give promise of sufficiently early practical results to warrant the provincial institute in attacking it. The decision on this point would rest with the provincial institute. It would be one of the chief duties of the central Government institute to survey the industrial possibilities of the Empire generally, and to initiate research having for its object the establishment of new industries in different parts of the country.

It will be seen, therefore, that the scheme suggested provided for the establishment of two very similar types of institution. One type, situated in each of the most suitable provincial centres, would be essentially practical in outlook. The other, situated at some convenient central place—the recommendation of Dehra Dun for this purpose by the Industrial Commission was endorsed by my Committee—would conduct research mainly fundamental in character, but would, nevertheless, deal in certain cases with investigations involving the practical establishment of a new industry.

One of the main advantages of this arrangement would be that the personnel could, to a certain extent, be interchangeable, a most desirable feature when it is remembered that each institution must necessarily act as a training centre for the personnel it employs. No university or technological system of training can be expected to discriminate between the men who are best fitted to act as leaders of research and those who are suited by natural characteristics and temperament to be leaders in the conduct of works practice. It is essential, where chemical manufacturers are concerned, that each type of man should have received the same grounding, and this is adequately effected by a system involving a course of instruction up to the honours graduation stage, followed by a training in research methods, the latter serving to impart the feeling of self-reliance and patience essential to success in a chemical worker, which cannot be obtained otherwise.

It is the final problem, that is, how to supply the training in works practice, and what is still more important, how to pick out the men most suited by temperament to profit by this training, which has to be solved not only in India but in Great Britain also. In the proposed chemical service this very real problem of type would be met by a frequent interchange between the individuals comprising the junior personnel

of the research staffs of the various institutes. Each man would, therefore, obtain his training in works practice, and I am convinced that such training would serve as a method by which the men could be separated into two distinct classes, namely, those having a practical bias, and those whose instincts led them to take up work of a more fundamental character in the laboratory.

Each provincial institute, as well as the central Government institute, would, therefore, be provided with a main general research laboratory equipped in the usual manner, a semi-large scale laboratory provided with small scale plant suitable for making material on, say, the 10 lb. scale, and another laboratory where the "unit" scale plant could be erected. It is probable that the two latter types could be combined into one laboratory. All that is required is an open floor space on which plant can be built up and pulled to pieces at will; it would have to be provided with the usual services of gas, water, etc. These proposals imply that, besides the main chemical staff, each institute would have to be provided with a suitable staff of engineers, whose main duty would be to act as instructors in general engineering practice.

The proposed scheme for the establishment of a chemical service would have to start in a small way, and, no doubt, in many of the provinces use could be made of some existing institute to act as the provincial research institute, until funds were available for the erection and equipment of a building especially designed for the purpose. The chief initial cost would be incurred by the erection and equipment of the new Government Research Institute at Dehra Dun, but it is understood that some of the money, at any rate, has been allotted for this purpose. Indeed, it is likely that a large capital expenditure and a considerable income would be necessary in order to start the scheme and to place it initially on a sure financial basis, because it is not proposed that any attempt should be made to make the service self-supporting, and the equipment of the new laboratories would have to be completely up-to-date. If the Service is to succeed, the Government must take the long view, and bear in mind, chiefly, the increase in wealth to be obtained by the development of the natural resources of the country. The opportunity is a splendid one, but to take advantage of it effectively requires courage and vision.

Problems of Muscular Receptivity.¹

By Sir CHARLES SHERRINGTON, O.M., G.B.E., P.R.S.

LET us revert now to the reflex "standing" exhibited by the decerebrate animal. We traced it to a postural contraction of the antigravity muscles, in each of which the contraction was due to a proprioceptive reflex excited somehow in that muscle itself. We can take as an example of the antigravity muscles the knee-extensor muscle. The tendon of that muscle bridges the extensor aspect of the knee-joint, and the super-incumbent weight of the body in the erect posture tends to flex the knee. Knee-flexion stretches the extensor muscle. Gravity in the erect posture acts therefore on the knee extensor as a stretching force. We have seen

that such a stretch is a stimulus to certain receptors in the muscle and provokes a postural contraction which counteracts the stretching force. The reflex standing of the decerebrate animal appears therefore as a postural stretch-reflex.

