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Spin-Parity Combinations for Levels in Mg^{24} and Si^{28}

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Parities of levels in Mg^{24} and Si^{28} have been found from observations on alpha-particle groups emitted in the forward direction following bombardment of O^{16} by C^{12} and O^{16} ions. The interpretation depends only on conservation laws and not on any assumption about the reaction mechanism. Of the lowest seven known states of Mg^{24} [$E_{ex}=0$, 1.37, 4.12, 4.23, (5.22), 6.01, 6.43 MeV] and the lowest five of Si^{28} [$E_{ex}=0$, 1.77, 4.62, 4.98, (6.28) MeV] only the two in parentheses have parity $(-)^{J+1}$. The spins (J) of all these levels are known, and because these two are the only members with J odd, it follows that all 12 levels have positive parity.

1. INTRODUCTION

It was noted by Litherland[1] that in nuclear reactions of the type $X(h_1,h_2)Y$, where X, h_1, and h_2 have zero spin and positive parity, h_2 cannot be emitted at 0° or 180° to the incoming beam, if the parity of Y(spin J) is $(-)^{J+1}$. Thus, when the level spin is known it is possible to assign parity unambiguously. Most methods used to find parity (fitting stripping patterns, β decay and angular correlations with polarization insensitive detectors) generally involve assumptions whose reliability depends on the particular situation.

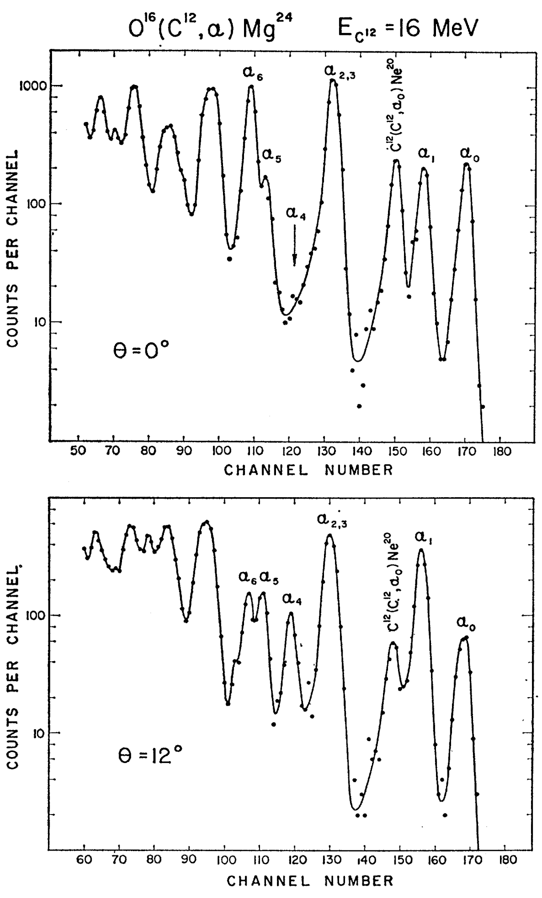

FIG. 1. Pulse-height spectra of alpha particles from the reaction $O^{16}(C^{12},\alpha)Mg^{24}$ at laboratory angles of 0° (top) and 12° (bottom). The incident C^{12} energy was 16 MeV.

In the experiments described here, the restriction noted above applied to the angular distributions of alpha particles from discrete states in Mg^{24} and Si^{28} following bombardment of an oxygen-16 target by C^{12} and O^{16} ions. Then detection of alpha particles at 0° was sufficient to establish parity of $(-)^J$ henceforth referred to as "natural" parity.

Absence of a particular group at 0° could be due to a small width for the reaction but this was not the case for the levels studied because the groups all appeared strongly at other angles. Then nonappearance at 0° can be attributed to either parity $(-)^{J+1}$ or destructive interference among compound nucleus resonances. Such a cancellation would not be expected to persist over a large energy interval, however, and in the two cases where alpha particles disappeared at 0° the behavior was found to persist at all the bombarding energies used. It was then possible in these cases to assert that assignment of "unnatural" parity, $(-)^{J+1}$, was exceedingly likely.

Previous measurements[2] on the twelve levels studied had allowed spin determinations. Parity assignments had been made by other methods, except to the 4.62- and 4.98-MeV levels in Si^{28} and the 5.22-MeV level in Mg^{24}. These assignments were confirmed and the unknown parities found in terms of the spin.

