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First Excited State of ^{35}S

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A hitherto unreported level in ^{35}S has been found at 1.56 MeV with the $^{37}Cl(d,\alpha\gamma)^{35}S$ reaction. Measurements have been made on the decay of this level and of the four previously known levels up to an excitation energy of 3 MeV. A J^π value of $\frac{1}{2}^+$ for the 1.56-MeV level, as predicted by Glaudemans from shell-model calculations, is not in disagreement with these measurements or those of others. There is convincing evidence, however, that neither the second level at 1.99 MeV nor the third level at 2.35 MeV corresponds to a level predicted in the same calculations to lie at 2.07 MeV with spin and parity of $\frac{5}{2}^+$.

INTRODUCTION

LITTLE is known about the nucleus ^{35}S.[1] The position of seven levels has been established with the (d,p) reaction[2] on ^{34}S and the (d,α) reaction[3] on ^{37}Cl; spin and parity of only the ground state are known.

We have started an investigation of the lower levels of ^{35}S with a study of the reaction $^{37}Cl(d,\alpha\gamma)^{35}S$. Targets of NaCl (approximately 100 $\mu g/cm^2$ on 10-$\mu g/cm^2$ Formvar and 10-$\mu g/cm^2$ carbon) both of natural abundance and enriched in ^{37}Cl (enrichment 93%) were bombarded with 50-nA deuteron beams from the Groningen 5-MV Van de Graaff generator at energies between 3.10 and 4.60 MeV. α particles were detected in an annular solid-state detector at angles between 168° and 173° with respect to the deuteron beam. γ-ray spectra in coincidence with α-particle groups to excited states in ^{35}S were measured with a 3 in.×3 in. NaI(Tl) scintillation counter placed at 55°.

EXPERIMENTAL RESULTS

In Fig. 1, two α-particle spectra are shown, measured at a deuteron energy of 3.68 MeV. On comparing the two spectra, we find that the areas of the α_0 and α_1 peaks from the $^{35}Cl(d,\alpha)^{33}S$ reaction go down by a factor of 11 when the natural target is replaced by a target enriched in ^{37}Cl, whereas the 7.9-MeV α_2 peak to the 1.97-MeV level in ^{33}S decreases only by a factor of 2.

This can be explained by assuming that this peak consists of two components, one leading to the 1.97-MeV level in ^{33}S and another corresponding to a transition to a hitherto unreported level in ^{35}S. An analysis of the two spectra of Fig. 1 shows that this level should have an excitation energy of 1.56±0.01 MeV.[4] The large error is due to instrumental uncertainties.

We verified the existence of this level by measuring the γ-ray spectrum in coincidence with the 7.9-MeV α-particle group, using an enriched $Na^{37}Cl$ target. The measurement was made with an Intertechnique 4096-channel two-dimensional analyzer. This spectrum

