still in general use in the sciences of Nature, we find that this also is not to be discovered among the particular selected sensory phenomena with which they deal. This concept of physical energy refers to a postulated persistent entity ('same thing'), constant in amount, which may be transformed from one state to another, and is capable of doing work in bringing about physical movements. To what source in experience can we trace this notion? It is not sensorially apprehended in the physical phenomena observed. It might at first sight seem that it should be traced to kinæsthetic experience, or the sense of effort in bodily activity by which different kinds of work are done; that we read this analogically into the physical phenomena, and project the result into a 'physical' world. But this cannot be a true explanation, because, like the properties of the book just considered, the sense of effort experienced in one case is only similar to the sense of effort experienced in another. It can in no sensory way be shown that they are identical. Likewise, the body, in the same way as the book, in any successive pulses of sensorial apprehension, displays no more than a relation of likeness. Accordingly, I appeal again to my immediate non-sensorial experience of self-identity, in which I discover an active self energising in one way or another. It is true I do not find any perpetual and unbroken continuity of self-consciousness; but, whenever I am conscious, notwithstanding all the changes that take place in the phenomenal world, including those of my own body, I am conscious of the same unitary and self-identical I. Can we find the basis of the concept of energy here? I maintain that we can, in the sense that this self does actualise, or energise, in different ways, now perceiving, now judging, now resolving, now enjoying, and the like. From this I infer that a self which does all these things can do any one of them, even if it is not actually doing that one at the moment. Here I find, in immediate living experience, the source from which the abstract concepts of energy and dynamism are drawn; and these concepts, applied to the phenomena of motion or change, become those of kinetic and potential energy, and are projected upon an extra-mental world of things which we have conceived on analogy with ourselves.

There are other lines of approach to the development of the thesis I am maintaining than the one I have taken; but I have chosen this because it most readily allows me to stress my point. Had we worked backward in the history of the evolution of the notion of causality, instead of forward as we have done, we should have found that we were leaving the region of remote inference for that of proximate inference, and this again for that of experience pure and simple, until at last we reach the immediate experience of the self as actively engaged with its mental objects. We should have reached then the central core, so to speak, of all experience. Here we find, not merely a concept nor a phenomenon, but an actual thing, or active substance existing in itself, from which the notions of thinghood, substance and activity are abstracted; we find here an efficient cause actually producing its effects, such as remembering a forgotten event or altering the character of phenomena by willing to do so, and from this the concept of efficiency is derived; we find a substantial cause in multiform relations with sensed-things and thought-things, among which is the goal relation, whence the idea of finality or teleology arises.

From such experiences as these, to which we apply relations likewise experienced, we derive proximate inferences such as those of retentiveness or mental energy. From them also, as well as from our immediate experiences of the apprehension of relations and the production of correlates, we infer the proximate principles of noetic eduction. And, lastly, from them again, by further applications of relations to them, to phenomena, and to correlates already produced in our thought, we reach the far more remote inferences of which use is made in the sciences of Nature; for here we refer our experiences to transexperiential, extra-mental causes. But the grandiose system of the natural sciences as a whole stands in virtue of these original experiences; and it would crumble away into less than dust did they not guarantee it.

It is for this reason, provided the meaning of the term be not limited to sensory experience only, but be extended to all and everything that may be experienced, that I maintain that psychology is the most empirical of all the sciences.

## Kinematic Design in Engineering

FEW if any of the mechanical engineers of last century can have imagined that the academic kinematic theories of Willis, Reuleaux and Maxwell would ever be applied to machinery. Strength and solidity was their ideal, and when portions of structures were to be united, large areas of contact with numerous strong bolts formed their standard practice. The same idea was followed in moving mechanisms, as shown in large flat lathe beds and crosshead guides, and long, closely fitting, rigid bearings. Realising that this practice necessitated very perfect fitting, they developed the art of producing large flat and cylindrical surfaces to a very high pitch of perfection, and their success has been shown by the accuracy and endurance of early British machine tools.

Modern mechanical construction has called, however, for constant increase of accuracy, and the limitations of the old method began to be revealed by the distortions produced by the forces required to secure contact over large areas, and by the stresses resulting from temperature changes.

In consequence, machine designers have been obliged more and more to adopt the teachings of kinematic theory, and in the twentieth Thomas Hawksley lecture to the Institution of Mechanical Engineers delivered on November 3, Prof. A. F. C. Pollard has given a very complete account of these principles and of their practical application.