A peculiarity which distinguishes the stretch-reflex from other reflexes is that, whereas in other reflexes the reflex contraction excited from a single source implicates whole groups of the limb muscles, the stretch-reflex excites in its limb just the one muscle stretched. The reflex standing of the limb is a harmonious *congeries* of stretch-reflexes, each component reflex being the self-operating reaction of an individual extensor muscle.

¹ Continued from p. 894.

This mode of production of the reflex posture allows it latitude in detail. The standing pose is still maintained though the observer shift in detail, within limits, the position of the feet. Thus a foot may be advanced or set backward, and the shift alters the position in detail, but the reflex animal still stands. The altered incidence of gravity involved by the shift compensates itself, and greater and lesser stretch wherever they occur excite, as we have seen, a correspondingly greater or lesser contraction which antagonises further yield and compensates the altered stretch.

The living reaction of plants and animals to gravity is called geotropism, and standing is a geotropic reaction. The stretch-reflex of the extensor muscles offers an explanation of how the limbs can antagonise gravity and stand, but that reflex provides no mechanism by which the reflex animal can, when non-erect, assume the erect posture; for that, as Magnus and de Kleyn have shown in a fascinating series of experiments, other reflexes provide, reflexes initiated by special gravity receptors in the head, the otolith organs. It is interesting to note that a group of stretch-reflexes operated by gravity should dovetail in with special gravity reflexes from the head, giving gravity still further reflex control of the whole animal's posture as regards standing. In instance of this further control there is the reflex discovered and elucidated by Magnus and de Kleyn in which, the reflex animal's initial posture being standing, a passive tilt of the head upward, thus inclining the head's gravity organs, changes the reflex posture from that of standing to that of sitting and looking up at a shelf. The hind-limbs flex and sink, the fore-limbs straighten more, bearing upward the inclined neck and head. Conversely, a passive downward tilting of the head causes, Magnus and de Kleyn have shown, the fore-limbs to crouch, bringing the fore-quarters lower than the hind, thus modifying the standing position to that for taking food from a platter. Accepting the stretch-reflex of the limb-extensors as existent in this reflex standing, the otolith organs, reacting in postures of the head, evidently suitably control that limb-reflex, depressing or reinforcing it as circumstances dictate. The stretch-reflex of the limb-extensors is, however, a reaction essentially independent of the otolith organs, although it can be regulated by the otolith organs; it still obtains (Liddell and Sherrington) after bilateral severance of receptive nerves of the latter.

Elicitation by gravity of the stretch-reflex of the limb-extensor suggests itself as a basic factor in this static geotropic reflex of standing. As such it offers an explanation of the postural contraction counteracting gravity, of the proprioceptive nature of that reaction, and of the latitude of detail allowed to the standing posture of the reflex limb. As to accepting without reserve this scope for the stretch-reflex, certain experimental facts enjoin caution. When, in obtaining the reflex preparation, the portion of brain removed encroaches backward, *i.e.* is larger, the standing of the limb is exaggerated in degree; whereas when the decerebration is more restricted, *i.e.* more of the brain-stem remains, the creature, though purely reflex, exhibits (Magnus and de Kleyn) a standing in which the postural contraction is practically normal in degree. In the former type, assuming for it the stretch-

reflex, that reflex is giving an exaggerated caricature of standing rather than truly normal standing. This may however merely mean that for full normality of reflex standing several reflex factors, involving successive brain levels, co-operate, among them being the stretch-reflex of the limb-extensors, and that this reflex occurs in exaggerated form when "released" by removal of co-ordinate centres further forward. Such would have analogy with the "release" exaggeration of the reflex postural extension of the fore-limbs, which regularly ensues when the post-brachial spinal cord is severed. There the "release" seems due to severance of an inhibitory path studied in cerebellar (vermis) cortex by Banting and Miller, by Camis, and by Bremer; and by Bremer traced from spino-cerebellar afferents, through cerebellum and mesencephalon, and thence back to reach spinal centres of the limb-extensors.

