ELASTIC SCATTERING OF DEUTERONS BY CHROMIUM AND ZINC ISOTOPES

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The angular distributions of 13.6-MeV deuterons elastically scattered by $Cr^{50,52,53,54}$ and $Zn^{64,68,70}$ isotopes are measured at angles from 2.5 to 150°. The curves of the ratio of the experimentally measured cross sections to the cross sections for Coulomb scattering have a diffraction nature (Figs. 1, 2). As the number of neutrons increases, the maxima shift in the direction of smaller angles and the cross section begins to decrease at a higher rate with increase in angle.

1. INTRODUCTION

IN the study of elastic scattering of protons by different isotopes, differences are observed in the shape of the angular distributions which have received the name of isotopic effects. A great difference has been discovered[1-3] in the cross sections for the large angle region in the case of Cr and Ni isotopes, which cannot be explained by the optical model[4] and finds a qualitative explanation within the framework of the compound nucleus model.

On the other hand, in the study of elastic scattering of protons by different Cr[5] and Zn[6] isotopes, an anomalous shift of the diffraction picture was observed which cannot be explained by simple increase in the radius of the nucleus according to the law $A^{1/3}$, but clearly requires an increase in the depth of the potential well with increase in the number of neutrons.

In connection with the successes of the optical model of the nucleus in the explanation of angular scattering of elastically scattered deuterons,[7] the possibility has appeared of studying isotopic effects for elastic scattering of deuterons, too. In this case, the success of the optical model has fundamental significance, since the effect of the difference of cross sections in the region of large angles was not observed there,[8] while the extraction of information on the anomalous shift is possible only by means of calculations on the optical model.

So far there has been very little research on the investigation of elastic scattering of deuterons by various isotopes,[8,9] in which connection the obtaining of new experimental data is of interest.

2. METHOD OF THE EXPERIMENT

The most convenient representation of the experimental results of the elastic scattering of charged particles is in the form of a ratio of the experimentally measured cross sections to the cross section of Coulomb scattering $\sigma_{elast}/\sigma_{res} \equiv R(\theta)$. The value of $R(\theta)$ is usually determined by multiplication of the experimentally determined cross section by $\sin^4(\theta/2)$, with a subsequent "addition" of the cross section of elastic scattering at certain angles to the value of $R(\theta)$ obtained by measurement of the absolute value. In this case, the accuracy of determination of $R(\theta)$ depends fundamentally on the accuracy of measurement of the absolute cross section which, as a rule, cannot be better than 20%. In the small angle region ($\theta < 25°$), the accuracy of the calculation of $R(\theta)$ is chiefly determined by the error in measurement of the scattering angle, so that a large scatter in the points is observed upon decrease in the angle, since $\sin^4(\theta/2)$ falls off rapidly at small angles.

To eliminate the scatter of points at small angles and the shifts of the angular distribution for different isotopes due to the inaccuracy in determination of the angle, the measurements were carried out on a rotating target[10] by which means it was possible to carry out measurements up to 2.5° with simultaneous experimental determination of the value of $R(\theta)$ by a comparison of the scattering by the element under study and by Au for each scattering angle. From the data of the research of Gofman and one of the authors,[11] it follows that at our energy, in the region of angles $\theta < 35°$, the scattering by gold is purely Rutherford,

Target	Isotopic content of target, %								
	Chromium				Zinc				
	50	52	53	54	64	66	67	68	70
Cr^{50}	87.7	11.1	0.9	0.3	—	—	—	—	—
Cr^{52}	0.2	99	0.7	0.1	—	—	—	—	—
Cr^{53}	0.2	13.8	84.3	1.7	—	—	—	—	—
Cr^{54}	0.4	10.9	10.1	78.6	—	—	—	—	—
Zn^{64}	—	—	—	—	91.0	4.8	1.3	2.3	0.6
Zn^{68}	—	—	—	—	3.7	4.9	3.9	86.6	0.9
Zn^{70}	—	—	—	—	14.7	15.8	3.9	20.6	45.0

as a consequence of which the accuracy of determination of R(θ) in this region of angles is determined only by statistical errors, which do not exceed 3% in our case.

The beam was monitored by means of a Faraday cylinder with a current integrator[11] and with two scintillation spectrometers. One of the spectrometers was located at an angle of 35° to the beam and the other was located on a movable bracket; in measurements at angles less than 60° the bracket was located at an angle of 10° to the beam, which made it possible to find the value of R(θ) very simply. For measurements at large angles, the spectrometer was set at an angle of 90° with respect to the beam.

The targets of the isotopes under investigation were free metal films, the method of producing which has already been described.[12] In the determination of the value of R(θ) by means of the rotating target, knowledge of the thickness of the target is not required. The isotopic content of the target is shown in the table.

