method of attack is usually most effective, especially in a works laboratory where some specific problem may require rapid solution. Its application to the university laboratory is subject to the difficulty that under team conditions the intellectual stimulus which attaches to the individual attack on specific problems is sometimes lacking, and it is in the highest degree desirable that this stimulus should be developed and maintained. Nevertheless, it is always possible so to divide a major problem as to make each section in itself a self-contained research and thus to give each investigator what is essentially a definite subject on which he can work in his own way and according to his own mentality.

CO-OPERATION WITH GOVERNMENT.

The Government of Great Britain has already discovered the two most valuable ways in which it can co-operate to the benefit of present and future chemical industry, namely, (a) by protecting young and struggling industries against competition from similar but established industries abroad and against competition arising from deflated foreign currency, and (b) by promoting research in pure and applied chemistry by financial assistance. Another way in which it has helped the application of science is by the provision of a free chemical advisory service in the interests of agriculture.

Research Associations.—There can be no question that the value of co-operative research in industry has been established. The Department of Scientific and Industrial Research has, therefore, rendered a valuable service to the industrial community and its initial policy has been fully justified. Nevertheless, the time has arrived when the varying appeal which the necessity for scientific investigation makes to different industries has made itself manifest, and the Department feels that any

further support on general lines would no longer be justified. It proposes, therefore, to treat each case on its merits.

Research Studentships and Fellowships.—The call for adequately trained research workers in science, and especially in chemistry, is increasing. It is therefore very disquieting to realise that the policy of the Department in connexion with the provision of maintenance grants for students in training appears to be changing. The outlook is serious, because it is quite impossible for the universities to provide funds for post-graduate training in any way commensurate with the present-day requirements of industry, and as the average science student is usually drawn from a comparatively poor class, it is not likely that the necessary money for an extended course will always be obtainable from parental sources.

Every director of a research school has had to tell some promising student who wishes to undergo post-graduate training and is, without question, likely to profit by such training, that no funds are available to enable him to extend his course and that he must, therefore, seek any minor post that may be open to him. The loss of such a man is a national loss, because his training is broken off at the stage where even one extra year would have enabled him to become a useful member of a research organisation, whereas, in the circumstances, he has to take up some position, probably one involving merely routine work, where the value of his early training will be lost and his initiative and enthusiasm destroyed. It is therefore to be hoped that the diminution in the number of research grants is merely a temporary expedient and that it does not indicate a reversal of a policy which has proved so fruitful during the past twelve years and has shown itself to be an essential part of research development in Great Britain.

The Functions of the Human Skull.¹

By WILFRED TROTTER.

THE development of science involves the two processes of collecting facts and of elucidating their relations. In the early days common experience so abounded with unrelated facts that an alert and contemplative mind was an adequate equipment for the man of science and could readily find material for generalisation. Knowledge was like an unexploited gold-field, in which the mere attentive wanderer might pick up nuggets of the metal. So were made the earliest discoveries in mathematics, astronomy, and physics. When the surface of the field no longer yielded such finds, the digger with his simple and homely outfit could still from easily accessible deposits gather with his own hand gold dust by the ounce and pound. This was the Golden Age of science; it lasted somewhere about two hundred years, and was nobly marked near its beginning by the "Principia" and near its end by

the "Origin of Species." It was the day of the individual digger, of simple apparatus and the still obvious predominance of the worker's mental quality over every accessory circumstance. It was a time in which relatively simple efforts in the collection of facts might have great results. Looking back at it we discern as a characteristic object Wollaston with his laboratory on a tea-tray, and as a characteristic incident Hans Christian Oersted noticing in 1819 the deflection of the magnetic needle by an electric current—an experiment it would not be very extravagant to call the most important event of the nineteenth century; or as not less characteristic Joseph Fraunhofer in 1814 observing and thinking it worth while to map out the dark lines in the solar spectrum—a dull-looking task that was, however, ultimately to yield a veritable measuring rod for the universe and a most effective probe of even its stupendous depths.

At the present day what we may call the surface

¹ Lecture delivered before the Anthropological Society of University College, London, on Jan. 25.

deposits of truth seem almost everywhere to have been worked over, and ours is the time of the thousand-yard shaft, the mile-long gallery, the battery of stamps, and the pennyweight yield to the ton. The mere collection of facts has become a difficult and elaborate enterprise, to which the solitary worker is rarely equal. In almost every branch of science complex equipments are necessary, the mere use of which may need years of training. Even genius itself is no longer inspired by the falling apples and spouting kettles of the Golden Age; the powers of Einstein are called out by the quintessential zero of the Michelson-Morley experiment, or those of Bohr by the incredible vacancies of the atom.