2. EXPERIMENTAL

The small scattering chamber used with the Chalk River tandem generator has been described.[3] A silicon solid-state counter (p-n diffused junction 10 000 Ω cm) was attached rigidly to the rotating lid of the chamber and used to detect and resolve the groups of emitted alpha particles. The range of angle of observation included 0°. A $\frac{1}{16}$-in.-diam aperture in front of the counter was $5\frac{1}{2}$ in. from the $\frac{1}{16}$-in.-diam beam spot on the target. This leads to an angular resolution of ±0.65°.

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[1] A. E. Litherland, Can. J. Phys. **39**, 1245 (1961).
[2] P. M. Endt and C. Van der Leun, *Energy Levels of Light Nuclei III* (North-Holland Publishing Company, Amsterdam, 1962).
[3] D. A. Bromley, J. A. Kuehner, and E. Almqvist, Phys. Rev. **123**, 878 (1961).

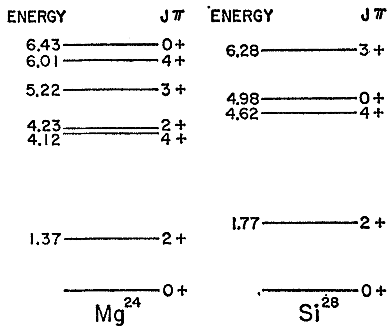

FIG. 2. Level diagrams for Mg^{24} and Si^{28} showing the levels studied in this paper.

The target was a film of alumina 1500 Å thick formed electrolytically on the surface of a 0.002-in. aluminum foil. This foil was not quite thick enough to stop the direct beam of heavy ions at the bomabrding energies chosen and a further aluminum foil (2 mg/cm^2) was placed over the counter. Additional foils could be moved in front of the counter from outside the chamber and the optimum thickness was that which just stopped all heavy ions. The ability to stop the direct beam and elastically scattered particles without serious slowing of the observed particles favors the method using heavy ions over $(\alpha\alpha')$ reactions where the spin-parity selection rule also applies.

After linear amplification the pulses from the counter were fed into a 300-channel pulse-height analyzer.

3. RESULTS

A. $O^{16}(C^{12},\alpha)Mg^{24}$—0° and 12°

Figure 1 shows the spectrum of alpha particles observed at 0° and 12° when the target was bombarded with 16 MeV C^{12} ions. The observed groups labeled α_0 to α_6 occur at energy intervals in agreement (see Fig. 2)

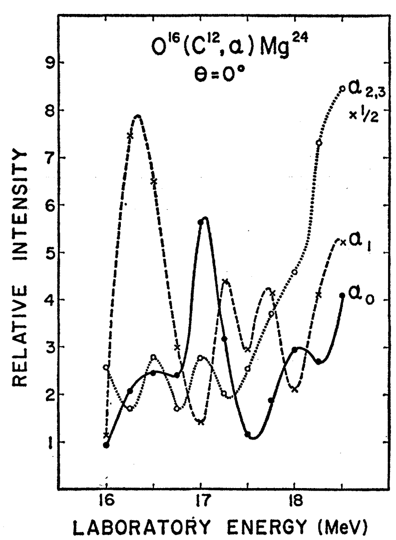

FIG. 3. Relative intensity at 0° for alpha particles from the reaction $O^{16}(C^{12},\alpha)Mg^{24}$.

