Excitation of individual levels in ^{16}O by protons of energy 1 GeV

S. I. Manaenkov

Moscow State University
(Submitted March 22, 1974)
ZhETF Pis. Red. **19**, 593–597 (May 5, 1974)

Form factors obtained by fitting electronic data were used to calculate the differential cross sections of the excited levels 6.05, 6.13, 6.92, and 7.12 MeV in ^{16}O by protons with $E=1$ GeV. The results are compared with the experimental data.

The purpose of the present article is to compare data on the scattering of high-energy electrons[1–5] and protons[6–8] by the ^{16}O nucleus. To this end, we use the single inelastic collision (SIC) approximation,[9,10] since it suffices to know the form factors for the calculations, and there is no need to use the wave functions of the nucleus. The amplitude of the transition of the nucleus from the state i to the state f as a result of collision with a proton is given in the SIC approximation by

$$F_{fi}(\mathbf{q}) = A\left\{f_{NN}(\mathbf{q})S_{fi}(\mathbf{q}) - \frac{1}{2\pi ik}\int f_{NN}(\vec{\Delta})S_{fi}(\vec{\Delta})\,\Phi(\mathbf{q}-\vec{\Delta})\,d^2\Delta\right\}. \quad (1)$$

Here $\mathbf{q}$ is the momentum transferred to the nucleus ($\hbar = c = 1$), A is its mass number, f_{NN} is the amplitude of the elastic nucleon-nucleon collision, $k=|\mathbf{k}|$, where $\mathbf{k}$ is the momentum of the incident proton, and the amplitude Φ is given by

$$\Phi(\mathbf{q}) = \frac{ik}{2\pi}\int e^{i\mathbf{q}\mathbf{b}}\left\{1-\left[1-\frac{1}{2\pi ik}\int e^{-i\vec{\Delta}\mathbf{b}} \times f_{NN}(\vec{\Delta})S_{ii}(\vec{\Delta})d^2\Delta\right]^{A-1}\right\}d^2b. \quad (2)$$

The form factors S_{fi} (S_{ii}) in (1) and (2) are connected with the wave functions Ψ_f and Ψ_i of the nucleus by the relation

$$S_{fi}(\mathbf{q}) = \frac{1}{A}\int \Psi_f^*(\mathbf{r}_1, \ldots, \mathbf{r}_A) \sum_{j=1}^{A} e^{i\mathbf{q}\mathbf{r}_j} \Psi_i(\mathbf{r}_1, \ldots, \mathbf{r}_A) d^3r_1 \ldots d^3r_A . \quad (3)$$

An idea of the accuracy of the SIC approximation in comparison with the initial Glauber formula[11,12] is gained from Fig. 1. Curves 1 and 2 describe the dependence of the differential excitation cross sections ($d\sigma^G/d\Omega$, in F^2/sr) of the levels 2^+ in ^{12}C and 3^- in ^{16}O by protons ($E = 1$ GeV) on q^2, calculated from the formulas of Glauber's theory with shell-model wave functions.[13] Curves 3 and 4 show the behavior of the ratios $(d\sigma^{SIC}/d\Omega)(d\sigma^G/d\Omega)$ for the states 2^+ and 3^- respectively. We see that in the region of the first diffraction maximum there is good agreement between the two theoretical curves, so that in this region of the values of q^2 the SIC can claim, like the Glauber theory, quantitative agreement with experiment. The calculated total cross sections differ by less than 10%.

Since the form factors given by different models of the nucleus describe quite poorly the electronic data for ^{16}O, they were not used in the calculations. The parameters A, B, and C of the form factors, which were chosen in the form ($f \equiv JM$, $i \equiv 0^+$, q in F^{-1})

$$S_{JM,0^+}(\mathbf{q}) = \sqrt{\frac{4\pi}{2J+1}}\, Y_{JM}^*(\mathbf{q}/q) S_J(q), \quad (4)$$

$$S_J(q) = q^L (B + cq^2) \exp\{-Aq^2/4\}, \quad (5)$$

were fitted to the experimental data of[1–5] by least squares, with corrections introduced to take into account the recoil of the nucleus and the finite dimensions of the protons. If J is the spin of the excited nucleus, then L

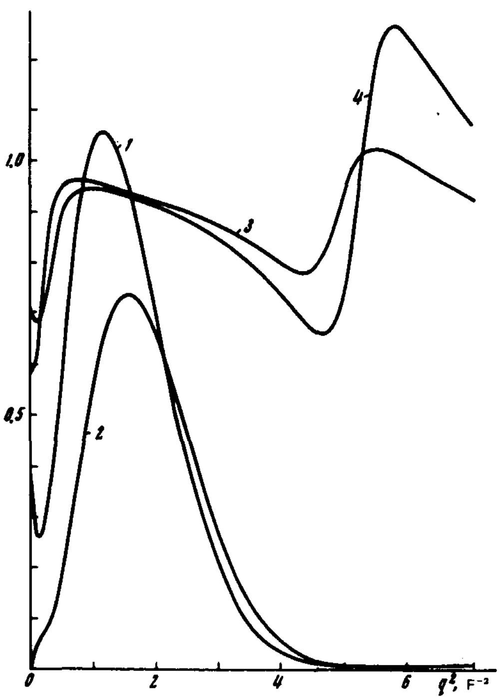

FIG. 1.

