CALCULATION OF POLARIZATION OF MEDIUM-ENERGY NEUTRONS

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The polarization of 0.1 — 1 Mev neutrons scattered by heavy nuclei is investigated. It is shown that the polarization can be described with satisfactory accuracy by introducing in the optical potential and additional term of the form $-\frac{\kappa}{r}\frac{dV}{dr}(\sigma\cdot l)$, where $\kappa = 3\times 10^{-27}$ cm^2. The best agreement between theory and experiment is obtained when the imaginary part of the ordinary potential is 2.5 Mev.

1. INTRODUCTION

EXPERIMENTS on neutron polarization are a very important means of determining the interaction between nucleons and nuclei. Experiments made at relatively small energies are the most interesting, since they yield a clearly pronounced dependence on the atomic weight and a readily interpretable angular dependence.

Naturally, the theory can yield good agreement with experiment only for spherical nuclei. In addition, an agreement with theory can be expected only at energies for which the inelastic scattering is small or, to the contrary, so large that the fraction of elastic scattering in the reaction cross section is negligible. Thus, the most suitable energy intervals are $E < 0.5$ Mev and $E > 3$ Mev. In the intermediate region between 0.6 and 3 Mev the comparison cannot be so reliable.

The optical model were used by us to investigate the polarization found in the experiments of Darden et al.[1,2] The phases were calculated with a "Strela" computer. The results of the calculations was a total cross sections, the absorption cross sections, and the angular distributions were published elsewhere.[3] We wish to dwell here specially on problems of polarization.

2. METHOD OF PHASE CALCULATION

The potential was chosen in the following form

$$V = V_1(1 + i\zeta) + V_2, \tag{1}$$

where

$$V_1 = -V_0/(1 + e^{\alpha(r-R_0)}), \tag{2}$$

$$V_2 = -\frac{\varkappa}{r}\frac{dV_1}{dr}(\sigma\cdot l),$$

$$V_0 = 50\text{ Mev},\quad 1/\alpha = 0.65\cdot 10^{-13},\quad \varkappa = 2.8\cdot 10^{-27}\text{ cm}^2,$$

$$R_0 = (1.16A^{1/3} + 0.36)\cdot 10^{-13}\text{ cm}; \tag{3}$$

with $k_0 = (1/\hbar)\sqrt{2mV_0} = \alpha$.

The Schrödinger equation with this potential was solved on a "Strela" computer. In this case the solutions of the Schrödinger radial equation, in the region where the potential vanishes, can be represented as

$$\psi = A\{r^{-1/2}H^{(2)}_{l+1/2}(kr) + \eta_l r^{-1/2}H^{(1)}_{l+1/2}(kr)\}. \tag{4}$$

For the functions $J_{l+1/2}(x)$ and $J_{l-1/2}(x)$ tables are available and therefore to determine η_l it is enough to know ψ in two points at which the potential vanishes within the interval. Such a method of solution accelerates considerably the operation of the computer, since the calculation of the asymptotic form of ψ would necessitate a considerably longer operation. The values of η_l for different energies were then computed manually.

The values obtained for η_l were used to calculate the polarization. At energies of 0.25 and 0.5 Mev, we took into account only waves with $l = 0$, 1, and 2. At 1.25 Mev we performed the calculation also for $l = 3$. The polarization was calculated here from the formula

$$P = \frac{\lambda\!\!\!{}^{-2}\,\mathrm{Im}\sum_l[(l+1)(1-\eta_{l+1/2}) + l(1-\eta_{l-1/2})]P_l(\cos\vartheta)}{2d\sigma_{\text{tot}}/d\Omega} \times\sum_{l'}(\eta^*_{l'-1/2} - \eta^*_{l'+1/2})P^{(1)}_{l'}(\cos\vartheta)$$

where $\lambda\!\!\!{}^{-}$ is the wavelength of the neutron, divided by 2π, σ_{tot} is the total cross section, and $d\Omega$ is the element of solid angle.

