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# Electric Quadrupole Excitation of the First Excited State of $^{11}$B

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*Abstract*

The Coulomb excitation of backscattered $^{11}$B projectiles has been used to measure the reduced E2 transition probability $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-)$ between the $3/2^-$ ground state and the $1/2^-$ first excited state of $^{11}$B. It is found that $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-) = 2\cdot1 \pm 0\cdot4\ e^2\,\mathrm{fm}^4$, which agrees with shell model predictions but is a factor of 10 larger than the prediction of the core-excitation model.

## Introduction

This paper reports a measurement of the reduced E2 transition probability $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-)$ between the ground state ($J^\pi = 3/2^-$) and the first excited state ($J^\pi = 1/2^-$, $E_x = 2\cdot125$ MeV) of $^{11}$B. The total width of the first excited state has been determined from resonance fluorescence measurements (Ajzenberg-Selove 1975). Recent inelastic electron scattering measurements (Kan *et al.* 1975) have confirmed expectations, based on sum-rule arguments (Wilkinson 1957), that the decay of the state is predominantly M1. The experimental value of $B(\mathrm{M1}; 3/2^- \rightarrow 1/2^-)$ is $0\cdot61 \pm 0\cdot05\ \mu_N^2$ (Ajzenberg-Selove 1975). The shell model calculations of Kurath (1957) predict values of $B(\mathrm{M1}; 3/2^- \rightarrow 1/2^-)$ in the range from $0\cdot6$ to $2\cdot0\ \mu_N^2$, depending on the value of the spin–orbit coupling parameter $a/K$. More recent shell model calculations give values ranging from $0\cdot7$ to $1\cdot2\ \mu_N^2$ (Cohen and Kurath 1965; Varma and Goldhammer 1969; Hauge and Maripuu 1973). Brut and Jang (1976) obtain $0\cdot84\ \mu_N^2$ from Hartree–Fock calculations, and Meder and Purcell (1974), by coupling a $p_{3/2}$ hole to the $0_1^+$ and $2_1^+$ states of a $^{12}$C core, obtain $0\cdot67\ \mu_N^2$. Thus, several calculations are able to reproduce fairly well the experimental value of $B(\mathrm{M1}; 3/2^- \rightarrow 1/2^-)$. However, only two of the above authors predict the reduced E2 transition probability: Meder and Purcell obtain $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-) = 0\cdot2\ e^2\,\mathrm{fm}^4$, while Kurath obtains values ranging from zero to $1\cdot44\ e^2\,\mathrm{fm}^4$, with a subsequent stated preference (Cohen and Kurath 1965) for $1\cdot06\ e^2\,\mathrm{fm}^4$, corresponding to $a/K = 4\cdot5$. A measurement of $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-)$ is clearly desirable in order to test these predictions.

## Experimental Procedure and Results

Our measurement utilizes the fact that a weak electric transition which is competing with a strong magnetic transition can be effectively investigated by Coulomb excitation in backscattering, since magnetic excitation is suppressed at backward angles (Alder and Winther 1975). The ANU 14UD pelletron accelerator was used

to produce beams of $^{11}B^{4+}$ ions, with energies between 37 and 40 MeV, which were Coulomb excited by scattering from a $^{208}PbS$ target on a thin carbon backing. The isotopic enrichment of $^{208}Pb$ was 99·1% and its partial thickness was about 50 $\mu g\,cm^{-2}$. Ions scattered through a mean laboratory angle of 165° were detected by an annular silicon surface-barrier detector.

