4-1-1972

Nuclear Quadrupole Coupling of B-12 in a Single Be Crystal

R. L. Williams Jr.

Richard C. Haskell
Harvey Mudd College

Leon Madansky
Johns Hopkins University

functions. Moreover, in a paper by Ripka and Gillespie[4] it has been shown that Jastrow correlation factors mainly change one single-particle determinant to another one. Thus they have very little relation to SRC's (or to the nucleon-nucleon potential).

(iii) It has been observed also by other authors[5] that Jastrow correlation factors usually introduce a wrong sign if self-consistency has been achieved. If the latter condition is observed the footnote 11 of Ref. 1 becomes meaningless.

In conclusion it must be said that the author's reply – although internally as consistent as our paper – practically deals only with the effect of improvements of the single-particle wave functions on elastic electron scattering. Also, in his formalism the true SRC 2p2h contributions are merely small corrections.[6] In our note we did not claim that there are errors in the algebra of the Jastrow correlation theory. We did – and still do – claim that they have practically nothing to do with SRC's, and that, owing to the smallness of true SRC's, at present they cannot be observed via elastic electron scattering.

[1] C. Ciofi degli Atti, Phys. Rev. C 4, 1473 (1971).
[2] M. Fink, H. Hebach, and H. Kümmel, Phys. Rev. C 3, 2075 (1971).
[3] H. Kümmel, in *Proceedings of the International Summer School on Nuclear Reactions, Predeal, 1970* (Inst. d. Fiz. Atom., Bucharest, Romania, 1970).
[4] G. Ripka and J. Gillespie, Phys. Rev. Letters 25, 1624 (1970).
[5] M. Gaudin, J. Gillespie, and G. Ripka, Nucl. Phys. A176, 237 (1971).
[6] C. Ciofi degli Atti and A. Kallio, Phys. Letters 36B, 433 (1971).

PHYSICAL REVIEW C VOLUME 5, NUMBER 4 APRIL 1972

Nuclear Quadrupole Coupling of ^{12}B in a Single Be Crystal*

R. L. Williams, Jr.,† R. C. Haskell,‡ and L. Madansky
The Johns Hopkins University, Baltimore, Maryland 21218
(Received 24 January 1972)

Quadrupole resonance lines of β-unstable ^{12}B have been distinctly resolved in a single crystal of Be, and have behaved properly under field reversal and variation of the angle θ between crystal c axis and external magnetic field.

In a previous publication[1] the quadrupole coupling of ^{12}B implanted in Be foil was discussed. The purpose of this note is to report the results obtained using a Be crystal instead of a Be foil.

The former measurement was made by stopping polarized ^{12}B nuclei, recoiling from the ^{11}B(d,p) reaction, in a Be foil and observing the NMR spectrum. The resulting powder pattern implied the existence of at least two inequivalent stopping sites in Be, one at which the quadrupole coupling was appreciable and one at which the coupling was negligible. The observed splitting was ascribed to nuclei which stop at Be lattice sites. The field gradient at these locations had previously been calculated,[2,3] and it was then possible to estimate the magnitude of the ^{12}B quadrupole moment.[4] The unsplit line was assumed to result from nuclei which stop at interstitial locations where, perhaps because of high symmetry, the field gradient was essentially zero. It was recognized, however, that repeating the experiments with a single crystal of Be might allow resolution of all the lines and thereby remove much of the ambiguity from the results.

The technique in the latter experiment was similar to that employed in the earlier work. A single crystal of Be was simply substituted for the metal foil, and mountings were devised to hold the stopping surface of the crystal at well-defined angles with respect to the magnetic field. The crystal was cut so that the c axis was at an angle of 45° with respect to the surface, which was etched to remove damaged layers.

The procedure was to scan the resonance lines for each of several values of the angle θ between the crystalline c axis and the external magnetic field. In one case the polarity of the magnetic field was also reversed. In this way the origin of the coupling was confirmed and a reasonably accurate value of the quadrupole coupling was obtained.

Since ^{12}B has spin 1, there are three Zeeman levels. When the perturbing quadrupole interaction is applied, one normally expects two resonance lines, separated from each other by twice the quadrupole splitting. A central line also appears, however, because some ^{12}B nuclei apparently stop at locations having very small effective field gradients. Figure 1 shows all three lines for $\theta = 87°$ and for both polarities of the field. This figure shows that the population of the $m=0$ level is not midway between the populations of the $m=+1$ and the $m=-1$ levels. It also shows that the location of the central lines is unaltered by the field reversal. The split lines exchange positions under field reversal because the $m=+1$ and the $m=-1$ levels exchange roles when the field is reversed.

Figure 2 shows the quadrupole splitting, $\Delta\nu$, as a function of the angle θ between the crystalline c axis and the external magnetic field. The lines corresponding to $\theta = 15$ and $\theta = 3°$ have been folded over for convenience, so that all the split lines appear to the right of the central line. These data establish the correct angular dependence of the splitting.

Table I gives the quadrupole splittings derived from the data of Figs. 1 and 2. Normalizing all the results to 90° and averaging gives $\Delta\nu = 20.6 \pm 0.2$ kHz, so that $e^2qQ/h = 54.9 \pm 0.5$ kHz. This value is consistent with the earlier result $e^2qQ/h = 59 \pm 15$ kHz inferred from the Be foil results.