Since the merely observational half of the scientific act has become so formidable, it is natural that the other half that comes of the speculative, contemplative, and relating turn of mind should as such have sunk somewhat in general esteem. It is perhaps correct to say that, among scientific people, work of any general speculative kind is a little under suspicion unless it is closely associated with actual observation as well, and that anyone who tries to correlate large groups of facts is unlikely to be listened to with great attention unless he has been concerned at any rate to some extent in the collection of the facts themselves. This attitude of the mind is on the whole sound and practical, but it should perhaps be qualified by two small reservations. In the first place, the justified predominance of observation may lead to a certain frigidity towards ideas as such, and even some risk of the automatic rejection of them.

In the second place, it must be remembered that there are still some few 'alluvial' deposits left unexhausted in the gold-field of truth. Here the observational side of scientific work may seem when judged by modern standards primitive and 'uneconomic,' and yet it may be capable of yielding appreciable finds. One such deposit is the great range of human behaviour, in which we all can be adequately skilled observers and need no more than the critically selective and relating turn of mind. Other such opportunities are apt to occur along the line where two fields of observation meet. Medicine has many such lines of meeting with the sciences, and its contact with anthropology is one of the most obvious. Medical men are interested in the same animal as are anthropologists and have to study it with some intensity.

When we study the boundary zone of two adjoining departments of knowledge, we may expect to find what instruction we are to get not so much in learning strictly ordered and documented facts as in getting fresh points of view; we may hope that the well-established and matter-of-course fact or principle from one side of the line may prove new and illuminating when viewed from the other side.

In such a study, then, we shall do well not to be too exacting in proof or too systematic in method. We must be willing to accept new light where we can find it, and to remember the old paradox that in science the primary duty of ideas is to be useful and interesting even more than to be 'true.'

We must be ready to entertain ideas freely and fairly, and no less ready to discard them without regret, glad enough when we gain an unexpected glint from "the blank face of familiar things." It will be with very limited pretensions, therefore, that certain considerations derived from surgical experience will be set out here. Nothing could be less dogmatic than the spirit in which they are put forward or more submissive to the principle of the aphorism, "Do not believe new ideas; use them."

While the essential object of all biological knowledge is the elucidation of function, the work of the surgeon is actually engaged in the direct study of function in a very special degree. He is concerned with the human body solely as a going concern and his unique object is to keep it going. In regard to the cranium, he has no direct interest in its size, its form, its types, its indices; he limits himself, with what for the anthropologist must seem a certain crudity, to the question what does it do? In the briefest possible terms, the cranium is to the surgeon the *capsule* and the *skeleton of the brain*.

THE CAPSULE OF THE BRAIN.

It is not usual to regard the brain as among the encapsuled organs, but to do so brings out an interesting aspect of its functional relations with the skull. If we consider encapsuled organs in general we at once see that the rigidity of the capsule is an important character. In regard to it, organs may be divided into three groups. In the first, which may be called the normal type and is represented by the kidney and spleen, the capsule is fully extensible; in the second, represented by the testis, only very slightly extensible; and in the third, represented by the brain and skull, it is absolutely rigid to all physiological forces. Such conditions have necessary and very important effects on the mechanics of the circulation in the various organs. There is of course a primary need for the flow of blood through any tissue to be continuous; this is effected in organs of the first group by the extensibility of the capsule permitting pulsation and elastic recoil to occur. In the case of the brain, however, a different mechanism is necessary. The brain itself expands with each arterial pulse, but, as the skull is unyielding, room must be made at each pulsation by the expulsion of a corresponding volume of the low pressure intracranial fluids. This is why the veins leaving the skull and the cerebro-spinal fluid in the sub-arachnoid space of the spinal cord show arterial pulsation.

The mechanism is adequate, but the margin by which it is so is not very large. After violent exertion, when the range of pulsation of the brain is at its widest, we are apt to be conscious of an unpleasant thudding in the head, which shows that the brain can only just find room for its circulatory excursions. Again, if one has a slight headache it is at once aggravated by exertion.

This circulatory peculiarity is fundamental in cerebral pathology and makes it possible to say

that, apart from purely destructive processes, all cerebral symptoms are of circulatory origin.

