The B(E2) value of the first excited state of ^{26}Mg (electron scattering study)

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LETTER TO THE EDITOR

The B(E2) value of the first excited state of ^{26}Mg

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Abstract. The first excited state of ^{26}Mg was studied by inelastic electron scattering in the momentum transfer range 0·4 to 1·05 fm^{-1}. The reduced transition probability and transition radius were measured to be $275 \pm 20e^2$ fm^4 and $4{\cdot}13 \pm 0{\cdot}06$ fm respectively. The reduced transition probability was found to be more accurate and of slightly smaller magnitude than existing experimental results. A Nilsson model form factor calculation was found to provide reasonable agreement with the experimental data.

The Glasgow electron scattering facility described by Hogg *et al* (1972) has been used for a systematic study of the stable magnesium isotopes. In particular, the excited states of ^{26}Mg have been studied to an excitation energy of 11 MeV (Lees *et al* 1973). It is the purpose of this letter to report new results for the first excited state of ^{26}Mg and to clarify the spread in reduced transition probability measurements obtained for this level by different experimental techniques.

Curran *et al* (1972) have previously reported the ground state parameters of ^{26}Mg measured by elastic electron scattering relative to ^{12}C. The data have since been re-analysed using the ^{12}C ground state parameters recently reported by Jansen *et al* (1972). We have followed the analysis procedure detailed in Curran *et al* (1972) and the results obtained using a two-parameter Fermi distribution are

$$c = 3{\cdot}04 \pm 0{\cdot}05\,\mathrm{fm}$$

$$t = 2{\cdot}31 \pm 0{\cdot}13\,\mathrm{fm}$$

$$\langle r^2 \rangle^{1/2} = 3{\cdot}06 \pm 0{\cdot}04\,\mathrm{fm}.$$

Use of the more recent ^{12}C parameters resulted in a 0·9 % increase in the root mean square radius, $\langle r^2 \rangle^{1/2}$, of ^{26}Mg.

A detailed description of the experimental and data analysis procedures involved in the inelastic electron scattering experiment will be published elsewhere (Lees *et al* 1973). The target was a self-supporting metallic foil of thickness 46·8 mg cm^{-2} and enriched to 99·7 % in ^{26}Mg. Inelastic scattering spectra were obtained at eight values of momentum transfer in the range 0·4 to 1·05 fm^{-1} and the inelastic cross sections were determined relative to the measured elastic scattering. The elastic parameters given above were used to evaluate the inelastic form factor defined with respect to the Mott cross section.

The experimental form factor was fitted using the DWBA code DUELS (Tuan *et al* 1968) with the transition charge density of Tassie (1956) and the two-parameter Fermi

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model. The code VAO5A of Powell (1971) was employed to obtain the parameters corresponding to the minimum χ^2. The results were

$$c_{\mathrm{tr}} = 2{\cdot}76 \pm 0{\cdot}23\,\mathrm{fm}$$

$$t_{\mathrm{tr}} = 2{\cdot}16 \pm 0{\cdot}15\,\mathrm{fm}$$

$$R_{\mathrm{tr}} = 4{\cdot}13 \pm 0{\cdot}06\,\mathrm{fm}$$

$$B(\mathrm{E2},\uparrow) = 275 \pm 20e^2\,\mathrm{fm}^4$$

where $B(\mathrm{E2},\uparrow)$ is the reduced transition probability for the E2 transition from the ground state to the 1·809 MeV level, and R_{tr} is the transition radius as defined by Rosen *et al* (1967).

It will be noted that the present experiment is primarily sensitive to the transition radius rather than the individual parameters of the Fermi distribution. The DWBA fit to the experimental form factor is shown in figure 1.

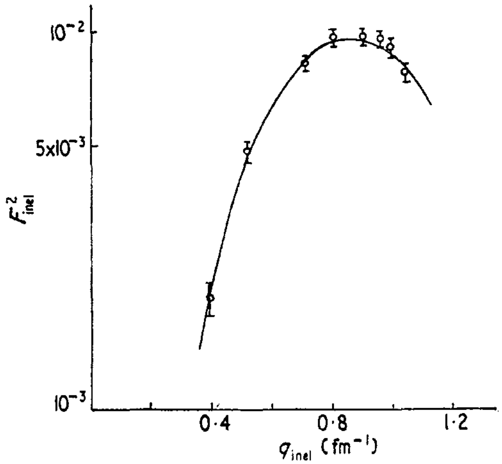

Figure 1. Inelastic form factor for the 1·809 MeV, 2^+ level in ^{26}Mg. The full curve is the best-fit DWBA form factor.

