IX. MOLECULAR BEAMS

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RESEARCH OBJECTIVES

Three kinds of research are pursued in the molecular beams group:

1. High-precision studies of atomic and molecular radiofrequency spectra, an example being the study of the rotational spectrum of HF.

2. The development and intercomparison of atomic frequency standards. The CS electric resonance studies and the ammonia molecule decelerator are examples. Work is also being done to determine the system properties of a cesium beam tube, and to develop complementary electronics to realize its latent frequency stability. These new clocks and others of different types will be intercompared by using the M. I. T. computer facilities in order to check for possible variations in rate with epoch.

3. Experiments that apply parts of these techniques to interesting problems in any area of physics, as in the following list:

(a) The measurement of the velocity of light in terms of atomic standards,

(b) the search for a charge carried by molecules,

(c) an experiment on an aspect of continuous creation.

These problems are well advanced. In an earlier phase are the following experiments:

(d) the velocity distribution of He atoms from liquid He,

(e) experiments with slow electrons (10^{-6} ev).

J. R. Zacharias, J. G. King, C. L. Searle

A. STARK EFFECT AND HYPERFINE STRUCTURE OF HYDROGEN FLUORIDE

The nuclear hyperfine-structure constants and the electric dipole moment of hydrogen fluoride, H^1F^{19}, in the ground vibration and first excited rotation state have been measured in a molecular beam electric resonance experiment. The hfs constants are

$$c_F = 307.6 \pm 1.5 \text{ kc}$$

$$c_P = -70.6 \pm 1.3 \text{ kc}$$

$$\frac{2}{5}\frac{g_P g_F \mu^2 nm}{h\langle r^3\rangle} = 57.6 \pm .44 \text{ kc}.$$

The apparatus was calibrated by observing Stark transitions in the ground vibration and first excited rotation state of carbonyl sulfide, $O^{16}C^{12}S^{32}$, and the results were:

$$\frac{\mu_{HF}}{\mu_{OCS}} = 2.554 \pm .0037 \quad \text{or} \quad \mu_{HF} = 1.8195 \pm .0026 \text{ debye}$$

by using $\mu_{OCS} = 0.7124 \pm .0002$ debye.

An absolute measurement of the OCS electric dipole moment gave

$$\mu_{OCS} = 0.7120 \pm .003 \text{ debye.}$$

A digitally computed solution of the Stark effect with magnetic hyperfine structure was necessary to interpret the data. The theory and experiment are in good agreement over the range of electric field strengths used in the experiment.

The hfs constants are in excellent agreement with the averaged absolute values of these constants as measured in a molecular beam magnetic resonance experiment.[1] The agreement has significance because of discrepancies between the results of the two resonance methods, for some other molecules, in previous experiments.

R. Weiss

References

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B. CS MASER

The rotational transition (J = 1→0) of CS should provide a more precise molecular frequency standard than other molecular resonances currently used. This transition occurs near 50 kmc.

The principal advantage of using CS, rather than NH_3 or others, is that C^{12} and S^{32} both have zero nuclear moments so there is no spin-spin or spin-rotational interaction.

The permanent dipole moment of CS is rather large (2 debye), so small rf fields are necessary to cause transitions, and small static fields are needed to deflect the beam. The physical construction of the proposed maser would be similar to the original "maser"[2] except that a two-pole deflecting field (state selector) and a two-cavity rf system[3] will be used.

The average lifetime is approximately 30 minutes in an enclosed vessel at room temperature,[4] so the CS must be produced as it is used. Sufficient quantities of CS for a molecular-beam experiment have been produced in our laboratory by dissociation of CS_2 in electrical discharge, and on a hot tungsten wire (2000°C). The resulting vapor is passed through a trap at -100°C, and thus the CS_2 is removed, leaving CS.

S. G. Kukolich

References

1. K. Shimoda, J. Phys. Soc. Japan 12, 1006 (1957).

2. J. P. Gordon, H. J. Zeiger, and C. H. Townes, Phys. Rev. 95, 282 (1954).

3. S. G. Kukolich, Measurements of the 1-1 Inversion Frequency of NH_3 and Experiments with a Two-Cavity Maser, S. B. Thesis, Department of Physics, M. I. T., May 19, 1962.

