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Hyperfine Structure of the Metastable $^3P_2$ State of Cd^{111} and Cd^{113}[†]

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The hyperfine intervals of Cd^{111} and Cd^{113} ($5s$, $5p$, $^3P_2$) are $\Delta\nu^{111}(F=\frac{5}{2}, F=\frac{3}{2})=(8232.341\pm0.002)$ Mc/sec; $\Delta\nu^{113}(F=\frac{5}{2}, F=\frac{3}{2})=(8611.586\pm0.004)$ Mc/sec. The measured hyperfine anomaly is $(0.0016\pm0.0003)\%$.

The isotopes Cd^{111} and Cd^{113} both have spin $\frac{1}{2}$ and have natural abundances of 12.86% and 12.34%, respectively. We have measured the hfs of the metastable $^3P_2$ state of these atoms in their natural abundance by the atomic beam technique described in an earlier paper.[1]

The transitions observed were the same as those for Hg^{199}. The Varian X-13 was the rf power source. The results are shown in Table I.

Klein and Waugh[2] have measured the ratios of the magnetic moments of the Cd nuclei,

$$g^{113}/g^{111}=\mu^{113}/\mu^{111}=1.046083\pm0.000003.$$

The hyperfine anomaly for the $6s$ electron of Cd is

$$\Delta(s_{\frac{1}{2}})=\left[\frac{a_s^{111}g^{113}}{a_s^{113}g^{111}}-1\right]=(0.0016\pm0.0003)\%.$$

Table I. Summary of results. The different rows refer to different runs.

Isotope	Lines observed, identified by g_F/g_J	No. of line shapes	$\Delta\nu$ (Mc/sec)
Cd^{113}	$-7/5$, $-3/5$, $-5/5$	3	8611.5828
Cd^{113}	$\pm5/5$	5	8611.5852
Cd^{111}	$\pm5/5$	5	8232.3418
Cd^{111}	$\pm5/5$	6	8232.3402
Cd^{113}	$\pm5/5$	6	8611.5875

The effects of the $6p$ electron and of second-order hyperfine interaction correction are less than the quoted error.

DISCUSSION

Bohr and Weisskopf[3] have shown that distributed nuclear magnetism (DNM) is a cause of hfs anomalies. They derived an approximate expression for the hfs anomaly,

$$\Delta_{\mathrm{BW}}=\epsilon(1)-\epsilon(2)=[(\kappa_s)_{\mathrm{av}}-(\kappa_l)_{\mathrm{av}}]\frac{g_sg_l}{g_s-g_l}\left[\frac{1}{g_I(1)}-\frac{1}{g_I(2)}\right],$$

where the ϵ's are the fractional reduction of the total hfs arising from DNM, the κ's are constants for the isotope pair, and g_s, g_l, and g_I are the g factors of nucleon spin, nucleon orbital, and total nuclear angular momentum, respectively.

In the case of even proton number, Z, odd neutron number, $(A-Z)$, isotopes, the interpretation of hfs anomalies was particularly simple. If the nuclear angular momentum comes from neutrons only, and the odd neutron has the same angular momentum assignment in both nuclei, $g_l=0$ and the anomaly is zero.

Using the Bohr-Weisskopf model as refined by Eisinger and Jaccarino,[4] we calculated the effect of DNM for the Cd isotopes. The theoretical values are $\epsilon^{111}\approx\epsilon^{113}\approx-0.56\%$, $\Delta_{\mathrm{BW}}=(0.009\pm0.005)\%$, where the stated probable error comes only from uncertainties in neutron separation energies used in the calculation.[4,5] This value does not differ significantly from experimental results, especially when one considers the many approximations which enter into the theoretical calculations. Thus, the experimental results are in agreement with the assumption that $g_l=0$.

The only other hfs anomalies for even-proton, odd-neutron nuclei are for Hg^{199} ($I=\frac{1}{2}$) $-$Hg^{201} ($I=\frac{3}{2}$) [1] and Xe^{129} ($I=\frac{1}{2}$) $-$Xe^{131} ($I=\frac{3}{2}$).[6] The $\Delta(s_{\frac{1}{2}})$ values are approximately -0.17% and 0.04%, respectively. These values differ significantly from the theoretical predictions of -1.1% and 0.19%, respectively. However, the observation of quadrupole moments for Hg^{201} and Xe^{131} implies that $g_l\neq0$. Therefore, we expect disagreement between experiment and the Bohr-Weisskopf theory.

The Breit-Rosenthal anomaly,[7] Δ_{BR}, arises from distributed nuclear electric charge. For Cd, a reasonable value for the anomaly is $\Delta_{\mathrm{BR}}\approx0.006\%$. Since the uncertainties in calculation of Δ_{BW} are comparable in magnitude to Δ_{BR}, it is clearly meaningless to attempt a comparison of experiment with the Breit-Rosenthal theory.

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