Only one previous electron scattering measurement exists for this state (Khvastunov *et al* 1970). This previous measurement had an experimental resolution of approximately 2 MeV and so was unable to clearly resolve the 1·809 MeV level from the elastic peak. Their analysis was in PWBA and employed the Helm model to yield $B(\mathrm{E2},\uparrow) = 349e^2\,\mathrm{fm}^4$ and $R_{\mathrm{tr}} = 4{\cdot}16$ fm. The present experimental resolution of $\leqslant 160$ keV and DWBA analysis should yield more reliable values for these parameters.

The error in the $B(\mathrm{E2})$ value quoted above is purely statistical and, before comparison with the results of other measurements is made, consideration must be given to the possible existence of systematic effects. The most significant systematic error is that which arises from the assumption of a particular nuclear model in the data analysis. Singhal *et al* (1973) have shown, by comparison of electron scattering results for ^{60}Ni and ^{90}Zr with accurate model independent measurements, for example (γ, γ') and Coulomb excitation, that this error is small ($< 5\,\%$) provided the data span the momentum transfer range given by $1{\cdot}5 \leqslant qR_{\mathrm{tr}} \leqslant 6{\cdot}0$. For the limited range used in the present experiment, however, similar comparisons have shown (Metzger 1970, Johnston 1972) that the B(E2) value obtained by inelastic electron scattering is lower than the corresponding result from model independent measurements by the ratio 0·92 ± 0·06. Applying this correction the reduced transition probability becomes

$$B(\mathrm{E2}) = 299 \pm 29 e^2\ \mathrm{fm}^4.$$

Table 1 lists a summary of the previous measurements of the 1·809 MeV level.

Table 1.

(*a*) Method	$B(\mathrm{E2}, \uparrow)$ ($e^2\ \mathrm{fm}^4$)	Reference
Resonance fluorescence	305 ± 131	Rasmussen *et al* (1961)
Coulomb excitation	370 ± 96	Andreev *et al* (1961)
Resonance fluorescence†	570 ± 231	Booth *et al* (1964)
DSA (α, $\alpha'\gamma$)	370^{+57}_{-51}	Robinson and Bent (1968)
DSA (p,p'γ)	397 ± 75	Hausser *et al* (1968)
DSA (p,p'γ)	703^{+234}_{-141}	de Kock *et al* (1970)
Recoil distance	305 ± 131	McDonald *et al* (1971)
DSA (α,pγ)	346 ± 57‡	Durell *et al* (1972)
(e,e')	299 ± 29§	Present work

(*b*) Method	Q_0 (fm^2)	$B(\mathrm{E2}, \uparrow)$ ($e^2\ \mathrm{fm}^4$)	Reference
(α,α') 104 MeV	(+)44 ± 3	193 ± 26	Rebel *et al* (1972)
Reorientation	+ 56 ± 14	311 ± 156	Schwalm et al (1972)
	(+42 ± 14)	(175 ± 117)	

† A natural magnesium target used in this experiment.
‡ ±25% additional uncertainty in slowing down theory.
§ Corrected for model dependence (see text).

Excluding the present work, the weighted mean of the results in table 1 (*a*) is

$$373 \pm 30 e^2\ \mathrm{fm}^4,$$

which differs by 20% from the present $B(\mathrm{E2},\uparrow)$ measurement corrected for model dependence. The experiment of Booth *et al* (1964) employed a natural magnesium target and obtained reduced transition probabilities for the first excited states of ^{24}Mg and ^{26}Mg. Their measured $B(\mathrm{E2},\uparrow)$ for ^{24}Mg is 50% higher than currently accepted values (Johnston 1972). It is therefore doubtful whether their results for ^{26}Mg have any significance. In addition, Doppler shift attenuation (DSA) experiments using protons as projectiles are known to suffer from large systematic errors in the slowing down theory due to the low recoil velocities of the excited ion. If one then omits the (p, p'γ) DSA experiments, all the remaining results in table 1 (*a*) are in fair experimental agreement.

