Title

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Abstract

By observing the inelastic scattering of 50 MeV alpha particles from samarium, we have made a definite correlation between reversed phase angular distributions and double excitation of second excited rotational levels. For the first time, we have also seen triple excitation of third excited rotational levels.

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The scattering of medium energy alpha particles from intermediate weight nuclei show distinctive angular distributions for elastic and inelastic scattering. These angular distributions are marked by distinct diffraction maxima and minima and result from the strong absorption of the incident alpha particles. Simple excitations of collective levels in even nuclei yield characteristic distributions for each angular momentum transfer (i.e., level spin) at small angles and asymptotically approach the Blair phase rule (BPRI) at large angles. Specifically, even parity states (2^+, 4^+) asymptotically produce diffraction maxima in phase with the elastic scattering minima. Such angular distributions can be fit quite well by the Fraunhofer model[1] modified by a slightly diffuse edge[2].

More recently, however, several examples of low lying states of known even parity have been observed to give rise to angular distributions with reversed phases[3]. Moreover these distributions were found to have flatter envelopes than those of the simple excitation. The combination of these two properties define the characteristics of Blair phase rule two (BPRII) distributions. It was found that the states giving rise to such distributions could often be thought of as two-surfon levels, such as second rotational states (4^+) or two-phonon vibrational states (0^+, 2^+, 4^+ triplet). Thus a correspondence was made between (BPRII) angular distributions and the "double excitation" of two surfon collective states. However, in no case was the collective nature of the level well established.

To explain these results, recourse was made to the extended optical model of Rost and Austern[4]. It is known that two second order terms of the transition matrix can give rise to double excitation. The first involves the second order term in the expansion of the nuclear potential in powers of the deformation. Although this term can be simply handled in DWBA approximation, it has been shown that this term alone cannot account for the experimental distributions[5]. The second term, corresponding to an excitational cascade through the one-surfon level, has been calculated only after further approximations have been made. It was then shown that this term, with interference effects from the first, can explain BPRII distributions. Austern and Blair[6] have developed such a theory in detail in which, however, the two terms cannot be separated. Calculations using the coupled-channels method have given similar results[7]. All these calculations depend on the purity of the two-surfon states; admixtures of this state with states of different character lead to results that are more complicated to predict.

In order to investigate the validity of the correspondence between double excitation and BPRII, we chose to look at the inelastic scattering of 50 MeV alpha particle from ^{152}Sm and ^{154}Sm. The requirement of experimentally accessible pure two-surfon states are well met by the rotational levels of the rare earths. The deformations, β, of these two nuclei are known to be .304 and .351 respectively[8].

Self-supporting samarium target foils about 300 μg/cm^2 thick were obtained by heating isotopic samarium oxide in the presence of lanthanum metal[9]. Scattered alpha particles were detected in four cooled lithium-drifted silicon detectors; energy spectra were stored in a multichannel analyser. The total beam passing through the target was collected and measured with a Faraday cup and checked with a fixed angle monitor counter. Target thicknesses were obtained by normalizing the elastic cross section to Rutherford scattering at small angles. Total experimental resolutions were about 45 keV, sufficient to resolve the 2^+ from the ground state at most angles. Particular care was taken to reduce backgrounds and low energy tails by using a highly polished cylindrical-edged gold plated analyzing slit located far from the target area. Similar care was taken with the counter collimators. Nevertheless, backgrounds proved to be our most severe experimental problem, and tails from the large elastic peaks at forward angles obscured much of the inelastic data below about 25 degrees. Extraction of the inelastic cross sections was aided by use of a computer program which approximated the spectra by a series of gaussian peaks plus background[10)]. Sample samarium spectra at larger angles are shown in fig. 1.

