# Observation of a spin-orbit splitting of the 3*p* peak in the neutron strength function

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The $p$-wave neutron strength functions for the $p_{1/2}$ and $p_{3/2}$ states have been determined separately from the average differential cross sections for elastic scattering of neutrons by nuclei in the mass range $A \sim 50–130$. The results reveal what is apparently the first demonstration of a spin-orbit splitting of an unbound state.

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Experimental data obtained in the early 1960s on the $p$-neutron strength functions suggested a "double-headed" peak at atomic weights in the range $A \sim 80–120$, and this peak was interpreted as resulting from a spin-orbit splitting of a one-particle $3p$ state into $3p_{1/2}$ and $3p_{3/2}$ states.[1] It was later learned, however, that there were errors in both the experimental and theoretical results, and the experimental case on the splitting of the $3p$ maximum was never closed.

According to the present understanding, the strength functions $S^1_{1/2}$ and $S^1_{3/2}$ corresponding to these two values of the total angular momentum of the $p$ neutron should form approximately identical peaks in the vicinity of the $3p$ peak, separated along the $A$ scale by $\Delta A \sim 7–10$. Since the widths of the peaks are much greater than $\Delta A$, the peak of the quantity customarily measured, $S^1 = 1/3(S^1_{1/2} + 2S^1_{3/2})$, is not split.

The strength functions $S^1_{1/2}$ anmd $S^1_{3/2}$ can be determined separately by making use of the parameters of the individual resonances. The simplest approach is to use even-even target nuclei in which the spin of the $p$ resonance is equal to the total angular momentum of the neutron. At present, the spins have been determined for 10 or more $p$ resonances for 12 even-even isotopes of Zn, Sr, Zr, Mo, and Sn. Using information from Ref. 2, we calculated the values of $S^1_{1/2}$ and $S^1_{3/2}$; the results are shown in Fig. 1. These results are consistent with the interpretation that the $S^1_{3/2}$ peak lies to the left of the $S^1_{1/2}$ peak, but the peaks coincide within the large errors. This result shows that even spectrometers with a record high resolution cannot reveal spin-orbit splitting in terms of the parameters of the individual resonances.

As in the case of the strength functions $S^0$ and $S^1$, the functions $S^1_{1/2}$ and $S^1_{3/2}$ can be determined more accurately by measuring cross sections averaged over the resonances. For this purpose it is necessary to measure the differential cross section for elastic scattering and make use of the fact that the resonant scattering by even-even nuclei is isotropic for spin-1/2 compound states and proportional to $1 + P_2(\cos\theta)$ for spin-3/2 compound states. The equations in Ref. 3 are derived by taking into account potential scattering and the resonant scattering which interferes with the potential

  

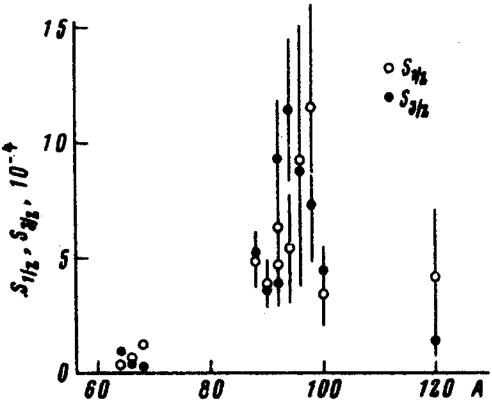


FIG. 1.

scattering, by taking an average over nonoverlapping resonances, by assuming that the radiative widths of these resonances are constant, and by taking Porter–Thomas fluctuations of the reduced neutron widths into account. In these equations the terms in the expansion of the differential cross section $\sigma_s(\theta)$ in Legendre polynomials are expressed in terms of the neutron and radiative strength functions and the potential-scattering phase shifts for $s$ and $p$ neutrons. The latter are related in an unambiguous way to the parameters $R_0^\infty$ and $R_1^\infty$ or $R$-matrix theory.