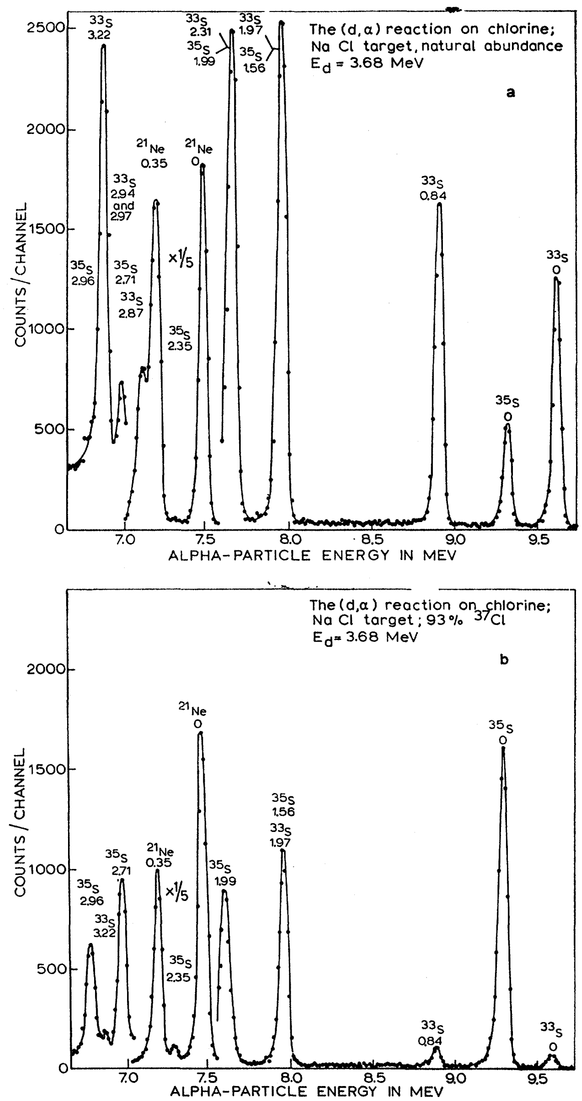

FIG. 1. α-particle spectra, taken at a deuteron energy of 3.68 MeV. The final nucleus and its excitation energy in MeV have been indicated for most of the α-particle groups. The thickness of the natural target (a) is 100 $\mu g/cm^2$ and that of the enriched target (b) 80 $\mu g/cm^2$. The peaks at 7.5 MeV from the $^{23}Na(d,\alpha)^{21}Ne$ reaction were used to normalize the intensities in the two spectra.

[1] P. M. Endt and C. van der Leun, Nucl. Phys. **A105**, 1 (1967).
[2] P. M. Endt and C. H. Paris, Phys. Rev. **110**, 89 (1958).
[3] C. H. Paris, W. W. Buechner, and P. M. Endt, Phys. Rev. **100**, 1317 (1955).
[4] We are indebted to P. F. Greve, who performed this analysis with his computer program.

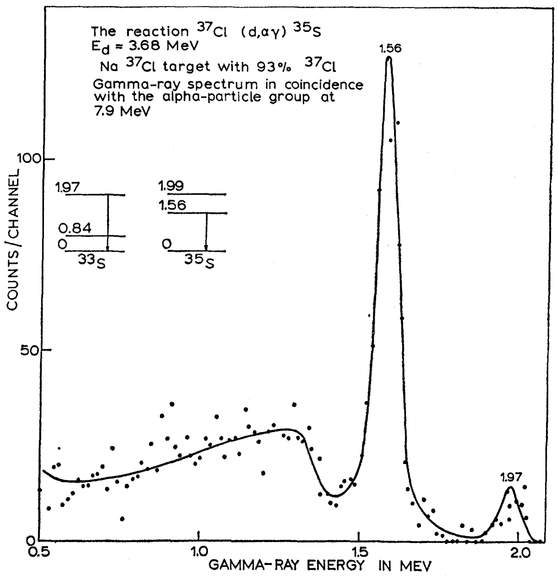

FIG. 2. γ-ray spectrum in coincidence with the α-particle group at 7.9 MeV. Both α particles to a 1.56-MeV level in ^{35}S and to the 1.97-MeV level in ^{33}S fall in the window, so that the two components of this spectrum originate from ground-state transitions from these levels.

(Fig. 2) indeed contains a γ ray of 1.56 MeV, confirming that there is a level of that energy in ^{35}S. The weak 1.97-MeV component in the spectrum originates from the $(d,\alpha\gamma)$ reaction on ^{35}Cl.

The 1.56-MeV level also plays a role in the decay of the 2.35-MeV level of ^{35}S; the γ-ray spectrum in coincidence with α particles to this level (Fig. 3) consists of a 2.35-MeV γ ray from the ground-state transition, together with two components of 0.79 and 1.56 MeV resulting from a cascade from the 2.35-MeV state through the 1.56-MeV level to the ground state.

The energy of the 1.56-MeV level, found from the γ-ray spectra, agrees within the error with that found from the analysis of the α spectra.

