GENERAL PHYSICS

I. MOLECULAR BEAMS*

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A. OPTIMIZATION OF MODULATION FREQUENCY IN SQUARE WAVE PHASE MODULATION

In our continued program of investigating both theoretically and experimentally the properties of Square-Wave Phase Modulation (SWPM)[1,2] in atomic clocks, an experiment has been performed to determine the response of the system to the frequency of modulation. The results indicate that a somewhat higher frequency is desirable than was initially predicted.[2] A second result shows some deviation from our first-order theory.

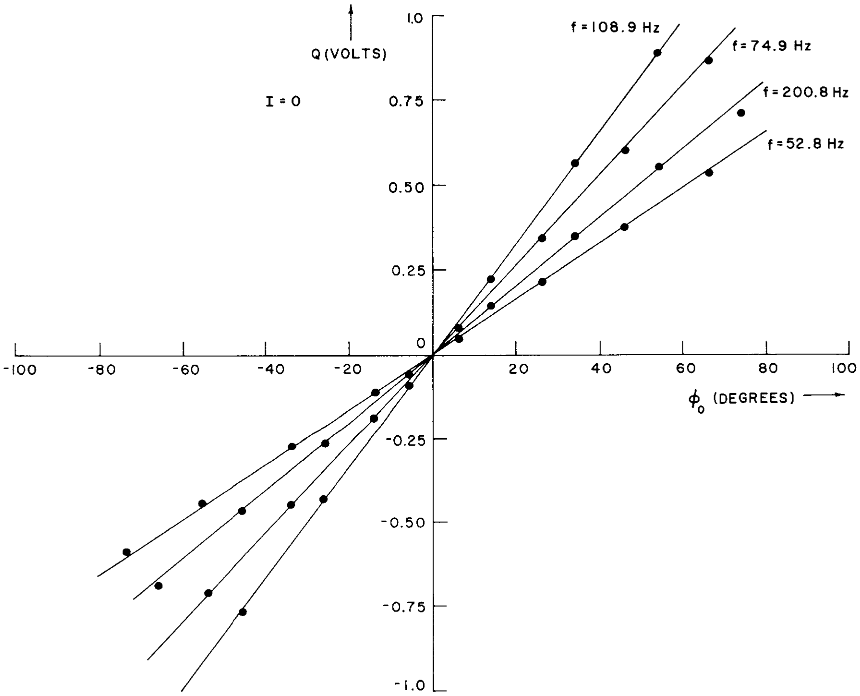

Fig. I-1. Variation of quadrature output with RF cavity phase error for various modulation frequencies.

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Figure I-1 illustrates a few of many quadrature signal response curves that were taken at various modulation frequencies. To obtain the data, the clock in-phase system was locked (I = 0) at the center of the resonance. The quadrature output, Q, was then measured with a synchronous detector whose phase had been adjusted to be 90° relative to the I-channel synchronous detector. A single curve on the graph represents this output for a given modulation frequency as a precision phase shifter varied the relative phase between the RF cavities in the microwave system. It should be mentioned that such curves have been obtained not only for the $4,0 \longleftrightarrow 3,0$ hyperfine transition but also for other σ and π cesium transitions.

A plot of the Q-loop sensitivity, $S_Q \equiv \frac{\partial Q}{\partial \phi_o}$, obtained from the slopes in Fig. I-1, is shown in Fig. I-2. It is seen that for the particular velocity distribution present in our apparatus (most probable velocity ≈ 160 m/sec) and the dimensions (RF cavity separation L = 128.7 cm, detector-to-cavity drift region L_1 = 100.7 cm) the maximum occurs at approximately 110 cycles. A theoretical curve, based on the calculations of D. Babitch and M. Bell, shows good agreement with the data except for the interesting "structures" at higher modulation frequencies. This phenomenon is still under theoretical scrutiny and is possibly associated with the RF field's making an integral number of phase steps

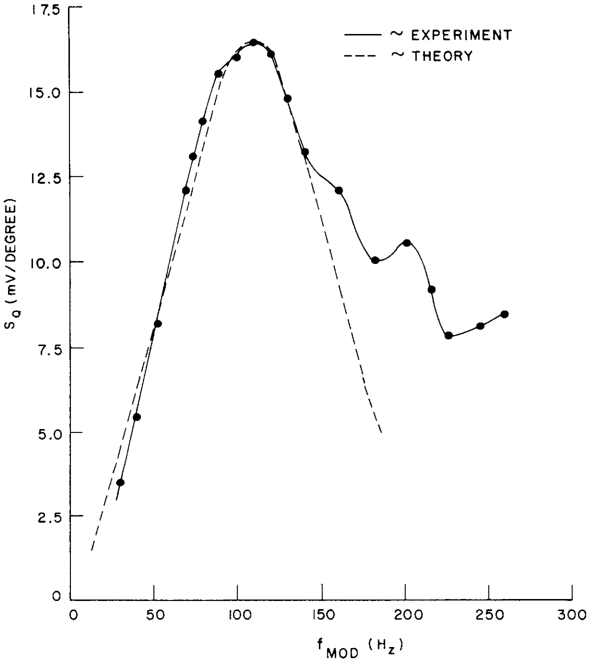

Fig. I-2. Quadrature sensitivity as a function of modulation frequency.

in the atom transit time between cavities.

