VI. MAGNET LABORATORY RESEARCH

Prof. F. Bitter	Dr. J. S. Waugh	H. H. Plotkin
Dr. S. P. Davis*	N. I. Adams III	J. R. Stanley
Dr. P. L. Sagalyn	G. R. Murray, Jr.	J. E. R. Young

A. NUCLEAR ORIENTATION IN MERCURY VAPOR

A new attempt is being made to obtain nuclear orientation in mercury vapor by "optical pumping" with circularly polarized light (1, 2, 3). Although this has been done in a beam (4, 5), the successful use of a vapor would facilitate the orientation of small amounts of radioactive isotopes.

To prevent condensation of atoms containing oriented nuclei, a hot quartz cell was sealed off with unsaturated vapor at the vapor pressure corresponding to ice temperature. The cell will be irradiated with light from an Hg^{198} arc in a very weak field. In such a field, the transition to the F = 3/2 level of the $^3P_1$ state of Hg^{201} overlaps with the single line of Hg^{198} which can be used, therefore, to orient Hg^{201}. Since a large magnetic field is not needed, the arc can be brought very close to the cell, giving considerably more light intensity than was available in previous attempts. The use of a 198 arc, rather than natural mercury, will considerably reduce the background from the even isotopes. It is planned to detect orientation by the method of Hawkins and Dicke (5), that is, by observing the degree of polarization of the scattered light as a function of a magnetic field parallel to the axis of the light beam. The degree of polarization is a function of the degree of orientation. The component of the earth's field transverse to the light beam axis will cause a disorienting precession of the nuclear magnetic moment which should have a maximum effect when the applied field just cancels the component of the earth's field parallel to the light beam axis. Calculations indicate that with the light intensity available, it should be possible to detect orientation if the thermal relaxation time in the ground state of Hg^{201} is greater than approximately 0.2 sec.

P. L. Sagalyn, J. R. Stanley

References

1. A. Kastler, J. phys. et radium 11, 255 (1950).
2. F. Bitter and J. Brossel, Phys. Rev. 85, 1051 (1952).
3. F. Bitter, R. F. Lacey, and B. Richter, Revs. Modern Phys. 25, 174 (1953).
4. J. Brossel, A. Kastler, and J. Winter, J. phys. et radium 13, 668 (1952).
5. W. B. Hawkins and R. H. Dicke, Phys. Rev. 91, 1008 (1953).

---

*Spectroscopy Laboratory, M.I.T.

B. NUCLEAR MAGNETIC RESONANCE IN GASES

In the nuclear magnetic resonance of B" in BF_3 gas at various pressures with various added gases, simultaneous measurements of linewidth ΔH and signal amplitude vs. applied rf amplitude were made. Theory gives

$$\left(\frac{\text{signal}}{\text{rf}}\right)\Bigg|_{\text{rf}\to 0} \quad \alpha \left(\frac{N_B}{\Delta H}\right)$$

where N_B is the number of atoms of B" per cm^3 and ΔH is the linewidth as rf $\to 0$. In these experiments ΔH was principally due to field inhomogeneity. At an rf value such that

$$\left(\frac{\text{signal}}{\text{rf}}\right) = \frac{1}{2}\left(\frac{\text{signal}}{\text{rf}}\right)\Bigg|_{\text{rf}\to 0}$$

theory gives

$$(\gamma H_1')^2 \, T_1 \, \frac{2}{\gamma \Delta H} = 1$$

In pure BF_3, T_1 is predicted to be proportional to the collision frequency. From kinetic gas theory, in pure BF_3, collision frequency is proportional to N_B. In a mixture one expects a similar dependence on all the types of collisions, although there may be some gas components of greater effectiveness than others.

One can thus define an equivalent B" density N_E such that pure BF_3 of that density would produce the observed T_1.