As was natural, the first practical application of kinematic principles was to scientific instruments, and Lord Kelvin was probably the pioneer with his well-known hole, slot and plane device, providing the six points of contact necessary to restrict the six degrees of freedom of a single element. The equivalent and nearly equally effective three-slot device has also come into general use in the tribrach supports of modern levels and theodolites, superseding the old four-screw device, which caused strain and sometimes damage. Either the hole, slot and plane or the three-slot device ensures perfect location without high accuracy of workmanship, and avoids all distortion by temperature changes, provided that the pressure on the contacts is not too great to prevent easy sliding. For heavy loads, ball-ended feet may be substituted, as in the 18-ft. measuring bench at the National Physical Laboratory, the surfaces of which could not be accurately trued until the friction of the contacts was reduced. Large surfaces can be supported without distortion on multiple systems of tribrachs as first introduced by Lord Rosse, followed by Sir Howard Grubb and Parsons, for the specula and polishing tools of reflecting telescopes.

Kinematic design has been adopted to an ever increasing extent in modern lathes, grinding machines and other machine tools, and has recently begun to find its way into the automobile industry; the engines of many cars being now mounted on three supports, two of which are usually in front and one behind the engine, thus preventing it from being strained by distortions of the chassis, and diminishing the effects of its own vibration.

The late Sir Horace Darwin was the great pioneer of kinematic design in instrument construction, and the numerous instruments he designed for the Cambridge Instrument Co., Ltd., commencing with the well-known rocking microtome, and proceeding to reading microscopes, comparators, the optical components of string galvanometers, etc., are outstanding examples of its application. Messrs. Adam Hilger, Ltd. have adopted it for their interferometers, comparators, and spectrographs; Mr. Wm. Taylor for his screw-gauge measuring machine, in which ball slides were first used, and Messrs. A. C. Wickman, Ltd. for a universal gauge measuring machine; while Messrs. E. Leitz were the first to employ kinematic ball bearing slides for the fine adjustments of microscopes.

Systems having one degree of freedom—sliding, turning, or screwing—constitute the most important class of mechanisms. A cylinder resting on four points has two degrees of freedom, which can be reduced to one of pure rotation by a single axial end contact, or to one of pure translation by providing it with a transverse arm bearing on a plane parallel to its axis, as in the Cambridge Instrument Company's reading microscope. If a helical groove is cut along the central portion of the cylinder, and the smooth portions rest on three points, and the groove on a single spherical point, we have the elementary kinematic screw. For a pure turning pair, the best practical construction is probably two self-centring conical bearings each having three balls, and at a sufficient distance apart to prevent rotations about transverse axes, one of the bearings being provided with an axial pressure spring.

The construction of accurate screws and nuts has probably always been the most difficult of mechanical operations. The methods of Profs. Rowland and Rogers of correcting the errors of the lead screw and of lapping by a split nut still remain unimproved, but Mr. R. S. Whipple has recently described an excellent method of constructing the nut by casting white metal round the finished screw, after which the nut is split into halves and the thread is cleared away so as to leave four portions in the guiding half, and two portions in the other half which apply the necessary pressure to ensure contact without backlash.

When the mechanism is completed, the most valuable test is the 'hysteresis loop' obtained by traversing it slowly forwards and backwards over its whole range and observing its indications at intervals. This reveals the amount of backlash or lost motion at every part of its range, and the great superiority of good kinematic design.

It cannot be doubted that the introduction of ball and roller bearings has been a most powerful influence towards the adoption of kinematic design, by showing that point or line contacts are capable of dealing with heavy running loads for long periods without undue wear. Maximum surface hardness as measured by the Brinell test appears desirable, and nitriding or chromium plating may probably prove advantageous. Sapphire or even diamond jewels and pivots, suitably cut with respect to their cleavage planes, are employed for small instruments. The Hertzian theory of the stresses and deformation of point contacts appears to give sufficiently reliable data for design, and 700 tons per square inch seems to be about the maximum safe stress for steel ball contacts. One trouble with such contacts has been their rusting, but Messrs. Keenock Gears have recently discovered that lubrication with oil mixed with 50 per cent of zinc oxide entirely eliminates rusting by depositing a film of zinc of molecular thickness on the surfaces.

Prof. Pollard has described a large number of kinematically designed instruments in detail. His lecture will probably remain a classic on the subject for many years to come, and should provide a valuable stimulus to the widespread adoption of kinematic design.

C. V. D.