EFFECT OF NUCLEAR COLLECTIVE MOTIONS ON S- AND P-WAVE STRENGTH FUNCTIONS

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(Received March 9, 1962)

In recent years, much experimental effort has been devoted to the measurement of the S-wave[1-3] and P-wave[4-6] strength functions. These functions can be related to average transmission coefficients derived from the nuclear optical model. The theory for S waves is discussed by Feshbach, Porter, and Weisskopf,[7] while a similar connection for P waves is easily defined.[5]

The experimental results for S-wave neutrons clearly indicated the 3s and 4s giant resonances predicted by the optical model for nuclei in the $A \approx 55$ and $A \approx 160$ mass regions. But it was evident that the $A \approx 160$ peak was actually split into two peaks (at $A \approx 140$ and $A \approx 180$) and that the $A \approx 55$ peak also showed some asymmetry. The splitting of the $A \approx 160$ resonance has been explained in terms of the strong permanent deformations of the rare earth nuclei.[8,9]

The optical model predicts a 3p resonance near $A \approx 100$. Experiment again indicates that the peak is asymmetric. The first suggestion[4] was that the spin-orbit coupling divided the peak into a $p_{3/2}, p_{1/2}$ doublet. However, calculations by Krueger and Margolis[10] have shown that the resonance can only be split by this mechanism if the spin-orbit strength is from two to three times the normally accepted value.

This is a serious discrepancy since no other type of neutron experiment requires such a large spin-orbit strength. We have found that the normal spin-orbit coupling has a negligible effect on the width and magnitude of the resonance. The weighted average $(2T_{3/2}+T_{1/2})/3$ of the transmission coefficients turns out to be closely the same as the transmission coefficient T_1 calculated without spin-orbit coupling, even though the $T_{3/2}$ and $T_{1/2}$ peaks themselves are separated by 5 mass units.

It should be noted that many even-even nuclei, while not permanently deformed, are easily set into quadrupole vibration, as evidenced by the strong excitation of low-lying 2^+ states by inelastic scattering. Hence it is not unreasonable that these dynamical distortions may have an effect on the strength functions similar to the effect of the permanent distortions.

We have employed essentially the methods of reference 9 to calculate the S- and P-wave strength functions for a large number of even-even nuclei. We used the axially symmetric rotator model[11] for the permanently deformed nuclei and the pure quadrupole vibration model[12] for the dynamically deformable nuclei. The interaction of a neutron with a diffuse edged collective nucleus is described by an expansion of the neutron-nuclear optical potential in powers of the collective coordinates.[9,13] We retained terms in the expansion only to first order in the deformation parameters.

The Schrödinger equation for the coupled scattering states coming from the 0^+ ground state and the 2^+ collective state can be resolved into sets of simultaneous differential equations for each partial wave. These sets of equations were solved on the IBM 7090 at Oak Ridge and the results of the numerical integrations matched to the free-state neutron wave functions at the nuclear surface in order to yield the scattering matrix elements. The calculations include the effects of spin-orbit coupling and were performed for an incident neutron energy of 40 keV, which is below the 2^+ excitation energy for all the nuclei considered. Hence the 2^+ state is only virtually excited and the external wave functions for this scattering state are exponentially decaying at infinity. Full details of these strong-coupling calculations and similar calculations of inelastic scattering cross sections for excitation of collective levels will be reported elsewhere.

The optical potential employed is defined below:

$$V = Uf(r) + iWg(r) + U_S\left[\frac{\hbar}{m_\pi c}\right]^2\left[-\frac{1}{r}\frac{df}{dr}\right]\vec{l}\cdot\vec{\sigma},$$

$$f(r) = \left[1+\exp\left(\frac{r-R}{a}\right)\right]^{-1}, \quad R = r_0 A^{1/3},$$

$$g(r) = 4\exp\left(\frac{r-R}{b}\right)\left[1+\exp\left(\frac{r-R}{b}\right)\right]^{-2}.$$

The parameters $U = 48$ MeV, $W = 11$ MeV, $U_S = 6$ MeV, $r_0 = 1.27$ F, $a = 0.65$ F, $b = 0.47$ F are equivalent local values derived from a nonlocal potential model[14] which gives a good account of a wide range of neutron scattering data. The