4. R. C. Mockler and G. R. Bird, Phys. Rev. 98, 1837 (1955).

C. AMMONIA DECELERATION EXPERIMENT

One method of increasing the interaction time of free molecular systems and electromagnetic fields would be to deal with molecules of slow velocity. A linear decelerator designed to provide slow molecules with an intensity that is increased over that predicted by the Boltzmann distribution has been described by Zacharias and King.[1]

The trajectories of ammonia molecules in that device have now been analyzed. We have concluded that the focusing of the last stage was too strong. It is estimated that the transmission of the first 24 stages is greater than $\sim (1/25)$, while the transmission of the last stage is $\sim 10^{-3}$. These estimates make no allowance for possible misalignment of the plates.

Plates with zero focusing have been designed, and the dynamic characteristics of an array of 15 such stages have been studied by using a computer. The duty cycle and bunching characteristics of these stages are not as satisfactory as the parallel plates, but the over-all transmission of the two systems is comparable.

Work is being done, at present, along three lines:

(a) An attempt to improve the characteristics of the nonfocusing plates by considering voltage waveforms other than square waves applied to the plates;

(b) Experiment with a hybrid system consisting of 24 parallel-plate stages and a nonfocusing last stage; and

(c) Consideration of an experiment to demonstrate the principle of deceleration in a limited number (2 or 3) of stages.

R. Golub, B. Brabson

References

1. J. R. Zacharias and J. G. King, Linear decelerator for molecules, Quarterly Progress Report, Research Laboratory of Electronics, M. I. T., January 15, 1958, pp. 56-57.

D. He_3 AND He_4 BEAMS

Initial study has been undertaken on the feasibility of producing and detecting beams of atoms evaporated from the surface of liquid He_3 and He_4 at low temperatures. It is proposed that an "Omegatron" type of radiofrequency mass spectometer[1] be employed as a detector, and such a device has been assembled and operated during the past quarter. A usable sensitivity of ~ 1 ma of ion current per mm Hg for He_4 has been obtained, at a background pressure of 10^{-7} mm Hg in an oil diffusion-pumped system. It is anticipated that this sensitivity is sufficient to permit analysis of beam velocity spectra, and it is hoped that information regarding phenomena in liquid He_3 and He_4 may be gained thereby.

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References

1. Cf. D. Alpert and R. S. Buritz, J. Appl. Phys. 25, 202 (1954).

E. MEASUREMENT OF THE VEOLCITY OF LIGHT

During the past quarter, all functions of the velocity of light apparatus, electrical, optical, mechanical, for the first time operated simultaneously. The schematic diagram of the apparatus is shown in Fig. IX-1. The figure emphasizes the electronics system

