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Nuclear Quadrupole Moment of Yb^{173}*

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Using separated isotopes, the hyperfine structure of levels due to the configuration $6s6p$ of Yb I was measured. The quadrupole moment of Yb^{173} without shielding correction was found to be 3.1 ± 0.2 b. If the shielding correction factor for the configuration $6s6p$ is assumed to be -0.1, the quadrupole moment $Q(Yb^{173})=2.8\pm0.2$ b is obtained. This brings the spectroscopic value in agreement with the published Coulomb excitation result.

USING natural ytterbium, Schüler, Roig, and Korsching[1] determined the nuclear spins of Yb^{171} and Yb^{173} to be 1/2 and 5/2, respectively. They found $Q(Yb^{173})=3.9$ b principally from the hfs of $6s6p\ ^3P_1$ of Yb I. However, their wave function did not lead to a correct value of $g(6s6p\ ^3P_1)$, resulting in an inaccurate value of Q. Krebs and Nelkowski[2] measured the hfs of the level $6p\ ^2P_{3/2}$ of Yb II, using natural ytterbium. They concluded that this level is perturbed, making it impossible to deduce the true value of $Q(Yb^{173})$.

Fabry-Perot spectrograms have been taken by one of us (JSR), using separated isotopes[3] (see Table I) excited by neon in a hollow-cathode source. From measurements on the lines λ5556 ($6s^2\ ^1S_0$-$6s6p\ ^3P_1$),[4] λ4109 ($6s6p\ ^3P_0$-$6s8s\ ^3S_1$), and λ4564 ($6s6p\ ^3P_2$-$6s8s\ ^3S_1$) the hfs of the $^3P_2$ and $^3P_1$ levels due to the $6s6p$ configuration of Yb I has been determined (see Table II). Fitting the hfs intervals in the usual formula

$$E=E_0+\tfrac{1}{2}AK+B\left[\frac{\frac{3}{8}K(K+1)-\frac{1}{2}I(I+1)J(J+1)}{I(2I-1)J(2J-1)}\right],$$

where

$$K=F(F+1)-I(I+1)-J(J+1),$$

the interval factor A and the quadrupole coupling constant B were obtained (see Table III).

TABLE I. Isotopic constitution (percent) of the samples of ytterbium.

	Isotope						
Sample	168	170	171	172	173	174	176
171	0.01	0.83	93.64	2.83	0.93	1.43	0.34
173	0.05	0.05	0.44	2.33	92.60	4.30	0.38
Natural	0.14	3.03	14.31	21.82	16.13	31.84	12.73

TABLE II. Hfs intervals of the spectrum of Yb I (10^{-3} cm^{-1}).

Level	Yb^{171}	Yb^{173}			
$6s6p\ ^3P_2$	223.3	−81.2	−93.8	(−82.6)	(−56.6)[a]
$6s6p\ ^3P_1$	198.6	−156.5	−50.1		

[a] Values in parentheses were calculated.

TABLE III. Hfs constants of the levels of Yb I (10^{-3} cm^{-1}).

Level	Yb^{171} A	Yb^{173} A	B
$6s6p\ ^3P_2$	89.3	−24.61	43.8
$6s6p\ ^3P_1$	132.4	−36.49	−27.41

The matrix element of $(3\cos^2\theta-1)/r^3$ for $sp\ ^3P_2$ has been given by Casimir.[5] Putting $Z_p{}^*=70-5=65$ and $R'=1.207$, $S=1.365$ (relativity correction factors for $\langle r_p{}^{-3}\rangle$) in his formula and then $H=1.105$ and $\zeta(6p)=1615$ in the usual formula for deducing Q, we get $Q'(Yb^{173})=3.0\pm0.2$ b, in which the prime means that the shielding correction[6] is neglected.

The intermediate coupling wave function for the level $6s6p\ ^3P_1$ (denoted as $^3P_1'$) is a normalized linear combination of the LS-coupling wave functions $6s6p\ ^3P_1$ and $^1P_1$:

$$^3P_1'(6s6p)=K_1\,{}^3P_1(6s6p)+K_2\,{}^1P_1(6s6p).$$

We determined K_1 and K_2 by use of the observed value of $g(=1.49)$,[7] obtaining $K_1=0.990$, $K_2=-0.141$.[8] The necessary formulas for deducing Q from the hfs of $sp\ ^3P_1$ have been previously published.[9] One gets

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[2] K. Krebs and H. Nelkowski, Z. Physik **145**, 543 (1956).

