing up. The flow through *b* will thus inhibit by drainage the flow from *a*. This rough mechanical illustration might be elaborated in greater detail;

but, rough as it is, it may aid us to conceive how the passage of the impulse through any one system of higher level paths may inhibit by drainage the passage through any other.[1] There are many good reasons for accepting this view of the inhibitory process. Firstly, it is applicable to the inhibitory processes of the spinal level, and evidence directly supporting it is afforded by the study of such processes in the sensory level. Secondly, if we do not accept it, we have to invoke the aid of "inhibitory centres," and find ourselves in inextricable difficulties when we attempt to show how one neural system, on becoming active, induces an "inhibitory centre" to aim its "inhibitory impulses" at any other system in any part of the brain that happens to be active at the moment. We shall in fact be driven to adopt some such incomprehensible hypothesis as the "apperception centre" which Wundt has postulated in the frontal cortex, and on which he throws the task of inhibiting at every moment all sense-impressions save the one which, for unassignable reasons, it chooses to let go uninhibited. Thirdly, and this is the most important point, the hypothesis of inhibition by drainage offers a satisfactory solution of that crucial problem, the direction of the discharge from the one perceptual system α to any other β excited in the succeeding moment. For it is the flow of energy, drained from α by β, that establishes a path of low resistance between them.

Now let us consider the process from another point of view. When the excitement of any one system α is immediately followed by the excitement of any other system β, we find that β becomes associated with α, *i. e.* we find that the excitement of α on a future occasion tends to spread

[1] In order that such a hydraulic system should work in the way described in the text, it would be necessary that each valve should tend to return to the closed position the more strongly, the longer it has been open. It is probable that the rapid rise of the resistance of the synapses, owing to fatigue of their substance, renders them valves of this peculiar nature. This is the property of the system that would be most difficult, perhaps impossible, to reproduce in any mechanical model.

at once to β, and from this we infer with confidence that an impulse has passed from α to β through some chain of intervening neurones, leaving it a path of lowered resistance between the two systems. Since α will discharge in this way to any system excited in immediate succession to itself, it is clear that the excitement of β exerts guidance upon the direction of the discharge from α, determining the discharge to take place from α to β rather than in any one of the many other directions it might take; β somehow *attracts to itself* the discharge from α, a tendency expressed in general terms by the phrase, the law of the attraction of the impulse. According to all physical analogies this can only be because β develops a negative potential as regards α, and so drains α through the interconnecting channels of conduction. In no other way can we conceive as a physical process the exertion by β of such guidance upon the direction of the discharge from α that the discharge finds its way to β, no matter in what parts of the brain α and β may be.

Whether, then, we regard the process of the turning of the attention from one object to another from the point of view of the inhibition of one neural system by the other, or from the point of view of the establishment of a path of low resistance between them, the formation of a neural association, we arrive at the same conclusion—the one system drains the other. The two effects, inhibition of the first excited system α by the second β and the formation of the path of low resistance from the first to the second (not as we shall see from the second to the first) are invariably conjoined, they are in fact two aspects of one process. And the fact that we can only conceive the formation of the path of low resistance as due to the attraction to itself by β of the discharge from α, confirms the hypothesis that the inhibition of α is effected by drainage.[1]

To sum up on this difficult question. The mere

[1] If this view should be found untenable we should be compelled to look for an explanation in some psychical guidance of the neural discharge

co-existence or immediate succession of excitement in two groups or systems of neurones, α and β, cannot in itself establish a path of low resistance between the two systems.

The direction of attention to the two impressions *a* and *b* in immediate succession is the most effective if not the only mode of forming an association between them.

The attention being given to *b* involves its withdrawal from *a*, and this in physiological terms means the inhibition of excitement in α by excitement of β, and this means the diversion to β of the stream of energy that was passing through α, through some chain of neurones lying between them. The passage of the stream of energy through this chain leaves it in a condition of lowered resistance in accordance with the law of neural habit, and it therefore becomes an association-path between α and β.

Introspective observation of the processes of association and reproduction reveals certain other features of interest that are in harmony with, and explicable by, the physiological principles we have now at our command. Some of these we may very briefly consider.

Confirmation of the validity of the physiological explanation of the process of association is afforded by the following consideration:—Various authors have proposed various "laws of association," association by contrast, by contiguity in space, by cause and effect, by similarity and so forth; but leading psychologists, working by the introspective method and without reference to physiological considerations, have arrived at the conclusion that association by contiguity in time is the one fundamental form of association of which all others, in so far as they occur at all, are but varieties. Now association by temporal contiguity is the one and only form of association that can be explained physiologically. Hence, if such forms of association as association by contrast or similarity could be shown to be true and fundamental forms, the physiological explanation would be out of court, but the fact that only association by temporal contiguity is fundamental is just what is demanded by the physiological hypothesis, and so in a measure confirms it.

Successive association seems to work chiefly in the forward direction, *i. e.* of a series of impressions made in immediate succession, each when repeated tends strongly to reproduce its successor in the series and but very feebly to reproduce its predecessor. The reader may readily convince himself of the truth of this statement by trying to say the alphabet backwards, or by making the following simple experiment:—Let him read aloud once this row of nonsense syllables, without allowing his eye or his attention to wander to and fro over the series—

tal
kep
mon
gid
foom
tud
buz
howj,

then close his eyes and attempt to repeat the series. He will find that after rapidly reading the series two or three or more times, he will be able to repeat it without hesitation. When he can do that, let him then try to speak the syllables in the reverse order beginning with howj. Unless he has exceptional powers of visualization and can read off the syllables from a primary memory image, he will fail;[1] the associations formed are effective in the forward direction and not in the reverse direction. The reading of each syllable involves the excitement of a neural system, and as each one is excited in turn, it drains the one excited in the previous moment, and the path of drainage becomes a path of low resistance for the passage of the impulse in the same direction. This is in accordance with one of the clauses of the law of neural habit, manifested most clearly in the spinal

[1] He may be able slowly to think out the positions of the syllables and so repeat them in the reverse order

cord, as we have seen, in the tendency for the impulse to pass only in the habitual direction, the tendency summarized by Prof. James in the phrase "the law of forward conduction."

Very careful and exact experimental researches into the association and reproduction of such syllables have been made, especially by Prof. G. E. Müller of Göttingen and his pupils, and many interesting facts have been established, all compatible with the kind of physiological explanation we have adopted. Among other things, it has been shown that each syllable of such a series has, when the series has been learnt (or read several times, though not sufficiently often to enable the reader to say it "by heart") a certain feeble tendency to reproduce its predecessor as well as a strong tendency to reproduce its successor. It seems, therefore, that the passage of the impulse through the association-path lowers its resistance to the passage in that direction to a great extent, and to the passage in the reverse direction to a slight extent.

Now, if, after learning the row in the one order, and noting the number of repetitions needed, the reader will proceed to learn it in the reverse order, he will find that a smaller number of repetitions suffices. This, together with the fact mentioned in the preceding paragraph, makes it probable that the association-paths formed in the two cases, the forward and the backward learning, are identical, that each of them becomes a path of low resistance for impulses of both directions. If this is the case, the "law of forward conduction" must be regarded as applying strictly to the lower levels of the nervous system only, and the facts we have been considering support the view that the tendency to forward conduction is in all cases merely one of the manifestations of neural habit.

It has been shown that the effectiveness of associations between such syllables rises with each repetition of the series, rapidly at first, more and more slowly with further repetitions, and that from the moment of the last repetition a decline of their effectiveness sets in, which is rapid at first and becomes gradually slower and slower. Even though the process of decline may in a few minutes have gone so far that repetition is no longer possible, it has been proved that after many months or even years the associations are still not completely destroyed, that some trace still remains, rendering the re-establishment of the associations easier than the formation of new associations of the same kind. It has been shown also that mental activity of any kind, in the minutes following the establishment of associations, tends to weaken them, and we know from cases of accident that a blow on the head may wipe them out completely.