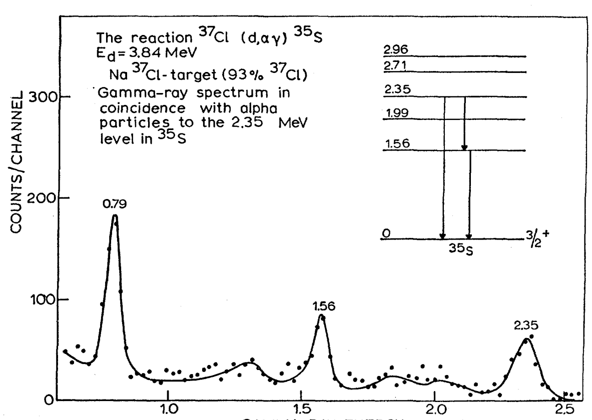

FIG. 3. γ-ray spectrum in coincidence with α particles to the 2.35-MeV level in ^{35}S. The insert shows the decay scheme of this level.

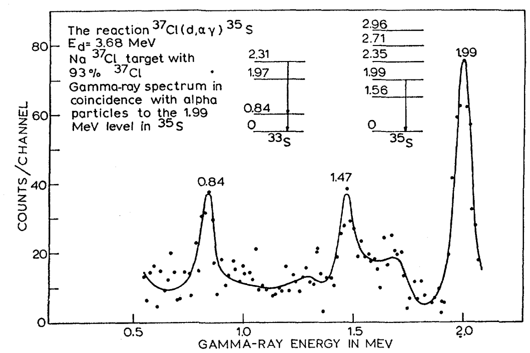

FIG. 4. γ-ray spectrum in coincidence with α particles to the 1.99-MeV level in ^{35}S. α particles to the 2.31-MeV level in ^{33}S have the same energy, so that also γ rays from the decay of that level occur in this spectrum. The decay schemes of the relevant levels are shown in the insert.

The γ-ray spectra in coincidence with the α-particle groups leading to the 1.99-MeV level (Fig. 4) and the 2.71-MeV level (Fig. 5) show ground-state transitions only. In the second case, the counting statistics are such that weak transitions to lower-lying levels cannot be ruled out. The γ-ray spectrum of the decay of the 2.96-MeV level (not illustrated) is very complicated because α particles to both the 2.96-MeV level in ^{35}S and to the 3.22-MeV level in ^{33}S fall in the window. However, a ground-state transition is visible and no transition to the 1.56-MeV level is seen. Here also the statistics are insufficient to rule out weak transitions.

DISCUSSION

Glaudemans *et al.*[5] have made shell-model calculations on energy levels in the $2s_{1/2}1d_{3/2}$ shell and they predict that the first excited state with positive parity in ^{35}S will be a $\frac{1}{2}^+$ level at 1.18 MeV,[6] which may correspond with the 1.56-MeV level found in our measurements. Endt *et al.*[2] did not see this level in the (d,p) reaction on ^{34}S but they may have missed this level because they used targets of natural antimony sulfide only. It follows from calculations of Glaudemans that

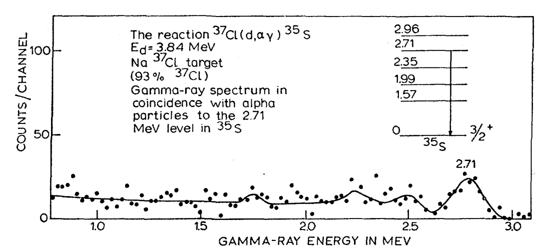

FIG. 5. γ-ray spectrum in coincidence with α particles to the 2.71-MeV level in ^{35}S. The insert shows the decay scheme of this level.

[5] P. W. M. Glaudemans, G. Wiechers, and P. J. Brussaard, Nucl. Phys. **56**, 529 (1964); **56**, 548 (1964).