3. COMPARISON WITH EXPERIMENT

A comparison with experiment can be made only for the data of Darden et al. The 380-kev energy is quite suitable for comparison with experiment. The radiative capture at this energy is small and the inelastic scattering is insignificant. Therefore

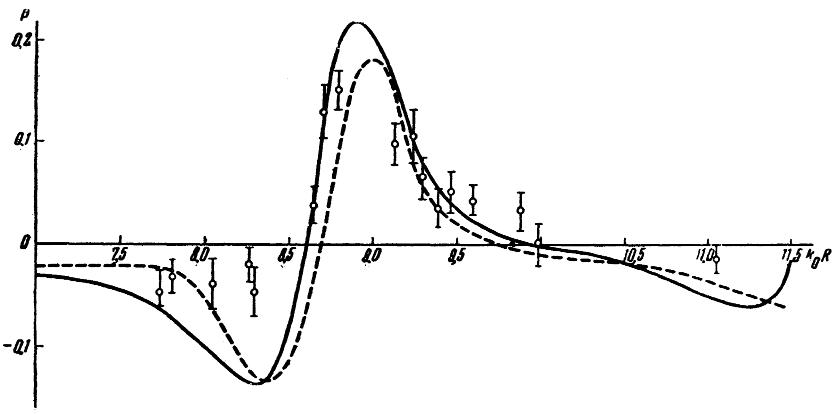

FIG. 1. Polarization of neutrons scattered at an angle of $\pi/2$. The abscissas represent k_0R. The solid curve corresponds to an energy of 0.5 Mev, the dotted one to 0.25 Mev for $\zeta = 0.05$; the experimental points pertain to 380 kev.

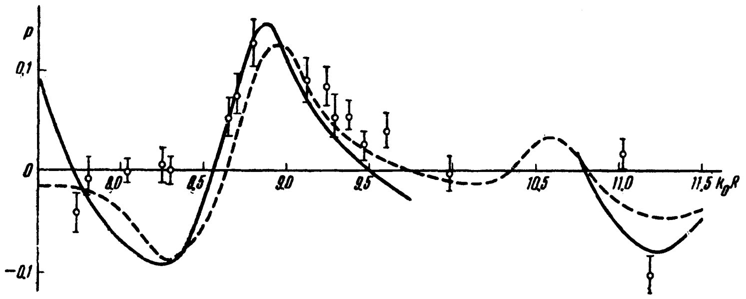

FIG. 2. Polarization of neutrons scattered at 55°. Symbols are the same as in Fig. 1.

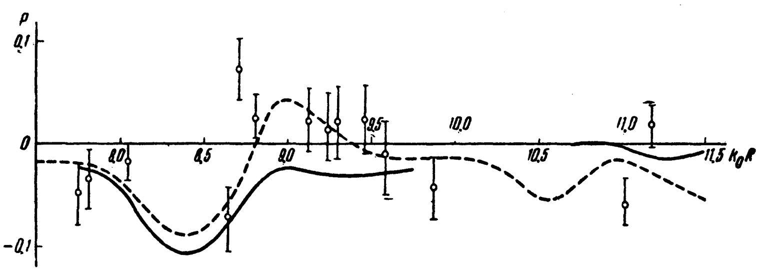

FIG. 3. Polarization of neutrons scattered at 130°. Symbols are the same as in Fig. 1.

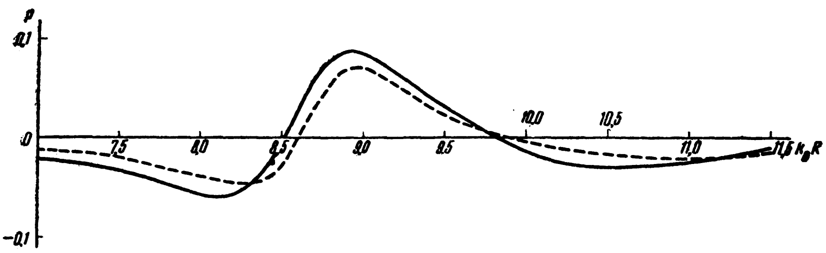

FIG. 4. Polarization of neutrons scattered at 90°. The solid curve corresponds to an energy of 0.5 Mev, the dotted one to 0.25 Mev, for $\zeta = 0.1$.

