ANGULAR DISTRIBUTIONS OF 6.8-Mev PROTONS ELASTICALLY SCATTERED BY CHROMIUM, NICKEL, AND COPPER ISOTOPES

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The angular distributions of 6.8-Mev protons elastically scattered by $Cr^{52,53}$, $Ni^{58,60,62}$, and $Cu^{63,65}$ isotopes were investigated. Appreciable differences in the variation of the differential cross sections were found in the various isotopes. The results indicate that in scattering studies the individual features of the nuclei should be taken into account.

In recent years, in connection with the development of the optical-model concept of the nucleus, a series of detailed investigations of the angular distributions of nucleons elastically scattered by nuclei was carried out within a wide energy range. Comparison of theory and experiment showed that the optical model of the nucleus is sufficiently effectual for the description of scattering processes.

However, almost all the studies of nucleon scattering were carried out with targets of natural isotope composition. The results obtained refer therefore to the averaged result of scattering by the different isotopes contained in the investigated target. It was difficult or simply impossible to observe in such measurements the peculiarities in the scattering by any individual isotope. Nonetheless, the peculiarities of "isotopic" scattering had been pointed out in a number of papers. Thus, in the investigation of elastically scattered protons by a group of nuclei with $Z = 24$ to 30, a substantial change in the angular distributions was noted from element to element.[1-6] Inasmuch as the mass number of the scattering nuclei changes little, similar results fit the optical-model concepts poorly, since to describe the above group of nuclei they require a considerable and irregular variation of the model parameters. This obviously raises the question of investigating separated isotopes. The first experiments in this direction showed that the angular distributions can change to a large extent from isotope to isotope.[7-10]

At present, the theoretical interpretation of these effects in the scattering of nucleons by nuclei runs into many difficulties. It is therefore desirable to investigate the scattering of nucleons by separated isotopes in a broad energy range. The accumulation and systematization of experimental data will add to our knowledge of the structure of the nucleus and of the interaction of nucleons with nuclei.

The present work is devoted to a study of angular distributions of elastically scattered 6.8-Mev protons by the $Cr^{52,53}$, $Ni^{58,60,62}$, and $Cu^{63,65}$ isotopes.

EXPERIMENTAL METHOD

Protons with an energy of (6.8 ± 0.1) Mev were obtained in the cyclotron of the Physics Institute of the Ukrainian S.S.R. Academy of Sciences. After extraction from the accelerating chamber, the beam was focused by magnetic quadrupole lenses, deflected by 30°, and passed through collimating diaphragms to the target. The target was placed at the center of a scattering chamber of 1.6 m diameter.

The scattered protons were registered by a scintillation spectrometer consisting of a CsI(Tl) crystal, a FÉU-20 photomultiplier, and of an AIMA-1 (reference 6) 50-channel pulse-height analyzer. The spectrometer in a special jacket was fixed to a mobile bracket in the scattering chamber and could be rotated about the target. The large dimensions of the scattering chamber assured good geometry.

The measurements were carried out every 5° from 20 to 160°. The precision in the setting of the scattering angle amounted to 0.3°. The energy resolution of the scintillation spectrometer at its half-width was 4 — 6%, depending on the effective target thickness. The relative proton flux on the target was measured with the aid of a scintillation counter.

The energy spectrum of the scattered protons was registered at each angle where measurements were carried out. The statistics of the elastically scattered proton group were chosen such that the statistical error should not exceed 2%. The group of elastically scattered protons was segregated in the energy spectrum. The results obtained for each angle were reduced to one and the same value of the monitor reading; the relative angular distribution was thereby determined.

After going over to the center-of-mass system (c.m.s.), the value of the differential cross section (in arbitrary units) was multiplied by $\sin^4(\theta/2)$, and was normalized to unity in the 20° range. Under the natural assumption that in the region of angles on the order of 20° pure Rutherford scattering takes place, the above-mentioned quantity is the ratio of the experimental cross section to the Rutherford cross section.

Targets in the form of thin 3- to 5-μ self-supporting foils, enriched to contain 93 — 98% of the investigated isotope, were used in the experiment. The composition of the targets is listed in the table.

MEASUREMENT RESULTS AND DISCUSSION OF THE DATA

For most nuclei studied in this work, the energy resolution of the scintillation spectrometer was sufficient to separate the group of inelastically scattered protons from the group of those elastically scattered. One example of an energy spectrum is shown in Fig. 1

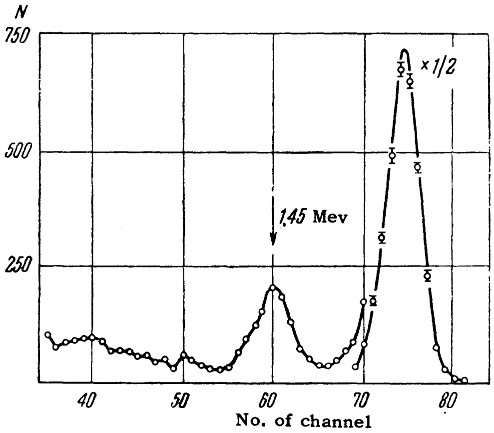

FIG. 1. The energy spectrum of protons scattered at 90° by the Cr^{52} nucleus.

