

## VII. GRAVITATION RESEARCH\*

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### RESEARCH OBJECTIVES

Research in this group is concerned with an experimental investigation of the gravitational interaction. At present, we are engaged in an experiment to measure periodic, as well as possibly secular, variations in  $G$ , the Newtonian gravitational constant, as predicted by a group of scalar gravitational field theories. The approach is to measure  $g$ , the Earth's gravitational attraction at the surface, with a stable molecular beam gravimeter that was described in Quarterly Progress Report No. 77 (pages 60-61). The experiment is in no sense a "clean" one, since the local value of  $g$  is dependent upon several geophysical factors that must be crosscorrelated with the gravimeter, in particular with radial earth distortions and tilt. Development of a stable tilt meter and a laser strain seismometer<sup>1</sup> is in progress.

An experiment to test the Freundlich cosmological red-shift hypothesis is also under consideration. The hypothesis states that photon-photon scattering of a variety not predicted by quantum electrodynamics is responsible for the cosmological red shift, rather than the recessional Doppler shift of an expanding universe. An experiment to determine whether 14-keV Mossbauer effect  $\gamma$  rays lose energy in traversing an X-band radiation field has been performed previously.<sup>2</sup> The experiment gave a null result; however, it demanded an extrapolation of the red-shift hypothesis from the optical region to 14-keV photons. Our present experiment will test the hypothesis for the interaction of the 6328 Å line of the He-Ne laser with an X-band radiation field. Impetus for the experiment stems from the recent observation by Penzias and Wilson<sup>3</sup> of an isotropic radiation background alleged to be due to a cosmic black-body temperature of 3.5°K. Although it is probably fortuitous, the Freundlich hypothesis predicts just such a temperature.

R. Weiss

### References

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2. R. Weiss and L. Grodzins, Phys. Letters 1, 342 (1962).
3. A. A. Penzias and R. W. Wilson, Astrophys. J. 142, 419 (1965).

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## (VII. GRAVITATION RESEARCH)

### A. LONG-TERM FREQUENCY STABILIZATION OF A LASER EMPLOYING A MOLECULAR OR ATOMIC BEAM AS PRIMARY FREQUENCY REFERENCE

A laser strain seismometer to measure long-period Earth distortions requires the development of a long-term laser frequency stabilization technique. Although existing gas lasers exhibit excellent short-term stability ( $\Delta f/f \sim 10^{-11}$  for a few minutes), they are still not suitable for measuring Earth distortions of  $\Delta \ell/\ell \sim 10^{-10}$  per year. Various feedback stabilization schemes have been proposed and some have been attempted:

1. Stabilization with reference to the Lamb dip at the natural atomic resonance in the Doppler-broadened laser gain curve.<sup>1,2</sup>
2. Stabilization relative to an absorption resonance in an external gas-discharge cell.<sup>3</sup>
3. Stabilization relative to an external high-Q cavity<sup>4</sup> or interferometer.<sup>5</sup>

None of these methods is entirely satisfactory. Scheme 1 suffers from pressure shifts, Scheme 2 from pressure shifts, as well as Doppler broadening, and in Scheme 3 the reference elements are subject to temperature dependence and material creep.

We propose to employ an absorption resonance as observed in an atomic or molecular beam as the reference element in a feedback stabilization scheme. The method has proved its effectiveness in the Cesium beam atomic clock. The beam offers the distinct advantages that (a) there is no interaction between the beam particles and consequently no shift of the natural resonance, and (b) since the beam is directed, the resonance does not suffer first-order Doppler broadening.

The difficulty with the beam is the following. Existing lasers rely on radiative decay to depopulate the lower of the two states between which the laser oscillation takes place. In order to maintain a population inversion, the lifetime of the lower level must be shorter than the upper level; typical lifetimes are of the order of  $10^{-8}$  second. It does not appear feasible to form a beam of these excited atoms directly. We are considering three approaches:

1. Use of an atom or molecule in the beam which is different from the one in the laser and has an optical transition from the ground state or a metastable state that matches the laser line. The matching condition is stringent; a frequency match of better than 1 part in  $10^5$  is necessary.
2. Once the beam is formed, the excited states are generated in the interaction region with the laser light. The excitation mechanism should not introduce Doppler or Stark shifts.
3. Design a laser that employs an atom or molecule for which the lower level of the oscillating transition is long-lived in the isolated conditions of the beam but can be made to have a short lifetime in the atmosphere of the laser, for example,

by collision quenching or field quenching.

Another consideration is whether to detect the absorption directly by measuring the change in intensity of the laser light as it passes through the beam or to measure the occurrence of an absorption by its effect on the beam. The second method gives promise of a better signal-to-noise ratio.

Thus far, Scheme 1 has not offered any possibilities. A comparison of published cw gas laser lines with optical transitions coupling the ground and metastable states of atoms from which beams can be produced conveniently has not uncovered any sufficiently close matches. The search for these is now being automated and extended to diatomic molecules.

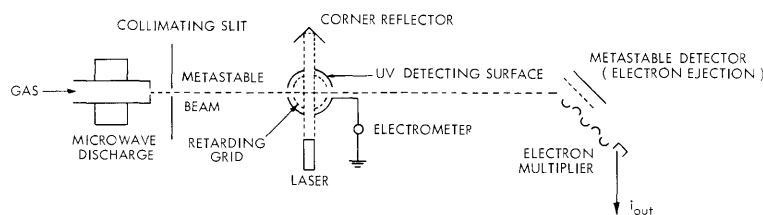


Fig. VII-1. Experimental arrangement.