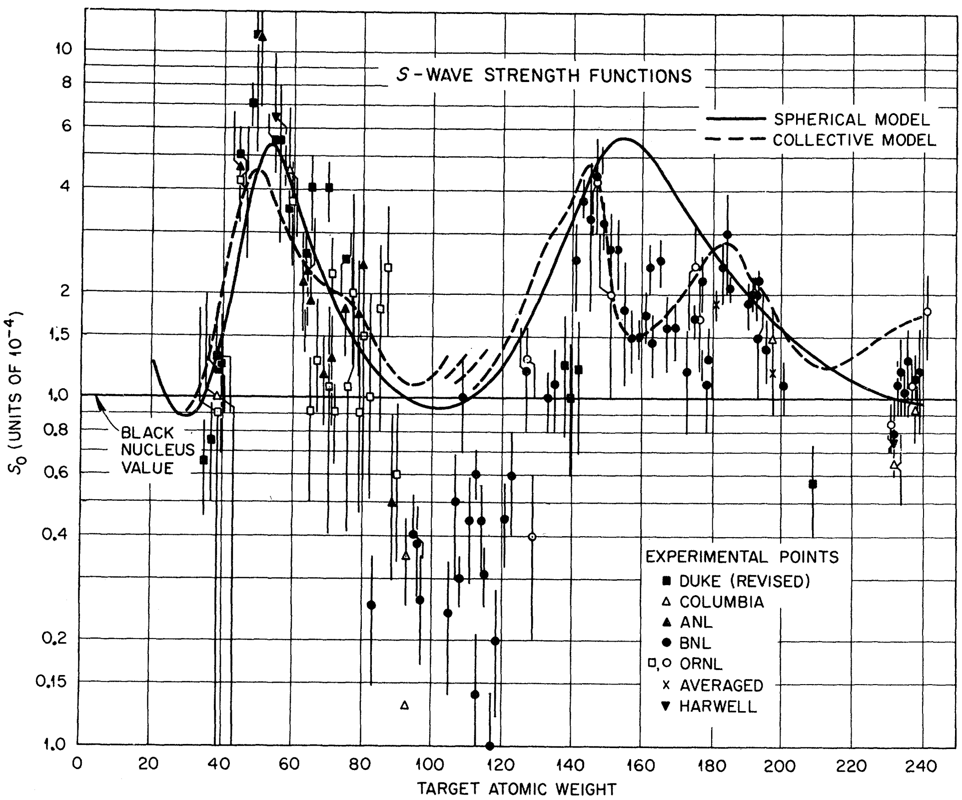

FIG. 1. Comparison of theory and experiment for the S-wave strength function.

function coupling the 0^+ and 2^+ states was taken to be the derivative of $f(r)$ with strengths appropriate to deformations measured by Coulomb excitation. Hence, no free parameters are introduced.

The results for the S- and P-wave strength functions are given in Figs. 1 and 2. In each figure the solid curve is the result of using only the spherical part of the optical potential, while the dashed lines indicate the effects of including the collective state.

The S-wave peaks in the rare earth region are now reproduced quite well, while the peak at $A \approx 55$ has developed a shoulder. The P-wave function shows a similar behavior. There is a shoulder near $A \approx 80$ in the region of the selenium isotopes and a sharp drop from $A \approx 94$ to $A \approx 104$. This latter region contains the theoretical results for the isotopes of molybdenum and ruthenium. The broken dashed lines are calculated results for the palladium and cadmium isotopes. Also noteworthy is the strong rotational splitting of the $4p$ resonance which shows that the strength function should have low values in the neighborhood of uranium. This is in agreement with experiment and markedly different from the prediction of the spherical optical model with normal spin-orbit coupling.

The published results of the Oak Ridge group[15] lie much higher than the results of other experiments in the $A \approx 100$ mass region. However, more recent analyses[16] of the same experimental capture cross-section data indicate reasonably good agreement with the calculations presented here.