[6] Recent calculations based on the surface delta interaction put this $\frac{1}{2}^+$ level at 1.56 MeV [P. W. M. Glaudemans (private communication)].

the cross section for the excitation of this level with the (d,p) reaction will be relatively low.[5]

Other levels in ^{35}S predicted by Glaudemans, all with positive parity, cannot correspond to the levels found at 1.99 and 2.35 MeV, as the latter have negative parity[1]; moreover these levels were seen by Endt in the (d,p) reaction on ^{34}S, whereas the levels calculated by Glaudemans will not be excited in a stripping reaction.[5] Further, Watson *et al.*[7] have investigated resonance states in ^{35}Cl with the (p,γ) reaction on ^{34}S and they have found two negative-parity states in ^{35}Cl at the correct energies to be the isobaric analogs of the 1.99- and 2.35-MeV states in ^{35}S.

The 1.99-MeV level in ^{35}S would then correspond to the 7.54-MeV state in ^{35}Cl, which is a $\frac{7}{2}^-$ state. If we tentatively assign a J^π value of $\frac{1}{2}^+$ to the 1.56-MeV level in ^{35}S, the decay of the 1.99-MeV level to only the $\frac{3}{2}^+$ ground state confirms a $\frac{7}{2}$ spin for this level; a cascade through the 1.56-MeV level would imply an octupole transition. Erné[8] has made shell-model calculations on odd-parity levels in nuclei in the range ^{33}S–^{41}Ca and he finds a $\frac{7}{2}^-$ level in ^{35}S at an excitation energy of 2.32 MeV, which might correspond to the 1.99-MeV level in that nucleus.

If the experimentally determined 2.35-MeV state in ^{35}S is the isobaric analog state of the 7.84-MeV level in ^{35}Cl, an assignment of $\frac{3}{2}^-$ is not in disagreement with the decay scheme of this state, again assuming a J^π of $\frac{1}{2}^+$ for the 1.56-MeV level.

ACKNOWLEDGMENT

We wish to thank Dr. Ph. B. Smith and the other members of the Van de Graaff group for their advice and assistance.

[7] D. D. Watson, J. C. Manthuruthil, and F. D. Lee, Phys. Rev. **164**, 1399 (1967).

[8] F. C. Erné, Nucl. Phys. **84**, 91 (1966).

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Inelastic Electron Scattering from ^{26}Mg at 180°

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The 180° inelastic electron scattering from ^{26}Mg has been studied at bombarding energies of 39 and 56 MeV. Eight magnetic dipole transitions are found from 1+ states at 8.52, 9.24, 9.67, 10.18, 10.63, 11.20, 13.33, and 13.66 MeV. The transition radii and ground-state radiation widths are calculated.

I. INTRODUCTION

THE study of nuclear structure by means of electron scattering is done in practice either (1) at 180° or (2) at a range of other angles. The experimenter who chooses 180° scattering must employ more complex apparatus than that required for other angles and cannot readily adapt his apparatus to other angles of scattering. In addition, one must expect small scattering cross sections at 180°.

On the other hand, the data at 180° serves as a valuable complement to that from other angles because it has a unique advantage. Effectively, only the transverse component of the cross section is nonzero. Usually this means that magnetic transitions, which are often overshadowed at other angles, are the most prominent features at 180°. This is demonstrated rather effectively in the work reported here on ^{26}Mg, where many magnetic dipole transitions are found. We discuss the properties of these transitions and also, briefly, the relationship of the results to the theoretical work of Morpurgo[1] and Kurath.[2]

II. THEORETICAL FRAMEWORK

The data are analyzed using the model-independent theoretical expressions given by Rosen *et al.*[3] This results in the determination of the multipolarity of the transition, the transition radius, and the strength (B or Γ_0) of the transition.

As our electron scattering data are taken at 180°, we assume a magnetic transition of multipolarity 2^L and obtain [Ref. 3, Eq. (5)]

$$\left(\frac{d\sigma}{d\Omega}\right)_{180°}=\frac{\pi\alpha}{[(2L+1)!!]^2}\frac{L+1}{L}\frac{q^{2L}}{k_1^2}B(ML,q)\,, \qquad (1)$$

where k_1 is the initial electron momentum; q, the momentum transfer; and B, the reduced transition proba-

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[2] D. Kurath, Phys. Rev. **130**, 1525 (1963).

[3] M. Rosen, R. Raphael, and H. Überall, Phys. Rev. **163**, 927 (1967).