Polarization of protons due to excitation of natural parity levels in C^{12} and O^{16} at $T_p = 1$ GeV

S. I. Manaenkov
Tul'skiĭ Polytechnical Institute

(Submitted 3 July 1979)
Pis'ma Zh. Eksp. Teor. Fiz. **30**, No. 6, 360–364 (20 September 1979)

A good description of the data for polarization of protons as a result of excitation of the 4.43–MeV level in C^{12} and of levels with $E^* = 6$–7 MeV in O^{16} is obtained in the approximation of a single inelastic scattering with experimentally determined electron form factors. The main contribution to polarization comes from the scalar and spin-orbit *NN* amplitudes.

PACS numbers: 25.40.Ep, 24.70. + s, 25.40.Rb

Recently, the polarization of protons as a result of excitation of the 4.43-MeV ($J^\pi = 2^+$) level in C^{12} and a group of energy-unresolved levels with $E^* = 6 - 7$ MeV in O^{16} was measured at Gatchina.[1] The 6.13 (3^-)- and 6.92 (2^+)-MeV levels with maximum cross sections were excited in oxygen at $T_p = 1$ GeV.[2-4] The purpose of this paper is to describe the experimental data obtained and to determine the information that can be extracted from them.

The calculations were performed by using an approximation of a single inelastic collision, which was suggested in Refs. 5 and 6. The Coulomb effects were taken into account by adding to the nuclear phases the eikonal Coulomb phases for the point charge and the nuclear recoil was taken into account by multiplying the nuclear excitation amplitude by the factor $\exp\{\alpha q^2/A\}$, where q is the momentum imparted to the nucleus, A is the mass number, and the parameter a is determined in relation (4).

The linear approximation for the invariant spin *NN* amplitudes works well for light nuclei. This is attributable to the small spin terms in the *NN* amplitude at $T_p = 1$ GeV.[7] In this approximation only two terms in the *NN* amplitude contribute to the polarization produced as a result of excitation of the natural-parity levels [only these terms are written explicitly in Eq. (1)]:

$$f_{NN}(\mathbf{q}) = A_{NN}(q) + C_{NN}(q)(\vec{\sigma}\mathbf{n}) + \dots \tag{1}$$

In Eq. (1) $\mathbf{n}$ is the unit normal to the plane of the *NN* scattering and the Pauli matrices $\vec{\sigma}$ act on the spin variables of the incident proton. Since the second term in Eq. (1) is diagonal to the spin variables of the nucleons in the nucleus, the same form factors are needed to determine its contribution to the nuclear excitation amplitude as those for determining only the first term. Thus, the same information about the nucleus (form factors) is needed for calculation of the polarization in the linear approximation of the *NN* spin amplitudes as that for calculation of the cross section without allowing for the spin effects.

The *NN* amplitude was parametrized in the form

TABLE I.

Nuclear	Level E, MeV (J^π)	C, F^J	d, F^{J+2}	f, F^{J+4}	a, F^2	Number of the set of parameters	Reference
C^{12}	0 (0^+)	1	- 0,3062	0	0.6889	I	[8]
	4,43 (2^+)	0.23	0.01043	- 0.005224	0.665	I	[9]
	0 (0^+)	1	- 0,296	0	0,6256	II	[10]
	4,43 (2^+)	0,24	- 0.0312	0	0,5089	II	[10]
O^{16}	0 (0^+)	1	- 0,3872	0	0.7744	–	[8]
	6.13 (3^-)	0.195	- 0,008	0	0,8125	–	[4]
	6.92 (2^+)	0,22	- 0.019	0	1,2	–	[4]

$$A_{NN}(q) = p\sigma(4\pi)^{-1}(i + \epsilon_c)\exp\{-\beta_c q^2/2\}, \tag{2}$$

$$C_{NN}(q) = \gamma q p\sigma(i + \epsilon_s)(4\pi)^{-1}\exp\{-\beta_s q^2/2\}, \tag{3}$$

where $\sigma = 4.4$ F^2, $\epsilon_c = -0.26$, and $\beta_c = 0.26$ F^2.[1] For C_{NN} we used two sets of parameters determined in Ref. 1 from the data on elastic scattering of protons by nuclei

