solutions, but it would seem that they would sort out as $2+2$, not $3+1$ as is required. We need a process which will give $4+4$ solutions, reduced to $3+1$ by Heisenberg's resonance principle (*Zeit. f. Phys.*, **38**, 411). This could probably not be done for most vector waves, but the permutations (6) suggest a way out; for in combining the two sets of variables there is no particular reason to select the same permutation of both. The actual number of possible selections is easiest seen from (3), where in adding the effects together we can interchange the meanings of f and g . We shall in this way get two systems of equations each with four solutions, just the number required. The question of two or more electrons is, I think, the most serious difficulty for the present theory, and this is only intended as an incomplete and tentative suggestion as to how it may be met.

Finally, we must consider the factor 2 which had to be introduced to obtain the tensor form. This is evidently the original difficulty of Uhlenbeck and Goudsmit. It was removed by Thomas, who showed that a rigid body when accelerating exhibits a sort of rotation on account of the kinematics of relativity. This brilliant explanation resolves the disagreement, but it really imports a foreign idea into mechanics; indeed relativity

and rotation do not take at all kindly to one another, and it is not surprising that no formal Hamiltonian method has been found to cover what is really a blemish in geometry rather than dynamics. As we here have nothing corresponding very exactly to velocity, we cannot use the same type of argument. But regarding the matter from a more abstract point of view, may we not perhaps draw an inference from the fact that our work has forced us to have equations of the third degree? Relativity is essentially a point theory and is governed by a quadratic form. To a first approximation motion is controlled by this form, and the associated wave equations are of the second degree. Now we have seen that the actual wave equations, though approximately of the second degree, are more accurately of the third. Taking the analogy back, may we not conjecture that the quadratic form of space-time wants amplifying in some way (I fear the idea is quite vague) by terms of the third degree, and that the reason why Thomas and Frenkel did not obtain a formal Hamiltonian is because 'quadratic' dynamics is only an approximation, which cannot be perfectly represented by importing into relativity theory the foreign idea of a rigid rotating body. But this speculation is too indeterminate to pursue further at present.

Nerves and Muscles: How we Feel and Move.

By Prof. A. V. HILL, F.R.S.

IT is not an easy task to give the Christmas Lectures at the Royal Institution, especially on a subject like physiology, in which experiments are much more difficult than in some others, at least when required to work without fail, to be intelligible and not to cause offence. The difficulty is increased by the fact that one's audience does not consist simply, in the words of the Royal Institution, "of juveniles between the ages of 10 and 16"; one finds oneself addressing distinguished adults in many walks of life, and not only these, but also through the publicity given to these lectures in the press, a considerable proportion of the people of Great Britain. One must reflect, however, in preparing them that they are intended for 'juveniles,' and that if others dare to come they do so at their own risk and will be assumed to be 'juveniles' for the purpose of the lectures. It is true, as a matter of fact, that most lecturers are apt to pitch their lectures at a level much too high for their audience, and that by attempting to make them interesting to a child of thirteen they may well succeed in absorbing the attention even of adults comparatively expert in the matter with which the lecture deals. We all like to have things put to us simply, and no lecturer to a juvenile auditory should pay any attention whatever to people above the age of sixteen.

The Christmas lectures at the Royal Institution are intended to include a considerable number of demonstrations and experiments, and without the use of live animals experiments on the functional working of the body are impossible. Two fortunate facts, however, make it practicable to give

suitable physiological demonstrations at the Royal Institution: (1) that the isolated organs and tissues of dead cold-blooded animals will continue to function for considerable periods after removal from the animal; and (2) that in recent years a great variety of perfectly good physiological experiments, often of precise quantitative as well as qualitative significance, have become possible upon men; and if upon men, then also upon children.

The fact that isolated tissues of animals will function for a long time after removal, although a commonplace of physiology, is not generally realised, and in itself is a matter of entrancing interest to those who come upon it for the first time: it awakens all kinds of questions, scientific and philosophical, which not only a 'juvenile' but also an adult urgently desires to see answered. The beating of an isolated heart, which will continue for hours or days after removal from its previous owner, provided that it be properly treated, is an extraordinary eye-opener to most people previously ignorant of physiology. There are few physiologists who do not remember the astonishment and interest which was aroused in them by their first sight of this phenomenon, or of the reflex movements of a frog whose head has been cut off, or of the contraction of a muscle preserved, sometimes for days, in salt solution, or of the electric current produced by an isolated nerve, or of the many other strange things that happen to little bits of tissue removed from the ordinary environment which their previous owner supplied. It is such things that bring physiology first into the region where exact experiments can

be made, and allow the factors at work in living tissues to be examined carefully and at leisure in the laboratory. The astonishment which we, as physiologists, have felt at intervals at such things, and which, if we have not grown too old, we still remember, is one thing we can and should communicate to our listeners, not only perhaps at the Royal Institution, but also at our classes in universities. The experience of the lecturer himself, at such a course of lectures as these, is valuable as showing him the kind of thing that appeals to intelligent, keen, unsophisticated, and natural people. There was no doubt from their applause that the audience approved of experiments in which the functions of organs were revealed by such experiments on isolated tissues.