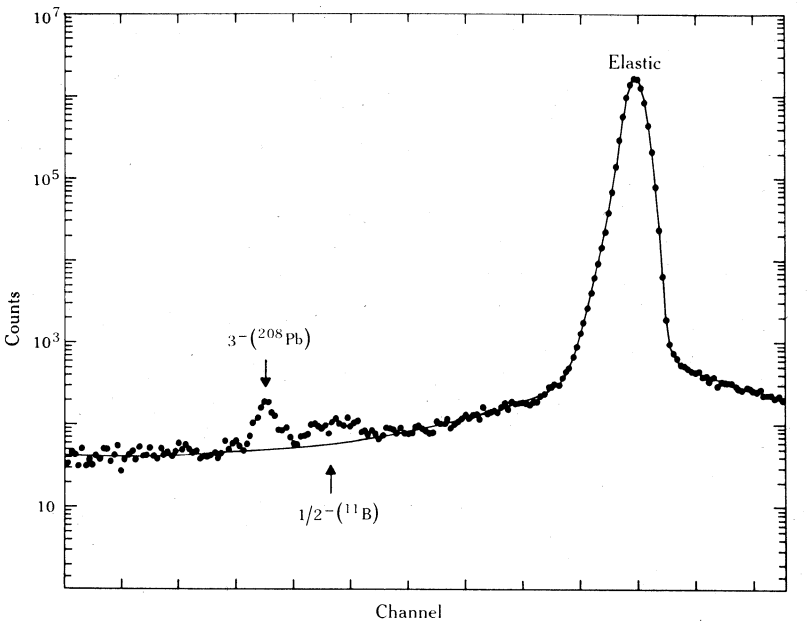


**Fig. 1.** Typical spectrum of 38 MeV $^{11}B$ ions scattered through a mean laboratory angle of 165° from $^{208}Pb$. The peaks are due to elastic scattering and to excitation of the first excited states of the projectile ($1/2^-$) and the target ($3^-$). The curve is a fit to the data as described in the text. The counts above the elastic peak are attributed to pileup.

A typical spectrum is shown in Fig. 1. Peaks due to excitation of the 2·125 MeV $1/2^-$ state in $^{11}B$ and of the 2·614 MeV $3^-$ state in $^{208}Pb$ may be clearly seen. The projectile-excitation peak is broadened by about 250 keV by recoil following $\gamma$ decay in flight. The curve is a fit to the data which is used to estimate the level of the low energy tail of the elastic peak under the projectile- and target-excitation peaks. The fitted line shape consisted of a skewed gaussian with an exponential tail; this line shape has been found to be satisfactory in previous analyses of similar data (see e.g. Esat *et al.* 1976).

Elastic scattering from target impurities in the mass range $A$ = 158–163 could contribute peaks to the spectrum in the region of the $^{11}B$ inelastic peak. Analysis of a spectrum obtained at 165° with 20 MeV $^{12}C$ projectiles showed that, at the level of two standard deviations of the background, an upper limit of 14% can be placed on contributions of such impurities to the inferred excitation probability for the 2·125 MeV state of $^{11}B$. This is of minor significance when compared with uncertainties of about 25% which arise in the spectrum analysis.

The reduced E2 transition probability $B(E2; 3/2^- \rightarrow 1/2^-)$ was deduced from the measured Coulomb excitation probability $P_{exp} = d\sigma_{1/2^-}/(d\sigma_{1/2^-} + d\sigma_{3/2^-})$ by using the multiple Coulomb excitation code of A. Winther and J. de Boer (reprinted in

the text by Alder and Winther 1966). The results are shown in Fig. 2, where $P_C$ is the excitation probability calculated on the assumption of pure Coulomb excitation and with allowance for the effects of the M1 excitation at 165° (assuming the experimental value of $B(M1; 3/2^- \rightarrow 1/2^-)$ quoted above) and of the magnetic-dipole and electric-quadrupole moments of the ground state (Ajzenberg-Selove 1975). The M1 moments together increase the excitation probability by 0·8%, and the ground-state quadrupole moment produces an increase of 13%. The uncertainties arising from these corrections are negligible. A correction has also been applied for the effects of the giant dipole resonance, assuming that the minus-two moment of the total photoabsorption cross section is equal to the hydrodynamic model estimate of this quantity (Levinger 1957); this correction decreases the excitation probability by 13%.

