COMPARISON OF THE STRENGTH FUNCTIONS AND POLARIZATION OF NEUTRONS IN VARIOUS OPTICAL MODELS

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Results of calculations for models with surface and volume absorption are compared. Strength functions for s and p waves and the polarization are calculated. It is shown that if the generally accepted potentials and parameters are employed, the discrepancy between the two models is not great at low energy.

1. INTRODUCTION

THE optical potential used in the theory of nuclear reactions is, as is well known, a complex quantity:

$$U(r) = V(r) + iW(r). \quad (1)$$

Although the originators of the optical model, Porter, Feshbach, and Weisskopf[1] initially used a rectangular well for the real part V(r), it soon became evident that a smeared edge corresponds more to the real physical picture and gives better agreement with the experiment. Since then, the universally accepted potential is that of Woods-Saxon[2]

$$V(r) = -V_0\left[1 + \exp\left(\frac{r-R}{a}\right)\right]^{-1}, \quad (2)$$

where R is the radius of the nucleus.

No such unanimity has been attained as yet with respect to the imaginary part W(r) of the optical potential. The most frequently used two forms of the radial dependence of the imaginary part are:

1) proportional to the real part

$$W(r) = \xi V(r), \quad (3)$$

2) concentrated on the surface of the nucleus; the most useful is the Gaussian form

$$W(r) = -W_0 \exp\left(\frac{r-R}{b}\right)^2. \quad (4)$$

Relation (3) enables us to get along in the theory with the minimum number of parameters; it was proposed[1] and extensively used by Nemirovskiĭ[3], who succeeded in choosing an optimal set of parameters for the model.

Relation (4) was brought into being by some theoretical considerations. Several authors[4], using very simple qualitative considerations (the weakened effect of the Pauli principle near the nuclear surface, etc) have indicated that a concentration of absorption is expected near the surface of the nucleus. Fernbach and Bjorklund[5] have shown that potential (4) agrees well with the measurements of both the total and differential cross sections for the scattering of neutrons at three values of the energy.

This raised the natural question: to what extent do the results of the theory for surface and for volume absorption differ so that existing experimental data can decide uniquely in favor of one of them? An attempt to investigate this problem was made by Amster[6]. He reached the conclusion that the data on the integral cross sections are satisfied to an equal degree in both assumptions. We note that although he used a somewhat artificial potential, it has been assumed that his results should not differ qualitatively from calculations in which the Woods-Saxon potential or some other sensible potential is used. However, in a paper by Khanna and Tang[7] it is stated that surface absorption yields qualitatively new results for the strength function of the s-neutrons in the region $90 < A < 130$. This result seemed rather strange and in contradiction with the earlier investigations, particularly Amster's. Khanna and Tang also use some artificial potential, rather than potentials in the form (2)—(4).

Finally, Krueger and Margolis[8] recently calculated the strength function for s- and p-waves, assuming surface absorption. They also obtained a drop in the minimum of the strength function for the s-wave, down to values $f = (\Gamma_n^0/D) \times 10^4 \sim 0.15$. However, the form and the parameters of their potential differ greatly from the standard one. In fact, in their case absorption is concentrated not on the surface, but beyond the limits of the nucleus, where the real part of the potential is very small. Such potentials have been obtained theoretically, but the

assumptions made are so crude that it is difficult to vouch for the reliability of this picture[9].

It is therefore natural to assume that either (a) the drop in the minimum of the strength function is common to all more or less reasonable potentials with surface absorption, or (b) it is typical of the given form of potential. It is therefore desirable to calculate the strength function using potentials (2)—(4) and a standard set of parameters that are known to describe well a large range of experimental data. The angular distribution and the polarization might be the effects most sensitive to the form of absorption. Many experimental data have been accumulated in this field, but no detailed comparison was made of the volume and surface absorption as applied to these effects. In order to fill this gap, polarization was calculated for both forms of absorption.