We may briefly inquire into how this comes about. The low pressure outflow that must accompany each arterial pulsation is chiefly in the form of venous blood. For it to occur the flow of blood in the veins must be quite free. But the pressure in the veins is very low, so that the least abnormal swelling of the brain or part of it causes collapse and obstruction of a greater or less venous territory. Thereupon further swelling from venous congestion occurs and the disturbance of function becomes progressive.

The brain is thus uniquely sensitive to any pathological change in its bulk. When an organ like the kidney is bruised and swells, it matters very little how soon or if ever it gets back to its normal size. When the brain has been bruised, it must get back to its normal size or its circulation will remain permanently disturbed. A simple bruise of no ultimate importance to an organ with a yielding capsule, is thus a relatively serious matter with the brain. The great difficulty with which the brain recovers from even simple injuries that cause swelling is one of the most important functional consequences of its rigid encapsulation by the skull.²

THE DEFENSIVE FUNCTION OF THE SKULL.

It is still a widespread opinion, even to some extent among medical men, that fracture of the skull is the most important feature of head injury, and that if the skull is not fractured not much harm can have been done. There is no more complete delusion. Fracture of the skull is usually an insignificant element in a head injury, and nothing has done more to limit the knowledge of trustworthy principle than the traditional reverence for it.

A fracture means that the skull has been distorted until the limit of its elasticity has been passed. It is the distortion, and not the crack that may or may not ensue, that is important.

Now surgical experience in Great Britain shows that the skull is susceptible to considerable degrees of distortion by even only moderately severe external violence. Because immediate and dramatic effects are not always produced, and because of the superstition about the significance of fracture, it is apt to be assumed that the average European cranium is on the whole very successful in preserving the brain within it from the effects of quite severe violence. Since the nature of what are called the minor injuries of the brain has been better understood, this faith in the beneficent fortitude of the skull has been considerably shaken. We now know that the skull in its protective function is only moderately effective. It is liable to bend under local violence and to permit of a localised bruising of the brain beneath; it is also liable in appropriate circumstances, especially such as falls on the head, to a far more serious general distortion. This general distortion causes the very

interesting instantaneous and transient paralysis known as concussion of the brain, and is also apt to produce a widespread bruising of the brain substance that is of great practical importance. It is important to note that all the evidence points to actual distortion of the skull being the immediate cause of most if not all injuries of the brain. There is no reason to suppose that injury is commonly if ever produced by the brain being thrown about inside an undistorted skull. It is probably true to say in so many words, no distortion of skull, no injury of the brain.³

This liability to relatively easy distortion seems to be in some special degree a character of the modern European skull. It appears to be fairly clear that in some races the resistiveness is decidedly higher. For example, the negro, judged by purely clinical, that is functional considerations, is little liable to receive cerebral contusions from the moderate degrees of violence that an Englishman could not endure with impunity. The willingness of the negro to use his head as a battering-ram has often been described, and it is said that an experienced policeman will use his truncheon on the head of a negro less hopefully than he would use it on an English head.

We arrive then at the position that the modern European skull is demonstrably far from completely effective in its protective function, and that this defect is not shared by all other races.

It will be noticed that we are not at all concerned so far with the anatomy of skulls. It may or may not be possible to show a difference in the thickness or rigidity of European and negro skulls. The test of function is far more delicate and trustworthy than that of structure, and it seems to show that a clear difference exists.

We have already seen that the bony capsule of the brain is a serious hindrance to recovery from minor injuries, so that the skull and brain mechanism is satisfactory only when the former is highly effective as a protective covering. Once the protective function is impaired the physiological disadvantages of the arrangement become fully manifest. It seems clear, then, that the present functional relation of brain and skull—plainly disadvantageous as it is—must be the result of some strong evolutionary tendency or must be accounted for by some advantage that compensates for it.

In a very broad and general way, it does appear to be the fact that there has been an evolutionary tendency towards a reduction in the massiveness of the human cranium; there can be no doubt that the modern European cranium is in comparison with many of its predecessors remarkably light and thin. It is not improbable, therefore, that a tendency towards the lightening of the cranium is an inherent character of the race and progressive. It is natural, therefore, to ask how far such a process could conceivably go. The European skull has already discarded a good deal of its protective rigidity; is a rigid cranium a necessary structure?

² It is interesting to notice that the testis—the only other organ in the body that approaches the brain in the rigidity of its capsule—shows the same susceptibility to minor injuries. As is well known, it may undergo complete atrophy after a simple bruise.

³ A contrary opinion is perhaps encouraged by the use of the time-honoured and now ineradicable phrases 'concussion of the brain' in English and 'Hirnerschütterung' in German.

THE SKELETAL FUNCTION OF THE SKULL.