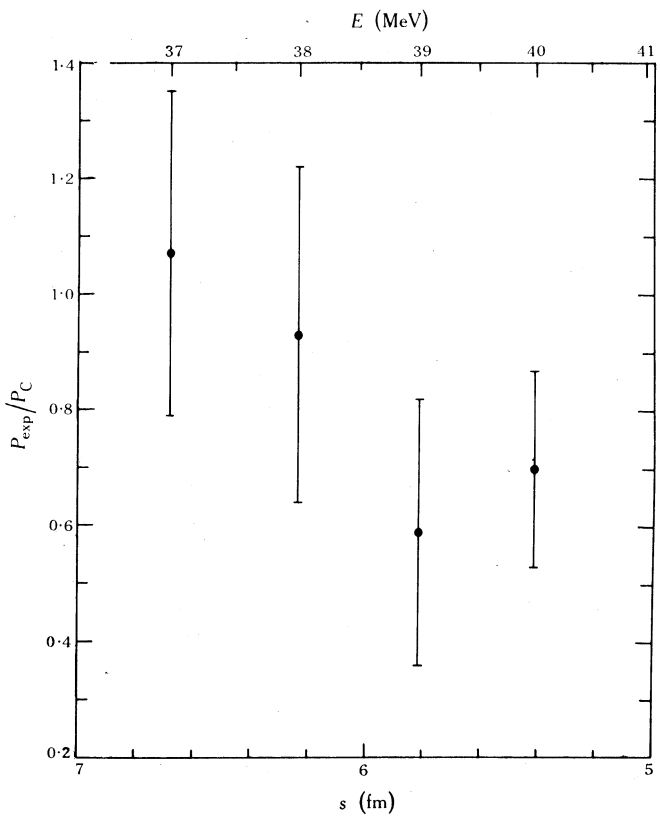


**Fig. 2.** Plot of the ratio $P_{exp}/P_C$ as a function of the bombarding energy $E$ and the distance $s$ of closest approach of the nuclear surfaces.

The ratio $P_{exp}/P_C$ is plotted in Fig. 2 as a function of bombarding energy $E$ and of the distance $s$ of closest approach between the nuclear surfaces. The quantity $s$ is defined in equation (2) of Fewell *et al.* (1979). The apparent decrease in $P_{exp}/P_C$ at the higher energies in Fig. 2 may be due to the onset of nuclear interference effects; e.g. in the case of projectile excitation of $^{18}$O by backscattering from $^{208}$Pb, Coulomb–nuclear interference has depressed the excitation probability by about 15% at $s = 5{\cdot}4$ fm (Fewell *et al.* 1979). Therefore, to be conservative, the E2 transition

probability is inferred from the two lowest energy data points only. The result obtained is $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-) = 2\cdot1 \pm 0\cdot4\ e^2\,\mathrm{fm}^4$. The error arises from uncertainties inherent in the spectrum analysis; other uncertainties such as that in the beam energy are negligible. It might be noted in passing that a similar analysis of the target excitation peak gives $B(\mathrm{E3}; 0^+ \rightarrow 3^-) = 0\cdot76 \pm 0\cdot09\ e^2\,\mathrm{b}^3$, which is in reasonable agreement with the more precise value of $0\cdot665 \pm 0\cdot035\ e^2\,\mathrm{b}^3$ determined by Joye *et al.* (1977).

## Conclusions

Our experimental value for $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-)$ corresponds to an E2 strength of 2·8 W.u. It agrees reasonably well with Kurath's (1957) shell model calculation (0–1·44 $e^2\,\mathrm{fm}^4$, with a preferred value of 1·06 $e^2\,\mathrm{fm}^4$ for $a/K = 4\cdot5$). This calculation was done without introducing effective charges. Recently I. Morrison (personal communication) has performed a shell model calculation using the (8–16)2BME interaction of Cohen and Kurath (1965) and assuming the usual effective charge values of $e_\mathrm{p} = 1\cdot5e$ and $e_\mathrm{n} = 0\cdot5e$ (see e.g. Saayman *et al.* 1973). He obtained $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-) = 4\cdot0\ e^2\,\mathrm{fm}^4$, which is about a factor of 2 larger than our experimental result.

The core-excitation calculation of Meder and Purcell (1974) gives $B(\mathrm{E2}; 3/2^- \rightarrow 1/2^-) = 0\cdot2\ e^2\,\mathrm{fm}^4$, which is an order of magnitude smaller than the experimental value. This is an interesting observation since the core-excitation model reproduces quite well the known static and dynamic M1 moments for $^{11}$B and $^{11}$C and the log*ft* value of the $^{11}\mathrm{C} \rightarrow {}^{11}\mathrm{B}$ $\beta$ decay. Also the core-excitation model tends to overestimate those E2 moments which had been measured in $^{11}$B and $^{11}$C prior to the present work. Measurement of other E2 moments in this mass region would be useful.

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