Although the quadrupolar nature of the splittings has definitely been confirmed, the presence of the central unshifted line remains somewhat puzzling. The hexagonal close-packed structure of beryllium offers two interstitial positions as potential stopping sites for ^{12}B recoils. Using the method of de Wette,[3] one can show that the contributions of the lattice ions to the field gradients at these points are substantial. It is of course possible that cancellation of these lattice contributions

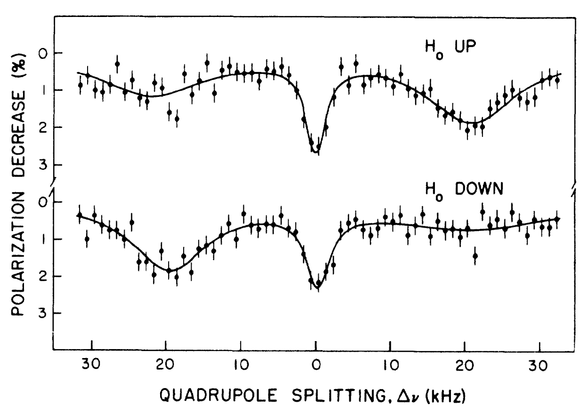

FIG. 1. ^{12}B resonance in a single crystal of Be for both directions of the external magnetic field. The statistical error on the data points is 0.26%.

TABLE I. Quadrupole splitting of ^{12}B implanted in a single crystal of Be, as a function of the angle θ between the crystalline c axis and the external magnetic field. Projected values at $\theta = 90°$ are also given. The average of the right-hand column is $\Delta\nu = 20588(200)$ Hz.

θ (deg)	$\Delta\nu$ (Hz)	$\lvert 3\cos^2\theta - 1\rvert$	$\Delta\nu$ normalized to 90° (Hz)
3	41568(276)	1.9918(55)	20870(150)
15	37845(370)	1.7991(131)	21036(256)
70	12606(343)	0.6491(168)	19421(729)
75	16442(307)	0.7990(131)	20578(511)
80	18718(337)	0.9095(90)	20581(423)
87	20866(599)	0.9918(55)	21039(615)

could arise from shielding by atomic and/or conduction electrons or from local distortion of the lattice by the implanted atoms. Further work is being undertaken in an effort to develop a thorough explanation of the origin of the central line.

In summary, quadrupole resonance lines of β-unstable ^{12}B have been distinctly resolved in a single crystal of Be, and have behaved properly

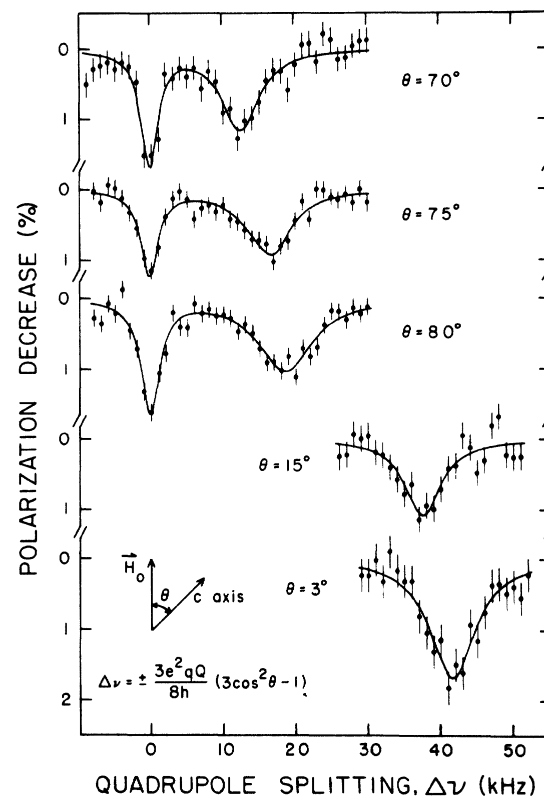

FIG. 2. ^{12}B resonance in a single crystal of Be as a function of the angle θ between the crystalline c axis and the external magnetic field. The statistical error on the data points is 0.26%.

under field reversal and variation of the angle θ between crystal c axis and external magnetic field. The resonance lines are narrow and, with a sufficiently strong quadrupolar coupling, the crystal can always be oriented so that the quadrupole splitting falls within a convenient range. Hence this technique of implantation in a single crystal appears to be a potentially effective tool in investigating nuclear moments and related solid-state phenomena.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Dr. O. C. Kistner of Brookhaven National Laboratory for the loan of the Be crystal and for many helpful discussions, and to Dr. D. E. Alburger for the extensive use of Brookhaven National Laboratory facilities and the generous cooperation of the Brookhaven laboratory personnel.

---

*Work supported by the U. S. Atomic Energy Commission.

†Present address: Harry Diamond Laboratories, Washington D. C. 20438.

‡National Science Foundation Trainee.

[1]R. L. Williams, Jr., L. Pfeiffer, J. C. Wells, Jr., and L. Madansky, Phys. Rev. C 2, 1219 (1970).

[2]M. Pomerantz and T. P. Das, Phys. Rev. 119, 70 (1960); T. P. Das and M. Pomerantz, *ibid.* 123, 2070 (1961).

[3]F. W. de Wette, Phys. Rev. 123, 103 (1961).

[4]The data presented in Ref. 1 are not sufficient to justify a sign determination of the ^{12}B quadrupole moment. The authors wish to thank Professor T. Minamisono for bringing this point to our attention.