The inelastic differential cross sections to the 2^+, 4^+ and 6^+ levels of ^{152}Sm and ^{154}Sm are shown in figs. 2 and 3. These levels were all clearly resolved from adjacent inelastic levels except for the 6^+ level of ^{152}Sm. This level could not be separated from the 0^+ level at 920 keV, but we do not expect significant contribution from the 0^+ level. Inspections of the 2^+ and 4^+ distributions for both target nuclei shows the expected BPRI distribution for the 2^+ levels and BPRII distributions for the 4^+ levels. Both the reversed phase and the flatter angular distribution of the 4^+ levels are apparent. In addition, the cross sections are roughly in the ratio to be expected from the additional factor β^2 which would multiply the double excitation cross section. Therefore we can establish a definite correspondence between known two-surfon levels and BPRII distributions for these nuclei.

We consider next the angular distributions of the 6^+ levels. These distributions have still another reversal of phase. The envelopes of their oscillations are even flatter than those of the 4^+ levels. The magnitude of their cross sections is reduced from that of the 4^+ levels again by about a factor of β^2. In addition, the ^{154}Sm data at about 25° indicates a minimum where one would not be expected for a direct ℓ=6 transition. We denote these characteristics by BPRIII and, by analogy with the 4^+ levels, relate them to "triple excitation" of the previously known 6^+ three-surfon members of the ground state rotational bands.

Extension of the Austern-Blair model to include triple excitation in the Fraunhofer limit provides qualitative agreement with our results. However the Austern-Blair model does not include coulomb excitation, which is certainly important for the excitation of the 2^+ level, but probably not for the other states. More important, deformations as large as those in the samarium isotopes lead to such strong coupling of the 2^+ and elastic channels that the DWBA approach is inappropriate. A coupled-channels program with coulomb excitation is indicated for more quantitative calculations.

The precise measurement of small amounts of higher order multipole deformations awaits such an improved theory. The constancy of the phase reversals and depth of the minima shown by our data are evidence that any such higher order terms are small. By means of the Austern-Blair model, we can place upper limits on these higher multipole mixtures. These limits are 0.1 for β_4 with a positive sign and 0.03 for β_6 with a negative sign. These limits are smaller by a factor of 3 for β's with the opposite sign. The limits compare with those of reference 11.

The regularity of the multiple excitation distributions also argues for a simplification of the excitation process. In addition to the two paths available to the double excitation, a triple excitation might also proceed via a mixed single-excitation, double-excitation cascade through either the 2^+ or 4^+ states. We feel that such a complicated mixture of excitation mechanisms would result in an angular distribution more featureless than the sharply structured patterns we see. The derivative relationship of ref. 5 seems to apply to these results.