One object may become mentally associated with many others, the corresponding neural system forms multiple associations, and the conflicts and co-operations of the reproductive tendencies of these multiple associations lead to divergent reproduction, reproduction that diverges from the train of serial reproduction of objects serially associated by temporal contiguity. These processes also have been experimentally investigated with great accuracy, and the results of these researches confirm and put in a clearer and more certain light the conclusions arrived at by introspection unaided by experiment. All these processes are compatible with the physiological principles of association we have adopted, and these principles in conjunction with those of fatigue and facilitation (see p. 36) enable us to form some vague conception of the marvellous play of neural processes that underlies the sequence of our ideas. But lack of space forbids any further consideration of these facts.

The processes of *reproduction of similars* and *reproduction by similars* have frequently been falsely represented as evidence of association by similarity. The process of reproduction of similars is of supreme importance for intellectual achievement, it is the most important form of divergent reproduction, and a few words must be said of it. Reproduction of similars consists in the bringing to mind of the idea of one object by the perception or idea of another object that is in some respect similar to the former. The two objects cannot properly be said to be associated in the mind until the one reproduces the idea of the other, when they become associated by temporal contiguity. We have to suppose that this reproduction is due to a partial identity of the complex neural systems involved in the perception of the two objects. Each system consists of many sub-systems, and one or more of these sub-systems is common to the two. When the one system is excited, its excitement spreads, not, as is most commonly the case, through some association-path previously established by temporal contiguity, but from the sub-system, which forms also a part of another system, radiates itself through that other system. In the commonplace type of mind this process comparatively rarely occurs. It would seem that in the brains of such persons neural systems tend to become circumscribed and individualized, whereas in a higher type of brain the neural systems are more complexly interwoven, sub-systems becoming freely associated with many principal systems. In a brain so constituted reproduction of similars will frequently occur, causing the dull chain of simple redintegration, the serial reproduction of impressions associated by temporal contiguity, to be broken across. The possessor of a brain so constituted will never be a commonplace person; he may be a crank or an original thinker, or merely a wit.

CHAPTER VIII

Mental Retention as Revealed by Modification of Conduct

Having studied mental retention as revealed by introspection we have now to study its manifestations objectively observed, or inferred from the modification of conduct by previous experience. To have attempted to consider retention in both aspects concurrently would have led to an unbearable prolixity.

We have distinguished three kinds of movement that are effected independently of previous individual experience :—(1) The purely reflex movement effected by reflex or sensori-motor arcs of the spinal level when excited by stimulation of sensory nerves. The process does not directly affect consciousness, is not controllable by the will and may be carried out by the mechanisms of the spinal level when separated from the brain. Certain facts indicate that in man the neural mechanisms of the spinal level never attain the complexity and independence that they have in most of the lower vertebrates. It would seem that the perfection of those that play upon the skeletal muscles is rendered unnecessary by the control of them so largely exercised by the brain from the time of birth onwards, while those that play upon the visceral organs are as well developed in man as in the animals, being much less subject to cerebral control. (2) The sensation-reflexes carried out by arcs of the second or sensory level and affecting consciousness; movements preceded or accompanied by sensations, but by sensations that have no meaning or reference beyond themselves, that are not synthesized in perceptions. (3) Instinctive movements, congenital perceptual activities, carried out by neural systems involving arcs of the higher levels; these are movements of a character that implies adaptation to the nature of the object that affects the senses, *i.e.* not adaptation to the painful or pleasing character of the sensations merely, but to complexes of sensations that signify objects or things of the external world. In order to emphasize their relation to the pure reflexes and the sensation-reflexes we may with advantage speak of instinctive actions as perception-reflexes.

As regards these two classes of movements in man we are in the same uncertainty as prevails in regard to the pure reflexes. The neural systems by which they are carried out are not present, or not fully developed, in man at birth, and their development is so modified by the individual's experience and by the control of the will all through the years of growth, that we cannot say exactly what form and what degree of development they would attain in the absence of such modification. This complication and overlaying of congenital by acquired dispositions is especially great in the case of the instincts, so that in us instincts are seldom, if ever, manifested as simple chains of perception-reflexes carried out by congenital systems only, and though, when our instincts are excited, the visceral efferent discharge is effected by the congenitally organized paths, the movements effected by the skeletal system of muscles are in part ideomotor and in part voluntary or willed.

But it is certain that we bring with us into the world tendencies to the formation of neural systems of all three classes, and that it is upon such dispositions, tending to assume definite forms leading to definite fixed modes of reaction to certain classes of impressions and objects, that experience and the will exert their moulding action. If all our co-ordinated purposive movements had to be learnt *de novo* the process of education would be infinitely more difficult and prolonged. All these movements, carried out by neural mechanisms that develop more or less spontaneously and independently of experience, may be likened, as Lotze has said, to an alphabet; they are the letters of the alphabet of movement which experience and the will combine into words and sentences, the simple elements of purposive movement of which the movements of higher complexity and significance are composed. As in hearing spoken words we are not aware of the elementary sounds of which the words and letters are composed, so in carrying out our ordinary ideo-motor and voluntary movements we are not aware of the elementary movements of which they are compounded.

Two processes of education of movement go on side by side in the developing child:—(1) Having certain congenitally organized modes of reaction in the presence of certain classes of impressions and objects, he learns to associate each mode of reaction with more definitely discriminated classes of objects, *e.g.* he learns to associate the thrusting out of the hands towards seen objects that are within his reach only, and he learns to associate a movement of withdrawal of the hand with glowing objects that at first excite the reaching out of his hands. This kind of education of movement involves no acquirement of dexterity, it is the only kind of adaptation of movement that is learnt by most of the animals. (2) He learns to combine the simple elementary reflex movements, the capacity for which he inherits in the form of congenital neural dispositions, in more complex and more precisely co-ordinated movements. This is the acquirement of dexterities.

As an example of the former kind of learning, let us consider the case of the burnt child who dreads the fire; the young child, who stretches out his hand to seize a candle-flame, gets burnt and thereafter avoids any like attempt. Prof. James has discussed the physiology of this case in a luminous manner, and his explanation may be given in his own words. The letters refer to the diagram (Fig. 8), which is similar in all essential respects to that used by Prof. James. He writes: "The sight of the flame stimulates the cortical centre s_1

which discharges by an instinctive reflex path into the centre m_1 for the grasping movement. This movement produces the feeling of burn as its effects come back to the centre s_2; and this centre by a second connate path discharges into m_2,

