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ABSTRACT

It is shown that when the contribution of the strong collective states to the optical potential is removed by treating them explicitly through solution of the coupled equations describing the scattering, the resulting optical potential is valid for both spherical and deformed nuclei over a broad mass range in the rare earth region. In a search for the nuclear shape in the deformed region, this has the very important effect of removing the optical parameters from the list of free parameters.

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The elastic scattering cross sections of spherical and deformed nuclei are qualitatively different even for such close neighbors as ^{148}Sm (spherical) and ^{154}Sm (deformed). This is illustrated for 50-MeV alpha particles[1)] in fig. 1. The slope is steeper and the amplitude of the oscillations smaller for the deformed nuclei. This difference reflects the stronger coupling to the excited states in the deformed nucleus. As a convenient measure of the coupling to the 2^+ state one can use the reduced transition probablility B(E2), which is about five times larger for ^{154}Sm than ^{148}Sm. The optical potential that reproduces the elastic scattering accordingly must be, and is, quite different in the two cases. The optical parameters for the elastic scattering are shown in Table 1 (first and last lines) and the solid curves in fig. 1 are the corresponding cross sections.

Table 1

Optical model parameters corresponding to Woods-Saxon shape and a uniform change distribution with a correct quadrupole moment

	V	W	r	a
^{148}Sm elastic only	65.5	29.8	1.427	.671
Coupled channels	65.9	27.3	1.440	.637
^{154}Sm elastic only	34.6	29.4	1.404	.819

Conceptually, the optical potential was introduced to reduce an infinite-channel problem to a one-channel problem (the usual optical model for elastic scattering) or a few-channel problem (the optical model and coupling between a few low-lying levels). By construction it carries implicitly the effects of all the eliminated channels on those that are treated explicitly[2]. The eliminated channels include the intrinsic excitations which are present in all nuclei, as well as rotations in the case of deformed nuclei. It is mainly the rotations which give rise to the difference in the elastic optical potentials, as we now show.

To discuss conveniently the difference between the two cases, we introduce Feshbach's[3] expression for the optical potential:

$$U_{el} = \langle 0|V|0\rangle + \sum_{C} \langle 0|V|C\rangle \frac{1}{E-E_C+i\epsilon} \langle C|V|0\rangle \tag{1}$$

where the sum C is over all the omitted channels, or in the case of the elastic optical potential, over all channels save the elastic. Except for those states which couple strongly to the ground state, such as collective levels, the sum will be dominated by the region of high level density in the nucleus. We can think of breaking the sum up into two parts, therefore, consisting of the sum over the low-lying collective states, and the sum over all others

$$U_{el} = U_s + \sum_{\text{Collective}} \langle 0|V|C\rangle \frac{1}{E-E_C+i\epsilon} \langle C|V|0\rangle \tag{2}$$

The sum over non-collective states U_s is now dominated by the high excitation region of the nucleus because of the high level density there. Since the level density at high excitations should be independent of the deformed nature of the ground state, this part should be essentially the same for all nuclei in a broad range of mass; the subscript s then denotes its smooth behavior. The more enhanced the collective states are, the larger the second term will be and hence the more the elastic optical potential will deviate from the smooth behavior we attribute to U_s.

We can easily test this division of the optical potential into a part which is peculiar to each nucleus due to the particular nature of its collective states, and a part which is slowly varying from nucleus to nucleus. This can be done by solving the coupled system comprising the elastic and collective channels. Once the collective channels are treated explicitly, they no longer contribute to the effective interaction. In other words, the second term of eq. 2 is removed from the optical potential of the coupled system. We search empirically for a parameterization of the remaining interaction.

As an example of a deformed nucleus we choose ^{154}Sm which we treat as a rigid rotor and include explicitly the levels of the ground state rotational band up to and including the 6^+ state[4]. We treat explicitly the collective vibrational 2^+ state in the spherical ^{148}Sm nucleus, employing the macroscopic description. After a search for the potential parameters we find that a single potential gives rise to the excellent agreement shown in fig. 2. In fact the same potential can be used, with only minor adjustments, from the spherical ^{148}Sm throughout the deformed region up to ^{178}Hf.

We identify this potential as U_s. It is given on the second line of Table 1. We note that it is quite similar to the elastic potential U_{el} for the spherical nucleus. This is understood in view of our discussion following eq. 2 and the weaker collectivity of the spherical nucleus. They differ in W and a in just the way expected.

This understanding of the optical potential has two important consequences. We are interested in determining the nuclear shape in the deformed region by analysis of inelastic alpha scattering through a solution of the coupled system[5]. Whereas it may have been assumed that the parameters of the problem include the optical parameters as well as the shape parameters β_2, β_4 ..., we have been shown that the former are essentially determined by the scattering on a neighboring spherical nucleus, and that the same potential can be used throughout the deformed region with only very slight adjustments.

