ENERGY DEPENDENCE OF LARGE-ANGLE ELASTIC ALPHA SCATTERING FROM Ar^{40}, Ar^{36}, S^{32}, Si^{28}, AND O^{16}

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(Received 14 September 1964)

In an earlier investigation,[1] the large-angle elastic alpha scattering from Ca^{40} was measured at 30.5 MeV at MIT and for several higher energies to 40 MeV at Lewis Research Center. The striking feature of these cross sections was that the large-angle structure exhibited a striking amplitude variation with energy while the angular positions of the minima remained relatively fixed. This behavior contrasts with that at the forward angles where the oscillatory pattern shifts with energy as predicted by the simple diffraction theory.

Several groups have met with little success in attempts to understand this phenomenon in terms of a conventional four-parameter optical model, leading to much speculation concerning the origin of the behavior. Two approaches have been advanced, the first based on exchange processes such as heavy-particle stripping, while the second involves the use of additional parameters to the standard optical model.

We have studied the large-angle scattering from the even-even nuclei Ar^{40}, Ar^{36}, S^{32}, Si^{28}, and O^{16} between 30 and 40 MeV, in order to determine whether the phenomena at these angles would exhibit any systematics or whether, according to one suggestion, the effects were peculiar to Ca^{40} and other closed-shell nuclei. The NASA 60-inch cyclotron was used for the measurements. For the lower energies, the beam was degraded through beryllium foils followed by a magnetic analyzer so that the incident-beam energy spread remained constant. Solid-state counters subtending 1.7° gave an over-all energy resolution of 1.5% (full width at half-maximum). All targets except silicon were gases.

The results of our survey, plotted as the ratios to the Rutherford cross section, are seen in Fig. 1. For clarity of presentation only a few data points with the larger error bars are shown, while the remaining data are represented by smooth lines. The Ca^{40} cross sections of reference 1 have been included for comparison. Measurements on Ar^{40} were quite different from those for Ca^{40}. The pronounced large-angle diffraction pattern is largely absent; only the last minimum remains stationary and the over-all cross section in this region is lower by an order

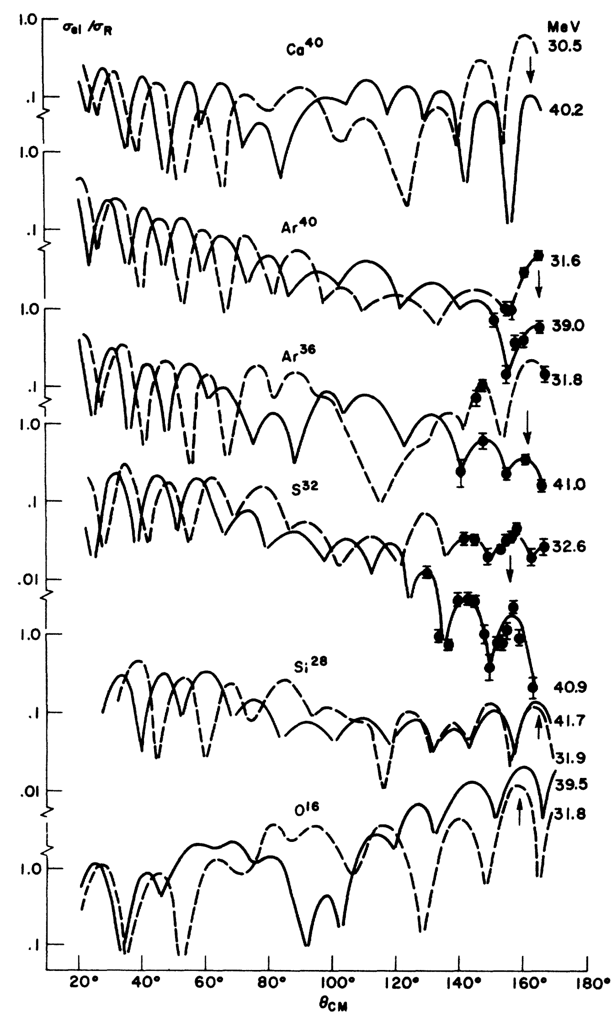

FIG. 1. Angular distributions of alpha particles elastically scattered by Ca^{40}, Ar^{40}, Ar^{36}, S^{32}, and O^{16}. The arrows indicate angles at which excitation functions were measured.