A more obstinate ground of difficulty appears in the experimental fact that the reflex creature, decerebrate through posterior colliculi and with otolith organs out of action by nerve-severance, retains a postural contraction of its limb-extensors when the line of gravity runs not lengthwise in the limb.

In reflex standing we met the stretch-reflex in its postural form. But, as we saw, it can also operate movements. Now locomotion, whether of walking or running, is a rhythmic movement of the limb grafted upon the erect attitude of the body. Just as the erect posture can be maintained by pure inconscient action of the nervous system, so likewise can the stepping of the limbs. In this inconscient stepping the contact of the foot with the ground might be thought to supply an important skin-stimulus reflexly evoking the step. But the receptivity of the skin seems not to actuate reflex stepping any more than it does reflex standing. Indeed, from the observations of Prof. Graham Brown, an intrinsic automatic activity of the spinal centres seems the essential nervous mechanism responsible for inconscient stepping, a central activity comparable with that of the respiratory centre in the bulb, and like this latter highly regulable by reflex action.

The motion of a limb in the step is broadly divisible into two phases—a flexion phase in which the hip, knee, and ankle are flexed, carrying the foot forward clear of the ground, and an extension phase in which the hip, knee, and ankle are extended, bringing the foot to the ground and pushing the body forward from the ground as point of support. In the flexion phase the bending of the knee by the flexor muscles stretches of course the extensor muscle of the knee. But at that time, judging by analogy from the well-known "flexion reflex," the proprioceptive arc of the extensor muscle lies under inhibition, a reciprocal inhibition, one of the main purposes of which may indeed be to preclude a potential stretch-reflex from impeding the active flexion. At completion of the flexion phase the lapse of its concomitant inhibition of the nervous arc of the extensor muscles must leave the stretch-reflex free. The step, in fact, repeats, though probably less abruptly, the experiment in which the stretch-reflex wakes to post-inhibitory freedom. The precurent flexor phase thus, so to say, compresses the spring which, when released, does the main work of the step. The extension phase itself in its turn, during the course of its

performance, by straightening the knee, effects relief of the stretch of the extensors, and so terminates itself by abrogating its own promoting stimulus.

Further contribution by the stretch-reflex to the extension phase of the step occurs also in another way. When the extensor muscle is actively contracting, a stretch applied to it enhances immediately and greatly its contraction. The myograph record (Fig. 3) exemplifies this from an experiment meeting the requisite conditions. A passive stretch, amounting to but 2.5 per cent. of the length of the active muscle, causes the contraction-tension of the muscle to become

FIG. 3.—Vasto-crureus. From C to C' stimulation of contralateral afferent peroneopopliteal nerve (break-shocks at 40 per sec., coreless primary fed by 0.2 amp., secondary coil 16.3 cm. from primary) evoking reflex contraction. At t a 2.5 mm. stretch; at t' relief of the residual stretched-posture. From t to t' stimulation of inhibitory afferent nerve; this nerve as frequently evoked, besides inhibition of the contralateral nerve's reflex contraction, slight reflex contraction on its own part, so that full inhibition revealing the passive tension component in the reaction to this stretch is fully evident only at n , where on cessation of the ipsilateral stimulus the slight ipsilateral contraction passed off though the inhibition temporarily remained. Myograph multiplying tendon-movement 62 times. Time in 0.1 sec. (Liddell and Sherrington.)

three times as great. Now, a part of the knee-extensor muscle, the "double-joint" portion, bridges across the hip as well as the knee. It lies across the flexor aspect of the former. In the extension phase of the step the angle of the hip, like that of the knee, opens. This opening of the angle of the hip necessarily stretches the part of the knee-extensor bridged across it. Thus a stretch is given to this part of the extensor not by its antagonists, but by its own ally-muscles, the extensors of the hip. This, happening as it does during the extension phase, occurs when the extensor muscle is already in action and obviously not under inhibition. This stretch must therefore, as our experiment shows, enhance further the reflex contraction already in operation, and do so at the period of mid-progress of the extension phase when the foot is in contact with the ground and the weight of the body bears most on it, because acting approximately vertically above. Later, with fuller straightening of the knee towards the end of the extension phase, this stretch upon the double-joint portion of the muscles diminishes and lapses, and with it the enhancement of contraction. The stretch-reflex thus in two respects plays an important part in the extension phase of the action of the step.

