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N. Ya. RUTKEVICH, V. Ya. GOLOVNYA, Academician of the Academy of Sciences of the Ukrainian SSR A. K. VAL' TER

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Abstract

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N. Ya. RUTKEVICH, V. Ya. GOLOVNYA, Academician of the Academy of Sciences of the Ukrainian SSR A. K. VAL' TER
and A. P. KLYUCHAREV

ANGULAR DISTRIBUTION OF PROTONS ELASTICALLY SCATTERED BY ISOTOPES OF NICKEL, COPPER, AND COBALT AT AN ENERGY OF 5.45 MeV

In recent years numerous studies have appeared devoted to the investigation of elastic scattering of protons by various atomic nuclei for proton energies from 5 to 40 MeV ($^{1-9}$). The angular dependence obtained in these experiments of the ratio of the measured scattering cross section to the scattering cross section due to the Coulomb field, σ/σ_{Rh}, has a diffraction character with clearly expressed maxima and minima. Not only qualitative but also quantitative agreement of the experimental results with theory can be obtained within the framework of the optical model of the interaction of nucleons with the nucleus over a considerable interval of scattering angles, if the scattering potential is taken in the form of a well with a diffuse edge.

However, in some investigations of proton scattering by nuclei at energies close to the potential barrier, results were obtained whose interpretation within the framework of the existing optical model at first sight does not seem possible. Thus, Bromley and Wall (^{1}) first found that the course of the angular dependence in proton scattering at large angles for nuclei of two neighboring elements, nickel and copper, is qualitatively different at a proton energy of 5.25 MeV. Subsequently Kondo et al. (^{5}), studying proton scattering at an energy of 5.7 MeV, found that the angular dependence σ/σ_{Rh} for nuclei with even Z (Ti, Cr, Fe) is the same as for even nickel. These studies showed that proton scattering by even-even nuclei differs from scattering by odd-even nuclei at energies near the potential barrier. Such a difference in the character of scattering disappears at higher energies. Thus, the angular distribution obtained in the study by Hintz (^{6}) at an energy of 9.8 MeV has qualitatively one and the same course both for even-even nickel and for odd-even copper. In this connection, considerable interest attaches to the study of the angular distribution of protons scattered by isotope nuclei and by isobaric nuclei.

Scattering on separated isotopes of light and heavy nuclei was investigated in works (^{7,8}), and on Li^6 and Li^7 in work (^{9}). However, these experiments were carried out in the region of energies considerably exceeding the potential barriers

Fig. 1. Schematic of the experiment. 1 —collimator, 2 —target, 3 —defining diaphragms, 4 —photographic plates, 5 and 6 —cassettes, 7 —Faraday cylinder

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of the nuclei. In the present work the measurements were carried out at an initial proton energy of 5.45 MeV—below the potential barrier of the target nuclei by approximately 1.5 MeV.

Method. Protons accelerated by a linear accelerator to an energy of 5.45 MeV passed through a magnetic analyzer with a deflection of 24°, a system of circular collimating diaphragms with diameters 3.2; 3.5; 3.3; 4.4 mm, and struck a target made of thin foil located in a vacuum chamber. The scattered protons were recorded by photographic plates placed at various angles to the incident beam in the range 20—160°, at intervals of 10°. In front of the photographic plates diaphragms of 4 mm diameter were placed. The angle of the diaphragm axis with the surface of the emulsion was 15°. We used nuclear emulsions of the K NIKFI type with an emulsion-layer thickness of 100 μ. Since the ranges of all registered

protons were completely stopped in the emulsion layer, we were able to measure the energy of the scattered protons. Since the intensity of Coulomb scattering is proportional to $(\sin\theta/2)^{-4}$, the distance from the center of the target to the detectors in the small-angle region was chosen so as to satisfy the relation $r(\sin\theta/2)^2 = \text{const}$, where r is the distance from the target to the detector and θ is the scattering angle. This arrangement of the photographic plates protected them from intense "fogging" by protons elastically scattered at small angles by the Coulomb field of the nucleus.