The cross sections $\sigma_s(\theta)$ were measured in Ref. 3 for five isotopes of tin, and the parameters $S^0, S^1_{1/2}, S^1_{3/2}, S_0^\infty$ and $R_1^\infty$ were determined. In the present experiments we measured $\sigma_s(\theta)$ for 12 more even-$Z$ elements which contain primarily even-even isotopes. The measurements were carried out in the neutron beam of the IBR-30 reactor; the apparatus and procedure are described in Refs. 4 and 5. In contrast with Ref. 3, we analyzed the data at energies up to ~400 keV and took into account the anisotropic contribution of the $d$-wave in the potential scattering. For each element and for each tin isotope we also incorporated in the analysis all the values of $g\Gamma_n$ from Ref. 2 without making use of an identification of the resonances on the basis of parity. For the fit we used the expression

$$\frac{\Sigma g\Gamma_n}{\Delta E} = \sqrt{E}\,[S^0 + v_1(S^1_{1/2} + 2S^1_{3/2})],$$

where $v_1$ is the penetrability factor of the centrifugal barrier for $p$ neutrons. For the elements studied, by us we found $\Sigma g\Gamma_n/\Delta E$ by taking an average over isotopes; for each sample we used values for 3–10 energy intervals. Finally, in all the expressions we replaced $S^0$ and $S^1_{1/2,3/2}$ by $S^0/d_0$ and $S^1_{1/2,3/2}/d_l$, where the factors $d_l$ reflect the influence of remote levels on the widths of the resonances in the $R$-matrix formalism.[6,7]

The values which we found for $S^1_{1/2}$ and $S^1_{3/2}$ are shown in Fig. 2, along with curves which were drawn by the method of least squares with three adjustable parameters and which correspond to Lorentz curves in the energy scale. From this figure and the numerical values of the parameters we conclude that (1) the $S^1_{1/2}$ and $S^1_{3/2}$ peaks are shifted $\Delta A = 17 \pm 4$ in the expected direction and (2) the heights and widths of the peaks agree within the errors. It should be noted, however, that it would be more

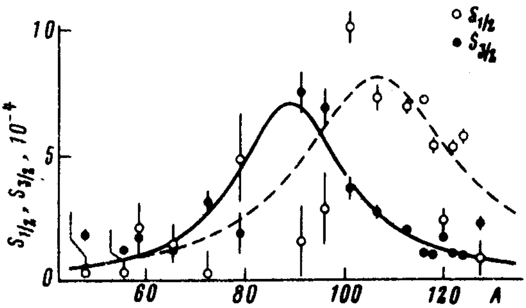


FIG. 2.

systematic to use for the analysis the $R_1^{\infty}$ data "split"[1)] into $R_{1/2}^{\infty}$ and $R_{3/2}^{\infty}$. In this case, as our estimates show, the $S_{1/2}^1$ peak would become roughly twice as high as the $S_{3/2}^1$ peak. We have also observed a greater height for the $S_{1/2}^1$ peak with an "unsplit" $R_1^{\infty}$ by using the boundary conditions $B_l = -l$, which lead to different factors $d_l$, in place of the conditions $B_l = 0$, under which the results in Fig. 2 were derived. This question of the effect of the $R_1^{\infty}$ splitting and of the boundary conditions on the ratio of the heights of the $S_{1/2}^1$ and $S_{3/2}^1$ requires further study.

In summary, the observed spin-orbit splitting of the $3p$ peak of the neutron strength function is in qualitative agreement with the optical-model prediction. With somewhat less confidence we can say that the extent of the splitting is slightly greater than the theoretical prediction and that the $S_{1/2}^1$ peak is higher than the $S_{3/2}^1$ peak. The reason why the $S_{3/2}^1$ peak is lower than the $S_{1/2}^1$ peak might be sought in dynamic deformations of these nuclei and a corresponding splitting of the $3p_{3/2}$ peak.

[1)] In our analysis, $R_{1/2}^{\infty}$ and $R_{3/2}^{\infty}$ are not determined separately and unambiguously because of the strong correlation between them.


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