JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN VOL. 34, SUPPLEMENT, 1973
PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR MOMENTS AND NUCLEAR STRUCTURE, 1972

II–7

A Value for the Ratio of $Q(^{12}B)$ to $Q(^{13}B)$ Deduced from Quadrupole Couplings in a Mg Single Crystal*

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Quadrupole couplings were measured at Brookhaven National Laboratory, using the polarized recoils ^{12}B and ^{13}B which are produced in the reactions $^{11}B(d, p)^{12}B$ and $^{11}B(t, p)^{13}B$, and which decay according to the scheme $^{12}B \rightarrow {}^{12}C + \beta^- + \bar{\nu}$ and $^{13}B \rightarrow {}^{13}C + \beta^- + \bar{\nu}$. The half-lives of ^{12}B and ^{13}B are 20.4 msec and 17.3 msec, respectively, and both beta end-point energies are 13.4 MeV. The angular momenta and parities of the ^{12}B and ^{12}C nuclear ground states are 1^+ and 0^+, respectively, while those of ^{13}B and ^{13}C are $\frac{3}{2}^-$ and $\frac{1}{2}^-$, respectively. Hence both transitions are pure Gamow-Teller, which, for a given polarization of the initial nuclei, yield the greatest asymmetry in the distribution of the emission directions of the decay electrons. The polarized ^{12}B and ^{13}B recoil nuclei were stopped in a single crystal of Mg where the respective nuclear quadrupole moments interact with the crystalline electric field gradient. The advantages of single crystal over polycrystalline stopping materials have already been demonstrated in the case of the ^{12}B quadrupole coupling in Be.[1,2] The experimental technique is simply resonant depolarization of the recoil nuclei and will be described briefly.

A thin layer of ^{11}B is deposited on Au foil and bombarded with 1.5 MeV deuterons (^{12}B) or 2 MeV tritons (^{13}B). The polarized recoiling nuclei are collimated so that the fraction centered about a laboratory recoil angle of 44°(^{12}B) or 23°(^{13}B) is allowed to strike a single crystal of magnesium. A large (~1 kgauss) vertical magnetic holding field is applied normal to the reaction plane. The subsequent beta decays are detected by two coincidence telescopes, one positioned directly above and one directly below the magnesium crystal. Each telescope contains one totally depleted silicon surface-barrier detector and one lithium-drifted silicon detector. The background counting rate is kept low by electrostatically chopping the deuteron or triton beam and counting only when the beam is off. Typical beam times are 20 msec on and 30 msec off. Since the recoils are partially polarized perpendicular to the reaction plane, this polarization can be detected by observing the asymmetry in the counting rates of the telescopes. Resonance lines are obtained by varying in discrete steps the frequency of a weak (~1 gauss) horizontal magnetic field, while keeping the large vertical magnetic field constant. The destruction of the nuclear polarization at a particular frequency is manifested as a fluctuation in the up-down beta asymmetry. The frequency changed approximately once each second so that random drifts in any part of the system are rapidly averaged out.

The magnesium crystal lattice is hexagonal-close-packed and possesses electric field gradients at both lattice and interstitial positions. The interaction of the quadrupole moments of the implanted recoil nuclei with these electric field gradients can be treated, in the cases to be considered, as a perturba-

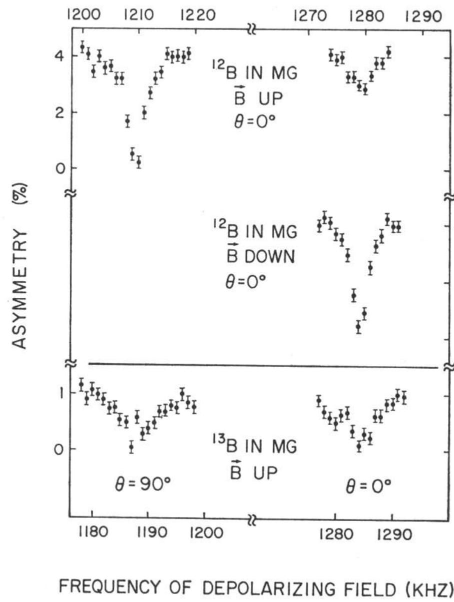

Fig. 1

* Work supported by the U.S. Atomic Energy Commission.
** NSF Pre-doctoral Fellow.

tion of the Zeeman splitting. As a result, instead of a single Zeeman resonance line, one obtains in general $2I$ quadrupole resonance lines. The experimental procedure is to scan these quadrupole resonance lines for different values of the angle θ between the crystalline c-axis and the vertical magnetic field.

