VI. MOLECULAR BEAM RESEARCH

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A. THE HYPERFINE STRUCTURE OF THE $P_{3/2}$ STATE OF STABLE BROMINE ISOTOPES

The hyperfine structure of the $P_{3/2}$ state of both stable bromine isotopes ($_{35}Br^{79}$, $_{35}Br^{81}$) has been measured. A report on this work is being prepared for publication.

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B. PROPOSED PRECISION MAGNETIC RESONANCE EXPERIMENT

As early as 1940, I. I. Rabi suggested that the hyperfine structure of the ground state of Cs^{133}, 9192 Mc/sec, as observed by the molecular beam magnetic resonance method, could be used as a time standard and that one might be able to measure the gravitational red shift of an atomic clock on the earth. Recently Lyons (1) and others of the National Bureau of Standards have made a careful measurement of this frequency and developed equipment for using it as a reference standard for time. Their precision is limited by the time that the cesium atoms remain in the radiofrequency field, and their present curves are about 3 kc/sec broad. It is the purpose of the present note to indicate how this precision may be extended to linewidths of 1 cps or less with corresponding improvement in precision timing to several parts in 10^{13}.

Consider a beam of cesium atoms moving upward in a well-evacuated vessel. Atoms with an initial velocity of about 10 m/sec will rise 5 m and fall back down onto a detector. In rising and falling they might pass through an inhomogeneous magnetic field which would serve as both deflecting and analyzing field in the molecular beam method. At the top of the path there could be located the collimating slit and a radiofrequency flopping field, perhaps 1 m long in which the atoms will remain for about 1 sec, allowing a linewidth of 1 cps.

It appears that this experiment can be performed without the loss in beam intensity that one might first expect because of gas scattering of slow atoms and the low population of slow atoms in a beam.

For a molecular beam, the expression for the distribution of speeds v is given by

$$(v^3/a^4)\, e^{-v^2/a^2}\, dv, \text{ where } a = (2kT/m)^{1/2}$$

giving approximately 300 m/sec for cesium at 400°K as the most probable velocity in a beam. We therefore consider working with $(0.03)^4$ or 10^{-6} of the total beam. Now the deflection of a beam in a molecular beam resonance experiment is proportional to $1/v^2$

so that we have $(30)^2$ more deflecting power than in the usual experiments. We can use this factor by making the area of the slit system (source, collimator, and detector) 1000 times greater in area (30 times wider and 30 times higher). Since the so-called intensity of a beam (total number of usable atoms) varies as the square of the slit area, we have a factor of 10^6 to cancel the loss mentioned above. The factor of 30 not used in slit width is used to increase the aperture in the deflecting and refocusing magnet, making the ratio of gradient to field 0.03 instead of about 1, as usual.

Concerning gas scattering: the mean free time in the apparatus would have to be a few seconds, which is to be expected at a pressure of 10^{-7} mm Hg. Naturally one should try to use lower pressures, which can indeed be obtained in clean systems with getter pumps or other devices.

If it really becomes possible to use this low-energy end of the Maxwell distribution, it should become possible for the first time to use highly effective (2, 3) focusing of a divergent beam. For instance, if the source of the beam is placed in a field of 10^4 gauss and the exit canal or canals are situated at a point of high magnetic gradient, it will be possible to collimate the beam from a rather wide angle into a ribbon 1 cm wide, as proposed here. Chromatic aberration of the magnetic lens is of no great concern, since gravity itself produces velocity selection at the top of the path. It should also be mentioned that we have here an analogy with ion optics with the additional feature that the sign of the deflection can be reversed in the field by means of radiofrequency flipping.

It should be noted that for cesium atoms discussed here with one Bohr magneton in 10^4 gauss, $\mu_o B \approx 10^{-16}$ ergs $\approx$ mgh $\approx mv^2/2$.

Consideration has been given to the possibility of mounting the beam source on a wheel which rotates in such a direction that it moves away from the detector when it faces it. At a peripheral speed of 3×10^4 cm/sec we would be using those atoms which have, in the oven, the most popular velocities. This process regains only two of the four factors of v and may not be worth the complication except in the case of molecules other than cesium to which this general precision technique may be applicable.

Experiments are now under way to find the low-velocity atoms, preparatory to building an apparatus for precision frequency control with cesium, and for precision measurements with other substances.

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References

1. Harold Lyons: NBS Report 1848, August 8, 1952, contains a complete discussion of this subject with many references
2. M. I. Korsumskii, Ya. M. Fogel: J. Exp. Theor. Phys. (U.S.S.R.) 21, 25, 1951
3. H. Friedburg, W. Paul: Naturwiss. 38, 159, 1951