VI. MAGNET LABORATORY RESEARCH

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A. MAGNETO-OPTIC STUDIES OF Hg^{196} AND Hg^{197}

The isotope shift for the 2536 A.U. resonance radiation of mercury for the isotopes of even mass number from Hg^{196} to Hg^{204} was reported in the Quarterly Progress Report of April 15, 1954, and illustrated in Fig. VI-1, page 26. The smooth trend shown by the data is believed to be substantially correct. It is in agreement with the results obtained by various observers using other spectral lines. Of these we quote only Murakawa [1], who recently published an estimate of the isotope shift for Hg^{196} in a sample in which the natural abundance of 0.15 percent was boosted to 1.46 percent. The observations on the line Hg II λ6150 are tabulated below, together with our own results on isotope shift, using a scale in which the 204-202 displacement is unity.

	204-202	202-200	200-198	198-196
Murakawa	1.0	1.0	0.85	0.60
Present Study	1.0	1.0	0.91	0.79

Considering the difficulty of Murakawa's estimate of 0.019 cm^{-1} for the 198-196 displacement in which the 196 line was unresolved, but appeared only as a somewhat diffuse edge on the 198 line, the agreement must be considered excellent.

We can hardly hope to discover the meaning of this trend in isotope shift for the theory of nuclear structure without a good deal more evidence. There are undoubtedly departures from the $A^{1/3}$ law for the nuclear radius for various different reasons in different parts of the nuclear "periodic table."

Wilets, Hill, and Ford [2] discuss a variety of reasons for anomalous isotope shifts, of which we shall take up only that attributable to nuclear electric quadrupole moments, first suggested by Brix and Kopfermann [3]. Mercury, with Z = 80, lacks two protons of having a closed shell with 82, and the isotope Hg^{204} lacks two neutrons of having a closed shell with 126.

As more and more neutrons are taken out of the closed shell, progressively larger quadrupole moments are to be expected. Exceptionally large quadrupole moments are found in nuclei in which 10 or more nucleons are lacking from closed shells. In this group, values of Q/R^2 in the range of 5-10 are observed. Since Hg^{196} lacks 10 neutrons from a closed shell, it is interesting to consider whether the observed trend in the

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isotope shift might be related to the intrinsic quadrupole moments.

Electronic energy levels are raised because of the finite size of a nucleus by an amount proportional to the mean value of ρ^2 averaged over the nucleus, where ρ is the nuclear charge density. For a nucleus with quadrupole moment Q and a volume equal to that of a sphere of radius R, the mean value of ρ^2 is proportional to

$$ZR^2 \left[1 + \left(\frac{5}{6} \frac{Q}{ZR^2} \right)^2 \right]$$

The change in an energy level δ resulting from a change in neutron number δN, assuming $R = R_o A^{1/3}$, is

$$\delta = \text{const} \left[\frac{2}{3} \frac{1 + \left(\frac{5}{6} \frac{Q}{ZR^2} \right)^2}{A} + \frac{d \left(\frac{5}{6} \frac{Q}{ZR^2} \right)^2}{dN} \right] \delta N$$

If we call the first term δ_R the isotope shift caused by the change in volume, and the second term δ_Q the isotope shift caused by the change in shape, the expression given above may be put into the form

$$\frac{\delta_Q}{\delta_R} = \frac{25\,A}{48\,Z^2} \, \delta \left(\frac{Q}{R^2} \right)^2$$

If we assume the normal volume effect for all the isotope shifts shown in Fig. VI-1 to be approximately $0.172\ \text{cm}^{-1}$, and the departures from this value to be the decreases in δ_Q arising from the change in quadrupole moment, we can compute the changes in Q^2/R from one isotope to another. The effects for 204-202 are too small for us to estimate. However, if we assume a value of Q/R^2 for Hg^{202}, the calculation of Q/R^2 from the data can be carried through for the other isotopes with the following results:

Assumed Value* of Q/R^2	Calculated Value of Q/R^2 from Observed Isotope Shift		
Hg^{202}	Hg^{200}	Hg^{198}	Hg^{196}
0.2	0.63	2.41	4.35
0.4	0.72	2.44	4.37
1.0	1.16	2.61	4.46

*The experimental value of Q/R^2 for Hg^{201} is 0.6

These values appear to be of the correct order of magnitude, and it would therefore seem reasonable to assume that, pending the accumulation of further evidence, the anomalous isotope shift for the even-even mercury nuclei is, at least in part, attributable to the variation of the intrinsic quadrupole moment from one isotope to another.

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References

1. K. Murakawa, Phys. Rev. 93, 1232 (1954).
2. L. Wilets, D. L. Hill, and K. W. Ford, Phys. Rev. 91, 1488 (1953).
3. P. Brix and H. Kopfermann, Z. Physik 126, 344 (1949). For a further discussion of intrinsic quadrupole moments of nuclei with spin 0 or 1/2, see also A. Bohr and B. Mottleson, Dan. Mat. Fys. Medd. 27, No. 16 (1953).

B. NUCLEAR MAGNETIC RESONANCE IN GASES

Boron resonances have been observed in BF^3 for pressures ranging from 60 to 1200 lbs/in^2. The expected pressure narrowing was observed.

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C. STEPWISE EXCITATION OF MERCURY

Large populations of mercury atoms in the metastable state $^3P_0$ can be produced by exciting mercury vapor with its resonance line in the presence of nitrogen. These states arise from collisions between nitrogen molecules and excited mercury atoms in the state $^3P_1$ which results in excited molecular vibrational states and metastable mercury atoms. It is hoped that this will make it possible to perform a "magnetic-scanning" study of the hfs of the mercury line 4047A which terminates on the $^3P_0$ level. (See reports of this group in previous Quarterly Progress Reports for description of this method applied to the resonance line itself.) As a preliminary step, the following experiment of R. W. Wood has been repeated.

A quartz cell containing saturated mercury vapor at room temperature plus 3-mm nitrogen was illuminated with the full mercury spectrum. A photograph of the spectrum of the resulting fluorescence from the vapor was taken on the Spectroscopy Laboratory's echelle. This showed that the resonance line 2537A was strongly absorbed and re-emitted; the line 4047A was absorbed in the metastable atoms to bring them to the $^3S_1$ level, from which they subsequently emitted the three lines of the strong mercury visible triplet. Since the 4047A line required metastable atoms to be absorbed, all fluorescence disappeared when the resonance line was removed from the incident light.

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