The following quantities were obtained from measurement:

$$A_o \propto \left(\frac{\text{signal}}{\text{rf}}\right)\Bigg|_{\text{rf}\to 0} \qquad W_o \propto \Delta H \qquad E_c \propto H_1$$

P_B = BF_3 partial pressure, P = total gas pressure

We see from the above that in pure BF_3, T_1 is proportional to N_B but also, in any case,

$$T_1 \propto \frac{\Delta H}{H_1'^2} \propto \frac{W_o}{E_c'^2}$$

Hence we expect that

$$\frac{W_o}{E_c'^2 \, N_B} = \text{constant.} \quad \text{Also, we see that} \quad \frac{A_o W_o}{N_B} = \text{constant.}$$

Taking the ratio, we have $A_o E_c'^2 = C_3$. Now, assuming Boyle's law, N_B is proportional to P_B, we get

$$\frac{W_o}{E_c'^2 P_B} = \text{constant} = C_1 \quad \text{and} \quad \frac{A_o W_o}{P_B} = \text{constant} = C_2.$$

Thus $C_3 = C_2/C_1$.

For mixtures we still have $(A_o W_o)/P_B = C_2$. And by definition,

$$\frac{W_o}{E_c'^2 P_E} = C_1$$

Now

$$C_3 = \frac{C_2}{C_1} = A_o E_c'^2 \frac{P_E}{P_B}$$

We can evaluate C_3 from pure BF_3 runs, that is,

$$C_3 = \overline{\left(A_o E_c'^2\right)}$$

averaged over the pure BF_3 runs. Thus

$$\frac{P_E}{P_B} = \frac{\overline{\left(A_o E_c'^2\right)}}{A_o E_c'^2}$$

We can now compare the effectiveness of an added gas to that of BF_3:

$$\left[\left(\frac{P_E}{P_B} - 1\right) \Big/ \left(\frac{P}{P_B} - 1\right)\right] \equiv \rho$$

We find for

H_2 : $\rho \sim 0.4$: one run, $P_{H_2} \sim 1400$ psi, $P_B \sim 300$ psi

N_2 : $\rho \sim 0.8$: two runs, $P_{N_2} \sim 700$ psi, $P_B \sim 1000$ psi

$P_{N_2} \sim 300$ psi, $P_B \sim 400$ psi

On a purely collision frequency basis, one expects, because of the mass differences for H_2, $\rho \sim 4$; for N_2, $\rho \sim 1.3$. Thus some other effect must be present, perhaps the difficulty of transfer of angular momentum from a light to a heavy rotator.

As a check, the constant C_2 was evaluated for each of eleven runs. In all but one, C_2 fell in the range 1.4 - 2.2. This seems to be the experimental error. In spite of an even larger spread in C_1 obtained from data on pure BF_3, a pressure range of a

factor 3 clearly shows pressure narrowing as expected. The value of T_1 obtained is 2.3 msec/psi for pure BF_3. The pressures used were around 1000 psi (4 runs) and around 300 psi (2 runs). The linewidth was approximately 70 milligauss for all runs, which corresponds to a T_2^* of 3 1/2 msec. One run was made with about 70 psi of O_2 and 1000 psi of BF_3. Oxygen, because of its strong paramagnetism, causes a decrease of T_1 with increase in oxygen pressure. The predicted change was negligible against the experimental error. No change was found. This seems to preclude small traces of air being able to produce variations in the results.

N. I. Adams III

C. STEPWISE EXCITATION OF MERCURY

The structure of the mercury spectral line λ4047A is being studied with methods described in previous reports from this group. This line arises from transitions from the state $^3S_1$ (valence electrons 6s and 7s) down to the metastable state $^3P_0$ (6s, 6p). (See Fig. VI-1.) Our procedure is to measure the absorption of the mercury line λ4047A in mercury vapor containing atoms in the $^3P_0$ state as a function of the frequency of this incident radiation.

To provide a density of metastable atoms sufficient for this experiment, a quartz resonance cell, containing a drop of mercury, is either sealed off with a known pressure of nitrogen, or connected to a vacuum system so that the atmosphere may be controlled. Atoms are excited from the ground state $^1S_0$ (6s, 6s) up to the state $^3P_1$ (6s, 6p) by illuminating with the resonance line λ2537A. Since the energy level $^3P_1$ to $^3P_0$ is in resonance with some vibrational levels of the nitrogen molecule, collisions while the mercury atom is excited knock some mercury atoms into the metastable state. It has been found that the intensities and lifetimes involved are such that a population of metastable atoms which is sufficiently large and constant may be maintained.