of magnitude than that of calcium. Ar^{36} shows a remarkable over-all similarity in Ca^{40} at the low energy in spite of the fact that the central region is very energy sensitive. At the high energy the large-angle cross sections are depressed as in Ar^{40} but the minima remain in phase as in Ca^{40}. S^{32} follows the behavior of Ar^{36} at large angles having large, in-phase amplitude variation with energy. Si^{28} and O^{16} share with the others the common feature of a large backward enhancement and sharp minima; however, in contrast, there is very little energy dependence of the amplitudes. It is interesting to note that the deep minimum between 120° and 130° c.m. is common to four of the nuclei studied.

In order to obtain a comparison of the energy dependence of the enhancement for the various nuclei in the region of interest we have measured excitation functions at angles indicated by the arrows in Fig. 1. Distortions of these curves due to slight angular movement of the maxima should be small. The results are seen in Fig. 2. Ca^{40}, Ar^{36}, and S^{32} have a similar smooth decrease in cross section with increasing energy, while S^{28} and O^{16} are relatively invariant.

In summary, we have found that the large-angle elastic alpha scattering cross sections from Ca^{40}, Ar^{36}, S^{32}, Si^{28}, and O^{16} exhibit pronounced diffraction patterns which have a constant angular position as the incident energy is varied between 30 and 40 MeV. Furthermore Ca^{40}, Ar^{36}, and S^{32} all show a strong and systematic energy dependence. Finally, the large difference between Ar^{40} and Ca^{40} suggests that the large-angle scattering might be sensitive to some facet of nuclear structure.

In light of these results, both of the explanations mentioned in the introduction seem to have difficulties in describing the large-angle scattering behavior of the heavy nuclei. The plane-wave stripping approach[2] gives the cross section as a function of the momentum transfer in the collision and thus would predict angular shifts with energy of the peaks similar to those in the forward hemisphere. This is in contradiction to our data. Also the cross section should decrease as the target mass is increased. While this seems to be true for the lighter nuclei it is in disagreement with the trend of S^{36}, Ar^{36}, and Ca^{40} as seen in Fig. 2.

It has been found[3] that the conventional optical model can easily reproduce the magnitude and the periodicity of those cross sections which are not enhanced at the back angles (Ar^{40} and the high-energy S^{32} and Ar^{36}) but no parameters were found which would emphasize the back angles. If, on the other hand, a modified optical model is used where the radius of the imaginary part is reduced from that of the real part, the cross section at back angles can be increased.[4] It has been suggested that this allows certain waves to resonate in the optical potential. Although it is impossible to delineate what a modified optical model cannot do, it

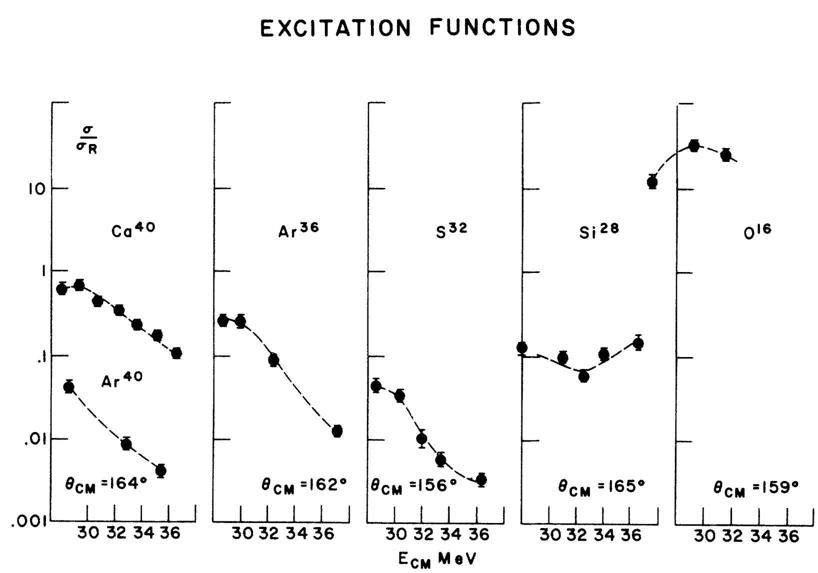

FIG. 2. Large-angle excitation functions for elastic alpha-particle scattering by Ca^{40}, Ar^{40}, Ar^{36}, S^{32}, Si^{28}, and O^{16}.

seems improbable that even this technique will give as strong an energy dependence as is found in the data.