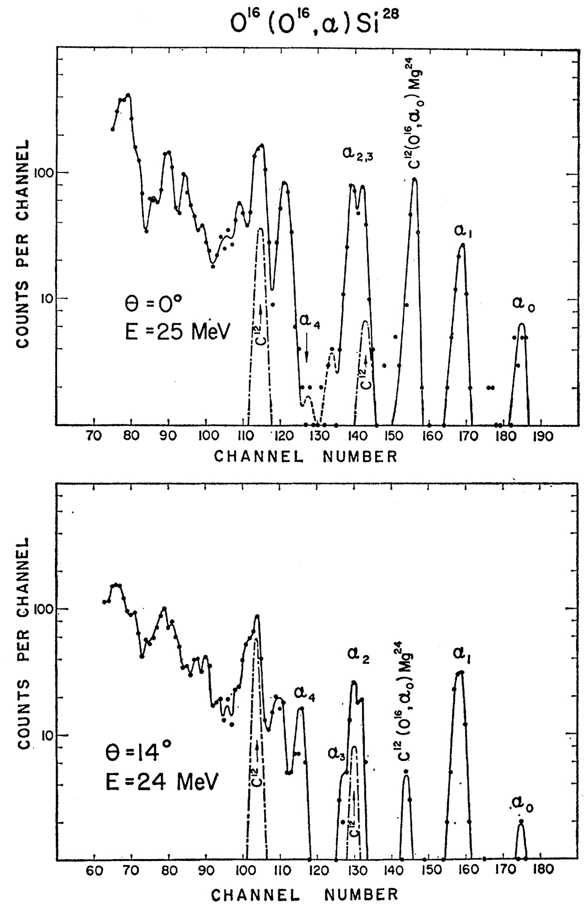

FIG. 4. Pulse-height spectra of alpha particles from the reaction $O^{16}(O^{16},\alpha)Si^{28}$ at laboratory angles of 0° (top) and 14° (bottom). The incident O^{16} energy is indicated in each case. The dashed curves are the intensities of alpha particles from the contaminant reaction $C^{12}(O^{16},\alpha)Mg^{24}$ for the same energies and angles and normalized to the ground state yield.

with the first seven known states in Mg^{24}. The addition of extra foils produced energy shifts in agreement with the known slowing down of alpha particles. The group marked as being due to the reaction $C^{12}(C^{12},\alpha_0)Ne^{20}$ is attributed to carbon impurity in the target because the peak position agrees with calculation. This identification is corroborated by the observation of the reaction $C^{12}(O^{16},\alpha_0)Mg^{24}$ when an O^{16} beam was used on the same target as is discussed in the following section. Other alpha-particle groups due to this impurity from higher states in Ne^{20} would be insignificant at 0° because they have been shown[4] to be less than 10% in intensity of the ground-state group at this energy.

The groups α_2, α_3, corresponding to states at 4.12 and 4.23 MeV in Mg^{24}, were not resolved. However, these groups have been resolved in work with the Aldermaston multichannel magnetic spectrograph[5] and in the

[4] J. A. Kuehner, Phys. Rev. **125**, 1650 (1962).
[5] S. Hinds, R. Middleton, and A. E. Litherland, Proc. Phys. Soc. (London) **77**, 1210 (1961), and private communication.

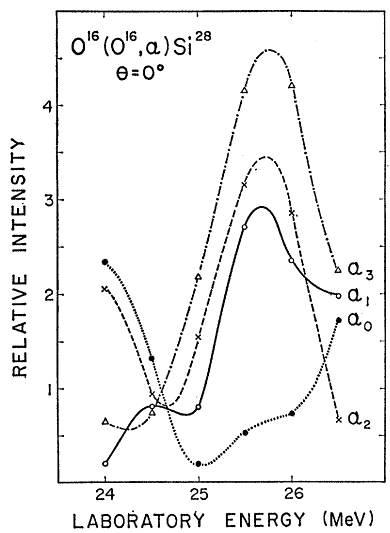

FIG. 5. Relative intensity at 0° for alpha particles from the reaction $O^{16}(O^{16},\alpha)Si^{28}$.

reaction $C^{12}(O^{16},\alpha)Mg^{24}$ at 24 MeV both these groups were observed at angles near 0°.[5]

The group α_4, present at $\theta_\alpha=12°$, is shown in Fig. 1 to disappear at $\theta_\alpha=0°$ for a bombarding energy of 16 MeV. This behavior was found to persist as the energy was raised by 250 keV intervals throughout the range 16–18.5 MeV. During this procedure the intensity of other groups fluctuated strongly as shown in Fig. 3, and it was clear that at least several compound nucleus resonances exist in this interval so that the possibility of accidental cancellation at all measured points was extremely small.

B. $O^{16}(O^{16},\alpha)Si^{28}$—0° and 14°

This reaction was studied at greater energy (25 MeV) because of the higher Coulomb barrier. The alpha-particle spectra obtained at 0° and 14° are given in Fig. 4. The spacing of the alpha-particle groups is in agreement with that calculated from the known level spacing in Si^{28} (see Fig. 2). The group labeled $C^{12}(O^{16},\alpha_0)Mg^{24}$ is ascribed to the presence of carbon in the target and the position of the peak coincides with that calculated from the known kinematics of the reaction $C^{12}(O^{16},\alpha_0)Mg^{24}$. For this reaction $\theta=0°$ corresponds to $\theta=180°$ for $O^{16}(C^{12},\alpha)Mg^{24}$ and the emission of α_0 at this angle confirms the result obtained in Sec. A for $\theta=0°$ in the reaction $O^{16}(C^{12},\alpha_0)Mg^{24}$.