E, MeV	$J^\pi(T)$	N	χ^2	n	A	B	C	σ, mb
6.05	$0^+(0)$	14	12.8	12	5.75	0.1	−0.0175	0.08
6.13(I)	$3^-(0)$	51	84.5	29	3.2	0.19	−0.008	5.33
6.13(II)	$3^-(0)$	51	242.7	29	3.25	0.195	−0.008	5.42
6.92	$2^+(0)$	32	63.0	22	4.8	0.22	−0.019	1.73
7.12	$1^-(0)$	19	45.3	19	4.0	0.14	−0.006	0.56

$= J$ for the level 3^+ and 3^- and $L = J + 2$ for 0^+ and 1^-. The results of the fitting are listed in the table, which gives also the total number N of the experimental points, the values of κ^2, and the number n of the points used to fit the parameters. The connection of a form factor with the electronic cross section was chosen to be the same as in[5]. For the 6.13 MeV level, two fittings were carried out: the first (I) without the use of the data of[5], where $q \geq 1.66$ F^{-1} and the levels 0^+ and 3^- have not been separated, and the second (II) with these data, and with the square of the form factor of the 6.05 MeV level with parameters obtained by fitting the data for 0^+ state[1,2] subtracted from the experimental values of the sum of the squares of the form factors. This procedure was used wherever the levels were not separated experimentally.

The form factors obtained from the electron data were used in the calculation of the differential cross sections for the excitations of the oxygen levels by protons ($E = 1$ GeV). The NN-amplitude parameters and the densities of the ground state of ^{16}O were taken from.[13] It is seen from Fig. 2 that curve 1, which describes the

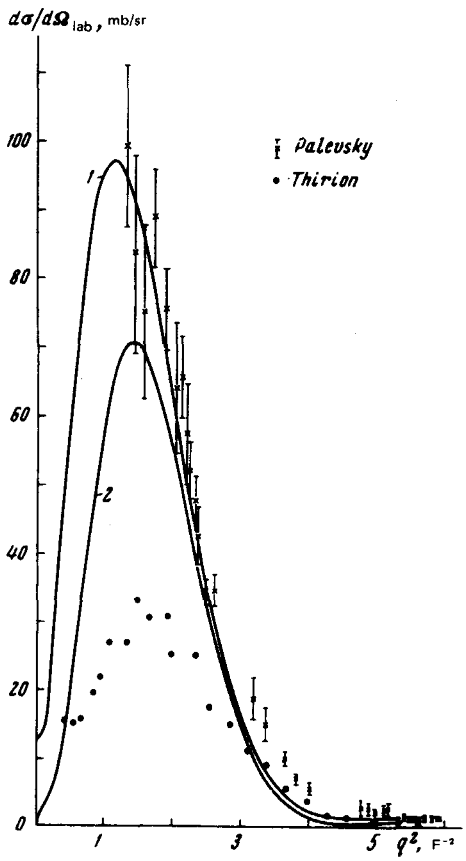

FIG. 2.

sum of the excitation cross sections of the levels 0^+, 3^-, 2^+, and 1^- on q^2, agree well with the data of[6]. The table lists the total cross sections for the excitations of these levels by protons. These, with the exception of the 2^+ level, also agree with the experimental values.[7] The theoretical value of the cross section for the excitation of the 6.92 MeV level turn out to be approximately three times larger than the estimate of[7]. The possible reason is that the emission of the 2^+ level has zero intensity at $\theta = 180°$ (θ is the angle between the photon momentum and the vector **k**), if the spin-dependent part of f_{NN} is neglected, and a strong Doppler broadening of the level, which is difficult to separate from the background, occurs at $\theta = 100°$. Yet the measurements of the γ-radiation intensity were carried out in[7] only at $\theta = 100°$ and $\theta = 178°$. It should be noted that the calculated differential cross section for the excitation of the 6.13-MeV level (curve 2) does not agree with the preliminary data of[8]. However, the preliminary results of[8] contradict the experimental data of[6].

The author is grateful to Yu.A. Simonov, L.A. Kondratyuk, I.I. Levintov, I.V. Kirpichnikov, N.A. Nikiforov and A.S. Starostin for useful discussions.

[1]M. Stroetzel, Z. Phys. **214**, 357 (1968).
[2]J.C. Bergstrom *et al.*, Phys. Rev. Lett. **24**, 152 (1970).
[3]G.R. Bishop *et al.*, Nucl. Phys. **53**, 366 (1964).
[4]H. Crannell, Phys. Rev. **148**, 1107 (1966).
[5]Y. Torizuka *et al.*, Phys. Rev. Lett. **22**, 544 (1969).
[6]J.L. Friedes *et al.*, Nucl. Phys. **A104**, 294 (1967).
[7]Yu. M. Goryachev *et al.*, Yad. Fiz. **17**, 910 (1973) [Sov. J. Nucl. Phys. **17**, 476 (1973).
[8]J. Thirion, Nuclear Reactions with High Energy Protons, Intern. Conf. on Nuclear Physics, Munich, August (1973).
[9]V.V. Karapetyan *et al.*, Nucl. Phys. **A203**, 561 (1973).
[10]L.A. Kondratyuk and Yu. A. Simonov, ZhETF Pis. Red. **17**, 619 (1973) [JETP Lett. **17**, 435 (1973)].
[11]R. Glauber, Review Paper, 3rd Internat. Conf. on High-Energy Physics, Columbia Univ., 1969.
[12]A.G. Sitenko, Ukr. Fiz. Zh. **4**, 152 (1959).
[13]R.H. Bassel and C. Wilkin, Phys. Rev. **174**, 1179 (1968).