V. GEOPHYSICS

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A. PLANETARY RADIATION BELTS

1. MIRROR-POINT MOVEMENT CAUSED BY PITCH-ANGLE SCATTERING

It has been argued[1] that the pitch-angle scattering collisions that are most effective in moving the mirror points of trapped particles in a radiation belt are those occurring near the equatorial surface of the magnetic field. This conclusion must be somewhat qualified when the second-order changes of the scattering angle are considered.

A charged particle gyrating in an inhomogeneous magnetic field moves in such a way that the "first" adiabatic invariant is conserved to a very close approximation[2]:

$$\frac{\sin^2 \alpha}{B} = \text{constant}, \tag{1}$$

where α is the angle between the velocity vector and the lines of force of the magnetic field, B. At the "mirror" field B_m, $\alpha = 90°$ and the particle is reflected. Then Eq. 1 can be written

$$\frac{B}{B_m} = \sin^2 \alpha. \tag{2}$$

If the pitch angle α is changed by a small amount ϵ in a collision, the mirror field B_m will change by a small amount b_m. Then,

$$\frac{B}{B_m + b_m} \cong \sin^2 (\alpha+\epsilon).$$

Expanding $\sin^2 (\alpha+\epsilon)$ and keeping terms through the second order, we have

$$\frac{B}{B_m + b_m} \cong \sin^2 \alpha + \epsilon \sin 2\alpha + \epsilon^2 \cos 2\alpha. \tag{3}$$

Using Eq. 2 to eliminate B in Eq. 4 and again expanding through second order, we find

$$\frac{b_m}{B_m} \cong -2\epsilon \cot \alpha + \epsilon^2 (1+3 \cot^2 \alpha). \tag{4}$$

If the collision occurs at the mirror point, Eq. 4 reduces to

$$\left(\frac{b_m}{B_m}\right)_m \cong \epsilon^2. \tag{5}$$

Comparing Eq. 5 with the case for a similar collision near the equatorial surface, with $\alpha = \alpha_e$, we find

$$\frac{\left|\frac{b_m}{B_m}\right|_m}{\left|\frac{b_m}{B_m}\right|_e} \cong \frac{\epsilon^2}{2\epsilon \cot \alpha_e} = \frac{\epsilon}{2 \cot \alpha_e}. \tag{6}$$

Collisions at the mirror point producing pitch-angle deflections greater than 2 cot α_e will be more effective in moving the mirror point than similar collisions at the equatorial surface. This will be the case for particles that cross the equatorial surface with fairly large pitch angles.

W. D. Halverson

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B. PERTURBATION OF A PLASMA BY A PROBE

An experiment is being carried out in an attempt to establish the validity of Waymouth's theory of the perturbation of a plasma by a probe.[1]

The experiment consists of determining electron density, electron temperature, and plasma potential in the neighborhood of a large probe that violates Langmuir's condition that probe size be smaller than the mean-free path of plasma particles. These parameters are to be determined as a function of the distance from the large probe by means of a small movable probe for which Langmuir's condition holds. Both probes are of a spherical geometry and are immersed in the positive column of an Hg-He discharge (DC) at a helium pressure of 1 mm Hg.

Results thus far for the large probe at floating potential give the following indications:

a. Electron temperature as a function of distance remains essentially constant, as is assumed in the theory, until the small probe is very close to the surface of the large probe (~mean-free path of the electrons).

b. Electron density falls off as $\frac{1}{r}$, as predicted by the theory.

c. Although plasma potential as a function of distance has not been established, small probe floating potential is perturbed in the close vicinity of the large probe.

R. G. Little

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C. LEVEL CROSSINGS IN Hg^{203}

The apparatus used for this experiment is as described in Quarterly Progress Report No. 73 (pages 17-20), except that a lock-in detection system was used to detect the level crossings.