The alpha-particle spectra from the contaminant reaction $C^{12}(O^{16},\alpha)Mg^{24}$ at the same energies and angles shown in Fig. 4 have been studied using carbon targets.[6] The groups from this reaction corresponding to excited states of Mg^{24} are shown by the dashed curves in Fig. 4. The yields of the excited-state groups which have been appropriately normalized to the value of the well-resolved ground-state peak make an insignificant background to the yield from $O^{16}(O^{16},\alpha)Si^{28}$ reaction in the region of interest.

The group α_4 is absent at 0° but appears at $\theta=14°$. Further, this group was absent at 0° when the bombarding energy was varied in 500-keV steps in the range 24–26.5 MeV. On changing the energy the intensity of the other groups fluctuated strongly (Fig. 5).

C. Angular Distributions

Angular distributions for laboratory angles less than 50° were measured for both of the reactions studied. The results are given in Figs. 6 and 7. In many cases the distributions are strongly forward peaked but it is not possible to infer direct interaction from this. Indeed the strong fluctuations with energy shown in Figs. 3 and 6 do not favor such an interpretation. Also, the distributions for $C^{12}(O^{16},\alpha)Mg^{24}$ obtained at Aldermaston[5] appear in many cases to favor symmetry about 90°. The sharp forward peaking does indicate that high angular momenta are included in the compound states.

4. DISCUSSION

The results of the last section confirm the parity assignments for levels in Mg^{24} and Si^{28} given in Fig. 2. With the exception of the two states shown to have "unnatural" parity, $(-)^{J+1}$, the parities are now known with the same certainty as the spins. The "unnatural" parity assignments to the 5.22 MeV (3+) level in Mg^{24} and 6.28 MeV (3+) level in Si^{28} depend on the reason-

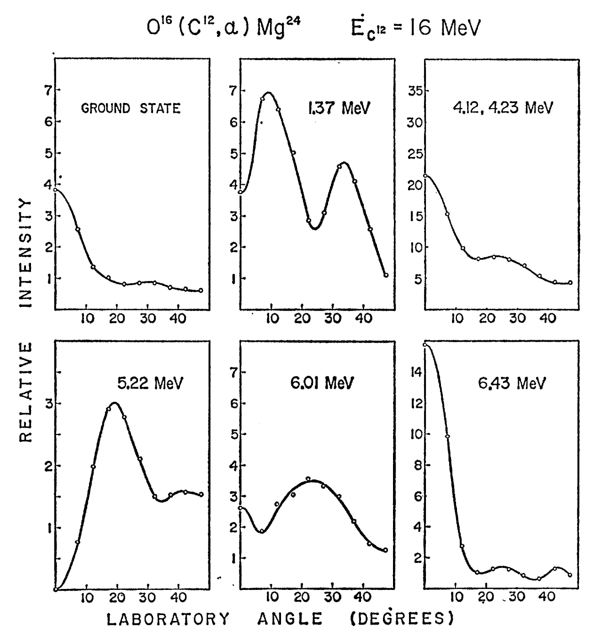

FIG. 6. Angular distributions (laboratory system) for alpha particles from the reaction $O^{16}(C^{12},\alpha)Mg^{24}$ at an incident C^{12} energy of 16 MeV. The excitation energy in Mg^{24} is indicated in each case.

[6] R. D. Bent, J. E. Evans, and G. C. Morrison (unpublished).

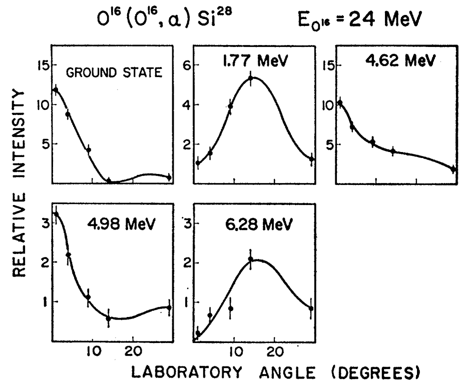

FIG. 7. Angular distributions (laboratory system) for alpha particles from the reaction $O^{16}(O^{16},\alpha)Si^{28}$ at an incident O^{16} energy of 24 MeV. The excitation energy in Si^{28} is indicated in each case.

able assumption that it is unlikely that zero yield at 0° will accidentally persist over a wide energy range.