The first 1.44-Mev level[11] of the Cr^{52} nucleus is well separated in the energy spectrum of the scattered protons. This group of protons is easily separated from the group of elastically scattered protons. At the same time, the groups of protons connected with the lower 0.54- and 1.01-Mev levels of the Cr^{53} nucleus may, in view of the insufficient energy resolution, contribute considerably to the elastic scattering, particularly at large scattering angles. The angular distributions of 6.8-Mev protons elastically scattered by chromium isotopes are shown in Fig. 2. In spite of the small shift in the positions of the angular-distribution maxima and minima, our attention is drawn to the considerably larger value of the Cr^{52} cross section compared with that of Cr^{53} in the region of large scattering angles. This difference may really be much larger than appears from our experiments, if the possible contribution of inelastic groups to the elastic scattering by Cr^{53} is taken into consideration. It will be possible to form an opinion about the magnitude of this contribution after additional experiments. Measurement results for the chromium isotopes are in good qualitative agreement with data on the scattering of 5.4-Mev protons (reference 9).

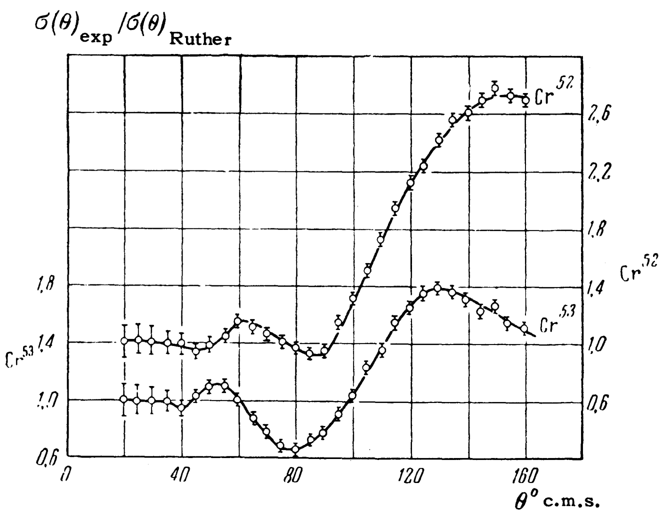

FIG. 2. The angular distribution of protons elastically scattered by chromium isotopes.

Target	Contents, %										
	Thickness, μ	Ni^{58}	Ni^{60}	Ni^{61}	Ni^{62}	Ni^{64}	Cr^{52}	Cr^{53}	Cr^{54}	Cu^{63}	Cu^{65}
Cr^{52}	5	—	—	—	—	—	98.7	1.23	<0.1	—	—
Cr^{53}	6	—	—	—	—	—	4.04	94.96	1.0	—	—
Ni^{58}	3.5	98.6	1.0	0.2	0.1	<0.1	—	—	—	—	—
Ni^{60}	3.4	1.2	97.9	0.4	0.5	<0.1	—	—	—	—	—
Ni^{62}	2.5	2	0.8	1.6	94.5	1.1	—	—	—	—	—
Cu^{63}	3.3	—	—	—	—	—	—	—	—	98	2.0
Cu^{65}	3.1	—	—	—	—	—	—	—	—	2.0	98

The first excited states of the Ni^{58}, Ni^{60}, and Ni^{62} isotopes are located above 1 Mev (1.44, 1.33, and 1.17 Mev, respectively). Proton groups corresponding to the above levels are well separated from the elastically scattered proton groups. The angular distributions of Ni^{58} and Ni^{60} (Fig. 3) are similar to each other, and duplicate in the main the result obtained with a natural mixture of nickel isotopes. This is not unexpected, since these two isotopes constitute the main part of the natural isotope mixture. It should be noted that the cross section for Ni^{60} in the range of large angles is somewhat larger than for Ni^{58}. This result is in good agreement with the observations made[10] in the scattering of 40-Mev protons by these isotopes.

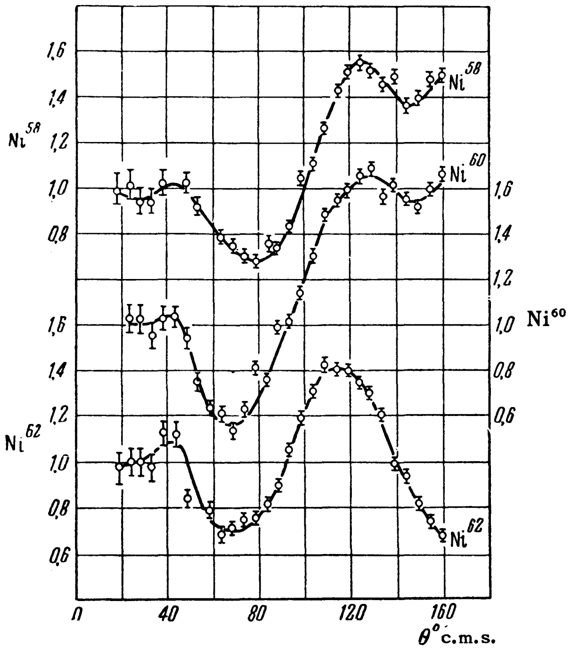

FIG. 3. The angular distribution of protons elastically scattered by nickel isotopes.