Without considering any other matter but function, this question can be given a perfectly definite answer. However much more of its protective massiveness the skull may lose, it must always maintain enough rigidity to preserve its form. This is because it is a function of the skull, not the less important for being usually overlooked, to support the brain. If we make in the treatment of injury or disease a considerable hole in the skull, and after healing of the scalp is complete the intracranial tension is normal, we find a tendency for the soft parts to sink into the cranial opening. This depression is most marked when the subject is standing and usually quite filled up when he is lying down. With an opening 3 or 4 in. across, the depression may perhaps reach a depth of as much as $1\frac{1}{2}$ in. at its centre. The larger the opening the greater the depression; and it is clear, therefore, that the exposed brain, when the intracranial tension is at its lowest, cannot support the atmospheric pressure and actually collapses under it. In certain cases the subjects of openings in the skull suffer severely from the exaggerated movements of the brain that in them accompany changes of posture. Such symptoms are always abolished when the opening is closed by restoration of the skull.

In the cranium, in fact, the vertebrate has rediscovered the principle of the external skeleton and exploited it in a remarkably interesting way that may be worth a moment's consideration. What may be called the constructional problems of such an immense mass of neural tissue as the brain are very complex. The obvious way of supporting a large mass of soft consistence would be the provision of a stiff stroma of ordinary connective tissue. Such a solution is inadmissible for very definite reasons. In the first place, direct contact between mesoblastic and neural tissues is a physiological impossibility, so that every strand of the hypothetical connective tissue stroma would have to be clothed, as is every cerebral vessel, with a so-called 'perivascular lymphatic' to its finest ramifications. At a moderate estimate this might double the bulk of the whole organ. Again, the presence of an elaborate and alien fibrous network would immensely complicate the system of intercommunication, which is the very essence of the brain as it is. How neat a solution of the problem does the exo-skeleton provide. With it, it is possible for the brain to be made up almost entirely of actual functional elements, and for the utmost complexity of communication to exist while the bulk of the whole organ is kept within bounds.

THE MEANING OF THE VULNERABLE SKULL.

We have seen that the low strength of the modern European skull is shown by actual experience to be producing serious effects in the way of a high susceptibility to disabling injuries of the brain. To discuss the meaning of this remarkable and perhaps a little disturbing state of affairs it is

necessary to enter into some rather general considerations.

There can be no doubt that in the growth side by side of the cranium and the brain, the latter is the predominant partner, and what it needs the former must on the whole provide. If the skull had no other function whatever but to be the capsule and skeleton of the brain, the correspondence would be absolute and every least developmental variation of the brain would be accurately accommodated by the skull. Now the skull or even the cranium does have other functions to fulfil than those concerned with the brain. It is involved with the muscles of the trunk, with the apparatus of mastication, with the respiratory tract. The provision for these accessory needs must, it seems reasonable to suppose, have some influence however minor on the growth of the cranium, and act as some restraint however minute on the control of it by the brain, and therefore on the freedom of variation of the latter. When, therefore, the skull is very massive and deeply involved with accessory functions, when it gives attachment to large neck muscles, when it is ridged and fortified for a heavy masticatory apparatus, the freedom of the brain to develop minor variations is perhaps less complete than when the cranium is stripped to the condition of a mere cerebral capsule.

Since it is possible that free variability of the brain through a very small range is of value in fitting man for a complex civilisation, it seems not a very extravagant supposition that the freeing of the skull from accessory functions has been a factor in human evolution.

EVOLUTION OF THE BRAIN AND SKULL.

In considering the evolutionary process in general, then, we have to think not merely of a progressive expansion of the cranium to accommodate the increasing brain, but also of a growing independence of the cranium.

It seems obvious that the anterior end of the segmental animal was the inevitable site for the chief nucleus of a centralised nervous system. The same region was equally inevitably annexed for the entry to the respiratory and the digestive tracts. An interesting series of complications has ensued from this necessary crowding of function into one extremity. It does not seem too fantastic to see two tendencies constantly at work and in conflict—the tendency on one hand to make use of the brain skeleton for functions connected with other systems, and on the other the struggle of the brain for autonomy and freedom from these burdens. Wherever the former tendency has been definitely the stronger, the progress of the brain has been arrested and the animal has found itself in an evolutionary blind alley. The most striking illustration of this process has been in connexion with apparatus of defence and attack. Such apparatus has a natural and inevitable localisation near the digestive inlet and at the anterior end of the animal. Nature in her experiments with horns, antlers, fangs, and tusks has found the skull waiting as a

convenient foundation for these useful but enslaving structures. The ancestors of man, with the steady avoidance of specialisation to which he so largely owes his zoological position, kept their craniums free from such encumbrances.

