ELASTIC SCATTERING OF 26–33 MeV He^3 *ON* C, Na, Mg *AND* Al *NUCLEI*

V. M. PANKRATOV and I. N. SERIKOV

Submitted to JETP editor October 29, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) 44, 887–893 (March, 1963)

Experimental results on the differential cross sections for elastic scattering of He^3 on C, Mg, and Al nuclei are presented for six energy values lying between 26 and 33 MeV and for the two energies 25.7 and 32.8 MeV for scattering on Na. The angular dependence of the cross sections has a pronounced diffractional structure. The energy dependence is manifested in variation of the absolute values of the cross sections and in the angular shift of the diffraction maxima. For each of the nuclei the interaction range computed on basis of diffraction on a "black" disc is found to be constant in the investigated energy range.

1. INTRODUCTION

THE differential cross sections for the elastic scattering of He^3 at an energy of several times 10 MeV have been investigated only for a small number of nuclei. Most investigations [1-4] have been carried out at an He^3 energy near 30 MeV, and one investigation [5] at 21 MeV. The differential cross sections in the case of light nuclei have a clearly pronounced diffraction structure, while in medium and heavy nuclei a smooth decrease in the cross section with angle is observed, in analogy with what takes place in the case of alpha-particle scattering. The results are usually interpreted either with the aid of the diffraction model for an absolutely black nucleus [6], or else using the optical model [7-8]. It has been found that the interaction radii for He^3 are in good agreement with the corresponding quantities obtained from experiments with alpha particles, while the values of the imaginary parts of the optical potential are much larger in the case of scattering of He^3, this being evidence of their stronger absorption. It is also shown that the scattering of He^3 is very sensitive to the magnitude of the optical parameter a, which characterizes the diffuseness of the surface of the nucleus. However, there are not enough experimental data at present to indicate essential differences between the interactions with He^3 and He^4. In the present article we report on an experimental investigation of elastic scattering of He^3 by C, Na, Mg, and Al, carried out in order to obtain the parameters of the optical model and to check on the existence of sharp irregularities in the course of the differential cross sections with energy, for small changes in the initial energy of He^3. Such irregularities were observed by a group of Japanese authors [9] in a study of the elastic scattering of alpha particles by carbon for eleven values of the energy in the range between 27 and 35 MeV. The results of the interpretation of the obtained data with the aid of the optical model will be published later.

2. APPARATUS AND MEASUREMENT PROCEDURE

The experiments were carried out with the 1.5-meter cyclotron of the Institute of Atomic Energy, using an extracted beam of He^3 ions accelerated to ~ 33 MeV [10]. The energy spread in the beam was ± 65 keV. We used a vacuum scattering chamber in which the angle of registration could be continuously varied from 10 to 160°. Diagrams of the chamber and of the detector are shown in Fig. 1. The beam of He^3 ions passes through a collimator with tantalum diaphragms, strikes the center of the target, which is turned through 45° relative to the beam axis, and then enters a Faraday cylinder. The measurement of the current was by means of a current integrator [11] with accuracy ± 1 per cent. The energy of the primary beam was measured with aluminum filters placed ahead of the collimator.

The charged product particles were detected with a telescope made up of a proportional counter and a scintillation spectrometer with thin CsI(Tl) crystal. The pulses from the spectrometer output were fed to an ÉLA-2 256-channel analyzer, controlled by a double-coincidence circuit. The proportional counter threshold was chosen such as to register only doubly-charged particles. The aver-

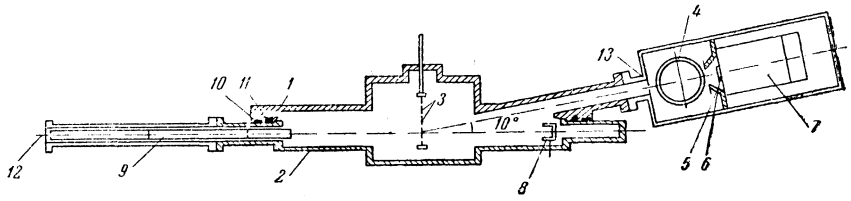

FIG. 1. Diagram of scattering chamber and detector: 1 – moving part of the scattering chamber, 2 – stationary part of the scattering chamber, 3 – targets, 4 – proportional counter, 5 – reflector, 6 – CsI(Tl) crystal, 7 – FÉU-14B photomultiplier, 8 – Faraday cylinder, 9 – input collimator of the beam, 10 – sliding rubber seal, 11 – support bearing, 12 – beam axis, 13 – input diaphragm of the detector.

