Cd^{111}-Cd^{113} Nuclear Moment Ratio and Hyperfine Anomaly*

M. P. KLEIN, *Lawrence Radiation Laboratory, University of California, Livermore, California*

AND

J. S. WAUGH, *Department of Chemistry and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts*

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A double-resonance method has been employed to measure the nuclear moment ratio Cd^{111}:Cd^{113}. The result is $\mu_{113}/\mu_{111}=1.046083\pm0.000003$. This value is compared with recently reported hyperfine coupling intervals. A similar experiment on Hg^{199} and Hg^{201} was not successful.

INTRODUCTION

THE evaluation of the hyperfine structure anomaly of the odd-nucleon isotopes of cadmium, Cd^{111} and Cd^{113}, requires a more precise determination of the nuclear magnetic moment ratio than has been reported previously.[1] The usual nuclear resonance method for making such determinations—the simultaneous observation of the two nuclear resonances in the same sample—may be difficult for reasons of sensitivity when the nuclear moments are small. Accordingly we have used a nuclear-nuclear double-resonance method, first applied by Royden[2] in another connection, in which the only spectroscopic observations required are of another nucleus having a much larger magnetic moment and coupled to the desired nucleus by an electron-coupled spin-spin interaction. Characteristic perturbations of the strong resonance occur when the sample is simultaneously irradiated at the resonance frequency of the nucleus of interest.[3]

EXPERIMENTAL

A sample of dimethylcadmium, $Cd(CH_3)_2$, kindly prepared by Dr. E. R. Bissell, was vacuum-distilled into a Pyrex tube and sealed off. The proton resonance was examined with a Varian Associates V-4300 high-resolution nuclear magnetic resonance spectrometer operating at 40.00 Mc/sec, and the spectrum is shown in Fig. 1. The strong central component arises from protons in those molecules containing cadmium isotopes of spin zero. The weaker doublets, almost coincident and both spaced symmetrically about the central line, arise from protons which are coupled to Cd^{111} (inner doublet) or Cd^{113} (outer doublet) with an interaction constant J in the neighborhood of 50 cps. An auxiliary oscillator and amplifier, which could be operated in the vicinity of either of the cadmium resonance frequencies (8.486 and 8.877 Mc/sec), was coupled to the same transmitter coil that induced the proton resonance and produced an oscillating field H_1 of about 1 gauss amplitude. As the frequency of the auxiliary oscillator was passed through resonance, the appropriate pair of satellites moved inward toward the central line and then outward again to its original position.[3] During this time the proton resonance frequency, after passage through a set of fast dividers, was used as the frequency standard for a Hewlett-Packard 524B counter which counted the cadmium frequency. Thus the counter indicated once a second the ratio of cadmium to proton frequency, independently of any external frequency standards. The satellite spacing was plotted against this frequency ratio several times for each cadmium isotope, and the result obtained was

$$\frac{\nu_{113}/\nu_H}{\nu_{111}/\nu_H}=\frac{\mu_{113}}{\mu_{111}}=1.046083\pm0.000003.$$

DISCUSSION

Faust, McDermott, and Lichten[4] have recently reported experimental values for the hyperfine coupling intervals in the metastable $^3P_2$ state of Cd^{111} and Cd^{113} obtained by the atomic-beam magnetic-resonance method. From their results one obtains

$$a_{113}/a_{111}=1.0460677\pm0.0000007.$$

The hyperfine anomaly as customarily defined[5] is

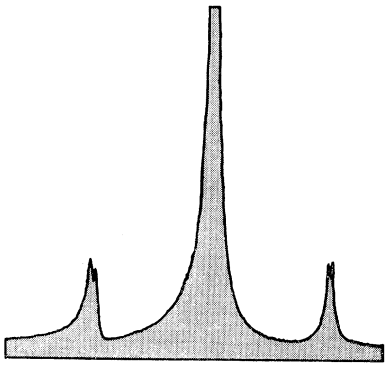

FIG. 1. Proton nuclear magnetic resonance in dimethylcadmium, $Cd(CH_3)_2$.

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given by

$$\Delta_{1,2}=(a_{111}\mu_{113}/a_{113}\mu_{111})-1,$$

which for the present case gives the "experimental" hyperfine anomaly

$$\Delta_{111,113}=+0.000015\pm0.000004.$$

This anomaly is unusually small. It is furthermore not possible to assess its significance directly in terms of theories of nuclear structure, in view of unknown corrections to the orbital g factor for non-s electrons in the Cd atom. Accordingly a discussion of the distribution of nuclear magnetization,[6] the Breit-Rosenthal effect,[7] etc., must await an extension of the theory of Schwartz[8] to this case.

Lacey and Bitter[9] are conducting a microwave double-resonance experiment on the $5s5p\ ^3P_1$ state of Cd to determine the hyperfine coupling ratio of the same pair of isotopes. Their preliminary value is

$$a_{113}/a_{111}=1.046079\pm0.000015,$$

which is not yet precise enough to permit further comment on the hyperfine anomaly but is certainly consistent with the values quoted above.

MERCURY

Our original interest in this experiment arose from a desire to determine the moment ratio for the odd-nucleon mercury isotopes Hg^{199} and Hg^{201}, where the small nuclear moments make the present sort of indirect measurement almost mandatory. The proton resonance of a sample of dimethylmercury (kindly prepared by Mr. R. Spenger) was examined and showed clearly a doublet arising from spin-spin coupling between the protons and the spin-$\frac{1}{2}$ Hg^{199}. However no trace was found of the expected quartet from the spin-$\frac{3}{2}$ Hg^{201}. It is probable that a time-dependent quadrupole interaction of the latter species produces a thermal relaxation time sufficiently short to completely obscure the components of this multiplet. Such a conclusion is in accord with a previous failure to detect the Hg^{201} resonance directly.[10] Thus the present double-resonance method for moment-ratio measurements may be limited to the relatively small number of cases in which both species have spin-$\frac{1}{2}$ or in which the quadrupolar nucleus is in an environment of sufficiently high symmetry to reduce the quadrupolar interaction to a very small value.

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