On the Redefinition of the Second and the Velocity of Light*

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Summary—**This summary article resulted from an informal discussion period held during the International Conference on Precision Electromagnetic Measurements, August 14–17, 1962. This session was presided over by Prof. Norman Ramsey of Harvard University. The Radio Standards Laboratory of the National Bureau of Standards in Boulder, Colorado, sponsored the meeting along with the IRE Professional Group on Instrumentation and the AIEE Instrumentation Division. Partial support for the conference came from a grant from the National Science Foundation.**

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A VERY POPULAR session at the International Precision Electromagnetic Measurements Conference was the Thursday night meeting called to discuss the proposed atomic definition of the second, and methods for measuring the speed of light. This discussion was moderated and stimulated by Prof. Ramsey, who entertained the participants throughout the two hour meeting with remarks such as his invitation to the proponents of the pendulum clock to speak up, with his diplomatic attempts at quelling various semantic debates, and with his impartiality in requesting the advocates of the various atomic devices to speak out for their systems.

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After Prof. Ramsey's opening remarks, the first part of the meeting was devoted to the redefinition of the second. Dr. J. M. Richardson gave a résumé of the historical developments that had set the stage for the discussion. The International Committee of Weights and Measures will make, in 1966, a recommendation to adopt a definition of the second based on an atomic system. It has created a subcommittee, the Consultative Committee for the Definition of the Second (CCDS) to study this question. During the evening, numerous proponents of cesium, thallium, hydrogen, ammonia, rotational molecular transitions, and optical pumped devices were found who made statements about the suitability of the substances or techniques for redefining the unit of time. Among them were several members of the CCDS subcommittee, namely, Drs. Essen, Markowitz, De Prins, Bonanomi, Henderson, Mockler, and Richardson. The consensus was that it seems to be too early to consider the inadequacy of any of the techniques presently under development. Prof. Ramsey summarized the information expressed in a few remarks to which there was no voiced objection. In effect, he said: We ought to stick to the 1966 date for defining the new unit of time. The definition ought to be the best that can be determined somewhat before that date by keeping our eyes open during the next two years for what will prove itself to be the best. Cesium is a good horse with a good head start and any other horse must show itself to be a really first rate one. There are some possibilities but no certainties that it will be overtaken.

Should some standards prove to be better than cesium it would be difficult with present techniques to effect the comparison between laboratories that would prove this. Dr. De Prins noted that estimated precisions obtained in a single laboratory are sometimes in parts of 10^{12}–10^{13} range, but comparisons between separate laboratories are reported in the 10^{10}–10^{11} range. There was a brief description of statistical difficulties in making intercomparisons. Among these are not only the discontinuities in data due to gaps in reporting by the several laboratories studied, but also the observed non-Gaussian nature of the fluctuations in frequency reported by the monitors. As a result, it was noted that atomic time comparisons have some advantage over frequency comparisons. However, a slide presented at the meeting to give a comparison of atomic times assigned to WWV pulses by the Naval Observatory and by the NBS showed over a four-year period a discrepancy that averaged to six parts in 10^{11} but at times was in parts in 10^{10} range. Dr. Bender expressed the opinion that the need for a system capable of comparing time scales to the 1-μsec level is a problem that needs a solution before 1966. Dr. Markowitz indicated that there was hope in using the Loran C modification by March 1963 between the European and North American continent for this purpose. During the week of the meeting, it was noted that a radio news broadcast told of the satellite Telestar making such intercomparisons.

Concerning the multiplicity of time scales, it may be noted that there are seven types of time for scientific purposes. One can, of course, have several scales of time such as a civil scale and a scientific scale that would have the same unit of interval, but the civil scale could differ by incorporating discontinuities in it similar to leap year.

The second part of the evening discussion was concerned with experiments in progress, or proposed, for determining the speed of light. Among these was described a microwave interferometer of the Michelson type to measure 50-kMc waves at the Boulder laboratories. Dr. Boyne of the NBS in Washington analyzed a novel method utilizing an optical maser as a source. Dr. Essen of the National Physical Laboratory is of the opinion that their determination of c will be to a few parts in 10^8.