age spectrometer resolution was 3 per cent in energy and 1.5° in angle. The stability of the recording apparatus was monitored during the course of operation with the aid of a Cm^{242} alpha source. The spectrometer was calibrated (the light yield of the CsI(Tl) crystal determined as a function of the energy) by observing the peak of He^3 elastically scattered by the Au. The energy of the primary beam was varied during the calibration by means of interchangeable aluminum absorbers.

Special investigations were made to determine the background due to inelastic scattering by target atoms, the edges of the tantalum diaphragms, and the exothermal (He^3, α) reactions. The background was found to vary with the type of target, angle of observation, and initial He^3 energy. When adjusted against the Au, the background in the angle interval from 15 to 90° ranged from 0.5 to 2 per cent of the elastic-scattering peak area for all energies. This value varied for the other targets within 0.5—3 per cent for carbon, and 1.5—30 per cent for sodium, magnesium, and aluminum. The background increased with increasing scattering angle. The investigated angle interval was therefore determined essentially by the possibility of reliable separation of the elastic-background peak from the background.

In all cases except sodium, unbacked targets measuring 2.4 × 1.6 cm and ~ 1 mg/cm^2 thick were used.

The sodium target, 0.9 mg/cm^2 thick, was made by sputtering sodium in vacuum on a thin cellulose nitrate film. A natural isotope mixture was used for the production of all the targets.

Figures 2—4 show typical spectra obtained for the interaction of He^3 with carbon, magnesium, and aluminum. The number of events in the elastic-scattering peak corresponded to a statistical error $\lesssim$ 3 per cent. As a rule, the measurements were made twice over the entire range of angles and energies. The absolute values of the cross sections were calculated directly from the measurement results. The accuracy of cross section determination was not worse than 10 per cent for all elements.

3. RESULTS

Carbon. The elastic scattering of He^3 on carbon was investigated in the c.m.s. angle interval

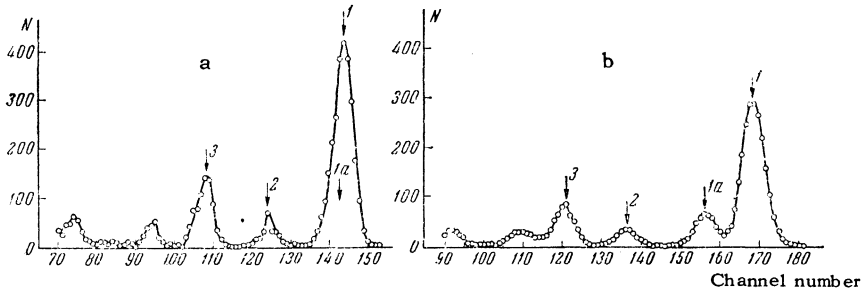

FIG. 2. Amplitude spectrum of He^3 and alpha particles produced in the interaction of He^3 with C^{12} (θ_{lab} = 31°29′, E_0 = 32.6 MeV): a – without additional absorber, b – with additional absorber of 27 mg/cm^2. The arrows indicate the positions of: 1 – elastically scattered He^3 ions, 1a – alpha particles from the $C^{12}(He^3,\alpha)C^{11}$ reaction (ground state), 2 – alpha particles from $C^{12}(He^3,\alpha)C^{11}$ reaction (1.99-MeV level), 3 – inelastically scattered He^3 ions (4.43-MeV level).

