THE NEUTRON STRENGTH FUNCTION ON THE OPTICAL MODEL

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We treat the effect of surface absorption on the behavior of the strength function for s neutrons in the region $90 < A < 130$. We show that surface absorption gives no new results beyond those for volume absorption, and is unable to resolve the discrepancy between theory and experiment in this region. We also show that including the spin-orbit coupling in computations for deformed nuclei leads to an additional splitting of the maxima of the strength function and makes possible an improved agreement between theory and experiment both in the region of the maximum at $A \sim 150$ as well as the maximum at $A \sim 50$.

1. INTRODUCTION

CALCULATIONS of the strength function for $l = 0$ neutrons have been made many times. In most computations it is assumed that the absorption occurs throughout the volume of the nucleus and that the real and imaginary parts of the optical potential have the same r dependence. One then gets a correct description of the behavior of the strength function $f = \Gamma_n^0/D$ (where Γ_n^0 is the neutron width referred to an energy of 1 ev, and D is the level spacing) as a function of atomic weight. Computations with volume absorption for nonspherical nuclei have improved the agreement with experiment in the region of large deformations. But in the region of the minimum of the strength function at $90 < A < 130$, the experimental data are considerably below the theoretical values. Two proposals have been made for eliminating this difficulty:[1] 1) introduction of surface absorption in place of volume absorption should improve the agreement with experiment; 2) assumption of an anomalously small value for the absorption in the region where N and Z are close to the magic number 50.

The first assumption was investigated in a paper of Khanna and Tang.[2] Their results indicated a different behavior of the strength function for surface and for volume absorption. But this result contradicts other work[3] in which it is asserted that the surface and volume absorptions differ very little at higher energies. We have therefore once again undertaken a computation of the strength function for surface absorption. Besides, the computations for deformed nuclei have been made previously without including the spin-orbit coupling. The present paper investigates for the first time the effect of spin-orbit interaction on the strength function for deformed nuclei.

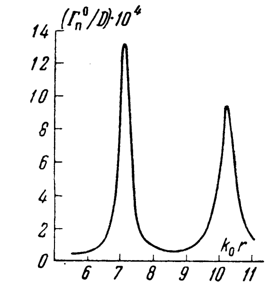

FIG. 1. Neutron strength function with surface absorption, for b = 0.5 and W_0 = 10 Mev.

2. THE SPHERICAL NUCLEUS WITH SURFACE ABSORPTION

We have calculated the strength function for s-neutrons for the case of a spherical nucleus with surface absorption. The real part of the potential is the same as that used in computations with volume absorption, and as was done previously,[4] we may write

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

where $V_0 = 50$ Mev, $a = 0.65$ fermis, $R = 1.24\ A^{1/3}$ fermi. For the imaginary part of the potential we took the expression[5]

$$W(r) = -W_0 \exp\{-(r - R)^2/b^2\}, \quad (2)$$

which corresponds to a surface absorption.

Computations were made for three cases: 1) b = 0.5, W_0 = 10 Mev; 2) b = 1, W_0 = 5 Mev and 3) b = 1, W_0 = 10 Mev.

For the first case (b = 0.5), the curve for the strength function f as a function of Ra^{-1} coincides for W_0 = 2.5 Mev[4] to within 10% with the result for the volume absorption

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

where ζ is the ratio of the imaginary to the real part of the potential (cf. Fig. 1, in which the curves for volume and surface absorption coincided).

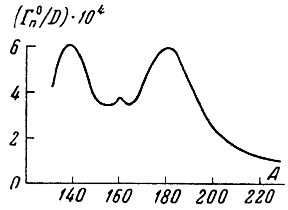

FIG. 2. Neutron strength function in the region 130 < A < 220.

For the second and third cases (b = 1 and W_0 = 5 Mev or 10 Mev) the curves, which are not shown in Fig. 1, also were close to those for volume absorption.

In contradiction to the assertion of Khanna and Tang,[2] the use of the potential (2) gives no new results at all for the strength function and does not eliminate the difficulties cited in Sec. 1. The computation showed that f_{max}/f_{min} is determined by the quantities W_0 and b, while the value of $(f_{max} f_{min})^{1/2}$, just as in the case of volume absorption, is determined primarily by the parameter a in formula (1), which affects the reflection at the nuclear surface.

