# POLARIZATION OF ELASTICALLY SCATTERED 6.5-MeV DEUTERONS

Yu. A. NEMILOV and L. A. POBEDONOSTSEV

Submitted to JETP editor March 22, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 103-106 (August, 1963)

Asymmetry of double elastic scattering of deuterons on Be, B, C, Mg, Al, Fe, Se, Sb, $Fe^{54}$, Au, Co, and Mn is studied. The polarization and quadrupolarization of deuterons scattered by Fe nuclei are estimated. It is found that the polarization characteristics vary gradually with Z of the nucleus and do not depend on its spin.

ELASTIC scattering of deuterons by nuclei gives rise to spatial ordering of the spins, characterized by a vector polarization **P** (analogous to nucleon polarization) and quadrupolarization Q (tensor polarization), which is a reflection of the relation between the probabilities of spin orientations parallel and antiparallel to the chosen direction and perpendicular to the latter. The values of **P** and Q are determined from the following relations[1]:

$$\mathbf{P} = \frac{d\sigma_+ - d\sigma_-}{d\sigma_s}\mathbf{n}, \qquad Q = \frac{d\sigma_+ + d\sigma_- - 2d\sigma_0}{3d\sigma_s}. \qquad (1)$$

The azimuthal asymmetry in double elastic scattering is of the form

$$F = \tfrac{1}{3} + \tfrac{1}{2}PP'(\mathbf{nn}') + \tfrac{3}{8}[Q_m Q'_{m'}(\mathbf{mm}')^2 + Q_l Q'_{l'}(\mathbf{ll}')^2 + Q_n Q'_{n'}(\mathbf{nn}')^2]. \qquad (2)$$

Here P, $Q_m$, $Q_l$, and $Q_n$ are the polarization and the components of quadrupolarization arising in the first scattering; $P'$, $Q'_{m'}$, $Q'_{l'}$, and $Q'_{n'}$ are the polarization and components of quadrupolarization which would arise on a second target were it to be stricken by a beam with P = 0 and Q = 0. The unit vectors **m**, **l**, and **n** are chosen as follows:*

$$\mathbf{m} = \frac{\mathbf{k}+\mathbf{k}'}{|\mathbf{k}+\mathbf{k}'|}, \qquad \mathbf{l} = \frac{\mathbf{k}-\mathbf{k}'}{|\mathbf{k}-\mathbf{k}'|}, \qquad \mathbf{n} = \frac{[\mathbf{kk}']}{|[\mathbf{kk}']|},$$

where **k** and **k′** are the momenta of the deuteron before and after scattering. According to (2), the intensity of the doubly scattered beam of deuterons can be written in the form ($\varphi$ is the azimuth angle)

$$I = I_0(A + B\cos\varphi + C\cos^2\varphi). \qquad (3)$$

To check on relation (3) we investigated the azimuthal asymmetry of double elastic scattering of 6.5-MeV deuterons for the following combinations of first and second targets: Fe–Fe, Fe–Co, Fe–Mn, Fe–Ni, and Fe–$Fe^{54}$ (in the latter case a target made of the enriched isotope $Fe^{54}$ was used). The first and second scattering angles were $\theta_1 = \theta_2 = 55°$.

A diagram of the setup is shown in Fig. 1. The targets were free-standing foils approximately 2 $mg/cm^2$ thick; the detector was a Ya2 photoemulsion approximately 50 $\mu$ thick, arranged in a circle with the second target as center. The result of the measurements for the Fe–Fe case are shown in Fig. 2, with mean-square errors in the determination of the number of tracks; the error in the determination in the azimuthal angle was estimated from geometrical considerations with

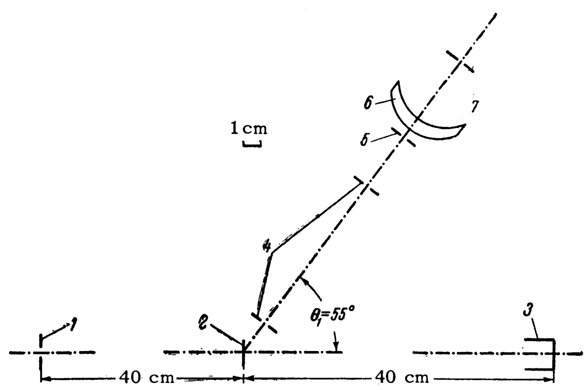


FIG. 1. Experimental setup: 1 – primary beam diaphragm, 2 – first scattering target; 3 – Faraday cylinder, 4 – scattered-beam collimator, 5 – second scattering target, 6 – working film, 7 – additional film.