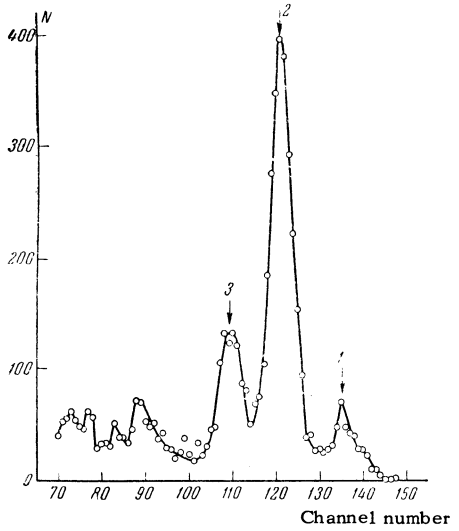

FIG. 3. Amplitude spectrum of He^3 and He^4 formed in the interaction of He^3 with magnesium ($\theta_{lab} = 36°13'$, $E_0 = 29.1$ MeV). The arrows indicate the positions of: 1 – alpha particles from the reaction $Mg^{24}(He^3,\alpha)Mg^{23}$ (ground and first-excited states), 2 – elastically scattered He^3 ions, 3 – inelastically scattered He^3 ions on Mg^{24} (1.38-MeV level), Mg^{25} (1.61-MeV level), and Mg^{26} (1.83-MeV level).

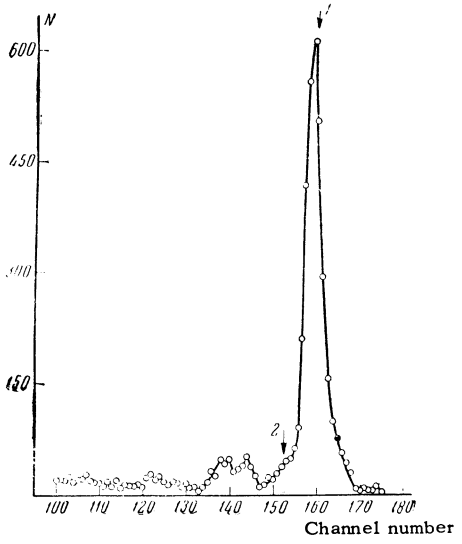

FIG. 4. Amplitude spectrum of He^3 and He^4 produced in interaction of He^3 with aluminum ($\theta_{lab} = 28°40'$, $E_0 = 33.0$ MeV). The arrows indicate the positions of: 1 – elastically scattered He^3 ions, 2 – inelastically scattered He^3 ions (0.85-MeV level).

from 22 to 123° for energies 32.6, 31.2, 29.7, 28.6, 27.4, and 26.1 MeV.

When C^{12} is bombarded by He^3 it is possible to get along with elastic and inelastic scattering also the $C^{12}(He^3, \alpha)C^{11}$ reaction with production of C^{11} in the ground and excited states. Since the energy of the C^{11} production reaction in the ground state is low ($Q = +1.86$ MeV), the alpha-particle peak corresponding to this state, in the angle interval 17—50° in the laboratory system (l.s.) lies so close to the peak of the elastically scattered He^3, that the spectrometer resolution is insufficient for their complete separation. In this case additional aluminum absorbers were used, 10 or 27 mg/cm^2 thick, placed directly ahead of the detector. With their aid we succeeded in separating almost completely the two peaks (see Fig. 2). In calculating the cross sections, the summary integral over the peaks, obtained during the measurements without the additional absorber, was divided in the ratio of the separated peaks. The percentage of losses due to multiple scattering in the additional absorber was assumed to be the same for both particles.

Figure 5 shows the obtained angular distributions. All the curves had a clearly pronounced diffraction structure. From a comparison of the curves we see that in the region of angles up to 80° the diffraction maxima shift with decreasing energy toward the larger angles. An interesting variation of the cross section with energy is observed near 80°, where there is a gradual transition from a clearly pronounced maximum at 32.6 MeV to a broad minimum at 26.1 MeV. At angles > 90° all the curves have approximately the same form—first a growth in cross section up to ~ 105° and then a smooth decrease.

The course of the curves at angles < 90° is that characteristic of elastic diffraction scattering. This portion of the curves was used to calculate the interaction radius R in accordance with the diffraction model. The calculations were made for each curve and the results agreed within the limits of experimental error. The mean value was $R = 5.4 \pm 0.3$ F. This value, and also the absolute values of the cross sections at 28.6 MeV, agree well with the data of Aguilar et al [2], where analogous measurements were made at 28.5 MeV. Unlike the results of the Japanese authors [9], we did not observe any sharp irregularities in the cross sections under small variations of the He^3 energy.

