NEW EXPERIMENTAL TEST OF SPECIAL
RELATIVITY

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The relative frequency stability of two beam-
type maser oscillators is used to test the de-
pendence of the velocity of light on velocity of
the frame of reference with considerably more
precision than has been obtained from experi-
ments of the Michelson-Morley 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 having their beams
of NH$_3$ molecules traveling in opposite directions.
Møller 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 transport-
ed 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 $u v/c^2$ due to motion through the
ether, assuming that the proper molecular fre-
quencies 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 op-
positely directed beams would be $2 \epsilon v$, or about
10 cps for $\nu$ equal to 23,870 Mc/sec, the NH$_3$
inversion frequency.

Although $u v/c^2$ is of second order in the veloc-
ities, 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 inter-
ferometer 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 ro-
tated 180° and the beat frequency recorded in the
new position.

The change in beat frequency, on the basis of
an ether drift, should be $4 \epsilon v$, 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 os-
cillators 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 shield-
ing 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 ran-
donated 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
$u v/c^2$ 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.

ANISOTROPY OF THE C\textsuperscript{13} CHEMICAL SHIFT IN CALCITE

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It has been shown by Ramsey\textsuperscript{4} 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,\textsuperscript{2} who attributed the asymmetry of the T\textsubscript{100} resonance in powdered T\textsubscript{1}O\textsubscript{3} to this effect. Shift anisotropies have also been invoked by Gutowsky and Woessner\textsuperscript{3} to explain the \( \delta \) difference between H\textsuperscript{1} and F\textsuperscript{19} in 1,3,5-trifluorobenzene, and by McConnell and Holm\textsuperscript{4} to account for the relatively short \( \tau \) of C\textsuperscript{13} in CS\textsubscript{2}.

A direct measurement of the anisotropy of the C\textsuperscript{13} shift in a single crystal of calcite (CaCO\textsubscript{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 4300B 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\textsuperscript{5} indicated a dipolar broadening of the order of 5 milligauss. \( \tau_1 \) 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\textsuperscript{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\textsuperscript{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\textsubscript{3}\textsuperscript{2-}) has a three-fold axis. The operation of the shift dyadic will, therefore, give a shift ellipsoid of revolution which can be

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\textsuperscript{1} A. A. Michelson and E. W. Morley, Am. J. Sci. 34, 333 (1887).
\textsuperscript{3} C. Møller, Suppl. Nuovo cimento 5, 381 (1957).
\textsuperscript{5} G. Joos, Ann. Physik 7, 385 (1930).