As for the possibility of an anomalously small absorption near N = 50 and Z = 50, this assumption seems questionable since there are indications[6] that for higher energies the absorption in this region of atomic weight is not significantly different from that in neighboring regions. Thus the question of the behavior of the strength function for 90 < A < 130 stills remains open.

3. DEFORMED NUCLEI

We know that nuclei have a static deformation for 150 < A < 190 and for A > 220. The axis of symmetry of the nucleus rotates relative to the space-fixed axes. Various authors[7] have shown that the motion of the neutron-nucleus system can be described by a wave function which depends on the coordinates of the neutron in the laboratory system and on the Euler angles which characterize the position of the nuclear axis in space. The potential $V(r, \vartheta')$ representing the interaction of the neutron with the nucleus depends on the angle ϑ' between the direction of the nucleon and the axis of the nucleus. The quantity $V(r, \vartheta')$ can be expanded in a series of Legendre polynomials, and one obtains for the radial wave functions a system of equations which couple waves with different l' and I′ which satisfy the condition $l' + I' = J$, where I′ is the angular momentum of the nucleus and J is the total angular momentum of the system. If we keep only the terms in $P_2(\cos\vartheta')$ in the potential and set all higher terms equal to zero, then for deformations $\beta \leq 0.25$, we mix into the wave function with $l = 0$ only the state with $l = 2$. (For zero energy, when there is no excitation of rotational levels, the state with $l = 2$ is different from zero only inside the nucleus.) An admixture of the state with $l = 4$ can occur only for very large deformations.

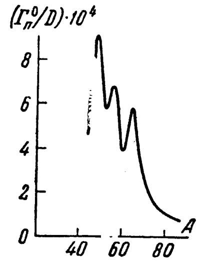

FIG. 3. Strength function in the region 40 < A < 80.

In theories without spin-orbit coupling, neutrons with $l = 2$ are described by a single wave function and, as a result, for slow neutrons one gets a system of two equations. For the strength function calculated in this way, the maximum at A = 150 splits into two maxima.

The importance of the spin-orbit interaction for neutrons with $l \neq 0$ has been shown in many papers. It is obvious that if we add to the potential $V(r, \vartheta')$ a term of the form $\mathbf{l}\cdot\mathbf{s}\, r^{-1}\partial V(r, \vartheta')/\partial r$, the scattering of slow neutrons will now be described by a system of three rather than two equations (one for $l = 0$, and two for $l = 2$ corresponding to $j = 5/2$ and $j = 3/2$). Thus in this case the spin-orbit interaction should also have an effect on the interaction of slow neutrons with a deformed nucleus. The corresponding computations will be given in more detail in a paper concerning the scattering of neutrons of higher energy by deformed nuclei.

As the computation showed, the inclusion of spin-orbit interaction led to an additional splitting of the peaks in the strength function curve. Figure 2 shows the strength function computed for even-even nuclei on the following assumptions: $I' = 0.2$, $\beta = 0.15$, the energy of the rotational level I = 2, E_2 = 90 kev; we used a volume absorption $W = \zeta V$, with $\zeta = 0.05$. As one sees, in addition to the two maxima found in [7] there is a bump on the curve in the region of the trough (A ~ 160) between these peaks, which corresponds to the situation observed experimentally. Thus the introduction of spin-orbit coupling improves the agreement between theory and experiment in the region of the giant resonance A ~ 160.

The giant resonance at A ~ 50 also exhibits a complex structure (as indicated by experiment). In particular it appears from the experimental data that one can conclude that there are bumps on the curve at A ≈ 65 and A ≈ 75. In this region of atomic weights ($40 < A < 80$) the nucleus again does not have a static spherical shape. But here the deformations are not static, but rather dynamic, resulting from asymmetric vibrations of the nuclear surface. Thus the conditions for applicability of the adiabatic theory, with a rotating deformed nucleus, are not fulfilled. However one may attempt to apply it in this region also (without any pretense at good quantitative agreement with experiment). Results of computations including spin-orbit interaction and using the parameters cited above are given in Fig. 3. Apparently the curve gives a qualitative picture of the bumps on the sides of the giant resonance.

In any case it appears obvious to us that including the nuclear deformation enables one to explain the relatively large values of the strength function in the region of $A = 65 - 75$, which are not gotten from the simple model of a spherical well.

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