Figure 1 presents the resonance scans of ^{12}B and ^{13}B in Mg. The ^{12}B scans were taken with different polarities of the vertical magnetic field, while θ was held at zero degrees in order to maximize the quadrupole splitting. The intensities of the two ^{12}B quadrupole resonance lines indicate the differences between the $m=+1$ and $m=0$ populations and between the $m=-1$ and $m=0$ populations. The lines exchange positions under field reversal because the $m=+1$ and $m=-1$ levels exchange roles when the field is reversed.

The resonance scans of ^{13}B were taken for $\theta=0°$ and $\theta=90°$, while the polarity of the large vertical field remained UP. The quadrupole splitting for $\theta=90°$ is one-half the splitting for $\theta=0°$ and in the opposite direction. To conserve accelerator time only the largest of the three ^{13}B quadrupole lines was recorded. The asymmetry in this line is due to a second smaller single crystal, also detected in X-ray analyses, whose c-axis makes an angle of a few degrees with the c-axis of the larger crystal.

The positions of the quadrupole resonance lines, including a generous allowance of $\pm 5°$ error in θ, are listed in Table I. The position of the absent

Table I.

^{13}B in Mg	$\nu_{13B}^{ZEEMAN} = 1219.3 \pm 0.3$ kHz
	$\nu_{13B}^{QUAD}(B\text{ UP}, \theta=90°) = 1187.0 \pm 0.8$ kHz
	$\nu_{13B}^{QUAD}(B\text{ UP}, \theta=0°) = 1284.5 \pm 1.2$ kHz
	$\nu_{13B}^{ZEEMAN} - \nu_{13B}^{QUAD}(B\text{ UP}, \theta=90°) = 32.3 \pm 0.9$ kHz
	$\nu_{13B}^{QUAD}(B\text{ UP}, \theta=0°) - \nu_{13B}^{ZEEMAN} = 65.2 \pm 1.2$ kHz
	$\dfrac{e^2qQ}{h} = 130 \pm 2$ kHz
^{12}B in Mg	$\nu_{12B}^{ZEEMAN} = 1243.7 \pm 0.5$ kHz
	$\nu_{12B}^{QUAD}(B\text{ UP}, \theta=0°) = 1209.5 \pm 0.6$ kHz
	$\nu_{12B}^{QUAD}(B\text{ DOWN}, \theta=0°) = 1279.3 \pm 0.6$ kHz
	$\nu_{12B}^{ZEEMAN} - \nu_{12B}^{QUAD}(B\text{ UP}, \theta=0°) = 34.2 \pm 0.8$ kHz
	$\nu_{12B}^{QUAD}(B\text{ DOWN}, \theta=0°) - \nu_{12B}^{ZEEMAN} = 35.6 \pm 0.8$ kHz
	$\dfrac{e^2qQ}{h} = 46.5 \pm 0.5$ kHz

Table II. Table of moments.

Magnetic dipole			
	$\mu(^{12}B)$	our value	$1.00285 \pm 0.00015\ \mu_N$
		Sugimoto	$1.003 \pm 0.001\ \mu_N$
	$\mu(^{13}B)$	our value	$3.1771 \pm 0.0005\ \mu_N$
	$\mu(^{8}Li)$	our value	$1.65326 \pm 0.00030\ \mu_N$
		Connor	$1.6532 \pm 0.0008\ \mu_N$
Quadrupole splittings in Be			
	^{12}B	$\dfrac{e^2\, {}^{12B}q_{Be}(1+{}^{12B}\gamma_\infty)Q_{^{12}B}}{h}$	$= \frac{4}{3}(41.2 \pm 0.4\text{ kHz}) = 54.9 \pm 0.5$ kHz
	^{12}N	$\dfrac{e^2\, {}^{12N}q_{Be}(1+{}^{12N}\gamma_\infty)Q_{^{12}N}}{h}$	$= \frac{4}{3}(170 \pm 20\text{ kHz}) = 227 \pm 27$ kHz
	^{8}Li	$\dfrac{e^2\, {}^{8Li}q_{Be}(1+{}^{8Li}\gamma_\infty)Q_{^{8}Li}}{h}$	$\lesssim 8(3\text{ kHz}) = 24$ KHz

Zeeman resonance line is calculated from knowledge of $|\boldsymbol{B}|$ and the g factors[2-4] of ^{12}B and ^{13}B, simply to display the symmetry of the quadrupole splittings. Assuming the Sternheimer antishielding factors for the two nuclei are equal, the ratio of the quadrupole couplings yields a value for $Q(^{12}B)/Q(^{13}B)$ of .358 $\pm$ 0.008 which is indeed close to the theoretical prediction of D. Kurath of about 0.40.[5]

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