The new calculations do not remove the discrepancy between theory and experiment for the S-wave function near $A \approx 100$. The experimental data are at least a factor of two less than the theoretical results. A similar discrepancy is apparent in the P-wave results between the $3p$ and $4p$ resonances. This could indicate that S- and P-wave neutrons see different optical absorption potentials in some mass regions. The

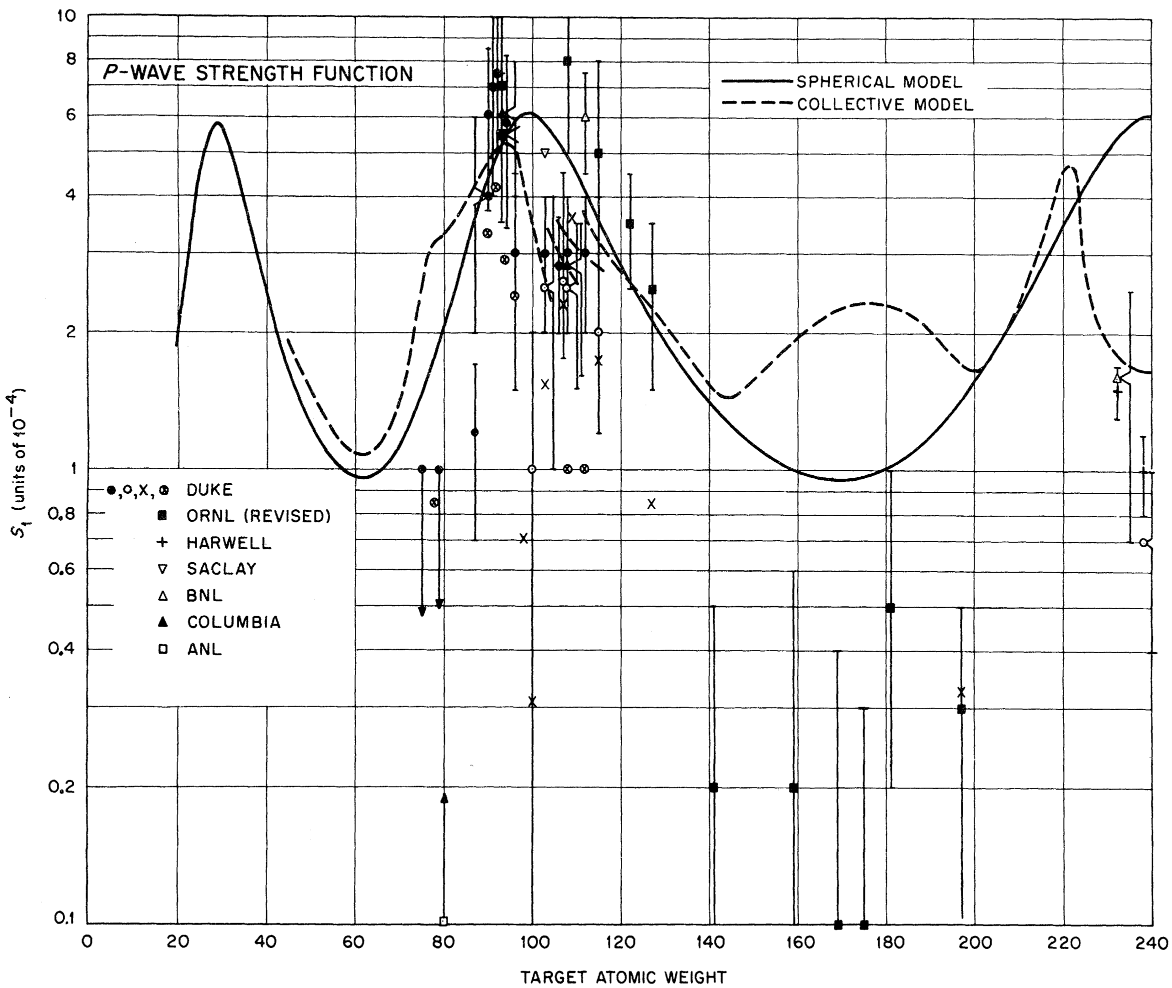

FIG. 2. Comparison of theory and experiment for the P-wave strength function.

anomalies in the strength function minima may have their origin in nuclear structure effects.[17,18]

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*Operated by Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.

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