The geometry of the experiment is shown in Fig. 1. The angular uncertainty in our experiments was ±5° for large angles. For small angles it was substantially smaller, amounting to only 34′ at 20°. Here we did not aim at "good" geometry at large angles, since preliminary experiments had shown a rather smooth dependence of the differential cross section for elastic scattering on angle, and the course of Coulomb scattering at large angles is not sharp. The experimental geometry was checked by scattering protons from gold foil of thickness 1 μ. The results of this check are shown in Fig. 3. As expected, for protons with energy 5.45 MeV the angular distribution of the scattered protons obeys the law $(\sin\theta/2)^{-4}$.

Fig. 1. Schematic of the experiment. 1 —collimator, 2 —target, 3 —defining diaphragms, 4 —photographic plates, 5 and 6 —cassettes, 7 —Faraday cylinder.

Targets in the form of thin metallic foils were obtained electrolytically. The target thicknesses and their composition are given in Table 1. The current of protons that passed through the target was measured by a Faraday cylinder with

Fig. 2

Figure 2: Fig. 2

a current integrator connected to it. Since the exposure time of the photographic plates situated to the right and left of the direction of the incident protons (Fig. 1) was different and, moreover, the position of the target relative to the incident beam was different, the “matching”of the two sections of the curve in the angular distribution was carried out both by the proton current and by the number of proton tracks in the photoemulsion at angles of 50 and 60°.

Table 1

Target	Thickness, μ	Ni^{58}	Ni^{60}	Ni^{61}	Ni^{62}	Ni^{64}	Cu^{63}	Cu^{65}
Co^{59}	2.6	–	–	–	–	–	–	–
Ni^{58}	1.7	98.6	1.0	0.2	0.1	0.1	–	–
Ni^{60}	1.3	21.2	77.9	0.4	0.5	0.1	–	–
Ni^{62}	1.6	2	0.8	1.6	94.5	1.1	–	–
Ni$_{\text{nat}}$	3.3	62.9	29.5	1.7	4.7	1.3	–	–
Cu^{65}	3.2	–	–	–	–	–	2	98

Results. The photographic plates were processed first of all in order to separate the groups of elastically scattered protons. Figure 2 shows the energy distribution of protons scattered at an angle of 140° by Ni^{62}. It is not difficult to see that the group of elastically scattered protons can be reliably separated from the inelastically scattered protons. The half-width of the maximum corresponding to the elastically scattered protons is equal to ±100 keV, which is about 2% of their initial energy. This half-width is due to

by the nonmonochromaticity of the primary beam and the inhomogeneity of the energy losses of the protons in the target and the photographic emulsion. Thus, the nonmonochromaticity of the primary protons was no more than ±100 keV.

All even-even isotopes of nickel have their first energy level above 1 MeV; therefore the groups of elastically scattered protons were easily identified. The admixture of Ni^{61}, which has lower excitation levels at 70 and 280 keV, could not make a substantial contribution to the elastic scattering, since its amount in the target was no more than 1.7%. Co^{59} has its first level at 1.1 MeV, and Cu^{65} at 0.77 MeV. The energy spectra of protons scattered by these nuclei likewise showed isolated elastic groups. Thus, in all cases the elastically scattered protons were reliably separated from the total spectrum.

Fig. 2. Energy distribution of protons scattered at an angle of 140° by Ni^{62}.

Figure 3A gives the results of measuring the angular distribution of protons elastically scattered by cobalt and by isotopes of nickel and copper (θ is the

Fig. 3

Figure 3: Fig. 3

Fig. 4. Comparison of angular distributions for three nickel isotopes

Figure 4: Fig. 4. Comparison of angular distributions for three nickel isotopes

scattering angle in the center-of-mass system). The vertical segments indicate statistical errors. On curve 2 for Ni^{58}, the control data obtained by studying elastic scattering in a scattering chamber 100 cm in diameter, described in [10], are shown by points. Detection of the scattered protons in this chamber was carried out with a scintillation crystal and photomultiplier in a better geometry than in the photographic chamber; the angular resolution here was $\pm 2.5^\circ$. As can be seen, measurements made by different methods give coincident results.

In Fig. 3B, together with the results of measuring the angular distribution of protons elastically scattered by natural nickel, the values of the angular distribution obtained by summing the experimental data for the three nickel isotopes that we investigated are given.