A second consequence concerns the search for systematics in elastic optical potentials. It is clear that whenever strong collective states exist, the elastic potential will be anomalous. Only when the contribution of the collective states to the optical potential are removed will the systematics appear, since it is U_s that is smoothly behaved.

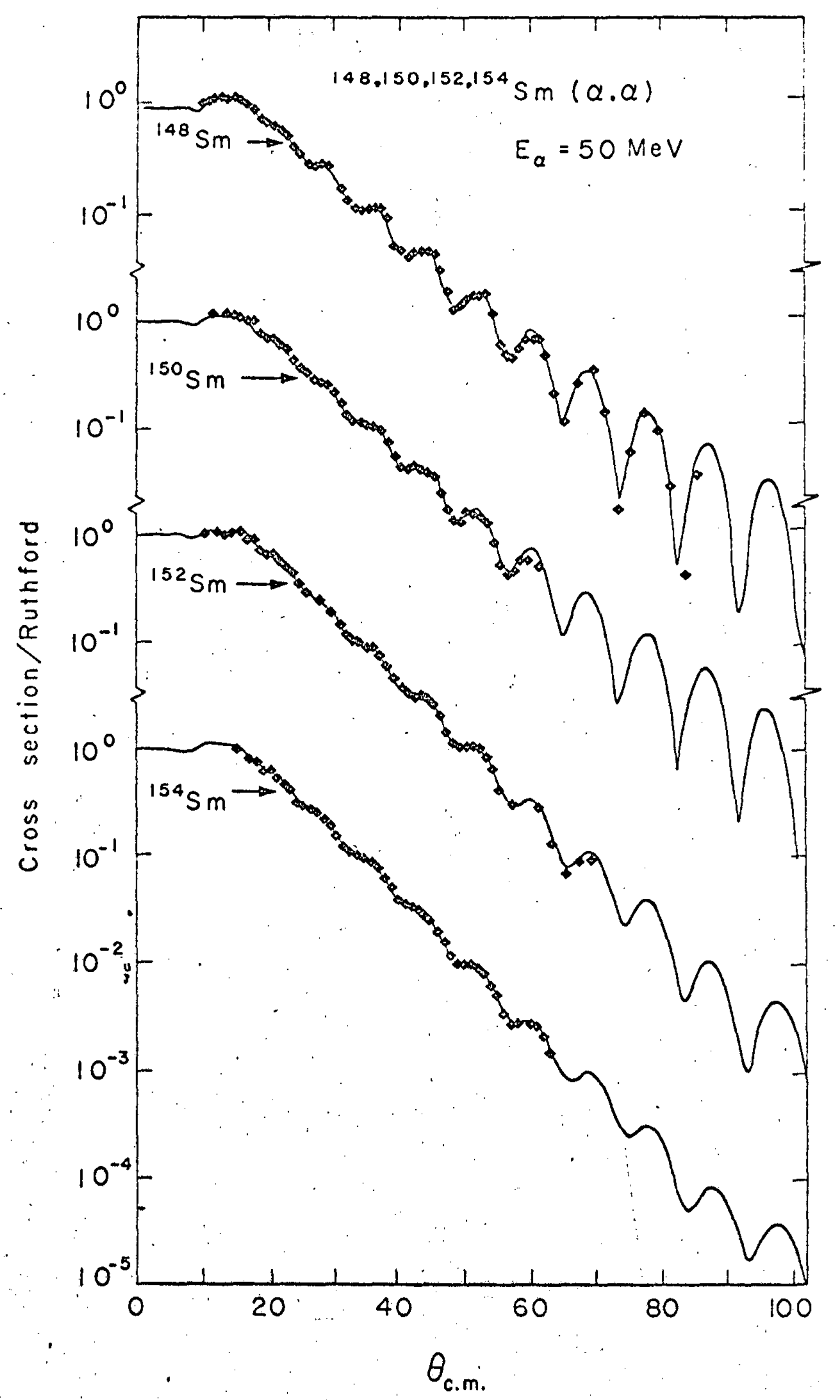
References

1. The experimental results are due to B. G. Harvey, D. L. Hendrie, O. N. Jarvis, H. H. Duhm, J. Saudinos, J. Valentin, and J. Mahoney. Similar systematic differences have been found in proton scatterings by P. Stoler, M. Slagowitz, M. Makofske, and T. Kruse, Phys. Rev. 155, 1334 (1967).
2. For a fuller discussion of this see N. K. Glendenning, UCRL-17503 (1967), to be published in the Proceedings of the International School of Physics 'Enrico Fermi', Course XL, Academic Press, New York (1967).
3. H. Feshbach, Annals of Physics (New York) 19, 287 (1967).
4. For details see ref. 2.
5. See the companion paper by D. L. Hendrie, N. K. Glendenning, B. G. Harvey, O. N. Jarvis, H. H. Duhm, J. Saudinos, and J. Mahoney, UCRL-17890.

