Basic Concepts of Measurement and the Michelson–Morley Experiment

ONE of the reasons for the success of the scientific method is the rigorous control of the conditions of measurement. The effect of varying one parameter is examined while the other conditions are maintained constant. It must not be overlooked, however, that some of the conditions cannot be varied, and their effects cannot therefore be examined in this way. All measurements which have been made so far have been carried out on the Earth's surface where there is a strong gravitational field due to the Earth, a rotational velocity, and a centrifugal force balancing the Sun's gravitational field.

The effect of this permanent environment is usually ignored. It is ignored, for example, in the definition of the units of measurement. Although the units of mass length and time are regarded as independent this is not quite true since their experimental realization must be effected in the gravitational field having dimensions involving both length and time. Moreover, since the Earth's gravitational field cannot be varied and indirect effects produced by the field cannot be examined, no allowance can be made for them. Possible effects of the field are ignored in experiments concerned with electricity and magnetism and in the formulation of the laws of electromagnetism including the velocity of propagation of electromagnetic waves.

In view of these unavoidable difficulties care must be taken in the interpretation of experimental results and theoretical predictions. The laws of physics developed in this particular environment might be expected to hold within this environment but not necessarily outside it. Consider the Earth revolving around the Sun. Its gravitational field moves with it, the gravitational field of the Sun is always balanced by the centrifugal force and the rotation of the Earth on its axis remains the same. The environment is unaltered and the laws might be expected to remain valid. In particular there is no reason to expect a change in the speed of light in consequence of the Earth's movement around the Sun and a null result would be expected for the Michelson–Morley experiment.

If, however, we assume that the particular environment can be ignored and that the speed given by Maxwell's theory is the 'free-space' speed, as is usually done, then a positive result would be expected. The simplest interpretation of the null result is that this extrapolation to 'free-space' propagation cannot be made. There is nothing to indicate whether the environment affects the propagation of light or the units of length and time; but if, as in the special theory of relativity, the velocity of light is made constant by definition, then it is the units of length and time which must be affected.

The contraction of length and time. The null result of the Michelson–Morley experiment can be brought into accord with the conception of free space velocity if the unit of length is changed so that the arm of the instrument in the direction of the movement around the Sun is reduced in length in the ratio $(1-v^2/c^2)^{1/2}$. Then, in order to preserve the constancy of the velocity of light, the unit of time must be modified in the same way. This purely empirical adjustment of the units is to be regarded as a first attempt to free the units of measurement from the restriction placed by the Earth's environment.

If one seeks a physical cause for the necessity of these adjustments it seems reasonable to look for it in the Earth's environment which is known to differ from the ideal 'free-space' condition.

Einstein's special theory of relativity. It seems to me that the derivation of the time and space contraction in Einstein's special theory is equally empirical. It is true that Einstein's paper[1] contains an important section on the synchronization of clocks in which it is pointed out that distant clocks cannot be synchronized unless some assumptions are made about the velocity of light. This section is particularly relevant to experiments that may be made in the future with atomic clocks in artificial satellites, but it is not relevant to any measurements that have been made in the past. Nor do these ideas play an important part in the derivation of the Lorentz transformations in Einstein's paper. He uses them to define time in such a way as to eliminate the ordinary pre-relativity Doppler effect, but this is a convenience rather than a necessity. It has been shown that the well-known clock paradox is predicted by the theory only by changing the meaning of the symbols during the course of the argument[2–4]; but there seems to be a more serious contradiction which has not yet been explained or indeed aroused any comment. This is, that although the theory is in accord with experimental results obtained in the Earth's environment, and was indeed inspired by the difficulty in explaining the Michelson–Morley result, the theory itself is deliberately restricted to another environment in which there is no gravitational field.

An experimental approach to gravitation. The main purpose of this communication is to direct attention to the fact that the restrictions in the environment placed by the gravitational field have at last been removed. Satellites have so far been used mainly to overcome the effects of the Earth's atmosphere on the absorption of electromagnetic and other radiations and to investigate the magnetic field and ionization at greater distances from the Earth than is possible by older methods. But the balancing of the Earth's gravitational pull by a centrifugal force may be a more important advantage. It may be possible to investigate gravitational and inertial effects by controlled experiment. Even simple experiments like Newton's rotating bucket might yield interesting results; and techniques now exist for measuring the precise frequency of atomic oscillators travelling in satellites both by means of recording instruments in the satellite and radio transmissions to Earth.

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1 Einstein, A., *The Principles of Relativity* (Methuen and Co., London, 1923).
2 Essen, L., *Nature*, **180**, 1061 (1957).
3 Essen, L., *Proc. Roy. Soc.*, A, **270**, 312 (1962).
4 Essen, L., *Air, Speed and Instruments*, edit. by Lees, S., 194 (McGraw-Hill Book Co., 1963).

Thermal Resistivity of Irradiated Graphite

Mason and Knibbs[1] have recently measured the thermal resistivity of polycrystalline graphite of various crystallite sizes irradiated for various doses at 250°–275° C. They explain the extra phonon scattering arising from the irradiation by attributing it to interstitial clusters, one cluster per crystallite-plane, and they reckon that vacancies make only a small contribution. This explanation is not entirely satisfying. For, at all crystallite sizes studied[1], the increase of thermal resistivity on irradiation was found experimentally to be comparable with the thermal resistivity before irradiation, implying that the mean free path of scattering from irradiation-induced defects, L_i, is comparable with the mean free path for crystallite-boundary scattering, L_a, which is taken as equal to the mean crystallite diameter. This means that if there is only one scattering defect per crystallite-plane, then the diameter of this defect is a substantial fraction of the crystallite diameter, and therefore the concentration of surviving interstitials is large, say at least 10 per cent. With a dose of only 177 MWD/Ate, however, the number of displaced atoms calculated by the Kinchin–Pease method[2] is only about 2 per cent and at 250° C a large proportion of these are lost by recombination with vacancies; this is confirmed by electron microscopy of single crystals[3] and by stored energy results[4]. There cannot,