Sodium. The differential cross sections of elastic scattering of He^3 on sodium were measured for two energies, 25.7 and 32.8 MeV, in the c.m.s. angle interval 20—90°. The insufficient resolution of the spectrometer did not permit separation of the inelastic scattering at the first excited level of Na^{23} (0.44 MeV) from the elastic scattering. Therefore both curves on Fig. 6 are summary cross sections of elastic and inelastic scattering. The distortions in the shapes of the curves, due to the superposition of these two processes, are strongest at large angles. In

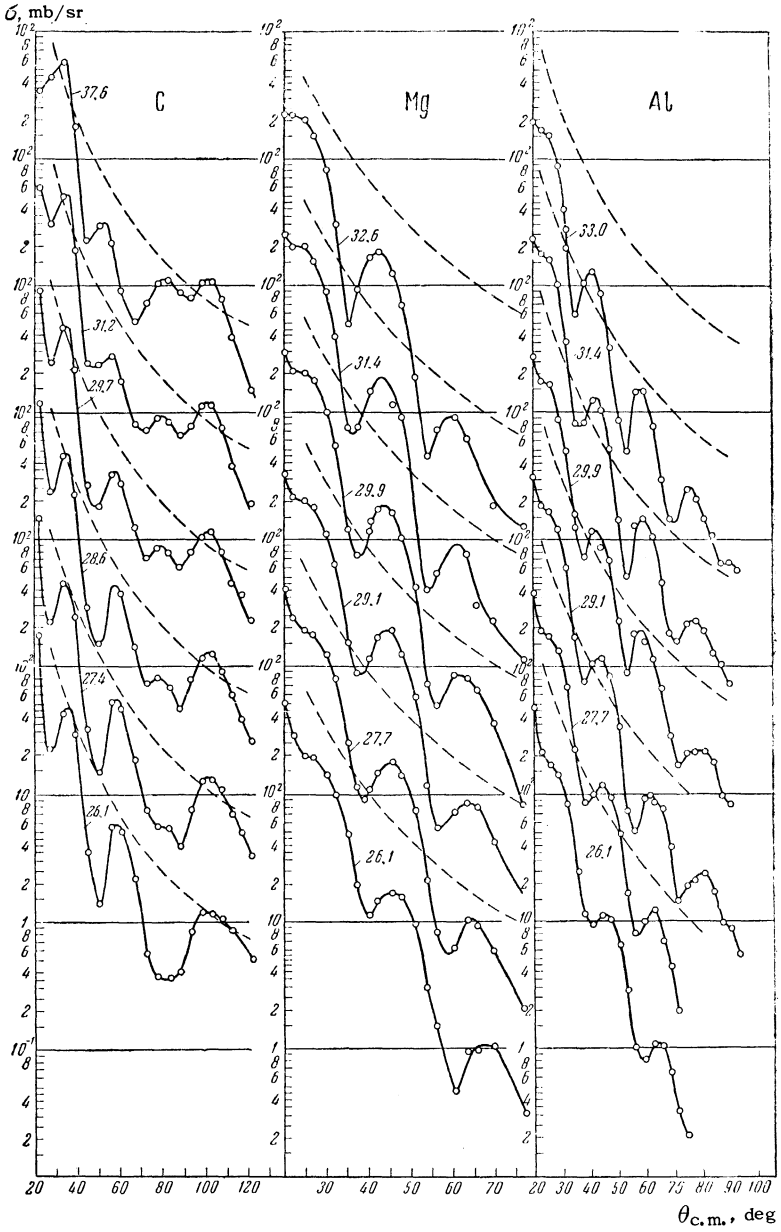

FIG. 5. Differential cross sections of elastic scattering of He^3 on carbon, magnesium, and aluminum. The numbers on the curves are the He^3 energies in MeV. The ordinate origins for neighboring curves are shifted by one order of magnitude. Dashed curves – cross section of Rutherford scattering.

