The Measurement of Time

By Prof. H. Dingle

TIME cannot be measured as any other physical magnitude is measured. Measurement is the determination of the number of 'units' contained in the assigned quantity, and the unit is defined either (as with mass and space) as an arbitrarily chosen, permanently preserved piece of the magnitude in question, or (as with temperature, electric charge, etc.) as that which produces a specified amount of an arbitrarily chosen effect ultimately measurable in terms of mass or space. But it is impossible to preserve a standard second, and time produces no effects—events occur *in* it but not *because of* it. Consequently measurement of time must be a special process.

The only practicable procedure so far conceived is the following. Choose a sequence of events (natural or artificial) between consecutive members of which there is an interval of some other (measurable) physical magnitude as well as an interval of time; then the time intervals can be defined as proportional to the corresponding intervals of that magnitude. This process involves three successive steps:

(1) Choice of the kind of measurable interval between the events.

(2) Choice of the particular sequence of events separated by intervals of this kind.

(3) Choice of the unit of measurement of those intervals.

Physics has chosen under (1) intervals of space; under (2) the successive spatial positions of an ideal body free from external forces—represented approximately by the successive directions of a specified radius of the earth; and under (3) an ideal rigid rod, represented approximately by the standard metre.

Each of these choices is in the last resort arbitrary; there is nothing in Nature to prohibit the selection, for example, under (1) of intervals of mass, under (2) of the successive masses of any particular body, and under (3) of any standard unit of mass. There are differences in convenience, of course: no sane physicist would normally define equal times as those in which a Californian redwood tree acquired equal increments of mass according to a standard piece of uranium. But so far as Nature is concerned, this and the traditional measure adopted by physics are equally valid.

Before the theory of relativity was formulated, it was thought that each of the three steps was prescribed by Nature. Time must be measured in terms of a sequence of spatial intervals; there was one unique uniformity of velocity defining the only valid sequence of spatial positions; and there was one unique standard for measuring the spatial intervals between those positions. Then came the discoveries that two rods, equal in length when relatively at rest, became unequal when in relative motion, and that in the latter circumstances it could not be determined which was moving. It followed that Nature's standard measuring rod in (3) could not be identified. Relativity saved the situation by pointing out that it was mythical, all standards being equally legitimate if used consistently. This discovery of the arbitrary character of step (3) is known as *special relativity*.

Steps (1) and (2) remained unique. This meant, first, that the unit of time must share the voluntary character of the unit of space, for since, under (1), time intervals were proportional to space intervals, any arbitrariness in the latter must appear also in the former; and secondly, that whatever choice was made under (3), the changes in space and time measurements could never convert uniform into accelerated motion, or vice versa, because, to preserve the uniqueness of (2), the units must be related so that the earth rotated uniformly. The supposed absoluteness of step (1) accounts for the common statement that time has become space. Having decided to measure time in terms of space measurement, it naturally follows that time and space measurements are related, but the relation does not belong to Nature. If intervals of mass or temperature had been chosen in (1), time would have 'become' mass or temperature. Again, the supposed uniqueness of step (2) accounts for the restriction of special relativity to uniform velocities: the equations of transformation had been determined experimentally for such velocities and the passage to accelerations was closed.

The next advance was the realization of the essential arbitrariness of step (2). Nature makes no demand that the earth shall rotate uniformly; we can choose *any* sequence of spatial positions, measure the space intervals between them by *any* standard rod, and define equal times accordingly. This discovery was *general relativity*; it destroyed the supposed absolute distinction between uniform and accelerated motion.

The effect on formal physical theory was in each case a simplification: special relativity eliminated time, and general relativity mass (or force), as independent conceptions. A velocity was no longer definable only as so many space units divided by so many time units. A velocity of 4 miles an hour was a movement through 4 miles while the earth rotated through 15°, and could be expressed as "4 miles per 15°". Space (or space-time, as it was called) measurement was thus adequate to describe velocity. A further elaboration of space measurement included force or mass, so the whole of metrical mechanics became expressible in terms of a single concept of space.