Study of the stretch-reflex in its greater completeness and entirety has been but recent. There can, however, be little doubt that the "knee-jerk," a reaction long familiar to the physician, is a fractional manifestation of it. The "knee-jerk" is a slight twitch-like contraction of the muscle of the front of the thigh. The physician evokes it by a light tap directed close below

the knee-cap. This stretches the thigh muscle slightly, and evokes from the muscle a slight contraction lasting some tenth of a second. The routine of the physician employs this brief reaction as a test where there is question of certain diseases of the nervous system. Where there is, as in tabes dorsalis, degeneration of the receptive nerves of muscle, absence or impairment of the knee-jerk is apt to be an early symptom. Of common occurrence in tabes dorsalis, along with impairment of the knee-jerk, are two other symptoms, namely, defect of the normal ability to walk or run, and impairment of normal ability to stand, especially with the eyes closed. The physician in testing the knee-jerk is in fact testing the stretch-reflex of an antigravity muscle. We have seen the rôle which that stretch-reflex plays in the performance of the step and in the maintenance of standing. In the light of that we can appreciate more clearly the bearing of the little evanescent twitch, the "knee-jerk," on the two fundamental acts, motor and postural, of stepping and of standing. That bearing emphasises the contribution made to the incontinent reflex performance of these acts by the receptivity of the muscles which they employ.

We have thus glimpsed something of the contribution made to bodily posturing and movement by reflex action arising in the muscular receptors. These same receptors connect also with the mental region of the brain. What kind of mental experience do they enable? I do but mention this in order that, regarding muscular receptivity, there shall not escape us the similarity which exists between its reflex and its sensual scope. This latter concerns the perception of our postures and our movements, their intensity, their direction, speed, and extent. In their sensual aspect the muscular receptors serve as means whence mental experience can work toward attainment of yet finer delicacy and precision for the muscular acts of the body, and arrive even at trains and combinations of them that, in so far, are acquisitions altogether new. The two reactional aspects, the sensual and the purely reflex, of muscular receptivity reveal therefore two sides of, broadly taken, one singly-purposed function addressed to a single problem, in brief, the taxis of execution, the management—from rough adjustment onward into minutely refined *finesse*—of the acts of our skeletal muscles, which is to say, in the language of the older physiologists, the movements and postures of our life of external relation.

Though the general problem is thus broadly definable, its content of unanswered questions is legion. Passive stretch applied to the extensor muscle provokes reflex contraction in it. The stretch stimulates receptors which through the receptive nerve of the muscle provoke contraction. The nerve of the muscle consists of several branches. Take one of these branches, cut it across, and stimulate its central end, the end connected with the nerve-centres. The receptive nerve is thus stimulated not, it is true, through the medium of stretch applied to its receptors, but directly. Yet no contraction of the muscle results. We should not, of course, expect contraction in that part of the muscle, the nerve-branch of which has been cut, because from that part we have, by cutting the branch, withdrawn the motor nerve-supply. But from the rest of the

muscle with motor supply intact, we might expect reflex contraction. Not only is there none, but further, the muscle, if reflexly contracting at the time, is thrown out of contraction. Instead of reflex contraction, there is therefore reflex inhibition. Evidently the muscle is provided with more than one kind of receptor; it possesses certainly two kinds with diametrically opposed functional effect. Like the heart, it has two opposed nerves, one of augmentor function, one of inhibitory function—only in the case of our skeletal muscle these two opposed nerves are afferent and not efferent.