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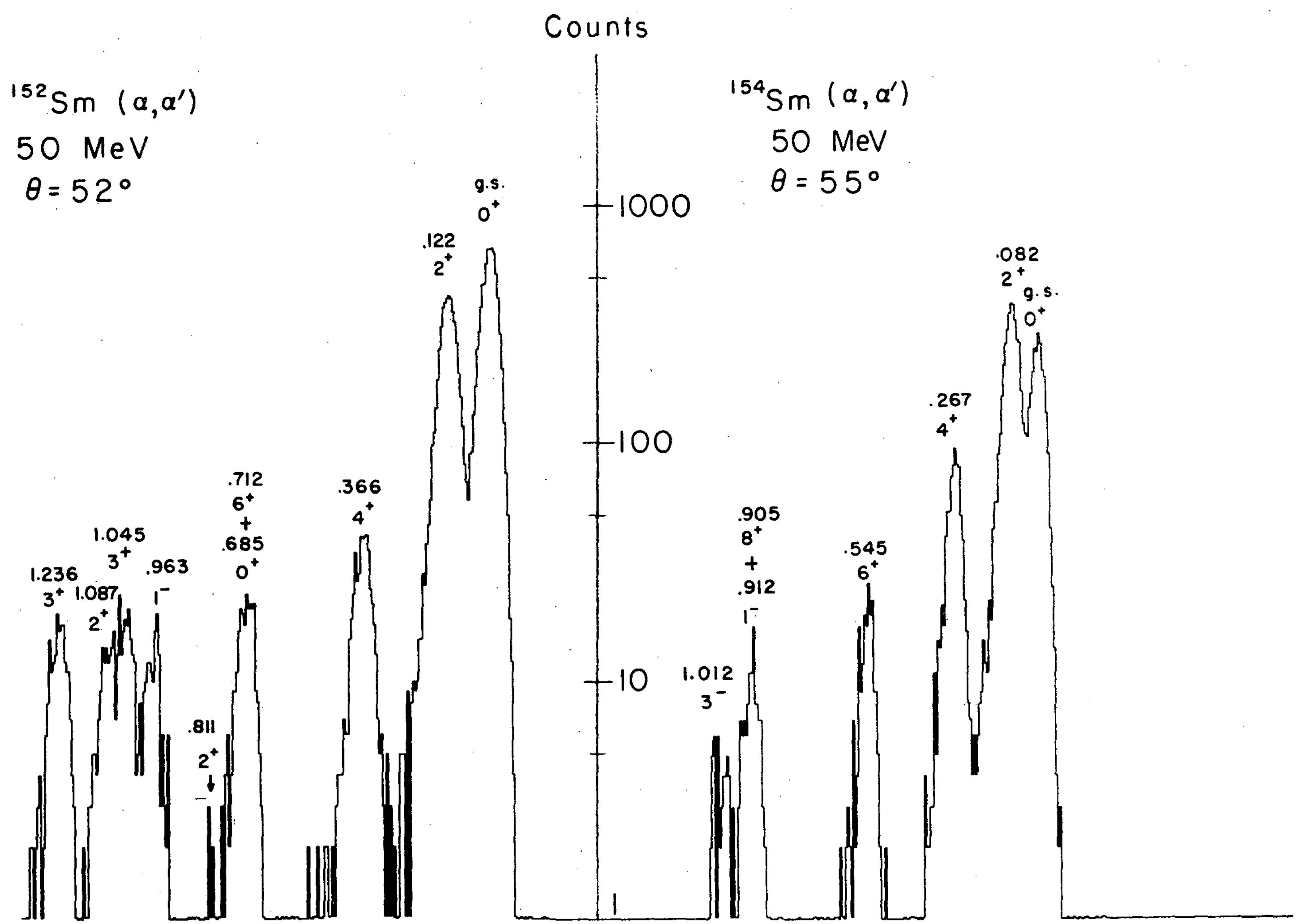
Figure Captions

Fig. 1. Energy spectra for the inelastic scattering of 50 MeV alphas from ^{152}Sm and ^{154}Sm plotted on a logarithmic scale. Positions of excited states are indicated.

Fig. 2. Differential cross sections for the 2^+, 4^+, and 6^+ members of the ground state rotational band of ^{152}Sm. Relative errors are, in general, smaller than the data points.

Fig. 3. Differential cross sections for the 2^+, 4^+, and 6^+ members of the ground state rotational band for ^{154}Sm. Relative errors are, in general, smaller than the data points. We did not find excitation of the 0^+ state at 1.012 MeV.