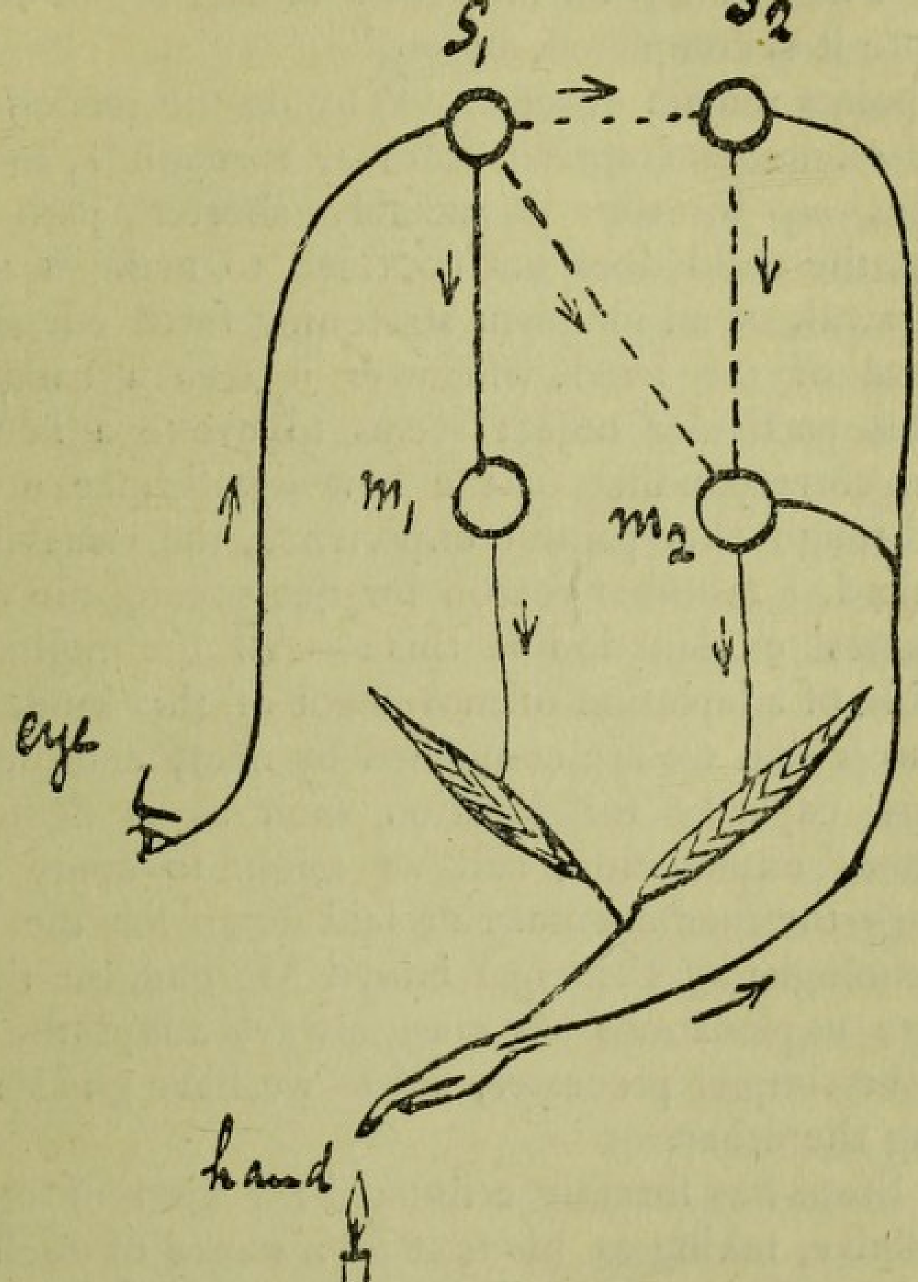

Fig. 8.

the centre for withdrawing the hand. The movement of withdrawal stimulates the centre s_3 (not included in our diagram), and this, as far as we are concerned, is the last thing that happens. Now the next time the child sees the candle, the cortex is in possession of the secondary paths which the first experience left behind. s_2 having been stimulated immediately after s_1, drained the latter, and now s_1 discharges into s_2 before the discharge of m_1 has had time to occur; in other words, the sight of the flame suggests the idea of the burn before it produces its own natural reflex effects. The result is an inhibition of m_1, or an overtaking of it before it is completed, by m_2."

Two points remain obscure—Why on the second occasion does the excitement spread from s_1 through s_2 to m_2 *before* it reaches m_1 by the presumably shorter path s_1 m_1? Secondly, the child does not continue to make a movement of withdrawal, or an incipient stretching forth cut short by a withdrawal of the hand, whenever it sees a candle-flame; rather, this particular object seems to evoke a new kind of behaviour corresponding to the new significance or meaning which, through this painful experience, the visual impression has acquired. Another reason for questioning the validity of Prof. James' explanation is this:—All the higher animals are capable of adaptation of movement of this kind, including animals to which we are compelled by many considerations to deny any capacity for ideation such as is demanded by Prof. James' explanation, and we ought to apply to human psychology the fundamental rule laid down for the comparative psychologist by Principal Lloyd Morgan, the rule that of alternative explanations we must always adopt the one that implies the simpler processes, unless we have good reason for preferring the other.

Prof. Stout has forcibly criticized the kind of explanation offered above, taking as his text an instance of such learning on the part of an animal described by Dr. Lloyd Morgan. A young chick has a reflex tendency to peck at all small objects on the ground, just as the young child has a tendency to grasp at all bright objects. Dr. Lloyd Morgan observed that a single experience of seizing in the beak an evil-tasting caterpillar, with prominent black and yellow markings, sufficed, in the case of some chicks, to cause avoidance, while in other cases a single repetition sufficed. Prof. Stout, discussing the kind of explanation offered by Prof. James in the similar case of the child and the candle-flame, says, "Now, it is probable enough that something which may be called a revival of the disgusting sensation, actually takes place; but this is not sufficient, and possibly not necessary, to account for the result. According to the proposed explanation, the chick has (1) a primary sense experience, the sight of the caterpillar, and (2) a faintly revived sensation of disgust. What must follow? Each of the two sensations, the one primary, and the other secondary, independently prompt to a certain kind of action, and the result can only be a sort of mechanical interference, not intelligent guidance. The visual experience prompts to picking and seizing. The revived distaste prompts to the act of ejecting or dropping from the beak. The tendency to ejection ought to interfere with the act of pecking only in so far as the two movements are mechanically incompatible. One would expect a nondescript blend of the two movements, or an alternation between them. Intelligent behaviour cannot be a product of such conditions. Two motor impulses of a quasi-reflex character are brought together in a mechanical way, and nothing can ensue except a sort of mechanical resultant." He describes the effect of an experience of this kind as "acquirement of meaning"; and he proceeds to say, "It is true that if it be granted that the sight of the cinnabar caterpillar has, from the first, a specific meaning, this meaning may be rendered more explicit by re-instatement of the sensation of disgust. But the mere re-instatement of the sensation of disgust taken by itself does not account for the result, whereas the acquirement of meaning might account for the result apart from the revival of the specific sensation."

There can be no doubt that this criticism is valid and that "acquirement of meaning" is more than the substitution of one reflex response for another. But it is extremely difficult to imagine any physiological process corresponding to it. However, it is perhaps possible to improve a little upon Prof. James' account. Let us note that while the first movement is a sensation-reflex or rudimentary perceptual reflex, the second movement, in both these cases, is probably a pure reflex carried out by arcs of the spinal level. If that is the case we have to suppose that the "impulse" initiated in the hand by the burn is transmitted directly to the muscles by way of m_2 (Fig. 8) as well as to s_2, so that the retraction of the hand is contemporaneous with, or may even precede, the painful sensation. We may perhaps suppose that the violent excitement of m_2 (and the excitement must be violent or the lesson is not learnt and the child continues to repeat the attempt to grasp the flame) following immediately upon the excitement of s_1 enables it to drain s_1 and to establish thus a direct path from s_1 to m_2 by which on repetition of the excitement of s_1 it discharges to m_2 instead of m_1. Possibly s_2 also drains s_1 to some extent establishing a path s_1 s_2 by which, on the repetition of excitement of s_1, s_2 is re-excited at the same time as m_2, so that, as Prof. Stout permits us to believe, that process may be accompanied by something which may be called a revival of the painful sensation. If this account of the process is truer than the other, the principal result of the experience is the establishment of a direct connexion between the system of sensory paths in the cortex s_1 and the motor system in the spinal level m_2. There are other reasons for believing that such associations are formed by such simple experiences. The process of learning by experience seems to be of this nature in the following case. Mr. Thorndike confined hungry cats in cages closed by doors that would fall open when certain catches within the cages were pushed or pulled in certain directions, and food was put near by where it could be seen by the cats. The result commonly was that the cat persisted in clawing and scratching at the walls of the cage, until it happened in the course of its random movements to push the catch and so to escape. On being put through the experiment time after time in the same cage under similar conditions, a cat usually repeated the same kind of random clawings and scratchings, but on successive occasions the time elapsing before the successful movement was made became less and less, until after a number of repetitions, varying from a small to a large number, the cat would perform the necessary movement at once every time that it was put into the cage.