The significance of this is at present obscure. The "lengthening reaction," it is true, may involve a reflex inhibition and is certainly proprioceptive. We must also not forget that muscles can give rise to pain. Cramp, rheumatism, muscular fibrositis, and neuritis evidence this only too commonly. Even a small partial rupture of a muscle makes it a seat of pain when it contracts. In all such cases the treatment that the physician's experience enjoins is rest; that is the treatment that Nature herself seems to aim at, for she enforces it, in the last resort prescribing pain, if rest be departed from. Existence of these inhibitory afferents from muscle suggests she enjoins involuntary desistance from contraction by reflex inhibition. Some involuntary, as well as voluntary, restraint from use of his lumbar muscles restricts the lumbago patient in rising from his chair. But the problem of the proprioceptive nerve, which inhibits its own muscles, certainly cannot be satisfied wholly in this way. Among such proprioceptives are some which, while reflexly inhibiting their own muscle, excite contraction of the antagonist, thus causing for their own muscles a stretch scarcely likely to be soothing to inflammation. Moreover, there are muscles which seem not to possess proprioceptors inhibitory of themselves.

The microscope likewise separates the receptors of muscle into species of more than one kind, well-differentiated forms, muscle-spindles, Golgi tendon-organs, basket-endings, tendril-terminals, Pacinian corpuscles, and so on. It is unlikely that for all these the adequate stimulus can be the same, or the functions identical. In perception of postures and movements there seem traceable, as underlying data, degrees of muscle-length on one hand and, on the other, degrees of muscle-tension. Some muscle-receptors may be length-recorders, others tension-recorders; one would

suppose the Golgi tendon-organs among these latter. As to the "muscle-spindles," the muscle fibres they enfold, though differing within the spindle from those outside, yet receive motor-terminals; one would suppose active contraction to supply their stimulus. Through them and through other receptive endings which clasp muscular fibres, the active contraction of the muscle might be expected to evoke reflex reactions, and to furnish a "contraction" datum for perception of active postures and movements.

At present, however, there seems little evidence that active contraction *per se* excites receptors in the muscle itself. Using that delicate index, the electric action-current of the nerve, and in the uncut nerve of the muscle, Forbes and Gregg and Forbes and Adrian have shown that the action-current in a reflex excited by a single shock is practically as brief lasting as in the direct reaction of the cut motor-nerve itself. No proprioceptive reverberation seems to ensue. Again, Cooper and Adrian, with the action-currents of the muscle in reflex tetanus, find secondary waves following the primary ones of the response. In view of the likelihood that these secondary waves might be a proprioceptive repercussion set up by the primary contractions, they paralysed these receptors, but only to find the secondary waves still persist. Germane to the general negative result with reflexes seems that unexpected feature of the "muscular-sense," revealed by perceptual examination of movements and postures, namely, that the fineness and accuracy of our perception of these when they are passively performed, *e.g.* by external means applied to a limb itself passive and inactive, is practically no less delicate than when they are performed by muscles themselves actively contracting. This would seem to suggest that the receptors of muscles are functionally merely on the same plane as are the receptors of the joints.

Muscular receptivity offers a wide field, and our view of it has perforce been but a glimpse. That glimpse, however, may have served to show that through their own nervous arcs the muscles have a voice in their own management and co-ordination, and they are, moreover, not motor machines only but sense-organs as well. Only by fuller study of them in these aspects can we know how best to use them. Should this short account serve to attract recruits to that study, it will have been of good augury for progress in the problems of muscular receptivity.

Obituary.

DR. R. M. WALMSLEY.

WE regret to announce that Dr. Robert Mullineux Walmsley died on June 15, after a street accident which happened two days previously when he was knocked down by a motor vehicle immediately after getting out of a tram-car. Every attention was given to him at the hospital, but he never regained consciousness.

As Principal of the Northampton Polytechnic Institute in Clerkenwell, Dr. Walmsley was very well known in connexion with engineering training. In 1901 he started day courses in that college in electrical and mechanical engineering. In 1903 the governing

body sent him to the United States and Canada to study the methods adopted in engineering training. The results he deduced from this tour were communicated to the Institution of Electrical Engineers in a lengthy paper read in February 1904. This paper gave rise to considerable discussion. He was of opinion that employers in Great Britain should be educated to the advantages of taking technically trained men. The system which he adopted at the Northampton Institute was a modified "sandwich" course, unsuitable men being gradually weeded out by examination.

Dr. Walmsley was born near Liverpool seventy years