2. STRENGTH FUNCTIONS

The M-20 electronic computer was used to calculate the strength functions for the s- and p-waves. The Woods-Saxon potential (2) was chosen for the real part. This potential is most "physical" in the sense that it is the smoothest and has no corners (all the derivatives are continuous). The use of such a potential guarantees against the appearance of effects which can in principle be due to the "non-smoothness" or irregularity of some other expression for the potential, not corresponding at the same time to the customary accepted physical notions (see, for example, [8]). The parameters are $V_0 = 50$ MeV, $a = 0.65$ F, and $R = 1.245\, A^{1/3}$ F. The imaginary part was taken in the form (3) (volume absorption) with $\xi = 0.05$ and (4) (surface absorption) with $W_0 = 5$ MeV, and $b = 1$. The Gaussian form (4) has the "smoothness" advantages referred to above. For the p-wave we took into account spin-orbit coupling in the form $\kappa r^{-1}(\partial V/\partial r)\mathbf{l}\cdot\sigma$, where $\kappa = 2.8 \times 10^{-27}$ cm^2 and V is the real part of the optical potential. The presence of the spin-orbit leads to the splitting of the p-wave into two, $p_{1/2}$ and $p_{3/2}$.

The results are shown in Figs. 1 and 2. (The continuous lines in Figs. 1, 3, and 4 correspond to volume absorption, while the dashed lines correspond to surface absorption; in Fig. 2 the solid lines correspond to surface absorption and the dashed ones to volume absorption.) It is seen that at the maxima the strength functions for the volume and surface absorptions are practically the same. At the same time, the minima for the surface absorption lie lower and are shifted to-

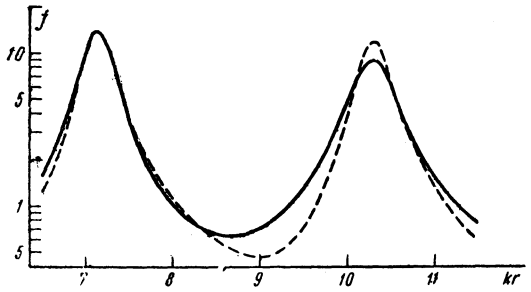

FIG. 1. Strength function for s-wave.

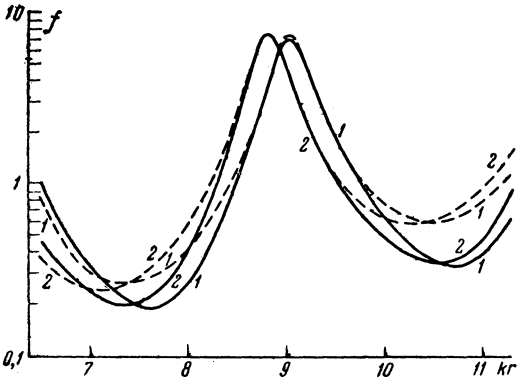

FIG. 2. Strength function for p-wave. The indices 1 and 2 correspond to the $p_{1/2}$ and $p_{3/2}$ waves, respectively.

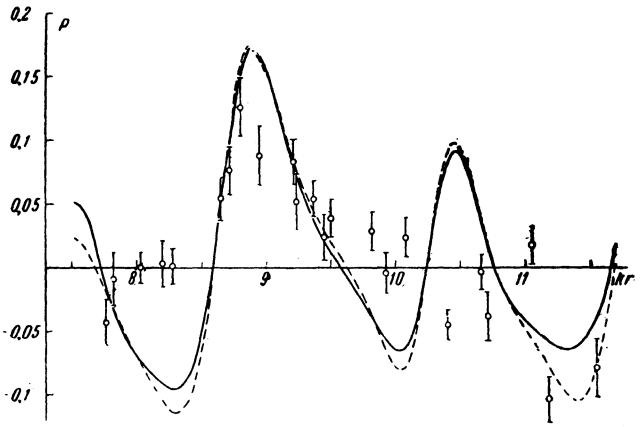

FIG. 3. Polarization of neutrons scattered at 55°.

wards larger values of the nuclear radius, i.e., larger A. However, this difference is relatively small. In particular, although the strength function for surface absorption of the s wave drops noticeably in the region $A \sim 100$, as compared with the curve for the volume absorption, nevertheless it lies appreciably higher (by a factor 2—3) than the curves of Khanna and Tang[7] or of Margolis and Krueger[8].