The prominent fluctuations with energy of the excitation curves (Figs. 3 and 5) suggest that a compound nucleus process dominates in the reactions. Of course, excitation of "unnatural" parity states cannot come through a one-step direct-interaction process and the fact that such states are strongly excited is additional evidence for the compound-nucleus process. The measured widths average ~170 keV c.m. for the $O^{16}(C^{12},\alpha)Mg^{24}$ reaction and ~600 keV c.m. for the $O^{16}(O^{16},\alpha)Si^{28}$ reaction, corresponding to mean lifetimes of 3.5×10^{-21} and 1×10^{-21} sec for the compound systems, respectively. The sharp structure and forward peaking of the angular distributions indicate that compound states of high spin are involved. This is not surprising since at the energies used here the incident nuclei can readily interact with 8 or 10 units of $\hbar$ of angular momentum. It is noted that, although the resonance structure is clearly evident in individual channels, it averages out to give a smooth featureless energy dependence of the total cross section.[7] This behavior is different from that observed in the C^{12}–C^{12} system at low collision energies where the total-reaction cross section shows clear resonance behavior.[7]

ACKNOWLEDGMENT

The authors are indebted to Dr. A. J. Ferguson for a critical reading of the manuscript.

[7] E. Almqvist, D. A. Bromley, and J. A. Kuehner, Phys. Rev. Letters, 4, 515 (1960), and to be published.

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L/K-Capture Ratio in Mn^{54}, Fe^{55}, Co^{57}, and Co^{58} Decays*

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The multiwire proportional counter method has been applied to measurements of the L and K radiations arising from orbital electron-capture in gaseous sources of 290-day Mn^{54}, 2.6-yr Fe^{55}, 270-day Co^{57}, and 72-day Co^{58}. The presence of gamma transitions and positrons in the decay of Mn^{54}, Co^{57}, and Co^{58} is shown not to interfere with an accurate measurement of the L/K-capture ratio. The experimental values of the L/K-capture ratio are 0.098 ± 0.006, 0.106 ± 0.005, 0.099 ± 0.011, and 0.108 ± 0.004 for Mn^{54}, Fe^{55}, Co^{57}, and Co^{58}, respectively. The result for Fe^{55} is in excellent agreement with the earlier value measured by Scobie, Moler, and Fink, although the present value has been corrected for counter escape somewhat more exactly. These values lie above the theoretical results of Brysk and Rose by some 9% for Mn^{54}, 9.3% for Fe^{55}, 7% for Co^{57}, and 17% for Co^{58}. These discrepancies are reduced by application of the exchange correction pointed out by Bahcall to the theoretical results of Brysk and Rose. This correction for the effect of exchange among the various electrons participating in the electron capture process apparently explains the well-established general discrepancy between the precision experimental values and the theory of Brysk and Rose. Remaining slight discrepancies probably can be traced to systematic experimental errors.

INTRODUCTION

EARLIER we reported[1] a precision measurement of the L/K-capture ratio in Fe^{55} decay using gaseous radioactive ferrocene in the counting gas (9:1 argon-methane) of a multiwire proportional counter. In the present work, Fe^{55} has been remeasured but with more exact corrections for counter escape, and the result is found to be in slightly closer agreement with theoretical results. In addition, L/K-capture ratios for 290-day Mn^{54}, 270-day Co^{57}, and 72-day Co^{58} have been measured by utilizing gaseous manganocene and cobaltocene as radioactive sources in the counter gas (see Appendix B).

A general discussion of experimental results on L/K-

* Supported in part by the National Science Foundation and the U. S. Atomic Energy Commission. This investigation is based in part on the M.S. thesis of R. B. Moler, which contains more detailed information concerning the experiments on Fe^{55} and Co^{58}.

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[1] J. Scobie, R. B. Moler, and R. W. Fink, Phys. Rev. 116, 657 (1959).