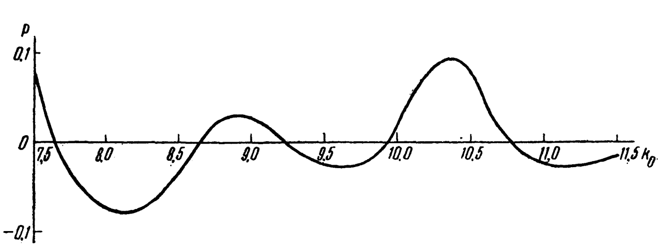

FIG. 5. Polarization of neutrons scattered at 55°. Symbols the same as in Fig. 4, energy 0.5 Mev.

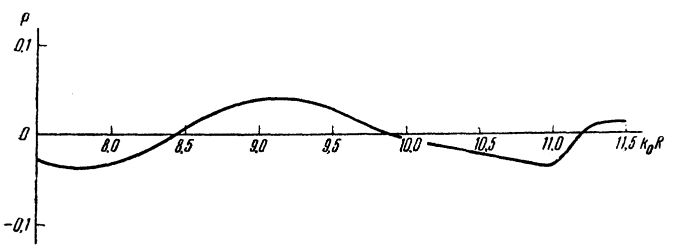

FIG. 6. Polarization of neutrons scattered at 130°. Symbols the same as in Fig. 4. Energy 0.5 Mev.

the assumption that the intermediate system breaks up only elastically is close to reality. We assume that there are no inelastic processes. The curves are given for angles 55, 90, and 180° for two values of the absorption coefficient and for two energies, 250 and 500 kev (Figs. 1 — 6).

The simplest curve is that for 90° (Figs. 1 and 4). It has one maximum A = 100 and two minima at A = 80 and 200. The course of the curve is determined essentially by the phase of difference* $\eta_{3/2}$-

* The phases of $p_{3/2}$ and $p_{1/2}$ are denoted $\eta_{3/2-}$ and $\eta_{1/2-}$.

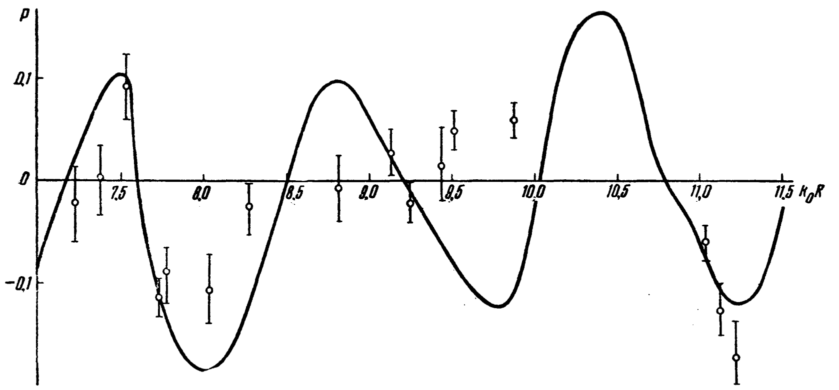

FIG. 7. Polarization of neutrons scattered at 55°. The curve corresponds to an energy of 1.25 Mev and $\zeta = 0.05$. The experimental points pertain to energy of 0.98 Mev.

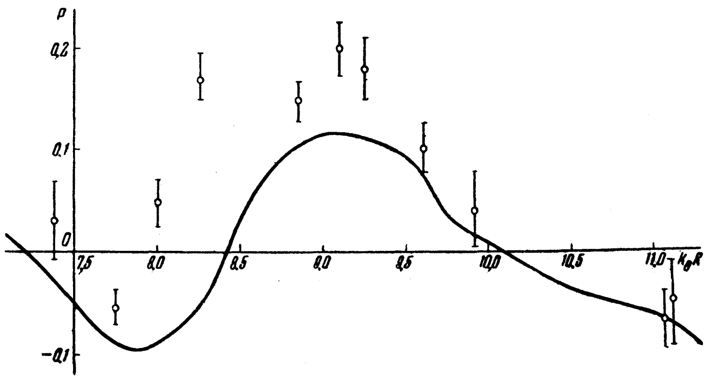

FIG. 8. Polarization of neutrons scattered at 90°. The curve corresponds to energy of 1.25 Mev and $\zeta = 0.05$.