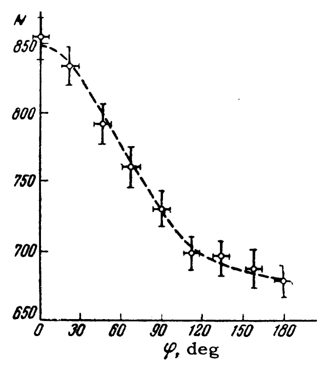


FIG. 2. Azimuthal dependence of intensity of double scattering of deuterons by iron.

*[kk′] = k × k′.

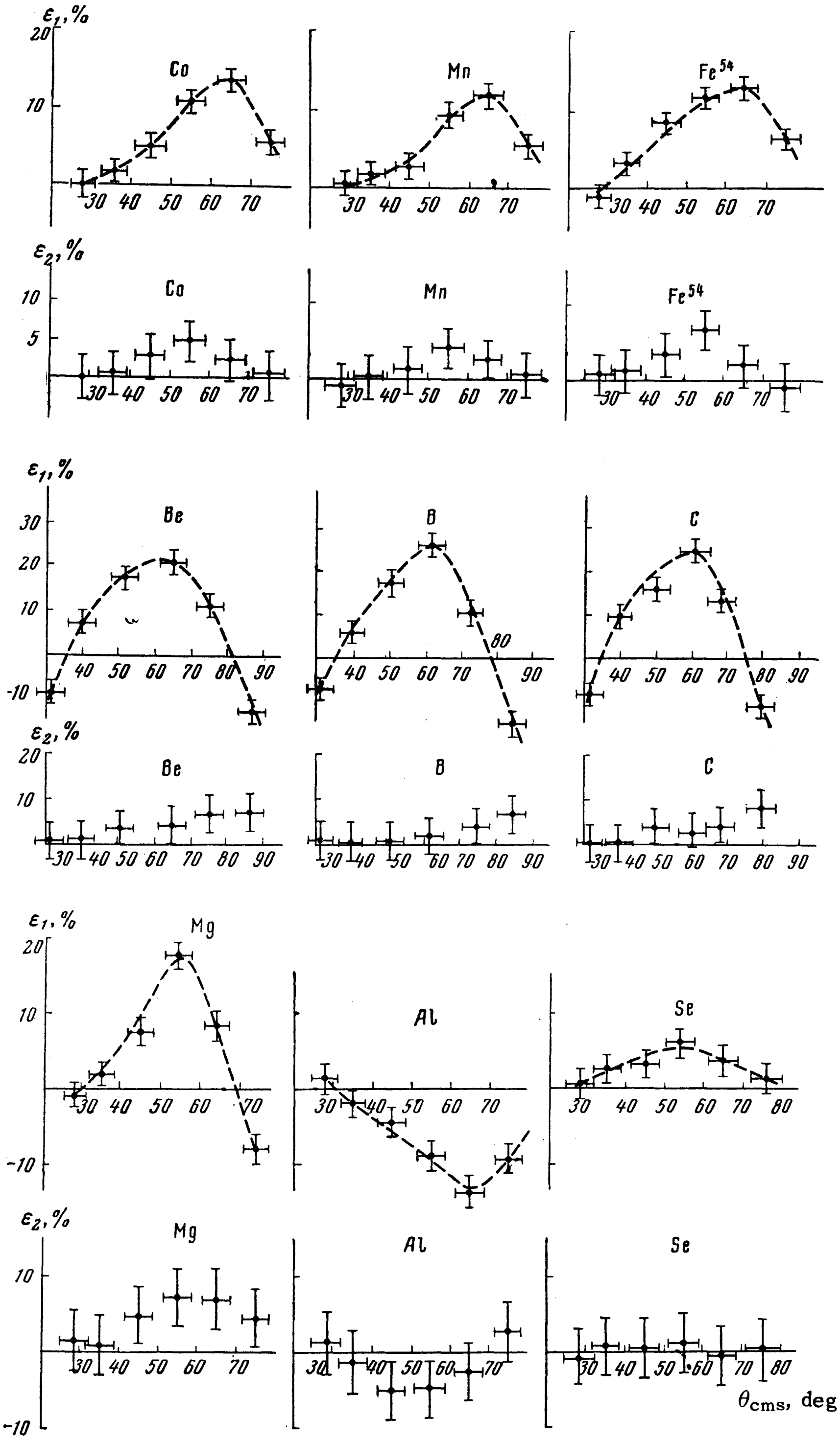


FIG. 3. Angular dependence of $\epsilon_1$ and $\epsilon_2$ for the nuclei Co, Mn, $Fe^{54}$, Be, B, C, Mg, Al, and Se.