A quartz light-scattering cell containing 10^{14} atoms of electromagnetically enriched Hg^{203} was made. The enrichment was done at Argonne National Laboratory, and the ratio of Hg^{203} to other Hg isotopes in this sample was between 1/5 and 1/3. With this cell four level crossings were detected in the 6s6p $^3P_1$ state of mercury. The results are tabulated below.

Crossed Levels $(F_1, M_1)-(F_2, M_2)$	Magnetic Field (Gauss)
(7/2, -7/2)-(5/2, -3/2)	7198.29 ± .10
(5/2, 1/2)-(5/2, -3/2)	7532.7 ± .6
(5/2, -1/2)-(5/2, 3/2)	7919.7 ± .8
(5/2, 5/2)-(5/2, 1/2)	8557. ± 3.

The assignments of the levels involved were made on the basis of the observed relative signal strengths and linewidths. The data were analyzed by an IBM 7094 computer program. The program makes a least-squares fit with hfs energy levels in a magnetic field calculated with magnetic dipole and electric quadrupole interactions. The analysis showed that the level assignments are consistent, and gave the following values for the magnetic dipole and electric quadrupole interaction constants A and B:

$$A = 4991.37 \pm .01 \text{ mc}$$

$$B = -255.0 \pm 1.0 \text{ mc.}$$

The second-order fine-structure correction has not been made.

These values agree with spectroscopic results obtained earlier.[1] By using these values of A and B, the isotope shift can be obtained with higher precision from the one measured hfs component at 2537 Å:

Isotope shift Hg^{202}-Hg^{203} = $0.052 \pm .004 \times 10^{-3}$ cm^{-1}

Staggering parameter[1] $\gamma = 0.59 \pm .05$

O. Redi

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D. LINE-SHAPE STUDIES OF MERCURY RESONANCE RADIATION AT ZERO MAGNETIC FIELD

Information about the excited states of atoms can be determined by experiments such as "double resonance",[1] level crossing at zero field,[2] and level crossing at high magnetic field,[3] which involve the mixing of two sublevels (Zeeman or hyperfine-structure levels) of the excited state. Using these methods, various observers have found that the measured lifetime of the excited state is a function of the experimental conditions and, most importantly, of the atom density in the vapor of the substance that is being studied. The lifetime is found to increase as the density increases. This measured time, called the "coherence time," is found to depend upon the existence of multiple scattering

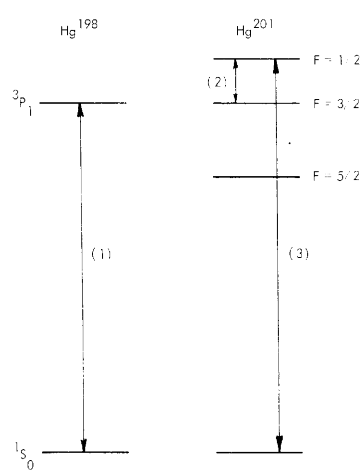

Fig. V-1. Resonance lines of Hg^{198} and Hg^{201}.
(1) Optical excitation of F = 3/2 level 2537 Å.
(2) Microwave transition to F = 1/2 level.
(3) Decay of F = 1/2 level.

of the resonance radiation and reduces to the true lifetime as the atomic density decreases to the point where multiple scattering ceases. This effect has been explained as being due to the coherence between the probability amplitudes of the various states of the system of atoms plus radiation. This effect has been studied by Kastler's group in France by using the double-resonance method, in which radiofrequency transitions between Zeeman sublevels of individual hyperfine structure levels ($\Delta F = 0$, $\Delta m_F = \pm 1$)

in the $^3P_1$ state of the mercury isotopes are employed.[4] They have shown the dependence of the effect on the hyperfine level that was studied, the isotopic composition of the mercury vapor, and the size and shape of the cell containing the vapor. Barrat[5] has developed a theory with specific application to the double-resonance method, the theory and experimental results being in good agreement. Omont[6] has similarly considered the double-resonance method with a magnetic field sufficiently large that the Zeeman separations exceed the Doppler width. More recently, similar effects have been observed in the $^1P_1$ state of zinc with the Hanle effect employed.[7] Likewise, the effects were observed in the high-field level crossing ($F = 3/2$, $m_F = -3/2$ and $F = 1/2$, $m_F = 1/2$) in the $^3P_1$ state of Hg^{199}.[8]