We are now engaged in the construction of a beam apparatus that can be used for any of the schemes (see Fig. VII-1). If we assume that a laser that has a metastable level as its terminal state will be successful, the detection of an absorption by the beam will be straightforward. The laser light raises the metastable beam atoms to a level that can couple to the ground state, and the absorption is measured as a reduction in the metastable beam. Another method that we shall try is to stabilize the  $6328 \text{ \AA}$  line of the He-Ne laser with a metastable Neon beam by a double-resonance method. The beam in the  $^1S_5$  metastable state is irradiated both by the  $5944 \text{ \AA}$  Ne line from a resonance lamp and by the laser. The double absorption can be detected either by the UV radiation from the  $^3S_2$  decay of the beam atom or the additional reduction in the metastable beam.

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#### References

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3. A. D. White, E. I. Gordon, and E. F. Labuda, *Appl. Phys. Letters* **5**, 97-98 (September 1964).
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B. COLLISION QUENCHING OF METASTABLE KRYPTON BY XENON

The collision quenching of the  $^1S_5$  and  $^1S_3$  metastable levels of the rare gases is being studied for their eventual application as the lower level of a laser particularly suited to the atomic beam stabilization method described in Section VII-A. The experimental arrangement is shown in Fig. VII-2. Light from a DC discharge resonance lamp is passed through a pulsed-discharge absorption cell containing the rare gas and a known and adjustable amount of quenching gas. The resonance radiation absorbed by metastable

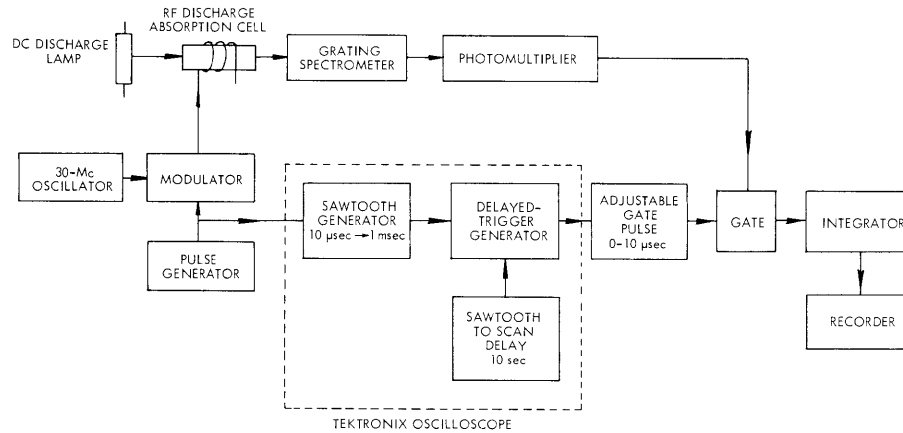
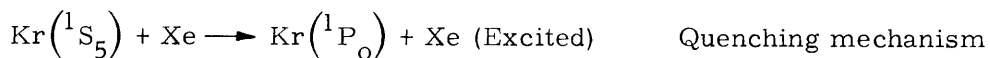
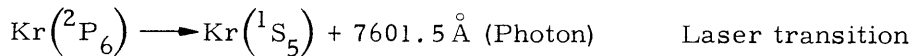
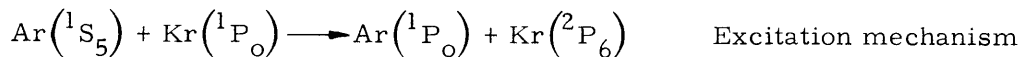


Fig. VII-2. Experimental arrangement.

atoms as a function of time after extinction of the discharge is recorded by a sampling technique. The following process for a possible metastable laser has been investigated:



The excitation mechanism appears to work. If 0.5 mm Hg of A is added to 0.1 mm Hg of Kr, the 7601.5 Å line is enhanced by a factor of 3. The quenching cross section of the  $^1S_5$  state by the Kr is  $Q \sim 2 \times 10^{-16} \text{ cm}^2$ . The quenching of the  $\text{Kr}(^1S_5)$  by Xe exhibits a cross section of  $Q \sim 3 \times 10^{-15} \text{ cm}^2$ . This would demand a high Xe pressure of 30 mm Hg to reduce the lifetime of the  $\text{Kr}(^1S_5)$  state to  $10^{-8}$  sec. The lifetime of the  $\text{Kr}(^2P_6)$  state is calculated to be  $2.6 \times 10^{-8}$  sec, with the Coulomb approximation matrix elements of Bates and Damgaard<sup>1</sup> used. It appears, however, that the Xe also



Fig. VII-3. Absorption vs time curve.

quenches the  $A(^1S_5)$  state, although not as effectively as it does the Kr. Another quenching scheme that we shall try is

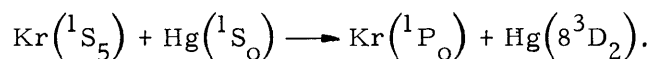


Figure VII-3 is a typical absorption versus time curve, in this case, the time-dependent absorption of the  $7601 \text{ \AA}$  Kr line by Kr  $^1S_5$  metastable atoms in the pulsed discharge. The Kr pressure is  $1.4 \times 10^{-1}$  mm Hg, while the Xenon pressure is first  $8 \times 10^{-3}$  mm Hg, and then  $1.6 \times 10^{-2}$  mm Hg. Each large horizontal division is  $60 \mu\text{sec}$ .

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#### References

1. D. R. Bates and A. Damgaard, Trans. Roy. Soc. (London) 242, 101 (1949).