The arbitrariness of step (1) is not yet generally realized, but clearly we are just as free to choose a sequence of, say, entropy intervals as one of space intervals to define a time scale, and as a result we might expect an expression of the laws of thermodynamics in terms of a timeless entropy just as the laws of mechanics are expressed in terms of a timeless space. Two opposite extreme attitudes of physicists to this matter require attention.

In the first place, though apparently no one has explicitly noted the arbitrariness of (1), it is inherent in Milne's recent kinematical theory. Milne points out that any sequence of events whatever is valid for enumerating time instants, and this clearly gives us permission to choose events separated by intervals of any kind to provide a measure system for time. But he goes no further: having claimed freedom he takes no advantage of it, so that his claim, though perfectly just, is also perfectly useless. Instead of proceeding to advance physics by measuring some physical interval between the events chosen and defining a time scale in terms thereof, he restricts his consideration to the numbers identifying the instants themselves. The result is naturally that nothing of physical interest emerges; it is impossible even to distinguish between relative rest and relative motion until some choice of clock is made. Milne tries to define a basis of choice by postulating a 'cosmological principle', but this, being obviously beyond experimental confirmation, is metaphysical, and furthermore has not succeeded in making the distinction mentioned. Time is essentially immeasurable by ordinary processes, and you get out of its so-called measurement just what you put in. If you measure time in terms of space, time becomes space; if you measure it in terms of temperature, time becomes temperature; and if you measure it in terms of a cosmological principle, time becomes metaphysics.

At the other extreme is the position taken by the majority of physicists who, ignoring the voluntary character of (1), by implication accept as a natural necessity the measurement of time in terms of space. Probably the most emphatic expression of this acceptance is Eddington's statement ("The Nature of the Physical World", p. 74) that the second law of thermodynamics holds "the supreme position among the laws of nature". His reason is that this law alone reveals "time's arrow". But clearly this distinction is arbitrary. Having elected in (1) to measure time spatially, we can choose, and have chosen, in (2) for defining equal time intervals the particular sequence of spatial events that puts an arrowless time in mechanical laws. Thermal laws, being temporally 'out of step' with mechanical laws, then show time's arrow. But if we choose in (1) to measure time thermally, and in (2) the sequence of thermal events which puts an arrowless time in the laws of heat (for example, we might define as equal times those in which a standard body radiates equal amounts of heat or falls through equal ranges of temperature or changes by equal increments of entropy, etc.—heat, temperature and entropy measurement, of course, being defined by an arbitrary choice under (3)), time's arrow goes over into mechanics, which then assumes the 'supremacy' now assigned to thermodynamics.

We must distinguish two things:

(*a*) The *order* of events in time.

(*b*) The *intervals between* events in time.

The first is independent of measurement and is not arbitrary. The second, which alone give us our mathematical 'laws of Nature', depend on measurement which is arbitrary in the three-fold manner indicated above. For example, the statement that entropy tends to increase belongs to (*a*); the statement that the increase tends towards a finite maximum value depends on (*b*). If we define equal times as those during which a standard body acquires equal increments of entropy, there is no finite maximum value, and the entropy of that body increases uniformly through eternity.

The system of measurement to be chosen depends on the question of interest. If we ask whether terrestrial life will ever cease through failure of solar heat supply, the appropriate system must be indicated by the biologist; if rhythmic vital processes adapt themselves to solar heat supply such cessation will never occur, but if they adapt themselves to our physical system of (approximately) uniform rotation of the earth, it probably will. The former would seem more likely to be the fact. There is, however, the further consideration that life may depend on terrestrial (determined by solar) temperature more than on heat supply (though the present maintenance of the same body temperature in the arctic and tropic zones prohibits dogmatism on this point), and the fact that the sun cools comes under (*a*) and not (*b*). That is true, but there is no evidence that it is a 'fact'.