MUB 13965

Fig. 1

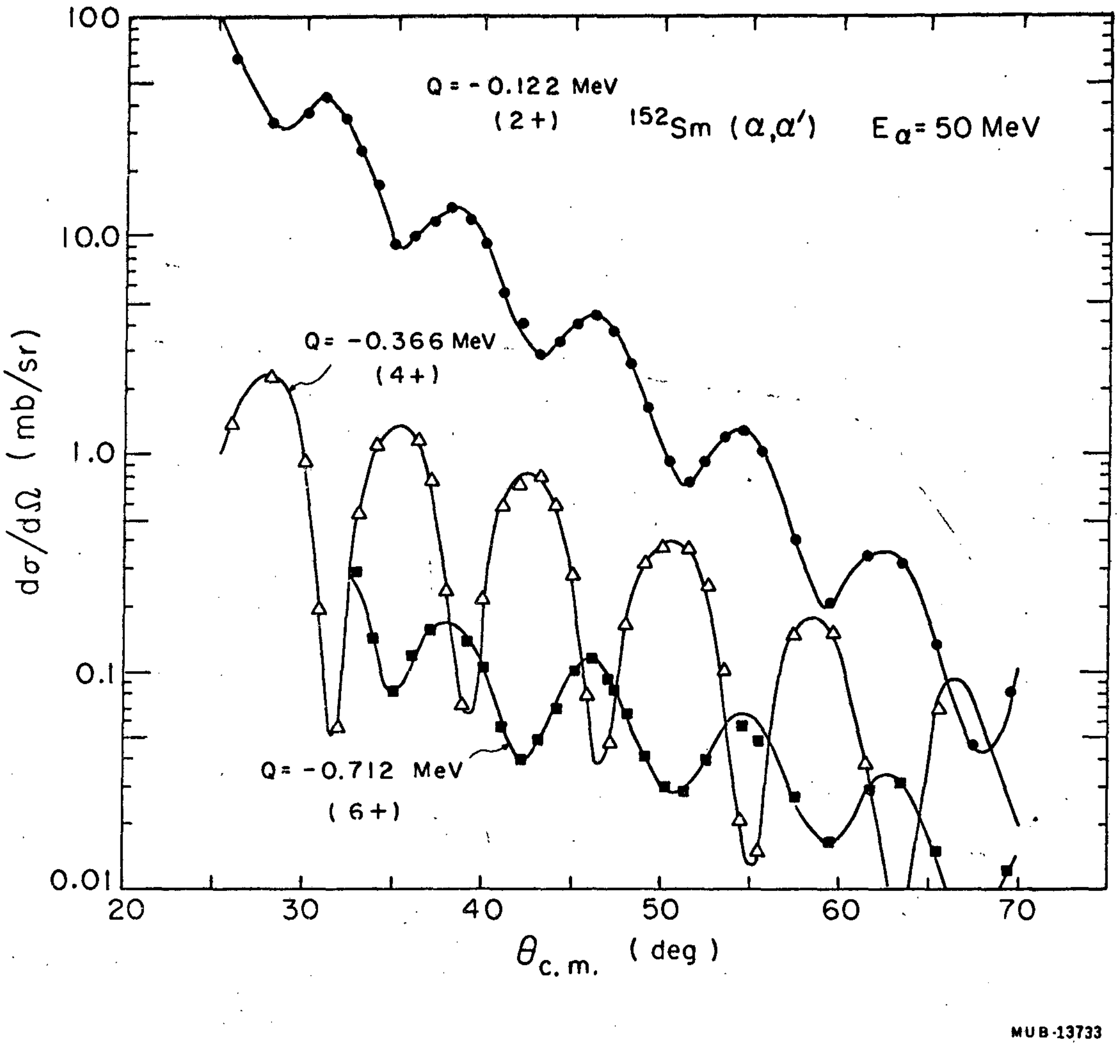
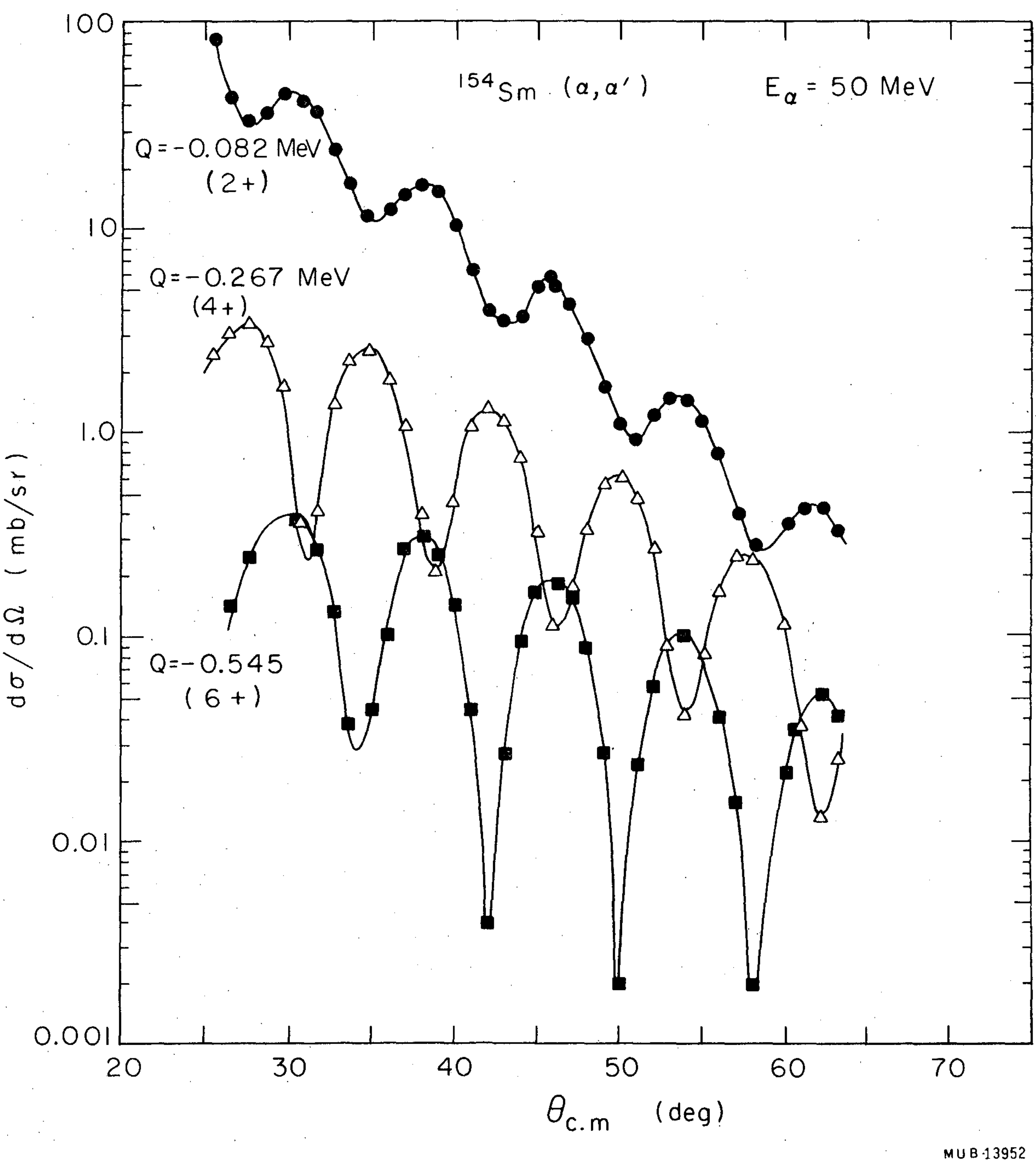

100
10.0
1.0
0.1
0.01
20
30
40
50
60
70
Q = - 0.122 MeV
(2+)
^{152}Sm (α,α′)
Eα = 50 MeV
Q = -0.366 MeV
(4+)
Q = -0.712 MeV
(6+)
dσ/dΩ (mb/sr)
θc.m. (deg)
MUB-13733

Fig. 2



100
10
1.0
0.1
0.01
0.001
20
30
40
50
60
70
^{154}Sm (α,α′)
$E_α$ = 50 MeV
Q=-0.082 MeV
(2+)
Q=-0.267 MeV
(4+)
Q=-0.545
(6+)
dσ/dΩ (mb/sr)
$θ_{c.m}$ (deg)
MUB-13952

Fig. 3