Thus, surface absorption actually leads to a drop in the minima in the region $A \sim 100$, but the

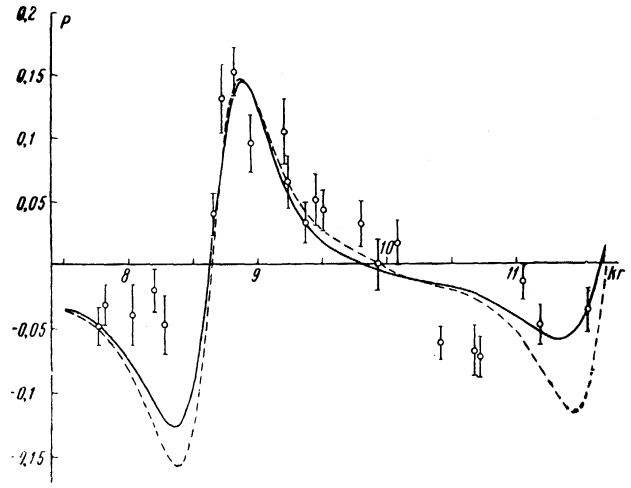

FIG. 4. Polarization of neutrons scattered at 90°.

question of the desirability of a strong reduction in the minimum in this region is no longer so undisputable, inasmuch as recent experiments have disclosed a tendency towards larger values of the strength function near the minimum. It is interesting to note that for surface absorption $\min(p_{3/2}) > \min(p_{1/2})$, while for volume absorption the situation is reversed. For large values of kR, the curves diverge more. This is explained by the fact that the larger the dimension of the nucleus, the greater the effect produced by the concentration of absorption on the surface.

3. POLARIZATION

The calculation was carried out with the potentials described in Sec. 2. The results have been compared with the data of Clement et al [10] on measurements of neutron polarization at E = 380 keV.

Figures 3 and 4 show readily that in the region of values kr = 8.5—9.5, where the nuclei have a stable spherical shape, the experimental data are in good agreement with both theoretical curves. Matters are worse in the regions kr = 7.5—8.0 and kr = 10.2—11.0, where the shape of the nucleus deviates from a sphere. At any rate it can be stated that calculations assuming a stable spherical nuclear shape are not satisfactory in these regions for either the volume or the surface absorption.

We note that an account of the static deformation leads to a much better agreement between theory and experiment in the region kr = 10.2—11.0. It is preferable here to choose surface absorption, but even then the difference is not large enough to reject volume absorption as unacceptable.

Summarizing, we can conclude that surface absorption describes the totality of the data somewhat better than volume absorption, although their difference in this respect is generally small. In several recent papers [11] the imaginary part of the optical potential is derived. A qualitative result common to all these investigations is the following picture: there exists a volume part of absorption and at the same time, near the boundary of the nucleus, the absorption increases and forms, as it were, a peak of considerable amplitude. First attempts at a model of this picture by means of some function [8,12] and at application of this function to optical-model calculations have already appeared. The authors of these papers have aimed to attain a considerable drop in the minimum of the force function, something in which they succeeded, although it was necessary not only to introduce new parameters in the imaginary part of the potential, but also to modify the parameters of the real part, which has lead to deviations from the data for other regions of atomic numbers and energies. The advisability of such adjustments is doubtful, since the existing experimental data possibly need to be reviewed so as to obtain larger values of the strength function in the region of the minimum. In general it can be stated that such a complication of the phenomenological potential of the optical model does not lead to new qualitative results. This seems quite natural in view of the fact that the two limiting cases, of pure volume and pure surface absorption, give results that are quite close to each other and none of them offers appreciable gain in the description of the available experimental material at low energies.

I wish to express my indebtedness to P. É. Nemirovskiĭ for a discussion of the work and for useful remarks.

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