Apart from arbitrary choice, there seems to be complete equivalence between mechanical and thermal processes. Both show a one-way tendency in (*a*)—moving bodies tend to stop and hot bodies tend to cool. We do not need a special entropy clock to show which of two instants is the later; a grandfather clock will do—the later instant corresponds to the lower position of the weight. In favourable circumstances (for example, the rotation of the earth), 'uniform' motion may be eternal, and in favourable circumstances (for example, the radiation of the sun) 'uniform' radiation may be eternal. There is no evidence that the sun's temperature is falling, apart from the laws of mechanics, which presuppose fall and are therefore inapplicable: on the contrary, there is much difficulty in accounting for the fact that the sun radiates *without* observable fall of temperature. We are no more compelled to say that an isolated body would move uniformly than that it would radiate uniformly: in each case we can observe only bodies that are not isolated, and we find, first, that neither motion nor radiation is uniform, and secondly, that the nearer we approach isolation the nearer we approach a *common* uniformity of both motion and radiation.

Space prevents discussion of the possibility of re-expressing thermodynamics in terms of a thermal time measure, but there seems to be a reasonable prospect that choice of the proper thermal quantity for the purpose, and application of relativity methods of relating time with this quantity, would introduce the quantum of action, h, in a manner analogous to the introduction of the velocity of light, c, into spatial relativity. The relation of one constant to thermal processes at least partly resembles that of the other to mechanical processes. If this possibility were realized, the way would be open for a completely unified field theory. This, of course, is at present a speculation, but the three-fold arbitrariness of time measurement and the deductions drawn therefrom rest on logic and historical fact.

Obituary Notices

Prof. Max C. W. Weber, For. Mem. R.S.

DR. MAX WEBER, for many years professor of zoology in Amsterdam, doyen of late of the whole brotherhood of zoologists, died at Eerbeck on February 7, in his eighty-fifth year. He was born at Bonn on December 6, 1852, of a Dutch mother and a German father, and learned his natural history from Franz Leydig in Bonn and from Eduard von Martens in Berlin. Leydig was an excellent anatomist, who gave Weber his lifelong bent towards mammalian anatomy; von Martens, a famous conchologist, who had travelled and collected in the East, was a man of fine taste and liberal education. In 1879, Weber went to Holland, where he taught anatomy, first in Amsterdam then in Utrecht, and presently went back to Amsterdam as professor of zoology. In 1883 he took out papers of naturalization, and married Mlle. Anna van Bosse, a young botanist of his own age, who proved herself the perfect wife and helpmeet.

Weber had already made a voyage to Barents Sea, in a little schooner 75 ft. long, the *Willem Barents*, named after Willem Barents who had discovered Spitsbergen at the end of the sixteenth century and so opened the way to that rich whale-fishery in which the Dutch had a paramount share for the next hundred years. The *Challenger* had not long come home, and Weber, like many another young naturalist, was all agog to go fishing in unexplored seas with dredge and trawl. For a few years after their marriage the Webers went every summer to Tromsö, he mostly to dissect whales, and she to study corallines or calcareous algæ, on which she was even then becoming the chief authority. In 1888 they went to the Dutch East Indies, where they made large and varied collections and where Max Weber took up in earnest the study of geographical distribution. He belonged to an age, and he was of late its most conspicuous survivor, when a man could take all natural history for his province, and could make discoveries in many diverse fields. In the *Ergebnisse* of this Dutch East Indian Expedition, in which many colleagues including his old master von Martens came to help him, Max Weber himself wrote on the freshwater sponges, on that queer trematode worm *Temnocephalus*, which is a parasite (and yet scarcely a parasite) on a river-crab, on the anatomy of certain Siluroid fishes, on local species of reptiles and of mammals, on the scaly coat of the pangolin and its associated hairs—which led him to think that all mammals were once scaly, and that in many the arrangement of the hairs recalled the ancestral pattern of the scales—and lastly, together with his wife, on the green and yellow algæ symbiotic (to use a word lately coined by De Bary) in *Spongilla*.

The Webers' next journey was to South Africa—it was always to some homeland of the Dutch—again to study the freshwater fauna, and in Max Weber's case to study the anatomy of *Chrysochloris* and certain other South African mammals: the results