In these cases there was clearly no understanding of the means of escape, even after the facility had been acquired. There was slowly acquired a tendency for a certain kind of movement to be made in a certain part of the cage. The movement was not a skilled movement that had to be learnt, it was merely one of the many compound reflexes carried out by congenitally organized neural mechanisms. And the process of learning consisted in the gradual association of one such movement with certain sense-impressions under certain conditions of hunger, and so forth. Under the instinctive excitement caused by the situation the cat makes many movements, each effected by some congenital motor mechanism; those in each part of the cage are guided by the visual impressions of that part of the cage acting by way of the visual cortex. Each group of visual impressions would thereafter, in accordance with the law of neural habit, tend to lead to the same movements more readily than before; but one of these impressions acquires this increased intimacy of association with a certain movement more rapidly and certainly than the rest, namely the visual impression made by that part of the cage in which the latch is situated, with that movement which results in the falling open of the door. The intimacy of this particular association is increased each time this particular movement is made until, as the cat casts its eye over the cage, the visual impression of that part of the cage at once evokes the movement. These seem to be the facts, the gradual rendering definite and fixed of an association between a certain visual impression and a certain motor mechanism to the exclusion of all the other loose associations of the other visual impressions with other motor mechanisms. The problem is,—Why does the connexion between this sensory path and this particular motor disposition become fixed, while similar loose connexions failed to become fixed? We can only answer, with Mr. Thorndike, that the former association gets "stamped in" by the pleasure which results from it, while others get "stamped out" by the pain of failure.

Much of the education of movement in a child is of a nature similar to that which we have been considering, *e. g.* the learning to grasp accurately and at once a seen object. The visual impression at first excites in the child random movements of the hands more or less in the direction of the object, until by one of these movements the palm of the hand is brought in contact with the object, when by a reflex process the fingers close upon it. Thereafter the hand finds the seen thing rather more rapidly than before, and each repetition of the process brings a further gain in the rapidity and certainty with which the hand is thrust out to the object. It seems probable that all the irregular movements of the first attempt are carried out by different spinal motor mechanisms played upon, and very imperfectly guided, by the neural system concerned in the visual perception; each movement results from the spread of the excitement through some path connecting the visual system with the motor mechanism by which it is effected. According to the law of neural habit each such path should be rendered in some degree a path of lowered resistance. But if such improvement of all these paths results, it is obscured by the greater improvement of the one path, that which leads to the motor mechanism by which the successful movement is effected. Here again, when we ask—Why does this association become established while the others fail to become established?—the only answer seems to be that the difference between the results seems to be causally connected with the pleasure of success and the pain of failure. It is a special case of a general law thus formulated by Prof. Stout, "Lines of action, if and so far as they are unsuccessful, tend to be discontinued or varied; and those which prove successful, to be maintained. There is a constant tendency to persist in those movements and motor attitudes which yield satisfactory experiences, and to renew them when similar conditions recur; on the other hand those movements and attitudes which yield unsatisfactory experiences, tend to be discontinued at the time of their occurrence and to be suppressed on subsequent similar occasions." That is the general statement of those effects which Mr. Thorndike calls the "stamping in" of one tendency by pleasure and the "stamping out" of others by displeasure or pain; it is the Law of Subjective or Hedonic Selection.

Let us consider now the process of acquirement of new dexterities or skilled movements. This involves the building up of new motor dispositions, a process of a higher type than the mere association of congenitally-given motor dispositions with various sense-impressions. The process consists in bringing together and associating the elementary motor-dispositions in new and more complex conjunctions, so that the acquired skilled movement is carried out by means of congenital mechanisms of the spinal level associated together as parts of a more complex motor disposition.

The learning to utter an unfamiliar sound, such as the German syllable *güt*, is a good example of such acquirement of dexterity. This is a process of trial and error. You hear the sound uttered by another person and attempt to pronounce it; you put your lips, tongue, and throat in such positions as seem to you likely to give a good result, and expel the air; your first attempt probably fails, you know at once that the sound you utter is wrong, and you try again. You put lips, tongue, or throat, or all of them in different positions, and again expel the air; so you continue to vary the combinations of the contractions of the many muscles concerned, until you hit off the right combination and so pronounce the syllable correctly. The new conjunctions of positions on the first occasion can only be voluntarily achieved by directing the attention to each of the organs in turn, bringing it into the desired position and maintaining it in that position while the other parts are in turn adjusted. Afterwards you can repeat the sound at will, you have acquired a new skilled movement; for you can remember the positions of the parts that gave the desired result, and you are able to do this because you attentively perceived those positions on the first occasion. When you are again asked to say *güt*, the auditory impression, having become associated with the kinæsthetic idea of those positions, reproduces it.

For the understanding of the physiology of such processes of acquirement of skill, the principle of the motor-circuit, expounded in an earlier chapter (see p. 45), is of the first importance. It was there said that each movement excites through sense-organs of the "muscular sense," a particular group of sensori-motor arcs in the Rolandic cortex, that each of these becomes the seat of a psycho-physical process which determines a kinæsthetic sensation-element, and that the arcs thus excited by the contraction of any group of muscles, tend to discharge themselves through motor mechanisms of the spinal level into just those same muscles and to give rise in this way to a repetition of the movement. And if these arcs are re-excited in the cortex through association-paths, the corresponding images are evoked, and the arcs discharge themselves again to the same muscles, those by whose contractions they are peripherally excited (see Fig. 5, p. 46).

The learning to pronounce the unfamiliar syllable involves these two processes:—(1) By successive adjustment of the muscles of the tongue, lips and throat, a conjunction of these organs, not previously experienced, is produced. Each of these successive adjustments is possible, because at some previous time it has been reflexly produced, has been perceived by means of the kinæsthetic sensations it has evoked and can therefore be recalled in idea. Attention being concentrated on this new conjunction of tensions and positions of the organs, the novel complex of kinæsthetic sensations is synthesized to a percept of the positions, and the corresponding arcs of the Rolandic cortex are united to form a new system. (2) This new-formed system becomes associated with that auditory system excited by the sound *güt*. Therefore when this sound again excites the auditory system, the excitement spreads to the kinæsthetic system, there reproduces the images of the movements, and issues from it along the motor paths by which the movements are reproduced. Here we are again confronted with the problem, Why, of all the combinations of movements attempted, does only the successful combination become associated with the sound of the syllable? Perhaps we should invoke here also the aid of the Law of Hedonic Selection, and regard the association of the successful movement-complex with the sound as confirmed or fixed by the pleasure of success. But we have perhaps a sufficient explanation in the fact that when the right sound is uttered it excites again just that auditory system whose previous excitement gave rise to the utterance of the sound, which will therefore tend to discharge once more to the kinæsthetic system evoking an immediate repetition of the utterance, such as usually takes place when the right sound has been achieved.