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[4] For measurement of the isotope shift in this line, see J. S. Ross, J. Opt. Soc. Am. (to be published).

[5] H. Casimir, *On the Interaction Between Atomic Nuclei and Electrons* (Verh. Teylers Tweede Genootschap, Haarlem, 1936), Vol. 11.

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[8] The sign of K_2 is compatible with the sign of the nondiagonal energy matrix element given by J. N. P. Hume and M. F. Crawford, Phys. Rev. **84**, 486 (1951).

[9] K. Murakawa, Phys. Rev. **98**, 1285 (1955).

$Q'(\mathrm{Yb}^{173})=3.3\pm0.2$ b from the level $6s6p\ ^3P_1$, the error coming from the uncertainty of the wave function used.

The mean of the two values is $Q'(\mathrm{Yb}^{173})=3.1\pm0.2$ b. If the shielding correction $\Delta(6s6p)=-0.1$ is assumed,[10] one obtains for the quadrupole moment

$$Q(\mathrm{Yb}^{173})=2.8\pm0.2 \text{ b}.$$

If one assumes a strong coupling between the unbalanced nucleon and the nuclear surface, our spectroscopic quadrupole moment yields, according to the formula given by Bohr,[11] the intrinsic quadrupole moment $Q_0(\mathrm{Yb}^{173})=8.0$ b. This is in good agreement with the value 7.8 b obtained from the Coulomb excitation investigation by Elbek, Nielsen, and Olesen.[12]

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[10] K. Murakawa, Phys. Rev. **110**, 393 (1958). We put $Q=(1+\Delta)Q'$, in which Q is the true quadrupole moment.

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Recoilless Nuclear Resonant Absorption in I^{129}†

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Recoilless resonant absorption has been observed with the 26.8-keV gamma ray of I^{129} using the parent, Te^{129m}, as a source. With a ZnTe source and $\mathrm{NaI\cdot 2H_2O}$ absorber the absorption spectrum has a structure which is interpreted in terms of quadrupole splitting in the absorber. The field gradient $q(1-\gamma)$ at the iodine nucleus is experimentally found to be $-2.3a_0^{-3}$. The broader spectrum which is obtained with a Te metal source appears to contain many unresolved lines. It is interpreted as resulting from simultaneous quadrupole splitting in source and absorber. From the observed linewidth, the first-excited state of I^{129} is estimated to have a mean life of 1.5×10^{-8} sec. The small observed percentage effects result, at least in part, from dilution by x rays emitted by the source and the absorber.

INTRODUCTION

ALTHOUGH the Mössbauer effect has already found applications in many branches of physics, its use is still limited by the fact that Fe^{57},[1] Sn^{119},[1] Tm^{169},[2] and[1] Dy^{161} are the only isotopes which show really large effects at easily available temperatures. It would be useful to have a beta-emitting isotope with large Mössbauer effect at room temperature. Such a source, in a ferromagnetic host, would make possible the parity and time-reversal experiments suggested by Morita.[3] In a search for such an isotope, we have studied the Mössbauer effect of the 26.8-keV gamma ray of I^{129}, using Te^{129m} as the source. Unfortunately, the magnitude of the effect is still small, but a structure has been observed which can at least tentatively be explained on the basis of known nuclear properties. A somewhat unique and annoying feature of this experiment is the radioactivity of the absorber.

EXPERIMENT

1. Source and Absorber

The sources of Te^{129m} were prepared by the irradiation of Te^{128}, 97% enrichment, in the Oak Ridge Research reactor for one week. The irradiated samples were dissolved, purified to remove iodine contamination, and reprecipitated in the metallic form.

The ZnTe sources used in some of the experiments were prepared by heating Zn and the radioactive Te in an evacuated Pyrex tube until the characteristic red ZnTe compound was formed.

The absorber material used for these experiments was fission-produced I^{129}, supplied by Oak Ridge National Laboratory in the form of sodium iodide dissolved in basic sodium sulphite solution. It contained 86% I^{129} and 14% I^{127}. The absorber was prepared by drying this solution on a polystyrene disk. The thickness was 40 mg/cm^2 of iodine. The absorber is assumed to be in the form of $\mathrm{NaI\cdot 2H_2O}$, which is triclinic.

I^{129} is unstable, decaying by beta emission (3×10^7 yrs; 150 keV) followed by a 40-keV gamma ray which is strongly converted. Thus, the absorber emitted 29-keV xenon x rays which were not resolved from the 26.8-keV gamma ray of the source; this caused some dilution of the observed Mössbauer effect.

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* On leave from Tata Institute, Bombay, India.

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