The angular distribution for Ni^{62} differs sharply from the analogous curves for the two lighter nickel isotopes. In the range of angles above 120° the differential cross section decreases. If account is taken of the fact that in going over from one isotope to the other the number of neutrons changes only by two, this result is somewhat unexpected. Nonetheless, this effect does not contradict the experimental results with 5.4-Mev protons.[7]

The variation of the cross sections with angle for the Cu^{63} and Cu^{65} isotopes is completely identical (Fig. 4). However, the curve of the heavier copper isotope is shifted towards smaller angles by about 5° relative to the Cu^{63} curve. An

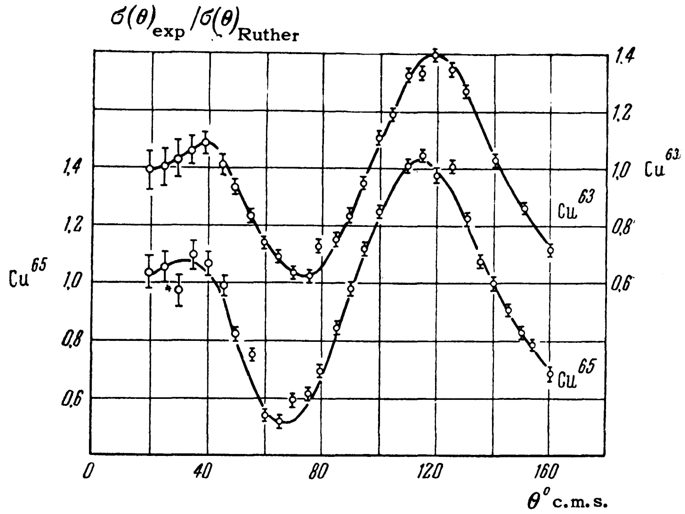

FIG. 4. The angular distribution of protons elastically scattered by copper isotopes.

analogous result is obtained in the scattering of 19.6-Mev protons by the same isotopes.[7] We note that the variation of the cross section with angle for Ni^{62} is in the main analogous to that observed for cobalt and copper isotopes.

It is known that in calculations according to the optical model the change in the imaginary part of the potential W causes a change in the maxima and minima of the differential cross section.[12] On the other hand, the imaginary part of the potential is connected with the value of the absorption. With decreasing W the absorption decreases; at the same time the differential cross section in the region of large angles increases. Thus, it is possible to speak of a possible change in the value of the absorption on going over from one isotope to another. At the same time, one can expect a somewhat different value of the elastic-scattering cross section connected with the formation of a compound nucleus. Taking account of interference effects, one can expect different results for the scattering. A similar set of arguments could serve as an explanation of such a considerable difference in the scattering by neighboring isotopes.

Obviously, the interpretation of the scattering results by separated isotopes, within the frame of the optical model, requires a considerable variation of the model parameters. This refers not only to the value of the imaginary part of W, but also to the real part of the potential V and to the radius R. The two last parameters are connected with the shift of the angular-distribution curves, and, as we have seen, for neighboring isotopes this shift may be considerable.

Apparently, to obtain fuller agreement between theory and experiment, account must be taken in the optical model not only of the spin-orbit interaction of the incident proton but also of the effect of the shell structure of the nucleus on the scattering process.

[1] B. L. Cohen and R. V. Neidigh, Phys. Rev. **93**, 282 (1954).

[2] B. B. Kinsey and T. Stone, Phys. Rev. **103**, 975 (1956).

[3] D. A. Bromley and N. S. Wall, Phys. Rev. **102**, 1560 (1956).

[4] W. F. Waldorf and N. S. Wall, Phys. Rev. **107**, 1602 (1957).

[5] Kondo, Yamazaki, Toi, Nakasima, and Yamabe, J. Phys. Soc. Japan **13**, 231 (1958).

[6] N. N. Pucherov, Ukrainian Phys. J. **4**, 313, 318 (1959).

[7] Vanetsian, Klyucharev, and Fedchenko, Compt. rend. (1959); Атомная энергия (Atomic Energy) **6**, 661 (1959).

[8] Rutkevich, Golovnya, Val'ter, and Klyucharev, Dokl. Akad. Nauk SSSR **130**, 1008 (1960), Soviet Phys. - Doklady **5**, 118 (1960).

[9] A. P. Klyucharev and N. Ya. Rutkevich, JETP **38**, 285 (1960), Soviet Phys. JETP **11**, 207 (1960).

[10] M. K. Brussel and J. H. Williams, Phys. Rev. **114**, 525 (1959).

[11] B. S. Dzhelepov and L. K. Peker, Схемы распада радиоактивных ядер Decay Schemes of Radioactive Nuclei, Acad. Sci. Press, 1958.

[12] Glassgold, Cheston, Stein, Schuldt, and Erickson, Phys. Rev. **106**, 1207 (1957).

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