We have studied the line shape of the $F = 3/2$-$F = 1/2$ hyperfine-structure transition in the $^3P_1$ state of Hg^{201} as a function of perturbation amplitude and atomic density, employing a method similar to that used by Kohler[9] for the measurement of the hyperfine-structure separations in this isotope. As shown in Fig. V-1, the energy of the $^3P_1$ state of Hg^{198} is nearly coincident with the $F = 3/2$ level of this same state in Hg^{201}. If Hg^{201} vapor in a cell in a microwave cavity is illuminated with 2537 Å light from a Hg^{198} source, the $F = 3/2$ level is selectively populated. With the microwave power in the cavity tuned to the frequency corresponding to the energy difference between the $F = 3/2$ and $F = 1/2$ levels, resonance will occur. The spontaneous decay of the $^3P_1$ state will emit light from the 3/2 and 1/2 levels. If this light is viewed through an Hg^{198} absorption cell, the light reaching the photomultiplier is primarily from the $F = 1/2$ level and the resonance can be easily detected by an increase in this light intensity. We have reduced the external magnetic field by mu-metal shielding to approximately 0.004 gauss, thereby reducing the Zeeman splitting to several orders of magnitude less than the natural linewidth, essentially "zero field." Measurements were made by frequency-sweeping over the line at varying microwave powers and extrapolating to zero power. Data were reduced by a least-squares fit to a Lorentzian line shape by use of the IBM 7094 computer. For comparison purposes, we have also studied the various $\Delta F = 1$, $\Delta m_F = 0, \pm 1$ transitions in a small magnetic field by both frequency- and field-sweeping.

We find that the resonance line shape is a Lorentzian with halfwidth $(\Delta\omega)^2 = aP + \frac{1}{2\pi T}$, where P is the microwave power, and T is the measured lifetime. We find that this lifetime at zero field increases with vapor density (Fig. V-2) from 1.14×10^{-7} second at 7×10^{11} atoms/cm^3 to 1.39×10^{-7} second at 6×10^{13} atoms/cm^3 with the particular geometry used. The French researchers report 1.18×10^{-7} second, and Kaul 1.15×10^{-7} second for the true lifetime of the $^3P_1$ state of mercury. We find also that the effects of power broadening apparently depend upon vapor pressure, and the line broadens more rapidly at high densities than at low densities. The factor "a" in the expression for the halfwidth above changes by a factor of 2.1 over the range of vapor pressures