The process of voluntarily combining a number of simpler movements or positions of parts of the body into a novel more complex movement or attitude is well illustrated in the learning of many games, especially well perhaps in learning golf and rowing. The beginner on the golf-links "addresses" the ball coached by an expert. The expert commands a re-adjustment of this and that limb, of the trunk and head, until the proper attitude is struck, and it is the learner's task to combine the kinæsthetic impressions which this attitude yields to a single percept that can be reproduced on future occasions. This is commonly only possible on repetition of the instructions on many occasions, while the learner's attention is given to the perception of the positions of the different parts in turn, until finally by repetition of the process the successively associated positions become simultaneously associated, are combined in a single percept and reproduced as an idea of the attitude which realizes itself immediately in the assumption of the attitude. The expert also, in "addressing" the ball before he strikes, is discovering by trial and error, or refreshing his memory of, exactly that combination of positions of parts which he must reproduce in idea, in order to reproduce it actually at the moment of striking.

Just so the rowing man who sits on his "Liddell and Scott" in his rooms and, recalling his coach's instructions, throws his shoulders back, his elbows down, and his head up, straightens his back and swings down between his knees, is learning to combine the successively perceived positions of the various parts in a single perception, and so acquiring the power of reproducing them simultaneously.

The acquirement of dexterity, then, depends upon the formation, growth and interconnexion by neural association of systems of arcs in the Rolandic or kinæsthetic cortex under the guidance of sense-impression of the various senses. Hence the capacity for acquiring dexterities of the different classes of animals runs parallel to the degree of development of the kinæsthetic area of the cortex, and of the pyramidal tract which consists of the efferent paths connecting the systems of this region with the motor mechanisms of the spinal level. Hence also in man, and in the higher apes in which these parts of the brain are well developed, the extent of any part of the kinæsthetic cortex in which the movements of any part or organ are re-presented is proportional, not to the size of the organ or the bulk of the muscles, but to the number and complexity of the dexterities that it is capable of acquiring, *e.g.* the areas in which the hand and the organs of speech are represented are relatively the largest.

Secondarily Automatic Movements.—The process of acquirement of dexterity is not completed when the power of making the new movement or series of movements has been acquired. Frequent repetition of such a series of movements under similar conditions results in their becoming what is called secondarily automatic, *i. e.* the person who frequently repeats such a series of movements, which as we have seen can only be acquired, and at first can only be executed, by direction of the attention to their kinæsthetic effects, becomes capable of executing them while his attention is otherwise occupied.

The playing of scales on the piano, the manipulation of knitting-needles, the repetition of the alphabet are familiar examples. In these cases and in many others, each member of the series of movements determines an impression of another sense as well as kinæsthetic sensations, and this other sense-impression co-operates with the latter in forming the link of association between each movement and its successor—thus, as the alphabet is repeated, the sound of each letter spoken gives rise to an auditory impression, which in conjunction with the kinæsthetic impression constitutes the cue for the utterance of the next letter. But this, it would seem, is not essential. When a man learns to swing Indian clubs, his guiding impression seems to be almost wholly kinæsthetic, and such series of movements become perhaps more perfectly automatic than any others.

What is the difference between the physiological processes in the two cases, the execution of the movements only just learnt by the aid of concentrated attention and the execution of them automatically after many repetitions?

We can give no certain answer to this profoundly interesting question, and opinions differ widely in regard to it. On the one hand it is maintained that the cortical systems cease to co-operate in the execution of such movements as they become automatic, and that they are carried out, when completely automatic, by mechanisms of the spinal or subcortical level only. But there are serious objections to this view. We know that the destruction of the Rolandic cortex not only abolishes the capacity for acquiring new skilled movements but also renders impossible the execution of those previously acquired, *e.g.* the destruction of that part of it in the left hemisphere known as Broca's area, the kinæsthetic speech-area, produces motor aphasia, a condition characterized by inability to articulate the most familiar words, although written and spoken language continues to be understood as well as before the injury; and any slow reacquirement of powers of speech in such cases seems to be due always to the education of the corresponding area in the right hemisphere.

Again, we can hardly believe that in those cases in which the automatic movements are executed under the guidance of complex sensory impressions made upon other senses than the kinæsthetic sense, the complicated connexions that are established in the first instance between the different sensory areas of the cortex and by means of which the different sensory impressions co-operate in the guidance of the movements,—we can hardly believe that all these extremely complex connexions became copied and replaced by a second set of similar functions, equally complex and delicately adjusted, in the sub-cortical level. The view that commends itself to the writer may be briefly stated as follows :—

The process of acquiring new movements is one requiring the concentration of attention upon the sense-impressions by which the movements are guided; this, as we have seen, means that the cortical paths concerned are made at the moment the main path of discharge of free nervous energy into efferent channels from all the higher parts of the brain. Postponing to a later page the few words that must be said about the Will, we may say that the Will concentrates the free energy of the brain along these new channels and that it is this concentration of energy which renders possible the breaking down for the first time of the resistance of these hitherto unused channels. We have seen reason to believe that this resistance is offered wholly or principally by the synapses, the junctions of neurones, and that the process of overcoming this resistance, the discharge of energy across these resisting barriers is the psycho-physical process, the process that immediately excites a psychical element. As with each repetition of the process the resistance offered diminishes in accordance with the law of neural habit, a less high pressure or potential of energy, a smaller degree of concentration of energy, is needed, and is used, for the overcoming of the resistances. The psycho-physical processes are therefore less intense, and their psychical effects proportionately diminished in intensity. Hence as the process is repeated time after time it requires less attention, less concentration of nervous energy, and affects consciousness in a less degree. The friction on the process of transmission of nervous energy decreases, and with it the intensity of the psychical effects which is in some way proportional to the degree of friction overcome. If this suggestion is accepted as an approximation to the truth it must be asked—How does such a cortical system become capable of continuing its activities, while the attention is given elsewhere, whereas at first its activity is inhibited by that concentration of the flow of energy in other channels which is the physiological condition of attention to any other object? And conversely—How is it that, while at first the activity of such a system involved inhibition of all others and so prevented the simultaneous direction of attention to other objects, it ceases to interfere with and inhibit the activities of other systems? If, it may be said, the system becomes in an increasing degree a system of paths of low resistance, it should tend in an increasing degree to drain, and therefore inhibit, all other paths and systems of paths.

To the former question it may be replied:—The paths of the automatized system having become open paths or paths of very low resistance, no concentration of energy is needed for the overcoming of their resistance; hence the diversion of the main stream of energy to other systems does not lead to a cessation of their activity, a small but sufficient stream of energy still finds its way through them. It is more difficult to find a satisfactory answer to the second question. It may perhaps take the following form:—As the neural elements that are connected together to form a neural system become more and more intimately united, they become also isolated in an increasing degree from all elements outside the system, so that as the system becomes consolidated it becomes also circumscribed. There are other facts known which indicate that such circumscription takes place, *e.g.* it has been shown that any impression which has become incorporated in any chain of association, will enter into other associations less readily than a similar but novel impression. In this fact we seem to see the first step in the process of circumscription that, as is suggested, accompanies the increasing intimacy of union of the members of a neural system.