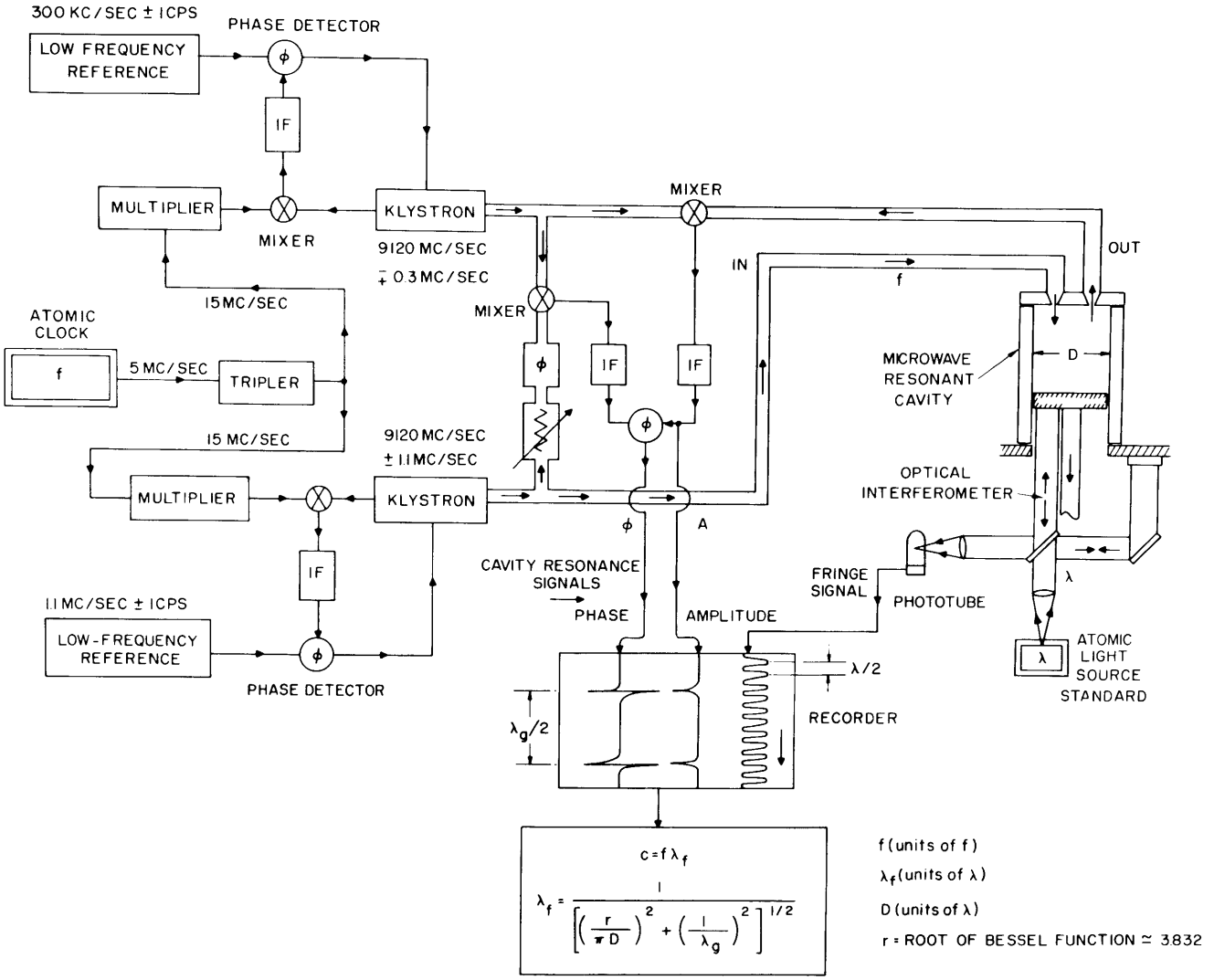

Fig. IX-1. Schematic diagram of velocity-of-light measurement method. The basic equation for the experiment is $c = f\lambda_f$, where λ_f is obtained by measurement of the guide wavelength λ_g in terms of optical interference fringes. Diameter D measurements can be eliminated by measurement of guide wavelengths at two frequences f, both determined with reference to the atomic clock.

because we have already given detailed description of the optical system and the hydraulic drive in previous reports. The system measures the relative phase of the cavity in order to achieve as precise a measurement of λ_g as possible. The signals derived from the microwave and optical systems will be recorded on an FM tape recorder to facilitate data reduction.

We have previously reported that the cylindrical quartz cavity has been optically polished so that its diameter has a precision $\frac{\delta D}{D}$ of approximately $\pm 3 \times 10^{-6}$. Now, from the basic equation

$$\lambda_f = \frac{1}{\left[\left(\frac{r}{\pi D}\right)^2 + \left(\frac{1}{\lambda_g}\right)^2\right]^{1/2}}, \tag{1}$$

which relates the free-space wavelength λ_f to the guide wavelength λ_g, and from the equation

$$c = f\lambda_f, \tag{2}$$

we find that, for the cavity diameter, D = 161.1 mm, and the guide wavelength, $\lambda_g \approx 33.88$ mm, used, we have

$$\frac{\partial c}{c} = \left(1 - \frac{6.5}{10^2}\right)\frac{\partial \lambda_g}{\lambda_g} \tag{3}$$

and

$$\frac{\partial c}{c} = \frac{1}{16}\frac{\partial D}{D}, \tag{4}$$

and therefore

$$\frac{\Delta c}{\Delta \lambda_g} \approx 2.25 \frac{\text{km/sec}}{\text{fringe}} \tag{5}$$

and

$$\frac{\Delta c}{\Delta D} \approx \frac{3.2 \text{ km/sec}}{10^2 \text{ fringes}}. \tag{6}$$

In other words, if no diameter corrections at all are made, then the apparatus should yield the value of C within a few parts in 10^7, provided that λg can be measured to within a few parts in 10^7 or approximately 1/100 fringe.

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