We gratefully acknowledge several helpful discussions with Dr. C. R. Gruhn and Professor N. S. Wall.

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NEW TWO-NEUTRON PICKUP REACTION: $Mg^{26}(He^4, He^6)Mg^{24}$ †

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(Received 12 August 1964)

Forty-MeV alpha particles from the Brookhaven 60-in. cyclotron were used to study levels of Mg^{24} excited by the $Mg^{26}(He^4, He^6)Mg^{24}$ reaction. The (He^4, He^6) reaction, a hitherto unobserved two-neutron pickup reaction, will be a useful tool in nuclear spectroscopy in that its use will complement the results obtained from the (p, t) reaction, and other two-neutron pickup reactions. A similar situation exists for the one-neutron pickup reactions (p, d), (d, t), and (He^3, He^4).[1] Here, we describe the observation of the $Mg^{26}(He^4, He^6)Mg^{24}$ reaction and make a qualitative comparison with the $Mg^{26}(p, t)Mg^{24}$ reaction.[2]

The detectors used for this work were transmission-mounted surface-barrier counters. Three detectors were used: a thin ΔE detector, a stopping detector, and a veto detector to reject events associated with long-range particles. Coincident pulses were required on the first two detectors, with anticoincidence in the veto detector. ΔE pulses were multiplied by E pulses that were produced from the addition of pulses from the ΔE and stopping detectors.[3] The product pulse, which is proportional to the particle mass, was analyzed in a single-channel analyzer to select the particles of interest. A mass discrimination between mass 4 and mass 6 of over 10^5:1 was attained.

Figure 1 shows a typical He^6 spectrum corresponding to the levels[4] of Mg^{24} at a scattering angle of 52.2 degrees. Figure 2 shows the angular distributions corresponding to the different levels shown in Fig. 1. The angular distributions are characterized by a strong oscillatory structure that persists over the angular range that was studied. The strong oscillatory structure indicates that the reaction probably is predominantly a direct-type process with relatively little contribution from compound-nucleus type processes.[5]

A number of interesting features are apparent when the angular distributions for the $Mg^{26}(He^4, He^6)Mg^{24}$ reactions measured at 40-MeV bombarding energy are compared with the angular distributions for the $Mg^{26}(p, t)Mg^{24}$ reactions measured at 28-MeV bombarding energy. There appears to be a substantial difference in the differential cross sections for the two reactions. The cross section for the $Mg^{26}(p, t)Mg^{24}$ reaction to the ground state is one hundred times as

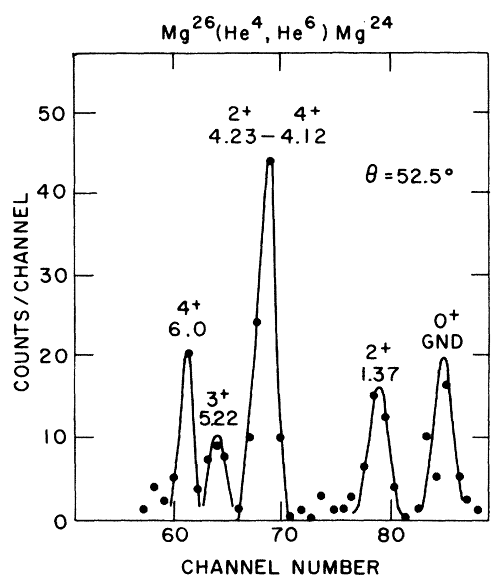

FIG. 1. Pulse-height distributions of He^6 particles produced in the $Mg^{26}(He^4, He^6)Mg^{24}$ reaction with 40-MeV alpha particles. The pulse-height analyzer was gated with pulses from a mass-identification circuit. The peaks have been labeled with the spin, parity, and excitation of the state produced in the residual Mg^{24} nucleus. The spectrum, taken at a laboratory angle of 52.5°, shows the strong excitation of the 3^+ unnatural-parity state at 5.22 MeV.