The consideration of the process of automatization of voluntarily acquired actions has suggested the view that the purely reflex actions carried out by mechanisms of the spinal level were also originally acquired by our remote ancestors as voluntary actions, or at least as actions involving sensation, feeling, and perhaps some rudiment of attentive consciousness, of focalization of mental process; that such actions have been repeated generation after generation, the increased intimacy and stability of organization of the neural systems, that result from repetition of the action in each generation, being transmitted in some degree however slight to succeeding generations. Then, just as in the individual the practice of a newly-acquired movement renders it automatic, and so sets free the attention for the acquirement of new complexities of movement, so in the course of biological evolution the further consolidation of acquired systems converts them into purely reflex systems, and sets free the attention for the acquirement of new modes of reaction and for the combining of the reflexes into groups and trains that constitute more complex movements adapted to deal with more complex conditions. This view is usually associated with the name of Wundt, who has forcibly advocated it. It implies of course the assumption that acquired characters are in some degree transmitted from one generation to another, a proposition which most biologists at the present time are inclined to deny because they cannot conceive how such transmission can be effected. Nevertheless, the rejection of this view leaves us with insuperable difficulties when we attempt to account for the evolution of the nervous system, and there are no established facts with which it is incompatible. If, therefore, we accept this view we shall regard the congenital neural dispositions, both those that determine pure reflexes and those that determine instinctive actions, as having been acquired and consolidated under the guidance of individual experience, with the co-operation, to a degree which we cannot determine, of natural selection. And since the muscular system works under the control of the nervous system and becomes moulded by the activities evoked in it by the nervous system, and since the muscles in turn largely mould the structure of the skeleton, we shall regard the structure of all the body as in a large measure the product of experience accumulated by transmission from generation to generation.

Subjective or Hedonic Selection.—In discussing acquirement of skilled movements and of new modes of reaction to impressions, we have had occasion to refer to the principle of Subjective Selection, the principle that pleasure accompanying, or resulting from, any action tends to determine a continuance or repetition of such action, while pain or displeasure tends to bring action to a stop and to prevent its recurrence. If we take the words appetition and aversion to express in the widest sense actions making for and against continuance and repetition of any kind of experience, we may express the principle of Subjective Selection in the phrase, pleasure determines appetition and pain determines aversion. Since, as we have seen, it seems impossible to explain the acquirement of new modes of action without the aid of this principle, pleasure and pain must be regarded as playing a part of the greatest importance in the evolution of animal forms. Hence the following question is one of profound interest:—Are we to understand the law of Subjective Selection in its literal sense, and to regard the psychical affections, pleasure and pain, as themselves factors in evolution, or are we to understand only that two peculiar kinds of physiological process, which are correlated with, or immediately excite, pleasure and pain respectively, are the effective factors? We have here presented in its clearest form the problem of psycho-physical interaction, and of mind as a factor in biological evolution. As was said in the introductory chapter, there is at present a large number of physiologists and psychologists who assert that psychical and neural processes do not in any way interact or react upon one another, that there obtains no causal relation between them. This view takes many forms, but all of them imply that the evolution of the nervous system and all the complex processes that underlie our psychical states must be explained without invoking the aid of psychical factors, that the physical processes form a closed system of causation into which psychical factors have no right of entry. Those who adopt this view therefore interpret the law of Subjective Selection in the sense that not pleasure and pain, but their physiological correlates determine appetition and aversion, and they seek to explain the correlation of pleasure with appetition and of pain with aversion as a product of natural selection, in the way suggested by Herbert Spencer. Spencer pointed out that pleasant experiences are in the main beneficial and painful experiences hurtful. This principle seems to hold strictly true of the animals, and though the application of it to man is somewhat obscured by the complexities of his mental life and social relations, and though it has been denied by certain gloomy religions and philosophies, there can be no doubt that it is broadly true of man also. Spencer suggested therefore that those animals which have tended to seek pleasurable and to avoid painful experiences, were in so doing seeking the beneficial and avoiding the hurtful; that therefore in the struggle for existence they have had a grand advantage over other animals in which these two tendencies were lacking, and still more over any in which the tendencies were reversed; and that hence in the course of evolution the more frequent survival of those in which these tendencies existed has confirmed these tendencies and rendered them well nigh universal in the animal kingdom.

Now if we regard pleasure and pain as in themselves ineffective, as having no influence upon nervous process and on conduct, we must regard them as merely signs or reflexions in consciousness of the occurrence of beneficial and hurtful physiological processes in the organisms. For the purposes of argument let us adopt the assumption, still current in some text-books, that the beneficial process which is mirrored in consciousness as pleasure is an excess of anabolic or constructive process over katabolic or destructive process, and that the hurtful process mirrored in consciousness as pain is an excess of the katabolic over the anabolic processes. The argument is not affected by the improbable character of this assumption. Let us call these supposed physiological correlates of pleasure and pain A and K respectively. We must then admit that natural selection may have determined in the way suggested a universal correlation between A and appetition, and between K and aversion. But the principle of natural selection is incapable of explaining how pleasure has come to be correlated with A and how pain with K. If pleasure and pain are themselves ineffective, we can see no reason why the reverse correlation should not obtain, why K, the hurtful process, should not have been attended always by pleasure and A, the beneficial process, by pain; for natural selection would still have determined the survival of those creatures in which K determined aversion, and A determined appetition. If this had been the case, the result would have been a world in which all well-adapted creatures, the only creatures that could survive to transmit their characters to succeeding generations, would have sought the painful and avoided the pleasant, a world in which pain would have predominated over pleasure to its almost complete exclusion; for the health-bringing experiences and activities of all creatures, the eating and digesting of good food, rest, warmth, shelter, play and all the instinctive activities would have involved A + pain, instead of A + pleasure as in our world.

If, then, we deny the causal efficacy of pain and pleasure, we shall have to explain the correlation of pleasure with A and of pain with K by the assumption that at the beginning of mental evolution a beneficent Creator assigned pleasure as the psychical correlate of A and pain as that of K. Let us note that this would not be the case if pleasure and pain differed merely as two qualities of sensation differ, as red differs from blue or warmth from coolness. If all beneficial experiences were tinged with redness and all hurtful experiences with blueness, then natural selection would have brought about a correlation of redness with appetition and of blueness with aversion; but that state of things would carry with it no such significance as the correlation that actually obtains between pleasure and appetition, pain and aversion. For we can as easily conceive a world in which the opposite correlations should obtain, that of blueness with appetition and redness with aversion, and the one would be as rational and intelligible as the other; whereas a world such as we have supposed, in which appetition and beneficial processes should be correlated with pain, and aversion and hurtful processes with pleasure, would be essentially and profoundly irrational. The difference between pain and pleasure is in fact the profoundest and most significant that we know, and we cannot suppose the universal correlation of pleasure with beneficial process and of pain with hurtful process to have been the result of a happy accident.

Thus the evolutionist finds himself confronted with the following dilemma:—either pleasure and pain are efficient causes of appetition and aversion, and therefore have played in biological evolution a part of incalculably great importance, or we must postulate divine interference with the course of evolution at some early stage of the development of the animal kingdom. Now in spite of the variety of the arguments by which it is sought to show that pleasure and pain and all other psychical processes have no causal efficacy as determinants of conduct, they are all made in the interests of the mechanical philosophy and are founded upon the assumption of the truth of that philosophy, the philosophy that would account for the evolution and growth and activities of all organisms by the laws of physics and chemistry. But the acceptance of either of the sole and necessary alternatives, the causal efficacy of pleasure and pain and the postulation of divine interference in the course of biological evolution, is incompatible with the principles of this mechanical philosophy. If, then, we have to admit the inadequacy of the mechanical scheme of things to explain biological evolution, there can be no doubt as to which of these alternative hypotheses is the more acceptable to science, and we are therefore at liberty to accept the conclusion unmistakably indicated by all psychological evidence, both subjective and objective, the conclusion that pleasure and pain determine appetition and aversion.