account of the size of the processed area of the photographic film and the dimensions of the spot due to the beam on the second target. The ratios $\epsilon_1 = B/A$ and $\epsilon_2 = C/A$, determined from all the experimental points, are as follows: $\epsilon_1 = (11 \pm 1)\%$ and $\epsilon_2 = (5 \pm 1.4)\%$. The dashed curve on this figure has the form

$$I = I_0 (1 + 0.11 \cos \varphi + 0.05 \cos^2 \varphi).$$

The curves showing the azimuthal distributions of the scattered deuterons for other target combinations were similar to that shown in Fig. 2, and are therefore not presented separately. A knowledge of the ratios of the coefficients $\epsilon_1$ and $\epsilon_2$ still does not make it possible to determine the polarization and the quadrupolarization, but they can be estimated approximately. For this purpose it is necessary to express $\epsilon_1$ and $\epsilon_2$

in terms of F, and also to use the inequality $Q \leq (2-3|P|)/3$, which follows from the definition of polarization and quadrupolarization. In the case of deuterons with $E_d = 6.5$ MeV, doubly scattered by iron through 55°, we obtain the following limits for the possible values of P and Q:

$$26\% \leqslant |P| \leqslant 31\%, \quad 17\% \leqslant |Q| \leqslant 42\%.$$

In view of the large similarity between the azimuthal dependences, these estimates are valid also for Co, Mn, Ni, and $Fe^{54}$.

With the aid of apparatus previously described [2], we also investigated the angular dependence of the quantities $\epsilon_1$ and $\epsilon_2$ for Co, Mn, $Fe^{54}$, Se, Sb, Au, Al, Mg, Be, B, and C. The targets were made in the form free-standing films with approximate thickness 2 mg/cm$^2$, and in many of these experiments the first target was an iron foil with natural isotopic composition. The results of the measurements of $\epsilon_1$ and $\epsilon_2$ for Co, Mn, and $Fe^{54}$ are shown in Fig. 3.

No asymmetry whatever was observed for Sb and Au, within the limits of experimental error, and this is natural since, owing to the large values of Z, the scattering on these nuclei should essentially be of the Coulomb type. The results for Be, B, C, Mg, Al, and Se, are shown in Fig. 3. Calculations for the polarization of 8.9-MeV deuterons scattered by $C^{12}$ were made by Robson [3]. According to these data, the polarization is negative in the 35—70° range; its magnitude and dependence on the angle agree with the values of $\epsilon_1$ obtained by us. Since $\epsilon_1$ is positive in this case, it follows that the polarization on iron at these angles is also negative.

An examination of the values of $\epsilon_1$ and $\epsilon_2$ for different nuclei, obtained in the present investigation and earlier [2], shows that the polarization and quadrupolarization vary smoothly with Z, with the maximum polarization observed in the region of light nuclei (B, C). The monotonic dependence of the polarization on the mass number of the nucleus and the similarity of the results for closely lying nuclei give grounds for hoping that these phenomena can be quantitatively dealt with in the optical model.

The value of $\epsilon_1$ decreases with decreasing C, compared with $\epsilon_2$. The maximum of $\epsilon_2$ for medium values of Z occurs at approximately the same place as the maximum of $\epsilon_1$, and shifts towards larger angles with decreasing Z. It can be proposed that when deuterons are scattered by light nuclei through 30—70°, the quadrupolarization is small and we deal with preferred orientation of the spins in a direction perpendicular to the scattering plane. What is striking is that for closely located nuclei $\epsilon_1$ and $\epsilon_2$ are practically the same, independently of the spin of the nucleus. We can conclude from this that the spin of the target nucleus does not affect strongly polarization phenomena with deuterons. Of all the nuclei investigated by us, Al has sharply different polarization properties; both $\epsilon_1$ and $\epsilon_2$ have signs opposite to those of the other nuclei. The reason for these peculiarities of the aluminum nucleus has not yet been clarified.

[1] I. S. Shapiro, UFN **75**, 61 (1961), Soviet Phys. Uspekhi **4**, 641 (1962).

[2] Gustova, Nemilov, and Pobedonostsev, JETP **44**, 100 (1963), Soviet Phys. JETP **17**, 68 (1963).

[3] D. Robson, Nucl. Phys. 22, 34 (1961).

Translated by J. G. Adashko
21