Figure Captions

Fig. 1. The elastic scattering of 50-MeV alpha particles from samarium isotopes which span the spherical (A=148) to deformed (A=154) region. Note the systematic trend to weaker oscillations and steeper slope of the envelope of maxima with increasing collectivity. Solid lines are elastic optical model calculations of the cross section. The data is from ref. 1.

Fig. 2. Elastic and inelastic scattering of 50-MeV alpha particles by the spherical ^{148}Sm and deformed ^{154}Sm nucleus. Solid curves are coupled-channel calculations of cross sections based on a vibrational description of 148 and a rotational description of 154. In each case the <u>same</u> optical potential was used (Table 1) even though the elastic cross sections are different. Shape parameters β_λ for each nucleus are indicated on the figure.



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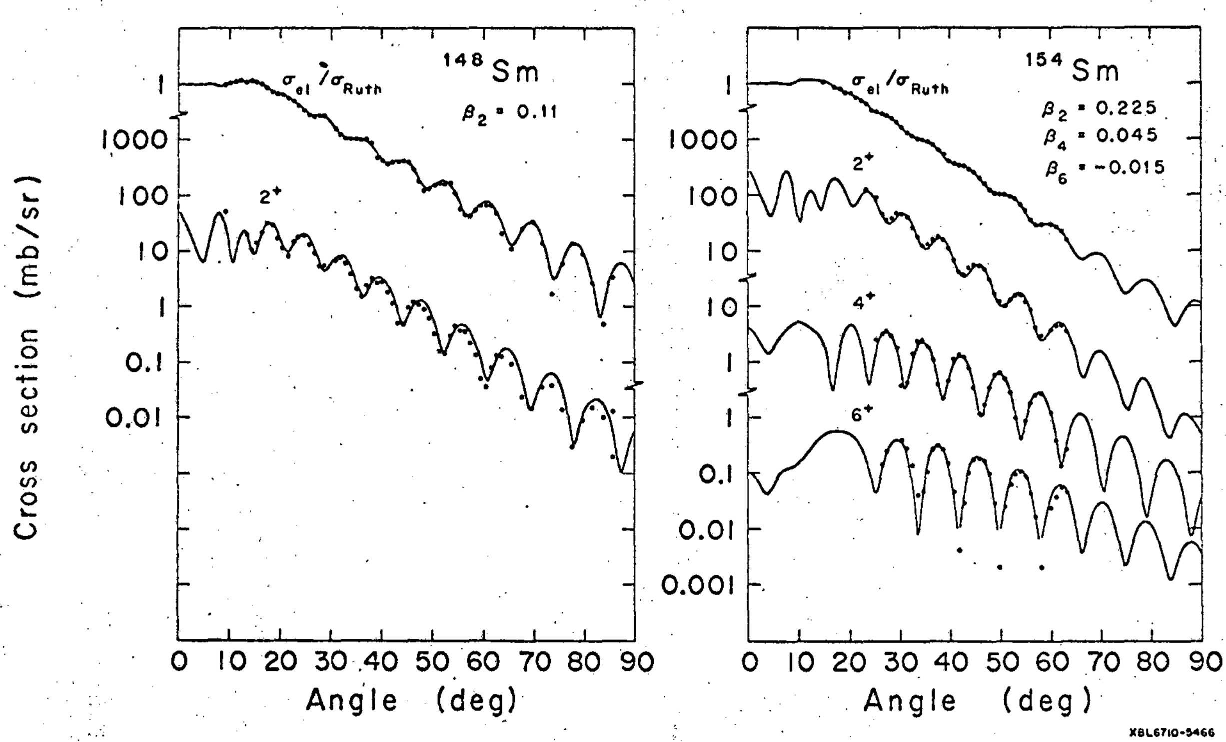

Figure 2.

Elastic and inelastic scattering of 50-MeV alpha particles by the spherical ^{148}Sm and deformed ^{154}Sm nucleus. Solid curves are coupled-channel calculations of cross sections based on a vibrational description of 148 and a rotational description of 154. In each case the <u>same</u> optical potential was used (Table 1) even though the elastic cross sections are different. Shape parameters β_λ for each nucleus are indicated on the figure.