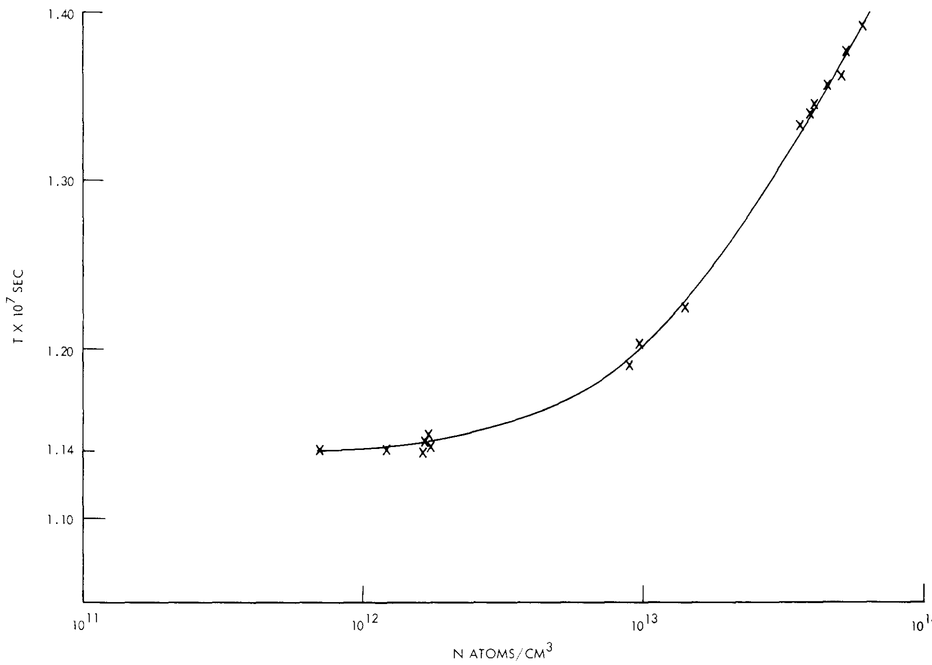

Fig. V-2. Measured lifetime as a function of atom density.

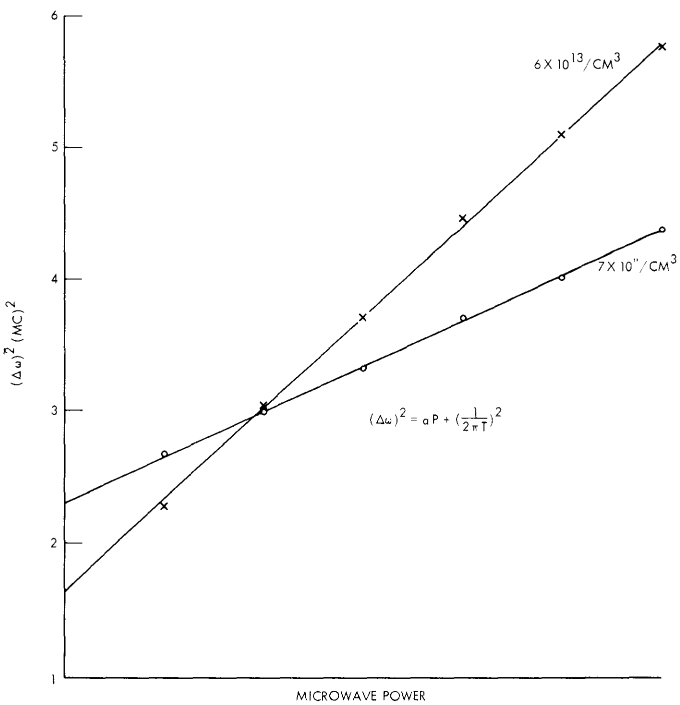

Fig. V-3. Typical results of linewidth squared vs power over the same power range.

employed (Fig. V-3). Our measurement of the hyperfine-structure separation is in agreement with that of Kohler, 7551.613 mc. We do note a slight decrease of 0.07 mc from this value as the vapor pressure is increased. In a magnetic field the density-dependent effects of lifetime and power broadening are somewhat reduced from their values at zero field, the range of lifetimes being 0.1×10^{-7} sec versus 0.25×10^{-7} sec at zero field, and the maximum "a" factor change being 1.5 versus 2.1 at zero field. We attribute this decrease to the fact that the removal of the degeneracy of the m_F levels effectively reduces the number of resonating atoms.

This experiment differs from the standard double-resonance experiments in that we are mixing two F levels. The theory of Barrat and the experimental results of the French group show a dependence of the "coherence time" on the F level that is being studied. It is not unreasonable to expect, therefore, that the quantities measured in an experiment such as this will be mixtures of those of the individual F levels. This leads to the possibility that at high atomic densities we are effectively inducing transitions between levels having different "lifetimes." This possibility is being considered theoretically, and a review of the theory of this type of resonance experiment is being carried out.

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