Even more, however, than experiments on surviving portions of dead animals did the audience appreciate the fact, which I am sure many of them had never realised before, that experiments of all kinds on the mechanism of the body can be performed on man, or in this case on children, without discomfort or danger. How many are the things which, when we were young, we wanted to know about the machinery inside which we live—and nobody told us. Gradually, perhaps, we thought that these things were not to be known, or were unknowable; gradually, perhaps, we reached the state, in which I fear a good many adults exist, of regarding the machinery of the body as something unwholesome or 'nasty.' If my audience had been simply one of adults, I might perhaps have been afraid of shocking them in taking a life-like model of a man to bits and trying to fit it together again, after describing its various parts. In the case of children no such fear is necessary. As I have already said, there are very few small boys and not many grown men who do not want to take machinery to bits to see how it works; and children are quite ready to realise that they live inside a mass of complex and beautiful machinery, and are only too glad to be given the chance of taking it to bits, at any rate scientifically speaking, and examining its parts.

To a child there is nothing 'gruesome' about seeing the heart beating in a live man, or in watching the food (by means of X-rays) travel along his inside; nor are they inclined to faint, as some adults are, if one amplifies the sounds made by a human heart, or shows a cinematograph film of the blood corpuscles swarming through the capillaries of the lungs. The advantage of the audience at the Royal Institution is that they are natural people without any obsessions, so one can speak to them as one natural human being talking to another. Possibly some adults may have thought that the children *ought* to have been shocked by some of the experiments we performed; I am sure, however, that very few of the children themselves lived up to such an expectation. It is only by continually suppressing one's desire to know more about, and to understand, the body in which one has to make a home for so long, that one gradually develops an obsession that there is something unnatural, unclean, or 'gruesome' about it.

It was most instructive to note which of the demonstrations, and which of the lantern slides, appealed most to the audience. Of the slides the one that seemed to please the audience best was a simple little diagram, taken from Cannon, showing how the food is propelled along the alimentary canal by a peristaltic wave, consisting of a contraction behind and a relaxation in front of the portion of food to be moved. This little diagram evoked prolonged clapping. I suppose many of the audience had long wondered how the food moved along their insides, especially perhaps at Christmas time, and maybe had wanted to ask but had found nobody to tell them. Another slide they obviously admired was a simple diagram of the central nervous system, taken from Prof. Pear's book, "Skill in Work and Play," by which I described how they themselves, sitting up aloft in the cortex of the brain, were able to carry out all kinds of automatic, or semi-automatic, activity by means of the 'telephone exchanges' existing in the cord below, and were able to appreciate muscular movement by the messages from muscles, tendons, and joints which pass up along the afferent nerves and into the different levels of the nervous system. Another slide which evoked obvious approval was a simple piece of arithmetic by which I explained how the greater the length of a race the slower one had to go. This is a fact of which we are all aware, but only recent progress in physiology has made clear what are the factors which determine it. The body has a certain 'income' of oxygen and a certain 'credit' upon which it can draw. If the 'credit' has to spread out over a longer period, less of it can be spent per minute, the effort must be smaller, and the speed lower. The fact that they obviously approved of this simple arithmetic, which certainly contained nothing sensational or dramatic, is a tribute to the intellectual level of the audience.

The first lecture dealt with "Nerves and the Messages they Carry." Isolated nerves and muscles were shown working, the electric current produced by an excited nerve was demonstrated, and an experiment was made on the stimulation of the ulnar nerve of a child. The messages coming along nerves were described, and the central nervous system was likened to an automatic telephone exchange.

The second lecture dealt with "Muscles and How they Move." In this, isolated muscles were stimulated, and a competition was organised between the muscle-nerve preparation of a frog and the muscles of a child stimulated through the ulnar nerve. The child won easily, because his circulation was able to supply his muscles with the oxygen they required in order to do the work, while physical diffusion alone was unable to bring oxygen rapidly enough to the frog's isolated muscle, which therefore rapidly fatigued. The electric change of the human heart was shown, and the physical and chemical basis of fatigue was discussed.