A source of λ4047A light of variable frequency is provided by a microwave discharge lamp containing only the isotope Hg^{198}. The light is taken parallel to a variable magnetic field, and one of the Zeeman components is removed. Absorption of the λ4047A beam in the mercury vapor is detected and measured by a photomultiplier that has been filtered to be sensitive only to the line λ5461A. This is one of the possible wavelengths emitted as the atom subsequently falls from the $^3S_1$ level.

The absorption vs. frequency patterns thus observed (Fig. VI-2) show the same qualitative features as have been found by high-resolution spectroscopy. (For a spectral plate of this line, see reference 1.) The even isotopes fall in a broad central peak. Since they do not have nuclear spin, they have no corresponding magnetic hyperfine structure, and the small shift owing to isotopic volumes has not yet been resolved. A tentative identification as hfs components corresponding to the odd isotopes Hg^{199} and Hg^{201} has been made for all of the subsidiary absorption peaks observed. The positions

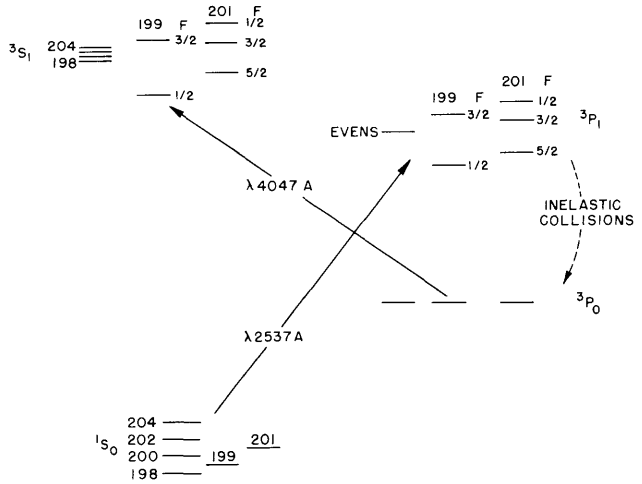

Fig. VI-1

Schematic term diagram of those mercury levels giving rise to the hyperfine structure of the lines λ2537A and λ4047A.

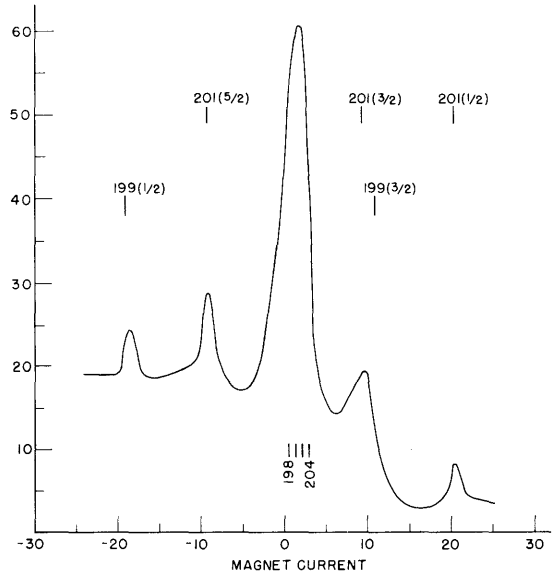

Fig. VI-2

Preliminary determination of the structure of the line λ4047A obtained by magnetic scanning. Vertical markers indicate positions of lines to be expected from previous spectroscopic data. This curve has not been corrected for variation of background signal with the leakage field from the magnet, which may be seen in the curving base line.

of these peaks have been found to satisfy the interval rule and their centers of gravity fall approximately where expected.

An attempt was made to determine which isotopes should be excited into the metastable state, with a pure isotope lamp as the source of the first resonance excitation. However, even if the frequency of the λ2537A radiation brings only atoms of isotopes 198 and 201 into the $^3P_1$ state, absorption peaks are found in the metastable atoms that correspond to the hfs of Hg^{199}. When the mercury pressure is that of the saturated vapor at room temperature, collisions and imprisonment of resonance radiation act to redistribute the excitation energy to all the isotopes.

H. H. Plotkin

References

1. Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., April 15, 1954, p. 28.