Figure I-3 illustrates the sensitivity of the I-channel $S_I \equiv \frac{\partial I}{\partial \phi_o}$ as a function of modulation frequency. Note that the resonance linewidth was 60 Hz with a modulation frequency of 52.5 Hz, and increased monatonically to 74 Hz at 250 Hz. The optimum S_I is seen to occur at approximately 90 Hz. Thus a reasonable, and convenient, operating point which balances the two channel sensitivities will be at $f_{mod} = 100$ Hz.

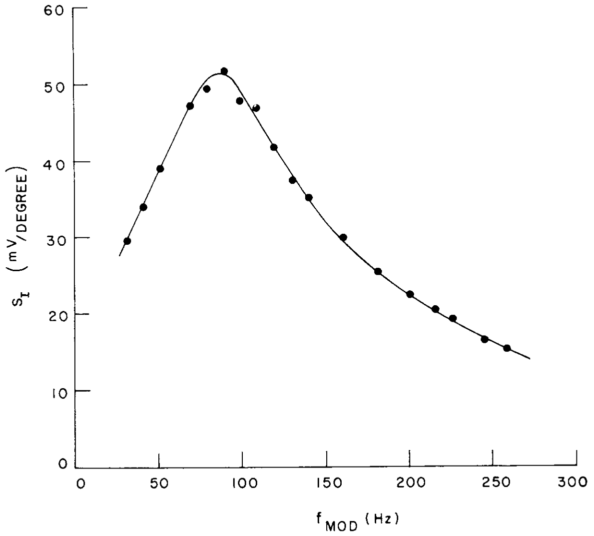

Fig. I-3. In-phase channel sensitivity as a function of modulation frequency.

K. W. Billman

References

1. R. S. Badessa, V. J. Bates and C. L. Searle, IEEE Trans. Vol. IM-13, No. 1, p. 175, January 1964.
2. S. G. Kukolich and K. W. Billman, J. Appl. Phys. 38, 1826 (1967).

B. THE TWO-CAVITY MASER AS A POSSIBLE FREQUENCY STANDARD

The J = 3, K = 2 inversion frequency of NH_3 has been measured, with the cesium hyperfine transition frequency used as a reference. These measurements were made in order to determine the frequence stability and resetability of the two-cavity maser system. The short-term stability over a period of 20 minutes with 20-sec averaging time was 3.2×10^{-11} (standard deviation). The standard deviation over a 3-hour period with 200-sec averaging time was typically 7×10^{-11}. The standard deviation for runs on different days was 5×10^{-11} for a 3-day period. These measurements indicate that this device could be developed into a useful frequency standard. The physical construction of this device has been described elsewhere.[1,2]

The molecular resonance Q of this device (frequency/line-width) is 7×10^{7}, and the signal-to-noise ratio is 10^{4} (1-Hz bandwidth) for this line. A signal-to-noise ratio of 10^{5} (1-Hz bandwidth) has been obtained on the $N^{15}H_3$ 3-3 line. This indicates a potential stability of 10^{-12}, or better.

The primary contribution to instability in the present system is the phase difference between the RF fields in the two cavities. This phase difference is monitored by using a square-wave phase modulation system[3] and corrected with a phase shifter. The error in setting this phase probably accounts for the measured stability. In spite of temperature stabilization of the cavities, the temperature of the cavities and waveguide system fluctuate slowly and introduce phase shifts that must be compensated.

The frequency of the central component of the 3-2 inversion transition was 22, 834, 184, 960. 0 ±1. 1 Hz for the 3-day series of measurements. These measurements were made with respect to the Al time scale which locates the cesium $(4, 0 \rightarrow 3, 0)$ zero field hyperfine transition at 9, 192, 631, 770. 0 Hz. The reference system for these measurements was a cesium atomic beam apparatus with 70-Hz linewidth. The reference frequency standard was operated with a C field of 82 mg.

S. G. Kukolich

References

1. S. G. Kukolich, Phys. Rev. 138, A1322 (1965).
2. S. G. Kukolich, Phys. Rev. 156, 83 (1967).
3. S. G. Kukolich and K. W. Billman, J. Appl. Phys. 38, 1826 (1967).

C. INVESTIGATION OF THE VORTEX STATE IN TYPE II SUPERCONDUCTORS BY MEANS OF AN ATOMIC BEAM

The vortex state in type II superconductors has been observed by both neutron diffraction and nuclear magnetic resonance, but only with moderate resolution. Also, these techniques cannot be extended to observation of the predicted motion of the vortices when a current is flowing in the superconductor. The proposed experiment will be able both to increase the resolution and to provide a technique for observing the theoretical vortex motion.