CHAPTER IX

Ideo-Motor and Voluntary Action

THE principles that we have already considered suffice for the explanation of ideo-motor action. In the developed human mind the succession of perceptual activities, such as constitutes almost all the mental life of animals, is complicated and interrupted by the free reproduction of ideas, and ideas frequently succeed one another in trains of considerable length without producing any immediate effects on conduct, without giving rise to actual movements. Nevertheless, every idea tends to find appropriate expression in movement, the excitement of every neural system tends to issue in motor paths, and whenever ideas are vivid their motor tendencies are clearly manifested; *e.g.* if you vividly imagine yourself playing a part in any exciting scene or adventure, a debate, a climb, or a fight, each idea will manifest itself in incipient motions, or at least tensions of muscles. Most of our ideas tend to become verbal ideas, we learn the name of the object or event, we associate the name with the thing by hearing and pronouncing the name when the object is perceived. The pronouncing of the name, achieved in the first instance by the method of trial and error described above, gives rise to a complex of kinæsthetic sensations and the formation of a system of arcs in the speech area of the Rolandic cortex; this sub-system becomes incorporated by the process of complication or simultaneous association in the total system that is excited by the object, so that, in the case of an object perceived by the eye, the perceptual system that it excites includes visual, auditory, and kinæsthetic sub-systems. Then, whether the system is re-excited, peripherally by the seeing of the object or the hearing of its name, or centrally through association paths in the course of a train of reproduction, the excitement tends to issue to motor paths by the sub-system of kinæsthetic arcs of the "speech area"; we see this motor tendency clearly manifested by those persons who are apt to "think aloud," and who in reading always move their lips as though reading aloud. Most of us, who do not thus habitually move our organs of speech in reading or thinking, may realize the motor tendency of words by holding the mouth wide open and thinking such a word as "mammon." One experiences a tendency for the lips and tongue to move which can only be controlled by an effort. Since every neural system has this tendency to discharge in the forward direction into motor paths, how are we to explain the fact that our ideational processes do not invariably manifest themselves in movement? Perhaps the fact is sufficiently explained by the assumption that as each idea reproduces its successor, the nervous energy, which otherwise would issue in motor channels, is drained off by the systems excited in the successive moments. It would seem that in this important respect individuals differ greatly, that while in some persons each neural system tends strongly to discharge itself at once into motor paths, so that ideas are apt to lead at once to action, in others it tends rather to discharge into other associated systems, so that reflection predominates over action. Apart from constitutional differences, education plays a great part in this respect; in the man whose brain contains the traces of much varied experience, in the form of many highly-elaborated neural systems intimately associated together, ideas will tend to awaken other ideas rather than to pass over at once into action; whereas in the uncultured, and especially in children, in whom associations are relatively few and feeble, ideas tend very strongly to realize themselves in action, if only in the movements of the organs of speech. Who has not seen a child wholly concentrated on the performance of some action, perhaps beyond its powers, apparently quite without any idea of a desirable end to be achieved by the action, and merely because the idea of the action has been aroused?

The kind of idea that tends to issue most directly in action is the idea of a movement, the kinæsthetic idea. But not every kinæsthetic idea of a movement is followed at once by the movement. When such an idea fails to produce movement, we can cause the realization of the movement by a volition, a voluntary effort or act of will, and the resulting action is a voluntary action in the strict sense of the word. The terms voluntary action, will, and volition are used in very different senses by different authors. Many authors speak of all actions as expressive of the will, others speak of all actions as voluntary that are not reflex, automatic, or involuntary; but that is too wide a use of the words, for by this usage the class of willed actions is made to include all simple ideo-motor actions, all actions which result immediately from the mere reproduction of the idea of movement by associated ideas and impressions. We may usefully distinguish (1) involuntary actions, those which occur in spite of efforts to avoid them; such are most of the pure reflexes, and some of the sensation-reflexes and instinctive and secondarily automatic actions; (2) non-voluntary actions, ideo-motor actions and most of the secondarily automatic actions; (3) voluntary or willed actions. A willed action is an ideo-motor movement preceded by a volition which re-enforces the idea of the movement; this re-enforcement either causes an idea of movement, which in the absence of volition would be insufficiently vivid to produce movement, to pass over into movement, or determines a more forcible contraction of the muscles than would result from the idea in the absence of voluntary effort.

In what does this re-enforcement consist, and how is it effected? Prof. James in discussing this question describes that which causes an ineffective idea of a movement to become effective, to give rise to the movement, as a *fiat* of

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the Will, and he suggests that the essential effect of this *fiat* of the Will is to bring about a suppression or inhibition of all ideas that tend to inhibit the idea of movement, and so to give the motor tendency of this idea free play, when the idea at once realizes itself in movement. This conception of the Will as a power of inhibiting rival ideas or processes that tend to inhibit the idea of movement, is thus essentially similar to Wundt's conception of the functions of his hypothetical "organ of apperception" (see p. 133), and for Wundt apperception is one aspect of volition. But in spite of the agreement of these two great authorities, we cannot accept this view of the Will as a negative function, a power of inhibition merely, for it is inconsistent with the principles expounded in previous chapters of this book. We have seen reason to regard inhibition of any neural system as always a correlative effect of the excitement of some other system, the effect of drainage of the former by the latter. And voluntary inhibition of movements or ideas is no exception to this rule, we can only inhibit one movement or idea indirectly by concentrating attention upon some other movement or idea; thus to control or inhibit an impulse to laugh, to strike, to run away, or to flinch, one clenches the jaws and fists, or contracts other muscles with the greatest possible effort; and to inhibit or banish unwelcome ideas one concentrates one's attention upon other matters.

Let us consider the volitional action more closely. I take in my hand a dynamometer, an instrument for measuring the power of squeezing an object in the hand; the instrument suggests the idea of squeezing, but if I am in a lazy mood the idea of the movement perhaps fails to produce movement, the kinæsthetic system, whose excitement underlies the idea of movement, does not discharge into the motor mechanisms of the spinal level a sufficient stream of energy to excite massive contraction of the muscles; then by a voluntary effort I concentrate attention upon the idea of movement, a fuller stream of energy issues from the kinæsthetic system and movement results; then, by a further effort of Will, I drive the index of the instrument still further up the scale, a still fuller stream of energy issues from the cortical system to the motor mechanisms and to the muscles, causing them to contract more forcibly. This power of voluntarily increasing the outflow of energy along any set of motor nerves is a familiar and unquestionable fact, which our behaviour illustrates every day and hour. But the degree of intensification of the motor outflow that the Will can accomplish seems to be defined within narrow limits by the general condition of the brain at the moment. Probably no effort of the Will of the normal man ever excites the muscles to contract with the maximum force of which they are capable, so that the limit of force of a voluntary effort is not set by the muscles. If a man is but just awakened from deep sleep, or if he is thoroughly fatigued, the most forcible contractions of the muscles that his Will can evoke are relatively feeble; if he is fresh and wide awake he can exert greater force; if he is emotionally excited, *i. e.* if a large part of his nervous system is in a state of high excitement, the force he can exert is still greater; and if his whole nervous system is in that state of extreme activity that characterizes the condition of maniacal excitement, he can exert a degree of muscular force far beyond any that he can achieve in any normal state. It would seem, in fact, that the Will concentrates along one system of channels the free nervous energy of all the brain at the moment, and hence the greater and more widespread the excitement of the brain, the greater the outflow along motor channels that the Will can determine, and the more complete the inhibition of all other processes.

Voluntary attention to any object, whether perceived or imagined, seems to be a process essentially similar to voluntary production or re-enforcement of muscular contractions; it is a re-enforcement of the idea or percept, in virtue of which it is held more vividly and continuously in the focus of consciousness to the exclusion of other percepts and ideas; and this, too, seems to imply a concentration of nervous energy in the neural systems whose excitement underlies the percept or idea, and, as in the case of willed movement, the effectiveness of this voluntary re-enforcement depends upon the amount of free energy in the brain at the moment.