The third lecture dealt with "The Heart and Some other Muscles," chiefly with the heart. X-ray pictures of the alimentary canal after an opaque

meal were followed later by a demonstration, kindly organised by Messrs. Watson and Sons (Electro-Medical) Ltd., in which a subject drank an opaque meal, which could be observed passing down into his stomach. Following this was an X-ray demonstration of the heart of the lecturer and others. The lecture had been started by a demonstration, organised by the Marconiphone Company, Ltd., in which the sounds made by the heart of a child were rendered audible throughout the hall. In the fourth lecture I dealt with "The Lungs and Blood: How the Muscles get Air and Fuel," in which perhaps the chief demonstration was that of a wonderful cinematograph film by Prof. Krogh, of Copenhagen, in which the blood corpuscles are seen circulating in the tissues of a frog. There is no means of which I am aware so good as this film of showing what the circulation of the blood really means. We discussed the energy derived from the fuel burnt in the muscles, and we saw experimentally how the oxygen consumed by man can be measured.

In the fifth lecture, "Nerves and Muscles Working Together," I discussed the basis of organised muscular movement, the nature of muscular skill and of muscular sensation, and all those automatic, or semi-automatic, actions of which a large part of our being is composed. A slow motion cinematograph film of a dancer, and another of a falling cat, were employed to emphasise the wonder of muscular skill, while a demonstration of the 'psycho-galvanic reflex' showed how our emotions cannot be hidden from certain quite simple physical apparatus. The sixth lecture, "Speed,

Strength, and Endurance," dealt with an application of some of these matters to such things as mountain climbing and athletics; the importance of an adequate supply of oxygen was demonstrated by an experiment on a boy who pedalled a bicycle, breathing oxygen at only two-thirds of the ordinary atmospheric pressure, until very tired, and was almost immediately relieved—and pedalled with renewed vigour—when given oxygen in high concentration. Finally, it was emphasised how a capacity for severe muscular effort depends mainly on simple considerations of energy, and of skill in the economy of energy, and how certain predictions can be made of a man's athletic capacity by means of physiological measurements.

As I said in my first lecture, many people who own motor-cars know very little about the insides of them and how they work, which is distressing enough, especially when they go wrong. How many more who own perfectly good bodies have only the vaguest idea of their machinery, or of the meaning and importance of the various parts. In these lectures I tried to give my audience some idea of the working of two of the most important parts of the body. One cannot hope yet to understand our living machinery in full, but even the little we know already can add delight to physical exertion, and can make us realise the complexity of muscular skill and the nature of strength and endurance. The effort to understand will help us to appreciate the beauty and wonder of the devices with which our bodies are endowed; and when we begin to understand a little we shall soon want to understand much more.

Obituary.

DR. EUGEN HULTZSCH.

BY the death at Halle on Jan. 16, in his seventieth year, of Eugen Hultzsch, the study of Indian epigraphy loses one of its most ardent and painstaking followers. Born in Dresden, he was educated at Leipzig and Bonn, studying under Aufrecht, the famous Sanskritist. From 1882 until 1886 he was assistant professor of Sanskrit at Vienna. He was then appointed epigraphist to the Indian Government, remaining in the Service until 1903, when he retired and accepted the chair of Sanskrit at Halle. This he held until his retirement some time after the War. During the greater part of his service in India, Hultzsch edited *Epigraphia Indica*, to which he contributed many valuable articles. His own researches were very largely devoted to the inscriptions of the Presidency of Madras. His "South Indian Inscriptions," published between 1890 and 1893, gave in three volumes critical texts and translations of between three and four hundred inscriptions, mostly from the Tamil country. His reports on Sanskrit manuscripts in southern India were published in three massive parts between 1893 and 1905. His reputation as a scholar, however, will rest mainly on his edition of the edicts of Asoka—a subject on which he was the acknowledged authority. The publication of this standard work was delayed by the War, but

it has recently been issued by the Indian Government on behalf of the Archaeological Survey. In it the whole of the previous literature of the subject is critically examined, and each text is given in the original with an English translation. Hultzsch was a contributor to the *Journal of the Royal Asiatic Society* and to that Society's prize publications, as well as to other orientalist periodicals, while in recent years he took a prominent part in the work of the German Oriental Society. Orientalists in Britain are particularly indebted to him for, first, the valuable collection of Sanskrit and other manuscripts made during his stay in India which is now in the Bodleian Library at Oxford, and, secondly, for his exertions in securing the return to the India Office and the Royal Asiatic Society of the valuable manuscripts and books on loan at the Leipzig exhibition when the War broke out.

WE regret to announce the following deaths:

Sir George Greenhill, F.R.S., formerly professor of mathematics in the Artillery College, Woolwich, on Feb. 10, aged seventy-nine years.

Dr. C. D. Walcott, secretary of the Smithsonian Institution of Washington, D.C., since 1907 and formerly director of the U.S. Geological Survey, on Feb. 8, aged seventy-six years.