During this part of the discussion, Mr. McNish made the point that present light speed measurements are all less accurate than length and time interval measurements. Dr. Ramsey also stated that since we have an MLT system, the speed of light must still be determined experimentally even though it is a theoretically invariant constant. In response to an expressed interest of Dr. Richardson as to just what are the present theoretical limitations in concept on the constancy of the speed of light, Dr. Shimoda noted that the possibility of a nonzero photon rest mass resulting in dispersion of light seems to yield a figure of one part in 10^{16} as an interesting region for investigation.

It is apparent that the main functions and results of these discussions were to raise and pose more questions than could be considered in detail in such a meeting. Some remarks of especial interest to the writers indicated a grave concern for the limitations which our present relativistic notions of space and time place on the definition of a standard clock, dissemination of time information over the earth, and the concept of the universal constancy of the phase speed of light. In fact, in his opening remarks, Dr. Richardson had expressed the thought that it would be wise to state in the report of the CCDS experimental limits to support the idea that what we call time, or more appropriately proper time, is in reality a single simple concept. We wish to add here a few comments on these questions and shall develop them at length in a later analysis.

We maintain the point of view of the theory of relativity and hold that time and space are relative concepts and the presence of gravitational fields is a manifestation of the curvature of space time. It is ordinarily asserted that a standard clock in an inertial frame of reference will record the *proper* time. The proper time intervals generated by two clocks in relative motion in different inertial frames are related by a Lorentz transformation. However, one should note that it is not possible to realize ideally the requirement that all parts of an atomic time standard should operate in a single inertial frame of reference. Consequently, studies should be made of the effect of departures of a clock from an ideal device. One should then be able to correct the standard unit generated by an operating device to ideal field-free conditions. Present estimates, for example, indicate that the elastic distortions produced by operation in a reference frame on the earth's surface yield negligibly small effects. We feel at present that the main contribution of such studies will lead to conceptual clarification rather than to significant numerical corrections for some time to come.

Concerning the speed of light, one should carefully distinguish between the coordinate speed which can depart quite widely from the value c and the speed as measured locally in proper units in an inertial frame of reference. The latter speed is always c. Any deviation from this using proper time and length units would be remarkable. Because the curvature of space time near gravitating masses produces an unavoidable distortion of our coordinate systems over an extended region, one can observe coordinate deviations of the speed of light. This should be interpreted as reflecting a change in local coordinate scale units and not in the proper light speed. The magnitude of such an effect on our coordinate scale units due to a difference in gravitational potential can be as much as one or two parts in 10^9 near the earth.

To describe, convert, and compare happenings at large distances and different times, people use coordinate systems. These coordinate systems must be specified by physical means. The question arises as to the effect of the rotation of the earth on the assignment of time and space scales at each point of the earth's surface. Since the earth is nearly spherical, gravitational field effects over the surface are small. Nevertheless, if one imagines clocks attached to the surface and generating at each point the proper time unit characteristic of that place, he will find that the spatial coordinate lines of latitude and longitude cannot be stationary; but if the time coordinate for the earth is generated by a single clock in the inertial system of the fixed stars and a stationary spatial network is introduced, the proper time at any point on the surface of the earth will depend on the latitude. Also, the coordinate speed of light will be different when measured from east to west or from west to east. These coordinate effects are reflections of the effect that no rigidly rotating frame of reference exists whose space time coordinate axes are all orthogonal in the relativistic sense. One method for generating a coordinate time scale for the earth is to use a clock in a satellite. In this case, in order to determine the proper time at a point, one would need, of course, to correct for the Doppler shift including the gravitational effect. To sum up, we emphasize that an inertial reference frame which covers the earth continuously cannot be found for which the spatial axes are always and everywhere perpendicular, for which the time coordinate measures the proper time, and for which the speed of light has the one coordinate value c. Space does not permit us a more detailed examination of these questions. We merely hope that our remarks have made clearer the limitations which must be considered in adopting a conceptually correct redefinition of the unit of time. It is our opinion that the conceptual requirements of relativity, indeed, furnish us with additional reasons why an atomic standard for proper time as well as one for length should be adopted.

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