NEW EXPERIMENTAL TEST OF SPECIAL RELATIVITY

J. P. Cedarholm, G. F. Bland, and B. L. Havens
International Business Machines
Watson Laboratory at Columbia University, New York, New York

and

C. H. Townes
Department of Physics, Columbia University, New York, New York
(Received September 29, 1958)

The relative frequency stability of two beam-type maser oscillators is used to test the dependence of the velocity of light on velocity of the frame of reference with considerably more precision than has been obtained from experiments of the Michelson-Morley[1] type. Expressed in terms of an ether, the maximum ether drift is shown to be less than 1/1000 of the earth's orbital velocity.

The experiment, which was performed at the Watson Laboratory, involves comparison of the frequencies of two masers[2] having their beams of NH_3 molecules traveling in opposite directions. Møller[3] has analyzed this case and given the change in frequency of a beam-type maser due to ether drift, assuming the molecules in the beam to have a velocity u with respect to the cavity through which they pass, and the cavity to have a velocity v with respect to the ether. The shift may be simply discussed by assuming that, if v is zero, radiation is emitted perpendicularly to the molecular velocity so that there is no Doppler shift. If the cavity and beam are then transported at velocity v through the ether in a direction parallel to u, radiation must be emitted by the molecules slightly forward at an angle $\theta = \pi/2 - v/c$ with respect to u. The fractional change in frequency due to the Doppler effect is then $\epsilon = u/c \cos\theta$ or uv/c^2 due to motion through the ether, assuming that the proper molecular frequencies are unchanged by such motion.

For a thermal molecular velocity of 0.6 km/sec and for the earth's orbital velocity (30 km/sec), $\epsilon = 2 \times 10^{-10}$. The difference in frequency due to the above effect between two masers with oppositely directed beams would be $2\epsilon\nu$, or about 10 cps for ν equal to 23 870 Mc/sec, the NH_3 inversion frequency.

Although uv/c^2 is of second order in the velocities, it is of first order in the velocity of the cavity, or of the laboratory, with respect to the ether. The present experiment measures the entire effect with a rather small fractional error, which affords a particularly small upper limit to v since this quantity enters in first order, rather than in second order as in the Michelson-Morley experiment. A somewhat similar term would occur in the latter experiment if the interferometer used were transported by a plane of speed u, and interference fringes were compared for two opposite directions of flight.

Two maser oscillators with oppositely directed beams were mounted with necessary auxiliary equipment on a rack which could be rotated about a vertical axis. The beat frequency between the two oscillators was adjusted to about 20 cps and recorded continuously. After approximately one minute of recording with the maser axes oriented in an east-west direction, the apparatus was rotated 180° and the beat frequency recorded in the new position.

The change in beat frequency, on the basis of an ether drift, should be $4\epsilon\nu$, or about 20 cps. Sixteen such comparisons were made during a period of about 20 minutes. These were repeated about once per hour during a time somewhat longer than 12 hours, so that the earth's rotation would sweep the east-west direction through a plane.

A relative change in frequency of the two oscillators amounting to about 1 cps was found when they were rotated through 180°. This change is largely due to the earth's magnetic field and other local magnetic fields from which no shielding was attempted. The significant observation is that this change was independent of the time of day (or orientation of the earth), as indicated in Fig. 1.

The first series of measurements was made during a week-day, when local magnetic fields and line voltages were varying. It showed some systematic variations in the effect measured as large as $\pm 1/20$ cps during the day. A second series of measurements, taken on a Saturday when local disturbances were less serious, showed no variation greater than $\pm 1/50$ cps as indicated in Fig. 1, and even these appear random and not simply correlated with time (or the earth's orientation). This precision corresponds to a comparison of frequencies of the two masers to one part in 10^{12}.

The results show that any term of the form uv/c^2 must be smaller by a factor of at least 1000 than what would be predicted by setting v equal to the earth's orbital velocity. That is, velocity with respect to an ether in a plane per-

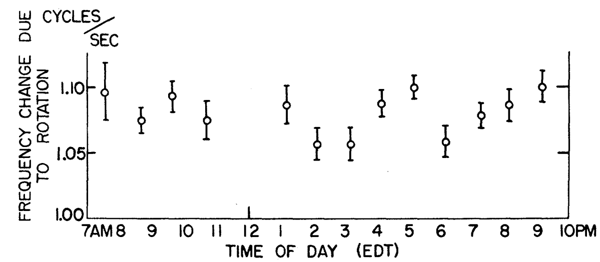

FIG. 1. Diurnal variation of the change in relative frequency due to rotating two ammonia masers through 180°.

