X. MOLECULAR BEAMS[*]

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RESEARCH OBJECTIVES

Three kinds of research are pursued in the molecular beam laboratory:

1. High-precision studies of atomic and molecular hyperfine structure, an example being the recent discovery and measurement of an octopole interaction in the bromine atom.

2. The development of atomic frequency standards by using atomic and molecular-beam techniques. The carbon monoxide electric resonance studies and the ammonia molecule decelerator are examples. Work is also being done to determine the basic characteristics of an atomic frequency standard that makes use of a cesium beam tube as a frequency reference, and to develop complementary electronics to realize its latent frequency stability. Studies are also being made of a method of generating an extremely stable microwave signal by using a super-cooled lead cavity oscillator. This could replace the usual crystal oscillator-harmonic generator method of beam-tube excitation.

3. Experiments that apply parts of these techniques to interesting problems in any area of physics, for instance, the measurement of the velocity of light in terms of atomic standards or the search for a charge carried by molecules.

<div align="right">J. R. Zacharias, J. G. King, C. L. Searle</div>

A. BROMINE EXPERIMENT

The atomic-beam magnetic-resonance method has been used to measure the hyperfine structure of the $^2P_{3/2}$ ground state of Br^{79} and Br^{81}. The values obtained for the nuclear dipole, quadrupole, and octopole constants, uncorrected for second-order perturbations, are in cps:

	Br^{79}	Br^{81}
a	$884,811,540 \pm 62$	$953,770,006 \pm 62$
b	$-384,880,292 \pm 200$	$-321,520,344 \pm 200$
c	163 ± 8	235 ± 8

The positive value of the nuclear dipole moment has been confirmed.

A paper describing this work is in preparation for submission to the Physical Review.

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B. NEUTRALITY-OF-MOLECULES EXPERIMENT

It can be said with fair confidence that molecules of argon, nitrogen, helium, and hydrogen carry charges less than 10^{-20} of an electron per molecule as measured by an extensive series of Piccard-Kessler experiments. Further analysis of the data, experiments with deuterium, and the construction of the largest economical apparatus should make it possible to improve the results still more.

J. G. King

C. CESIUM BEAM TUBE INVESTIGATION

The cesium atomic clock (Fig. X-1) can be divided into three basic parts: the stable microwave source, the beam tube itself, and the control circuitry necessary to center the microwave signal on the cesium resonance curve. At the present time, two cesium atomic clocks are being constructed with the use of the electronics described in the following sections. Also under construction is a measurement system to determine the frequency stability of the clocks, and to evaluate the performance of the varactor multiplier chains.
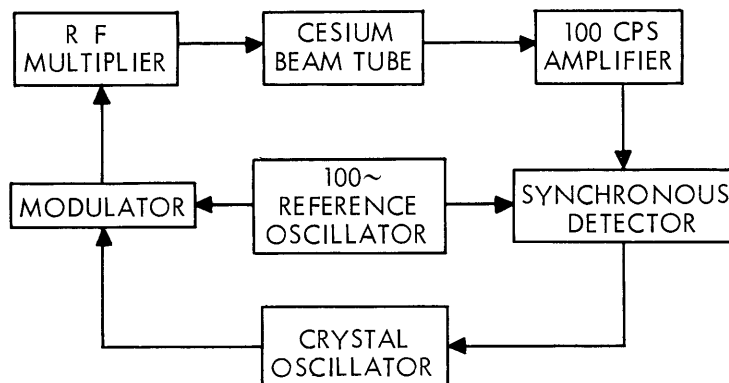
Fig. X-1. Atomic-clock block diagram.

The National Company's cesium beam tubes, which are being used, are the standard models that undergo cesium resonance shifts when variations in power level of the X-band excitation signal occur. Efforts are being made to stabilize the output power of the varactor multipliers to reduce this error. Eventually beam tubes of newer design, which do not have this effect, will be used.

1. Control Circuitry

To achieve stabilities of a few parts in 10^{12}, the electronic circuits of the atomic clock must split the cesium resonance curve by approximately 10,000. Such high

degrees of splitting require a control loop that is capable of as rapid a response as the signal-to-noise ratio and the beam-tube delay time will permit. For the present system the controlled crystal oscillator frequency will be slaved to the beam tube to such an extent that its own noise, or tendency to drift, will be completely overshadowed by that of the beam tube. In addition to this rapid response requirement, the control loop must not introduce internal drifts capable of off-setting the position of lock by more than one part in 10, 000 of the width of the cesium resonance curve.