An effort of Will seems then to be always the voluntary concentration of attention upon some object, the re-enforcement of percept or idea, and its essential physiological result seems to be a higher degree of that concentration of the free energy of the brain along one system of paths which, as we have seen, is the physiological condition of all attention. Attention, as we have seen, is not always a voluntary or willed effect, it is involved in all perceptual and ideational process; we have regarded percepts and ideas as being brought to the focus of consciousness by the play of impressions on the sense-organs and of the "nervous impulses" among the neural systems of the brain, and we have attempted to understand how the concentration of energy involved in all such non-voluntary attention may be accounted for by the general principles of neural activity. Can we hope to find a purely physiological explanation of that concentration of energy in a higher degree which is the essential and immediate result of volition? Introspection leads us to recognize that one essential condition of volition is distinct self-consciousness; as Dr. Stout has it, "What is distinctive of voluntary decision is the intervention of self-consciousness as a co-operating factor," and this is true of a voluntary decision to force up still further the index of the dynamometer, as well as of a decision to resist temptation or to scale the heights of fame. Self-consciousness in all probability has for its physiological correlate the excitement of large and complex neural systems, and it may be suggested that it is the co-operation of these systems and the flow of nervous energy from them that re-enforces the innervation current in voluntary muscular effort. But this vague suggestion hardly seems to justify the expectation of a physiological explanation. The concentration of nervous energy that results from volition is unlike the behaviour of all known kinds of physical energy, the universal law of which is diffusion from the place of higher potential to places of lower potential. In volition we seem to concentrate nervous energy from places of low potential into the place of highest potential, and perhaps we shall have to recognize in this concentration of nervous energy a unique effect of psychical activity.

It is not proposed to attempt to deal with the higher forms of mental process, but one remark may be made. The physiological process underlying our conceptual processes of thought involves probably the activity of vastly complex neural systems, gradually built up in the course of experience and reflexion, and the working of these systems seems to be analogous to that of the systems which effect well-practised skilled movements. Thus, when an expert, swinging Indian clubs by a series of complicated movements that have become automatic, wishes to introduce a new complication, he concentrates his attention wholly on this novel feature of the series of movements, while the routine movements are maintained by the automatic functioning of the pre-formed neural systems. Just so in thought much of the routine work seems to be effected by the automatic functioning of well-practised, well-organized neural systems, while the attention is concentrated upon relatively novel elements or features which alone come prominently before consciousness. We have good reason to believe that the law of psycho-neural parallelism,[1] the law that some neural process invariably accompanies every state of consciousness, holds good of the higher as of the simpler mental states, and if we make any attempt to formulate the relation of these higher states of consciousness to neural process, it must take some such form as this :—Just as a compound quality of colour, like purple or blue-green, is a psychical resultant of the separate actions upon the soul of two elementary psycho-physical processes, and just as a simple perception involves, in the same sense, a synthesis of a complex of elementary psychical affections or psychical elements, so in any of the higher mental processes, an ethical

[1] Not to be confused with the hypothesis of psycho-physical parallelism.

judgment or an æsthetic comparison, consciousness at any moment is a psychical synthesis of a higher order, a synthesis involving more groups of psychical elements and proceeding according to higher psychical laws.

Can we form any conception of the way in which the psychical processes react upon the neural processes to modify them? Perhaps a physical analogy may help us a little. Imagine two wires *a* and *b* laid near together; then, if an electric current is passed through *a* it generates a field of magnetic force about it, and if a current is then passed through *b* it will modify the field of magnetic force and at the same time will be itself modified by it, and the current in *a* will also be modified by the modification of the field of magnetic force. And if we add other wires, *c*, *d*, *e*, etc., and pass currents through each of them, the addition of each one will modify in some way the magnetic field and, through it, the flow of the currents in the other wires. As the currents ebb and flow in any of the wires, so the magnetic field varies and the currents in other wires delicately respond.

In this crude simile the wires stand for nervous arcs, the electric current for the flow of nervous energy through each arc, the magnetic field generated by the current in each wire flowing separately for a psychical element, and the total magnetic field, when several or many wires are in action, for the state of consciousness. And this simile suggests some questions with which this little book, which throughout is so largely a confession of ignorance and a suggestion of unsolved problems, may fitly close. Are the wires the only existents presupposed by, and necessary to, the production of these effects? Is all else fleeting process? No, we are compelled to postulate, as a necessary condition of the development of the magnetic field, a medium or substance which we call the ether. Just so we are compelled to postulate an existent, an immaterial being, in which the separate neural processes produce the elementary affections which we have called psychical elements, and this we call the soul. The soul then is the ground of unity of psychical process, of individual consciousness. Is it anything more? We conceive the ether as homogeneous and constant in character wherever it may be found. Are we also to conceive souls as homogeneous and alike wherever they may be, or has each soul its specific characters? If so, do these characters change and develop with experience, or is all experience embodied in the nervous system alone? Does the soul come into existence at the moment of conception or of birth, or does it exist before the union of those two tiny specks of protoplasm from which each mortal body and marvellous brain arise? Does it come, as so many have believed, trailing clouds of glory or of shame? Does it play a part in directing the growth of that tiny germ, or does that material germ contain within itself alone the thousand delicate peculiarities of form and function that mark each child as the offspring of both parents? Lastly, does it continue to exist when the brain has ceased to live, and, if so, does it retain its individuality and all or anything of that which we call personality?

These are questions that can never be laid to rest by the dictum that the soul is nothing but the sum of psychical events, or by any other dictum of the logician or metaphysician reasoning from the data at present available. They can only be answered by the discovery of new empirical evidence. The physiological psychologist above all men must proclaim a sceptical agnosticism, not that spurious agnosticism which says, We shall not and cannot know, but that nobler agnosticism which says, We do not know, let us try to find out.

The following is a list of books that will help those readers who are anxious to pursue further the study of physiological psychology, and may be read with advantage in connexion with this primer :—

Sir M. Foster. *Text-book of Physiology.* (Vol. III., and the parts of Vol. IV. dealing with the sense-organs.) Macmillan and Co.

Schäfer. *Text-book of Physiology.* (Vol. II. Articles on the nervous system and the senses.) Messrs. Black.

J. Loeb. *Comparative Physiology of the Brain and Psychology.* J. Murray and Co.

Ed. Thorndike. *Animal Intelligence.* Monograph supplement to Psychological Review. 1898.

Llgyd Morgan. *Introduction to Comparative Psychology.* The Contemporary Science Series.

" *Habit and Instinct.* Ed. Arnold.

Th. Ribot. *Evolution of General Ideas.* / *Psychology of Attention.* } The Open Court Publishing Co.

W. James. *Principles of Psychology.* Macmillan and Co.

G. F. Stout. *Analytic Psychology.* Sonnenschein and Co.

" *Manual of Psychology.* W. B. Clive.

W. Wundt. *Physiological Psychology*, translated by E. B. Titchener. Sonnenschein and Co.

T. H. Huxley. *Essay on Animal Automatism.* Collected Essays, Eversleigh Series.

J. Ward. *Naturalism and Agnosticism.* A. and C. Black.

A. E. Taylor. *Elements of Metaphysics.* Methuen and Co.

R. H. Lotze. *System of Philosophy.* (Book III.) Eng. trans. Clarendon Press.

And for those who read German :

Lotze. *Medizinische Psychologie.*

Fechner. *Elementeder Psycho-physik.* (First and last parts.)

H. Elbinghaus. *Grundzüge der Psychologie.* Veit und Co., Leipzig.

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