Spin-orbit interaction and distribution of the density of nuclear matter

G. D. Alkhazov, S. L. Belostotskiĭ, A. A. Vorob'ev, O. A. Domchenkov, Yu. V. Dotsenko, D. Legrand,[1] N. P. Kuropatkin, V. N. Nikulin, M. A. Shuvaev, and J.- L. Escudie[1]

B. P. Konstantinov Institute of Nuclear Physics, USSR Academy of Sciences
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The polarization was measured in diffraction scattering of protons by the nuclei ^{16}O and ^{90}Zr. The parameters of the nuclear-matter density distribution, with account taken of the spin-orbit interaction, are obtained for a number of magic nuclei.

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The scattering of protons of medium energy by nuclei is an important source of information on the structure of the nucleus. Thus, analysis, with the aid of the Glauber–Sitenko theory, of the data on the diffraction scattering of 1-GeV protons has yielded, for a number of nuclei, fundamental nuclear characteristics such as the nuclear-density distribution parameters.[1] A joint analysis of experiments on electrons and protons yielded next the parameters of the neutron density distribution. These results, however, were obtained in the zero-spin variant of the theory, i.e., the spin structure of the amplitude of the nucleon–nucleon scattering was not taken into account in the calculations. Attempts at including the spin effects were made by a number of workers,[2–4] but the corresponding calculations were subject to great uncertainties because of the poor knowledge of the spin nucleon–nucleon amplitudes.

It is known that a good approximation for the nucleon–nucleon operator in the analysis of the scattering of protons by nuclei with zero spin is

$$f(\mathbf{q}) = f_c(q) + f_s(q)(\vec{\sigma}\mathbf{n}) . \quad (1)$$

Here **q** is the momentum transfer, **n** is the normal to the scattering plane, $\vec{\sigma}$ is the spin operator of the incident proton, and $f_c(q)$ and $f_s(q)$ are the central and the spin–orbit amplitudes. The parameters of the central amplitude can be specified with the aid of data on free *pp* and *pn* scattering. To determine the spin–orbit amplitude and accordingly to take into account the spin–orbit proton–nuclear interactions, we can use data on the polarization in the diffraction scattering of protons by nuclei.[5,6]

We have measured the polarization in elastic scattering of 1-GeV protons by the nuclei ^{16}O and ^{90}Zr. The differential cross sections and the polarization were analyzed for a number of magic nuclei; a set of spin–orbit parameters was determined from the aggregate of the obtained data; the parameters of the nuclear-density distribution were determined with the spin–orbit interaction taken into account.

The experimental procedure and the basic formulas for the analysis are given in Refs. 5 and 6.

Figures 1 and 2 show the results of the joint reduction of the differential cross

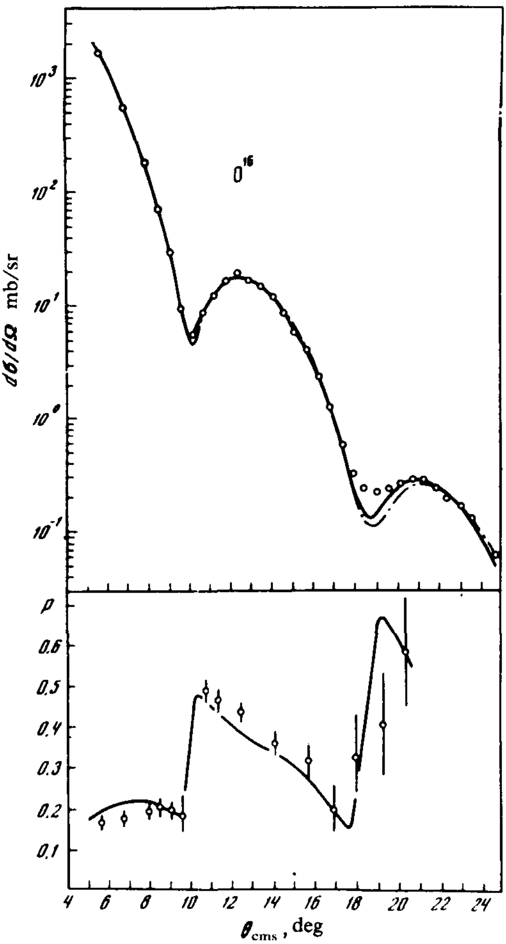

FIG. 1. Differential cross section and polarization in elastic scattering of 1-GeV protons by ^{16}O nuclei. Solid curve–least-squares fit. Dashed–spin-orbit interaction included.