Fig. 3. A. Angular distribution of protons scattered by Co (1); by nickel isotopes: Ni^{58} (2), Ni^{60} (77.9%) + Ni^{58} (21.2%) (3), Ni^{62} (4); Cu^{65} (5) and Au (6). Circles—data obtained by the photographic method; points—data obtained by the scintillation method. **B.** Angular distribution obtained for nickel of natural composition (circles) and obtained by summing the results measured on isotopes (points).

taking into account their percentage content in nickel of natural composition. The results agree satisfactorily.

Figure 4 gives the angular distributions of protons elastically scattered by the nuclei Ni^{58}, Ni^{60}, and Ni^{62}. As can be seen, the height of the maximum and the depth of the minimum are not the same, and the position of the minimum shifts noticeably toward smaller angles as the mass number of the scatterer increases. A considerable difference is obtained in the intensity of the yield of scattered protons at large angles as a function of mass number. Of the two copper isotopes, we studied Cu^{69}, whose content in the natural mixture is 30.9%. The angular distribution of protons scattered by copper and cobalt is qualitatively the same, but at large angles it differs noticeably from scattering by the nickel isotopes.

Fig. 4. Comparison of angular distributions for three nickel isotopes

We have preliminarily measured the angular distribution of protons elastically scattered by Cu^{63}. The qualitative behavior of this distribution is the same as for Cu^{65}. The nucleus Cu^{63} is obtained by adding one proton to Ni^{62}, while the Co nucleus can be obtained if one proton is removed from Ni^{60}. The difference we observed in the angular distribution of protons scattered by these nuclei indicates a substantial change in the form of the nuclear potential when the number of protons in the nucleus is changed by one. Apparently, the same effect should be expected if the number of neutrons is changed by one. To confirm this assumption, we intend to carry out a study of elastic proton scattering by the isotopes Cr^{52} and Cr^{53}.

The addition of two neutrons to the nucleus does not lead to a qualitative change in the course of scattering as a function of angle, as is shown by the results we obtained for the nickel isotopes. However, even in this case the difference in the intensity of protons scattered at different angles and the shift of the minimum of the distribution curve indicate a noticeable change in the scattering potential. The data obtained are certainly insufficient for general conclusions—further accumulation of experimental data on elastic scattering by different nuclei is needed. The difference in the pattern of elastic scattering of protons with subbarrier energy by odd-even nuclei and by nuclei of even-even nickel isotopes indicates that the interaction of nucleons with atomic nuclei has its own specificity for each nucleus and, apparently, the optical model in its present form, even with the addition of a spin-orbit term in the interaction potential, will hardly be able to describe the character of the interaction of a nucleon with a nucleus.

Physical-Technical Institute
Academy of Sciences of the Ukrainian SSR

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REFERENCES

1. D. A. Bromley, N. S. Wall, *Phys. Rev.*, **102**, 1560 (1956).
2. W. F. Naldorf, N. S. Wall, *Phys. Rev.*, **107**, 1602 (1957).
3. G. W. Greenlees, L. G. Kuo, *Proc. Roy. Soc.*, **243A**, No. 1233, 206 (1957).
4. A. P. Klyucharev, P. I. Bolotin, V. A. Luchik, *JETP*, **30**, 573 (1956).
5. J. Kondo et al., *J. Phys. Soc. Japan*, **13**, 231 (1958); N. Hints, *Phys. Rev.*, **106**, 1201 (1957).
6. R. A. Vanetsian, A. P. Klyucharev, E. D. Fedchenko, *Atomn. energ.*, **6**, 661 (1959).
7. R. A. Vanetsian, A. P. Klyucharev, E. D. Fedchenko, report at the International Congress, Paris, July 1959.
8. R. A. Vanetsian, A. P. Klyucharev, E. D. Fedchenko, report at the

International Congress, Paris, July 1959.

9. M. K. Brussel, S. Chen, N. M. Hints, J. H. Williams, *Ann. Progr. Rep. Minnesota*, November, 12 (1958).
10. E. D. Fedchenko, R. A. Vanetsian, *JETP*, **30**, 577 (1956).

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