It was, however, probably the beginning of the upright posture that was the decisive change in favour of the independent skull. It has not, so far as I know, been much remarked upon that the upright posture changes the whole mechanics of attack and defence from that of the quadruped. The head is withdrawn from the front of the animal, and thus being no longer available as a foundation for offensive or defensive structures, the cranium is at last and finally safe from them. Another and more familiar way in which the cranium was helped by the upright posture to free itself from accessory functions was in the limitation in the movements of the mandible that necessarily ensued. With a poised instead of a slung skull, the mouth can no longer be opened freely enough for the aggressive use of fangs. Thereupon the cranium is no longer called upon to find attachment for the correspondingly massive muscles.

When we see an evolutionary tendency so strong as that seems to be which has stripped and lightened the cranium until it has reached the degree of fragility and simplification seen in the modern

European, we are inclined to ask whether even yet its force is exhausted. There are perhaps signs that even now the cranium is, so to say, intolerant even of the light burden of accessory function it still has to bear. It is scarcely possible to be familiar with the lower jaw of the modern English without wondering whether the unexhausted tendency we have been considering is not at work to free the cranium even of the temporal muscle. It is clear that the molar region of the mandible is shrinking, and experience already suggests that 8 fully erupted molar teeth are nearer the actual normal than 12. Since the temporal muscle is especially concerned with the use of the molars, it is perhaps permissible to wonder whether it, rather than the jaw, is not the real object of evolutionary attack.

The tenuity of much of the foregoing speculation must be obvious. The argument, however, makes no attempt to be rigorous, and is intended to be illustrative rather than demonstrative. The object of it has been to find out whether the old-fashioned method of general qualitative survey might not in so favourable a situation as the frontier between two branches of knowledge, present the familiar facts of one side of the line in a way that would have freshness and perhaps interest on the other.

News and Views.

THE Postmaster-General has written an excellent letter, dated Mar. 27, to the Baird Television Development Company. He states that he has seen a demonstration of the Baird system and that he could recognise with sufficient clearness the features and movements of persons posed for the purpose in the transmitting studio. He is a little doubtful whether it is at present practicable to reproduce simultaneously more than two or three individuals, and they must be staged in very close proximity to the transmitting apparatus. In his opinion the Baird system represents a noteworthy scientific achievement. Taking into consideration the present limited scope of the objects which can be reproduced, he does not consider that it is at present practicable to include television in the broadcasting programme in broadcasting hours. He is anxious, however, to give facilities so far as practicable without impairing the broadcasting service for continued and progressive experiments to be made with the Baird apparatus. He consents to a station of the British Broadcasting Corporation being utilised for this purpose outside broadcasting hours. The Company would probably have little difficulty in negotiating satisfactory terms with the Corporation. It is very desirable that experimental demonstrations of television should be accompanied by the broadcasting of speech. Consequently, two wave-lengths and two transmitters are required. It would be very difficult to provide a second transmitter in a suitable locality which would not interfere seriously with important radio services in central London, until the new station of the B.B.C. at Brookmans Park be opened next July. In the mean-

time, the engineers could jointly discuss the best methods. In order to get a television service during broadcasting hours, wave-lengths outside the bands now being used for speech broadcasting must be used. Unfortunately, these bands are much congested. It is important, therefore, that the Company should press on with experiments on as low a band as possible. Purchasers of receiving apparatus are warned that they buy them at their own risk, as the system is not yet sufficiently advanced to warrant giving it a permanent place in the broadcasting programmes.

It is interesting to learn from a *Daily Science News Bulletin*, dated Feb. 26, issued by Science Service, Washington, D.C., of the paternal attitude adopted by the Federal Radio Commission towards the many applicants who are anxious to start television broadcasting in the United States. Eleven licences for television broadcasting have already been granted, but in all cases precautions have been taken that such activity is for a limited period and is purely experimental. The licences are only for six months. The broadcasters have to give monthly reports of their activities and of the scientific work they are doing to advance the art. The Commission apparently is not yet convinced that radiovision can render real service comparable, for example, with that of sound broadcasting. They are naturally anxious to prevent anyone broadcasting radiovision with the main purpose of selling radiovision receivers. The Commission has allotted to radiovision, or, as they call it, 'visual broadcasting,' which includes still pictures, 'radiomovies,' and pictures of living actors, four bands of frequencies.