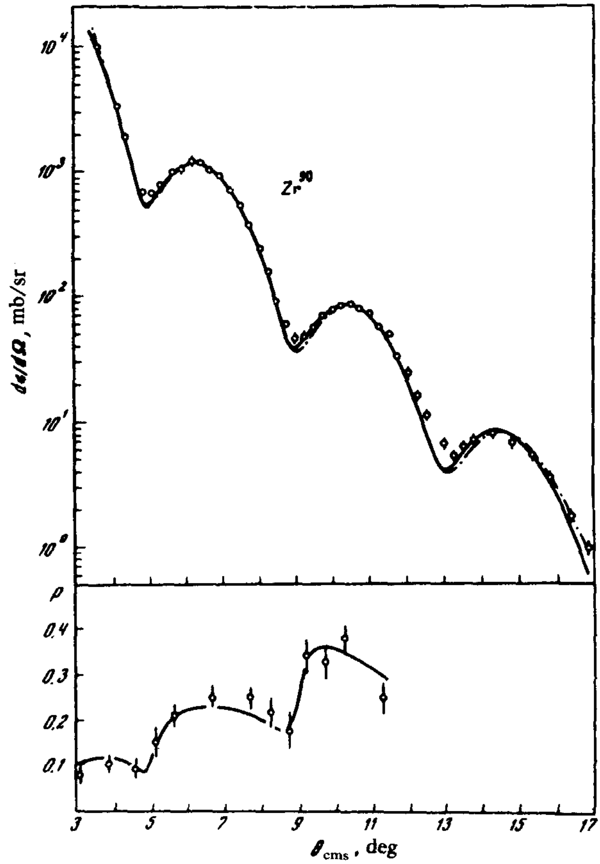

FIG. 2. Differential cross section and polarization in elastic scattering of 1-GeV proton by ^{90}Zr nuclei. Solid curve–result of a least-square fit. Dashed–spin–orbit interaction included.

sections and of the polarization for the nuclei ^{16}O and ^{90}Zr. The dashed curve corresponds to inclusion of the spin-orbit interaction. As follows from Figs. 1 and 2, despite the appreciable polarization, the influence of the spin–orbit interaction on the cross sections is very small.

Table I lists the values of the parameters of the nuclear-matter distribution and the parameters of the spin–orbit nucleon–nucleon amplitude, obtained by a least-squares fit. For comparison, the parentheses contain the quantities obtained without the spin–orbit interaction. In all cases, the changes due to allowance for the spin do not exceed 0.04 F.

The parameters of the spin–orbit amplitude for all the magic nuclei agree within the limits of errors. Some differences in the case of ^{12}C may be due to peculiarities of the structure of the ^{12}C nuclei, which were not taken into account in the analysis.

Notice should be taken of the limited character of the customarily employed parametrizations. Phase-shift analyses point to a more complicated character of the dependence of the amplitudes on the momentum transfer. In particular, the slopes turn out to be different for the real and the imaginary parts of the amplitudes. Unfortunately, the phase analyses available for 1 GeV are not single-valued.[7] There is practically no information on the polarization parameters in the case of *pn* scattering. An

TABLE I. Parameters of the distribution of the density of nuclear matter and of the spin–orbit nucleon amplitude obtained as a result of a joint reduction of the differential cross section and the polarization data.

Nucleus	Nuclear-density distribution parameters $\rho(r) = \rho_0\left(1 + W\frac{r^2}{R^2}\right)\left[1 + \exp\left(\frac{r-R}{a}\right)\right]^{-1}$				Spin-orbit amplitude parameters $f_s(q) = \gamma q \frac{k\sigma}{4\pi}(\epsilon_s + i)\exp(-\beta_s q^2/2)$		
	R, F	a, F	W[1]	$\langle r^2\rangle^{1/2}$, F	γ, F	ϵ_s	β_s, F²
^{12}C	2.16 ± 0.01 (2.17)	0.53 ± 0.01 (0.55)	–0.11	2,41 (2.44)	0.15 ± 0.01	–0.1 ± 0.1	0.56 ± 0.03
^{16}O	2.50 ± 0.01	0.54 ± 0.01	–0.05	2.73	0.14 ± 0.01	–0.5 ± 0.1	0.64 ± 0.04
^{40}Ca	3.69 ± 0.01 (3.7)	0.61 ± 0.01 (0.63)	–0.17	3.45 (3.49)	0.14 ± 0.01	–0.8 ± 0.3	0.71 ± 0.09
^{90}Zr	4.95 ± 0.01 (4.96)	0.57 ± 0.01 (0.56)	–0.09	4.32 (4.32)	0.13 ± 0.02	–0.3 ± 0.3	0.7 ± 0.1
^{208}Pb	6.55 ± 0.01 (6.58)	0.57 ± 0.01 (0.58)	–0.06	5.42 (5.45)	0.13 ± 0.01	–0.5 ± 0.2	0.9 ± 0.2

[1]The parameter W was fixed.

analysis of the proton-nuclear scattering can therefore serve, in all appearances, as an additional criterion when the nucleon–nucleon amplitudes are reconstructed.

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