1) $\gamma = 0.14\ \Phi,\quad \epsilon_s = -0,5,\quad \beta_s = 0,67\ \Phi^2,$

2) $\gamma = 0,16\ \Phi,\quad \epsilon_s = -0,03,\quad \beta_s = 0,58\ \Phi^2.$

The form factors of the $0^+ \to J^\pi$ transitions were chosen in the form

$$S_J = q^J(c + dq^2 + fq^4)\exp\{-aq^2\}. \tag{4}$$

To describe the excitation of the 2^+ level in C^{12} by protons, we used the set of parameters of the form factors from Refs. 8 and 9 (set I) and also one of the sets used in Ref. 10 (set II). The form factors of the inelastic transitions in O^{16} were taken from Ref. 4 and that of the elastic transition was taken from Ref. 8. All the indicated form factors were extracted directly from the electron data whose parameters, given in Table I, correspond to the distribution of matter in the nucleus. To compare form factors (4) with the electron data, they should be multiplied by the factors allowing for the nuclear recoil and finite radius of the proton (see, for example, Refs. 8–10). The proton radius r_p is assumed to be equal to 0.8 F.

The q dependence of the polarization is shown in the upper part of Fig. 1 and that of the differential cross section for excitation of the 2^+ level in C^{12} is shown in the lower part. Curves 1 and 5 represent the calculation with the first set of parameters of

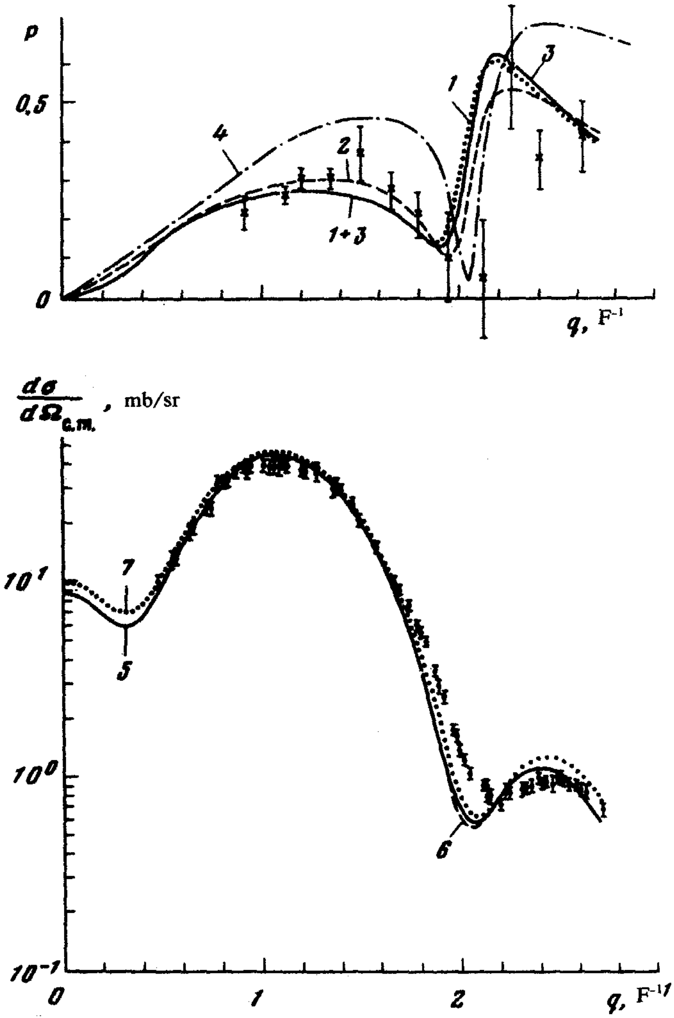

FIG. 1.

the NN amplitude and with set I of the form factors (for brevity, 1I), curves 2 and 6 and 3 and 7 denote the same as above for 2I and 1II, respectively, and curve 4 was taken from Ref. 10. The data for the excitation cross section were taken from Ref. 11. It can be seen that curves 1–3 describe well the experimental data of Ref. 1 everywhere except the region of the diffraction minimum of the cross section, and curve 4 is at variance with them. Since curves 3 and 4 were calculated by using the same form factors, the lack of agreement in case of the curve 4 indicates that the set of parameters of the Lambert and Feshback NN amplitude used in Ref. 10 is rather poor. A comparison of curves 1 and 2 and also curves 3 and 4 illustrates the sensitivity of polarization to the parameters of the NN amplitude.