The experiment will be performed by passing a state-selected beam of atoms near the surface of a superconductor. By observing the velocity distribution of the flopped atoms, it will be possible to obtain the spatial variations in the field distribution at the surface, since, to atoms moving at velocity v, a spatial variation of magnetic field of wavelength ℓ will appear as a time-variant field of frequency $f = v/\ell$. Therefore knowledge of f and v will lead to ℓ. The motion of the vortices can be observed as a shift in the velocity distribution of the flopped atoms, provided samples of sufficient purity can be obtained so as to avoid pinning.

During the last quarter, the construction of the experimental apparatus has been completed, and the apparatus assembled. The Helium dewar has been leak-checked for both vacuum and heat leaks. The heat leak is 50% less than the limit allowed in the designing stage. The gain of the electron multiplier has been measured and found to be 10^6 at 200 volts/stage with 15 stages. The C-magnet has been calibrated and the field is within the needed range. Wider slits have been put into the potassium oven, in order to get a higher beam intensity. This has been observed in a measurement of 7×10^9 atoms/sec of induced low-frequency flop with 10% direct beam.

The necessary electronics equipment is now being designed. This consists of various preamplifiers, coincidence gates, integrating circuits, etc. A GR 1392-A pulse-delay generator will be used to measure the time of flight of the atoms. When the electronics is completed, it will be possible to maximize the signal-to-noise ratio for a selected velocity range.

T. R. Brown, J. G. King

D. QUARK SEARCH

An experiment designed to search sea water samples for quark ions has been performed. The basic assumptions will clarify the underlying principles involved in the experiment.

Basically the experiment consists of taking a sample of sea water (obtained from Woods Hole, Massachusetts) and concentrating the ion and quark-ion content by evaporation of water. Such evaporation is done in a typical hot-water heater, and the concentration of the sample determined by flame photometry. For much of the experiment described herein, a 10:1 concentration is used.

The sample is then put into vapor form by a two-step process consisting of atomization and evaporation. The atomizer used is a pneumatic type which breaks the sample into very small droplets. The droplets are then evaporated in a flame which is swept of negative particles by an electric field, thereby collecting ions and quark ions. Since the collecting surface is at a positive potential, the regular negative ions will become neutral or form oxides. The quark ion will maintain its net charge of $-1/3$, regardless of its reaction history. The collected quark ions are then introduced into a detection system consisting of an electron multiplier capable of detecting single particles. The time of release of the quark ion from the collecting surface is determined

Table I-1. Results of analysis of 10 runs.

Actual sea water sampled	12.3 moles
Equivalent sea water sampled	123 moles
Number of molecules sampled	7.38×10^{25}
<u>Analysis</u>	
Average background during runs	m = 0.52 counts per observation period
Background to 90% confidence	$3\gamma = \pm 3\sqrt{m}$ $= 0.3$ counts
Efficiency of the detection system	0.5
Minimum number of quark ions which could be detected per run	8
Total particles detected	<80
Limit: $\dfrac{\text{No. quark ions}}{\text{No. water molecules}}$	$\leq 1.08 \times 10^{-24}$
$\dfrac{\text{No. quark ions}}{\text{No. nucleons}}$	$\leq 6 \times 10^{-26}$
$\dfrac{\text{No. quark ions}}{\text{liter}}$	≤ 36

by controlled heating of the surface, as well as by controlling the potential restraining the quark ions.

The experiment is based on the following assumptions:

1. A quarked atom or water molecule has a permanent net charge of $-1/3$.
2. Because of the solvation energy associated with an ion in water solution, a quark ion will remain in solution at temperatures of 100°C. This allows the concentration of quark ions by evaporation.
3. The energy required to remove a quark ion from solution is adequately supplied by a pneumatic atomizing, flame evaporation system.
4. Once the quark ions are free of the sea water, they may be collected by an electric field. Since they have a fractional charge, they will not be neutralized by a positive probe, but held as ions.
5. The neutralization of three quark ions by an integral charge is an unlikely event.

6. The collected quark ions may be released by means of controlled heating and favorable potential conditions.

7. The quark ions can be counted with an efficiency of ≈100% by an electron multiplier and counting system.

Since these assumptions are pertinent for a successful search, each must be justified.

Results

Preliminary runs designed to look for relatively large numbers of quark ions with a sensitivity of approximately 100 particles per run showed less than 100 quark ions per mole of regular sea water.

Later runs with a total system efficiency estimated at 50% sampled 12.3 moles of 10:1 concentrated sea water. Each run consisted of an 18-msec observation period during which counts were recorded, and from three to six 18-msec periods which served to determine background during the run. Although the actual background was of the order of 1600 counts/min, the background during the 18-msec run time varied between 0 and 4 counts.

The 10 runs are analyzed on a cumulative basis and the results are given in Table I-1.

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