Beams of the two masers were oppositely directed and in an east-west direction. The change of about 1.08 cps is primarily due to local magnetic fields. Maximum deviation from this value during the day is 1/50 cps. Lengths of lines indicate probable errors computed from fluctuations of 16 measurements at each point.

pendicular to the earth's axis must be less than 1/30 km/sec. Results from experiments of the Michelson-Morley type vary from an ether drift of about 8 km/sec reported by Miller[4] to an upper limit of 1.5 km/sec given by the experiments of Joos.[5] Of course a major part of the advantage of the present experiment is its first-order rather than second-order dependence on v.

Those who are already completely convinced of the correctness of special relativity, or who do not wish to consider an ether model, should note that postulates of special relativity are not necessarily inconsistent with the existence of a frequency shift in the above experiment or of an anisotropy in space. These can result from the presence of matter external to the earth which is not uniformly distributed, or which is not moving with the earth's velocity.

The preliminary results quoted here apply to September 20, 1958. It is expected that the experiment will be refined further and that additional measurements will be made at other times during the year.

---

[1] A. A. Michelson and E. W. Morley, Am. J. Sci. 34, 333 (1887).

[2] Gordon, Zeiger, and Townes, Phys. Rev. 99, 1264 (1955).

[3] C. Møller, Suppl. Nuovo cimento 6, 381 (1957).

[4] D. C. Miller, Revs. Modern Phys. 5, 203 (1933). See also Shankland, McCuskey, Leone, and Kuerti, Revs. Modern Phys. 27, 167 (1955).

[5] G. Joos, Ann. Physik 7, 385 (1930).

ANISOTROPY OF THE C^{13} CHEMICAL SHIFT IN CALCITE

Paul C. Lauterbur
Mellon Institute,*
Pittsburgh, Pennsylvania
(Received October 10, 1958)

It has been shown by Ramsey[1] that the chemical shift of a nuclear magnetic resonance can be anisotropic. Since the shift tensor is a dyadic, the shifts will be a function of the orientation of the molecule in a magnetic field for nuclei in environments of lower than tetrahedral symmetry. An indication of the presence of such an anisotropy was first found by Bloembergen and Rowland,[2] who attributed the asymmetry of the Tl^{205} resonance in powdered Tl_2O_3 to this effect. Shift anisotropies have also been invoked by Gutowsky and Woessner[3] to explain the T_1 difference between H^1 and F^{19} in 1, 3, 5-trifluorobenzene, and by McConnell and Holm[4] to account for the relatively short T_1 of C^{13} in CS_2.

A direct measurement of the anisotropy of the C^{13} shift in a single crystal of calcite ($CaCO_3$) has now been made. This substance is ideal for such an experiment because all magnetic nuclei are present in such low abundance that dipolar broadening is negligible and a sharp strong line is observed. The apparatus used was a Varian 4300*B* High Resolution NMR spectrometer operating at 8.5 Mc/sec, and a Varian 12-inch electromagnet. The dispersion mode was used and the lines were measured under rapid passage conditions. The observed line widths, about 20 milligauss, were the result of H_1 broadening. The magnetic field inhomogeneity over the sample volume was about 10 milligauss, and approximate calculations by the method of Kittel and Abrahams[5] indicated a dipolar broadening of the order of 5 milligauss. T_1 was found to be about 40 minutes in the sample used, which was a cleavage rhombohedron of clear colorless "Iceland spar" about 0.3 cm^3 in volume. The crystal was aligned visually with its trigonal axis in the plane of a graduated glass ring which was set vertically in a tube filled with acetone, whose C^{13} resonances were used as secondary standards. The whole assembly was turned by a goniometer head attached to the probe. Final alignment was made by observation of the angular variation of the shift and was accurate to within about one degree.

The carbonate ion (CO_3^{--}) has a three-fold axis. The operation of the shift dyadic will, therefore, give a shift ellipsoid of revolution which can be