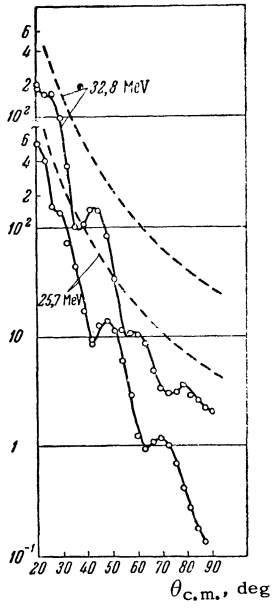

FIG. 6. Differential cross sections of elastic scattering of He^3 by sodium. The ordinate origins for neighboring curves are shifted by one order of magnitude. The dashed curves are the cross sections of the Rutherford scattering.

this region, first, the relative contribution of inelastic scattering is more significant and, second, the absolute errors in the determination of the background increase. Nonetheless, both curves have a clear-cut diffraction structure. At lesser energies, the diffraction maxima are shifted toward the larger angles. The average value of the interaction radius, calculated as in the preceding case, turned out to be the same for both energies, $R = 5.7 \pm 0.2$ F.

Magnesium. The elastic scattering of He^3 on a natural mixture of magnesium isotopes was measured at energies 32.6, 31.2, 29.7, 28.6, 27.4, and 26.1 MeV in the c.m.s. angle interval from 20 to 77°. Figure 5 shows the corresponding curves. The curves may be affected by the contribution of inelastic scattering on the first level of Mg^{25} (0.58 MeV). However, the small percentage con-

tent of this isotope (10.11 per cent) gives grounds for assuming that this contribution is relatively small and does not introduce noticeable distortion in the course of the cross sections. All the curves are similar in form to one another and differ only in their absolute values and positions of the diffraction maxima, which readily shift toward the larger angles with decreasing energy. The interaction radius is constant for all energies at $R = 5.8 \pm 0.2$ F.

Aluminum. The measurements were made at He^3 energies 33.0, 31.4, 29.9, 29.0, 27.7, and 26.1 MeV in the c.m.s. angle interval 20—93°. The results obtained are shown in Fig. 5. Inelastic scattering from the first level of Al^{27} (0.85 MeV) could be separated from the elastic scattering with sufficient reliability. All curves have a diffraction character. The energy dependence is the same as in the case of sodium and magnesium. The interaction radius is $R = 6.2 \pm 0.2$ F. The absolute values of the cross sections, obtained in the present work at energy 31.4 MeV, are close to the corresponding values given by Gonzalez-Vidal et al [4] at 31 MeV. Small discrepancies in the absolute values of the cross sections can be attributed to differences in the initial energies.

The fact that the interaction radii calculated for the diffraction model remain constant with varying energy, and also the reasonable numerical values of these quantities, indicate that these nuclei are sufficiently "black" in elastic interaction with He^3 ions at energies in the range 26—33 MeV. However, the degree of "blackness" can be determined only from calculations by the optical model. These calculations are now being carried out.

The author is grateful to S. P. Kalinin for continuous interest and help with the work, to A. A. Shubin for preparation of the targets, to A. M. Chukanov, B. I. Molodkin, and Yu. M. Varentsov for help with the measurements and data processing, and also to the cyclotron crew for operating the accelerator.

[1] G. W. Greenlees and P. C. Rowe, Nucl. Phys. **15**, 687 (1960).

[2] Aguilar, Burcham, England, Garcia, Hodgson, March, McKee, Mosinger, and Toner, Proc. Roy. Soc. **257**, 13 (1960).

[3] Greenlees, Lilley, Rowe, and Hodgson, Nucl. Phys. **24**, 334, (1961).

[4] Gonzalez-Vidal, Igo, and Markowitz, UCRL-9566, 158 (1961).

[5] H. E. Wegner and W. S. Hall, Bull. Amer. Phys. Soc. **3**, 338 (1958).

[6] R. E. Eisberg and C. E. Porter, Revs. Modern Phys. **33**, 190 (1961).

[7] P. E. Hodgson, Nucl. Phys. **21**, 28 (1960).

[8] Buck, Maddison, and Hodgson, Phil. Mag. **5**, 118 (1960).

[9] Mikumo, Yamaguchi, Nonaka, Hitaka, Miki, Mikai, and Nakajima, Proc. Intern. Conf. on Nuclear Structure, Kingston, Canada, 1960, p. 391.

[10] Venikov, Golovanov, Konyaev, Starostin, Chumakov, Atomnaya énergiya **2**, 213 (1961).

[11] A. A. Kurashov and A. F. Linev, PTÉ, No. 2, 70 (1957).

Translated by J. G. Adashko
150