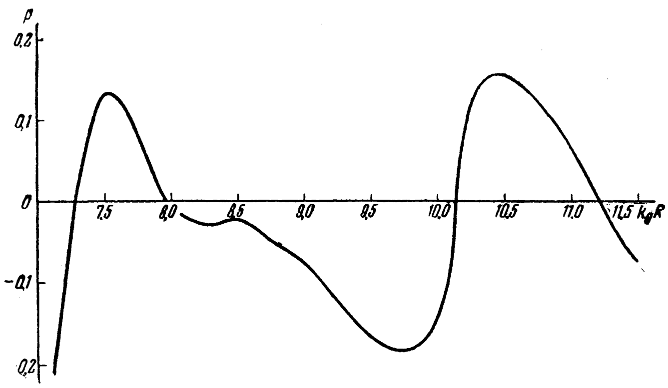

FIG. 9. Polarization of neutrons scattered at 125°. The curve corresponds to energy of 1.25 Mev and $\zeta = 0.05$.

and $\eta_{1/2}-$, i.e., with $l = 1$. As the energy is increased, the width of the maximum at A = 100 increases. If the coefficient of absorption is large the maximum is lower, but not wider. The experimental maximum at A = 100 is in agreement with the curve for $\zeta = 0.05$, although, possibly, the experimental values of the polarization are somewhat lower than the theoretical ones.

Of the 18 experimental points (5 points correspond to nuclei with static deformations), 12 agree with the theoretical curves. The deviation is particularly large for Se and Br. The reason of the deviation in the case of these nuclei must be sought apparently in their structure, since the discrepancies occur also at different angles and energies.

The 500-kev curve for 55° has three maxima (Figs. 1 and 4), one corresponding to the p wave and two corresponding to the d wave. One of the d maxima is at A = 50, where measurements were not performed, while the second occurs for nonspherical nuclei. We have therefore noted on the experimental curve only the maximum at A = 90 — 100. For this angle the agreement is somewhat poorer, Se, Br and Hg being in particularly poor agreement with the theory. The sign of polarization for the case of Hg disagrees with experiment.

For 130° both the theoretical and experimental values of the polarization are small. The experiment confirms the theory in this respect. However, the errors in the experimental values are so large, that the comparison with experiment can hardly be given any great weight.

The comparison for 980 kev is considerably more complicated (Figs. 7-9). Inelastic scattering can occur at this energy. For comparison with theory, nuclei with small inelastic scattering cross sections are the most suitable. From this point of view, nuclei with A = 50 — 60 are of interest. At an angle of 55° one should observe in the case of these nuclei a narrow maximum (large positive polarizations) followed by a broad minimum (large negative polarizations) (at $\zeta = 0.05$). Actually, measurements for V, Mn, Co, Cu, and Zn gave a picture close to that expected theoretically. The maximum at A = 100 is not clearly pronounced for $\vartheta = 55°$, but is quite clear at $\vartheta = 90°$. Here the polarizations are quite larger than the theoretical (at $\zeta = 0.05$), if elastic scattering is assumed as the only process. However, in nuclei with A ~ 100 inelastic scattering is very large, so that only a small portion of scattering goes into elastic scattering via the intermediate nucleus. Then the denominator in the expression for the polarization decreases and the experimental data generally do not disagree with the theory. For A = 200 agreement with experiment at $\vartheta = 55°$ is also satisfactory.

The experimental errors in the 125° case are so large, that it hardly makes sense to make comparisons with experiment. Again, the data for selenium are in sharp disagreement with the theory.

In conclusion we can state that a total analysis of the existing data on polarization shows the following:

(1) The spin-orbit constant $\kappa \approx 3 \times 10^{-27}$ cm^2, selected from data on the stationary states,[4] describes fairly well the polarization of slow neutrons.

(2) The imaginary portion of the potential for low-energy neutrons is close to 3 Mev, in good agreement with experiments on the total cross sections and on radiative-capture cross sections.

The causes of disagreement between theory and experiment are still not clear in the case of several nuclei.

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