In the case of O^{16} we used only set I of the parameters of the NN amplitude. The results of the calculations of the cross sections, which differ little from those published

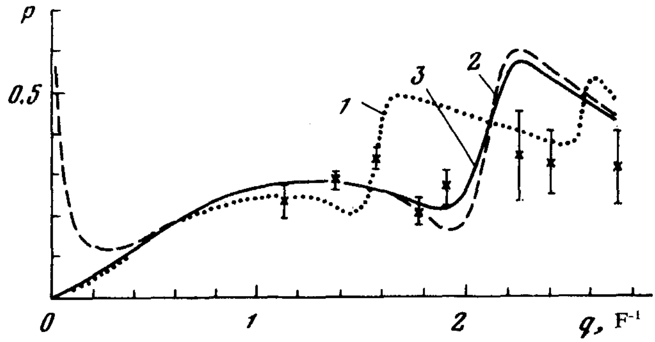

FIG. 2.

earlier,[4] are not shown in Fig. 2. Curve 1 in Fig. 2 represents the polarization as a result of excitation of the 2^+ level in O^{16} and curve 2 denotes the same for the 3^- level. Curve 3 illustrates the behavior of the total polarization (taking the weights into account) as a result of excitation of these two levels. It can be seen that it describes satisfactorily the data of Ref. 1. The peak at $q \leqslant 0.1$ F^{-1} on curve 2 is attributed to the fact that in the odd levels the main contribution to the differential cross section, which is due to the A_{NN} amplitude, approaches zero when $q \to 0$ as q^2.

Thus, since at $T_p \geqslant 1$ GeV the linear approximation of the invariant spin NN amplitudes works well, only the A_{NN} and C_{NN} amplitudes are needed for calculations of the polarization and excitation cross section. The cross section is sensitive to the A_{NN} amplitude and the polarization is sensitive to the C_{NN} amplitude. It is clear that only these two amplitudes can be extracted from the data for the cross section and polarization. The same form factors are needed for calculation of polarization as for calculation of the excitation cross section, if the spin effects are disregarded.

I thank S.L. Belostotski, M.A. Shuvaev, and G.D. Alkhazov for sending us the experimental results and A.L. Karpenko and N.I. Manaenkov for their help with the computer calculations.

[1]G. D. Alkhazov *et al.*, Preprint LIYaF No. 448, Leningrad, 1978.
[2]J. L. Friedes *et al.*, Nucl. Phys. **A104**, 294 (1967).
[3]Yu. M. Goryachev *et al.*, Yad. Fiz. **17**, 910 (1973) [Sov. J. Nucl. Phys. **17**, 476 (1973)].
[4]S. I. Manaenkov, Pis'ma Zh. Eksp. Teor. Fiz. **19**, 593 (1974) [JETP Lett. **19**, 308 (1974)].
[5]V. V. Karapetyan *et al.*, Nucl. Phys. **A203**, 561 (1973).
[6]L. A. Kondratyuk and Yu. A. Simonov, Pis'ma Zh. Eksp. Teor. Fiz. **17**, 619 (1973) [JETP Lett. **17**, 435 (1973)].
[7]G. D. Alkhazov *et al.*, Physics Reports **42C**, 90 (1978).
[8]H. F. Ehrenberg *et al.*, Phys. Rev. **113**, 666 (1959).
[9]R. M. Haybron *et al.*, Phys. Rev. **156**, 1136 (1967).
[10]R. D. Viollier, Ann. Phys. (N.Y.) **93**, 335 (1975).
[11]R. Bertini *et al.*, Phys. Lett. **45B**, 119 (1973).