The response time of the control loop used in this investigation was shortened considerably by eliminating the mechanical tuning of the crystal oscillator. In its place was substituted a variable-capacitance diode capable of changing the frequency electronically. The "varicap," which was mounted inside the temperature-controlled oven of the crystal, was found to have negligible effect on the crystal-oscillator stability.

Three potentially serious sources of drift in the control loop were eliminated. The first of these was the drift in the synchronous detector. A conventional synchronous detector has a reference signal with an amplitude that is generally a few times greater than the signal that is being detected, and is introduced into the circuit in a balanced fashion so that changes in the amplitude of the reference cause a minimum of unwanted dc voltage to appear in the output. Since any disturbance introduced into a loop having reasonably high gain will cause the loop to generate an equal and opposite reaction, the effect of a spurious dc voltage that appears at the output of the synchronous detector is to shift the frequency of the crystal oscillator to a point slightly removed from the peak of the cesium resonance. Considerations of signal-to-noise ratio and degree of resonance-curve splitting required for a stability of a few parts in 10^{12} have shown that the tolerable dc drift from reference unbalance is approximately 0. 04 per cent of the reference magnitude. This is an extremely difficult balance to maintain for any reasonable length of time, and this is the reason that a mechanical type of synchronous detector was chosen for the present application. The detector consists of a synchronous motor locked to 100 cps and having on its shaft a special commutator which serves as a signal chopper. This arrangement was chosen in preference to a vibrator chopper, partly because of its greater reliability and partly because a precise duty cycle of 50 per cent is easily maintained.

A second source of drift in the control loop was eliminated by providing sufficient 100-cps signal drive to the synchronous detector to increase its output and thereby make dc amplification unnecessary. Since a mechanical synchronous detector was used, the permissible drive was virtually unlimited.

A third source of drift in the control loop is associated with dissymmetry in the cesium-resonance characteristic. If such dissymmetry exists, any change in the modulation index of the 100-cps frequency modulation on the X-band excitation will result in a shift of the quiescent operating position on the cesium-resonance peak. To minimize

such effects, a modulator that was capable of maintaining a stable phase deviation was required. In the present system it was found convenient to do this mechanically by driving a variable capacitor from the same shaft as the synchronous detector and using it in an appropriate phase-shifting network.

2. Beam-Tube Excitation

The system that is being used at present for the cesium beam tube excitation incorporates a highly stable crystal oscillator whose frequency is a subharmonic of the cesium resonant frequency. The vacuum-tube oscillator circuit used for both clocks will yield a short term (1 minute) frequency stability of one part in 10^{-10}, provided that the crystals are mounted in a 0.01°C proportional control oven. Two different types of varactor multiplier were developed for generating the 9192-mc signal from the 16-mc oscillator signal: a high-level (1 mw) five-stage type previously reported[1,2]; and a low-level four-stage type that has recently been developed. Briefly, the new multiplier consists of a 5-volt, 16-mc amplifier stage, three cascaded doublers that furnish 200 mw at 131.5 mc, a unity gain amplifier stage at 131.5 mc, and a single ratio-seventy multiplier stage. The output power of the new multiplier is 50 μw.

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References

1. V. J. Bates, Cesium beam tube, Quarterly Progress Report No. 61, Research Laboratory of Electronics, M. I. T., April 15, 1961, pp. 107-109.

2. V. J. Bates, Cesium beam tube investigation, Quarterly Progress Report No. 62, Research Laboratory of Electronics, M. I. T., July 15, 1961, p. 125.

D. SUPERCONDUCTING LEAD CAVITY

Two attempts to cool the lead cavity to liquid-helium temperatures by using the system previously described[1] have proved unsuccessful. Two probable causes for this failure are the very low efficiency in the heat-scrubbing process, and the high thermal resistance between the liquid-helium container and the lead cavity. Since extensive modifications were performed on the cooling apparatus before the second abortive attempt, it was decided to abandon this apparatus. A double-dewar apparatus is now being constructed.

J. E. Steelman

References

1. J. E. Steelman, Superconducting lead cavity, Quarterly Progress Report No. 61, Research Laboratory of Electronics, M. I. T., April 15, 1961, pp. 108-109.