In table 1 (*b*) the reduced transition probabilities have been evaluated within the framework of the axially symmetric rotational model, namely,

$$B(\mathrm{E2}, \uparrow) = \frac{5}{16\pi} e^2 {Q_0}^2 |C^{J_0 2 J}_{K 0 K}|^{-2},$$

where Q_0 is the intrinsic quadrupole moment, K is the quantum number of the rotational band, and C is a Clebsch–Gordon coefficient. The experiments of Rebel *et al* (1972) resulted in 20% discrepancies for nuclei in the 2s–1d shell between the electromagnetic probability measurements and the probabilities deduced from (α, α') deformation studies. Recently, this discrepancy has been removed for ^{20}Ne and ^{28}Si by re-analysing the data incorporating the finite size of the α particle. It is expected that this will also remove the discrepancy for ^{26}Mg (Rebel 1973, private communication). Schwalm *et al* (1972) have measured ^{26}Mg to be prolate and list two values for Q_0 corresponding to the two possible signs of the interference term arising from virtual excitations through the second excited 2^+ state at 2·94 MeV. For agreement with the electron scattering data the interference term would require to be negative.

It will be noticed that the resonance fluorescence scattering (Rasmussen *et al* 1961), the recoil distance, the reorientation and the electron scattering result corrected for model dependence yield values for the first excited state of ^{26}Mg which agree very well. Unfortunately the accuracy of the experiments which agree with the electron scattering result is poor. A further accurate resonance fluorescence and self-absorption or Coulomb excitation experiment would be useful in confirming the present result.

The Nilsson model has been applied with some degree of success to deformed nuclei in the mass region 25. Drake and Singhal (1971) have calculated the electron scattering form factor for the first excited state of ^{26}Mg using an extended Nilsson model. This calculation included the mixing of all orbitals in the first seven major shells and the resulting minimum energy of the nucleus corresponded to a value of +4·5 for Nilsson's deformation parameter η. They used a value of the oscillator parameter (1·76 fm) determined from the elastic electron scattering experiment of Curran *et al* (1972). The calculated form factor is shown in figure 2 and agrees fairly well with the experimental data. (The experimental data have been corrected for distortion effects by using correction factors as defined in Schucan (1968). This then results in equivalent PWBA experimental data which can be directly compared to theoretical predictions.)

The present $B(E2,\uparrow)$ value also agrees with that calculated by Kurath (1972) using a triaxially deformed rotor model. A deformation parameter η of +4 produced a

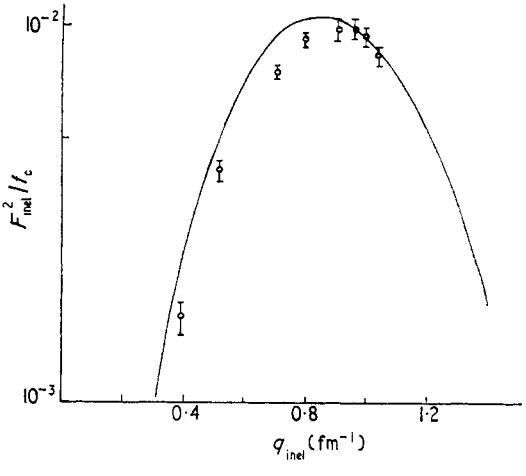

Figure 2. The Nilsson model prediction in PWBA for the form factor of the 1·809 MeV level. The experimental data points have been corrected for the effects of Coulomb distortion (see text).

value of $280e^2$ fm^4. Finally, the results of Gunye (1971) indicate that when the first five major shells are included in Hartree–Fock calculations the present value for the reduced transition probability for the first excited state can be reproduced with effective charges of only 0·1e.

Thus the value of the reduced transition probability of the first excited state of ^{26}Mg is shown to be less than the currently accepted value and is in better agreement with theoretical predictions.

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