The scattered deuterons were detected by means of a telescope consisting of two scintillation spectrometers,[13] in which selective recording was carried out with respect to the values of dE/dx and E (the specific ionization loss and the total energy). To obtain a pulse proportional to dE/dx, a crystal of CsI(Tl) of 100 μ thickness was used; to obtain a pulse proportional to E, the thickness used was 1.5 mm. Pulses proportional to E and dE/dx were fed to an electronic multiplication circuit, the output of which controlled a proportional transmission circuit. The resolution of the spectrometer amounted to 3—3.5%. The spectrometer was located inside an evacuated 1½ meter scattering chamber, which made it possible to carry out the measurements in the angular range θ = 0—150°. Zero angle was determined directly by the incidence of the direct beam on the input diaphragm of the spectrometer and by the symmetry of the angular distributions about the zero angle.

The measurements were carried out on the cyclotron of the Institute of Physics of the Ukrainian Academy of Sciences.

3. RESULTS AND DISCUSSION

The experimental data obtained are shown in Figs. 1 and 2, in which the statistical errors do not exceed the dimensions of the points on the curves. As is seen from the drawings, the scattering at an angle less than ~ 16° for Cr and ~ 18° for Zn is purely Coulomb. Beginning with these angles, the transverse cross section of elastic scattering for all the isotopes of Cr and Zn under study was less than the Coulomb cross section, which indicates the large role of deuteron absorption[14] brought about by nuclear interaction.

Chromium isotopes (Fig. 1). In the investigation of the elastic scattering of protons by Cr isotopes,[1,3] a large difference in the character of the angular distributions was observed in the region of large angles: the differential transverse cross sections for Cr^{52} in the region of angles above

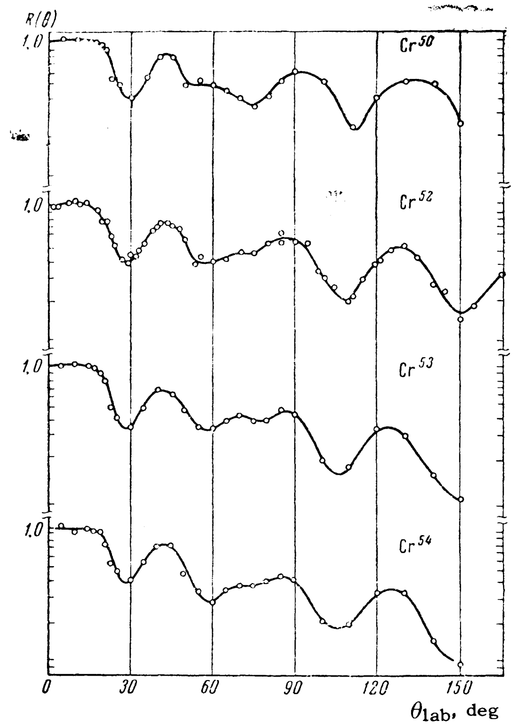

FIG. 1. Angular distributions of deuterons elastically scattered by Cr isotopes (θ_{lab} – scattering angle in laboratory system).

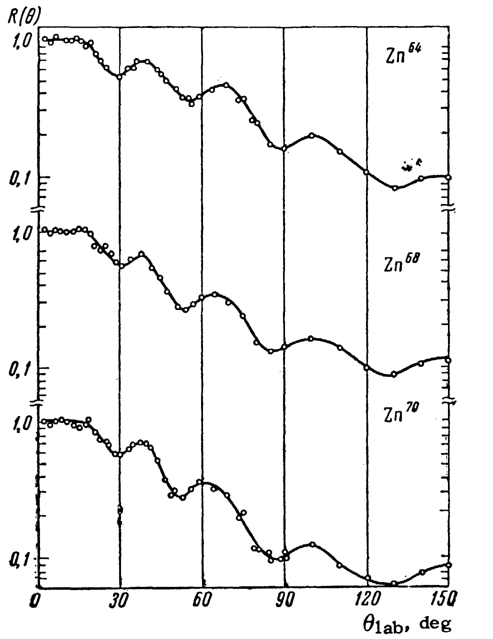

FIG. 2. Angular distributions of deuterons elastically scattered by Zn isotopes.

120° significantly exceeded the corresponding values for Cr^{53}. In the scattering of deuterons, as is seen from Fig. 1, the difference in cross sections for the region of large angles is not large. However, there is some difference between the shape of the angular distribution for Cr^{50} and the angular distributions for the remaining isotopes of the region of angles 50–75°.

Inasmuch as the measurements of elastic scattering of deuterons by Cr were carried out first, it is necessary to turn, for the analysis of this fact, to data referring to nearby nuclei.[10,15] In particular, the curves for Cr^{54} and Fe are very similar, while for Fe the peaks at 70 and 85° are no longer separated. On the other hand, the shape of the angular distribution for Cr^{50} is very close to the similar curve for Ti in the sense that both curves display an "anomaly" near $\theta = 60°$.

The decrease in cross section at large angles relative to an increase in the number of neutrons should be pointed out, and also the increase in the shift of the maxima of the angular distributions with increase in angle.

Zinc isotopes. As is seen from Fig. 2, the angular distributions for all three Zn isotopes show a clearly marked diffraction structure (in contrast with the isotopes of chromium). The data for Zn^{64} are in sufficiently good agreement with the results obtained for natural Zn, and with data on elastic scattering by Ni^{64}.[8]

The angular distribution of protons from the Zn isotopes was studied for 5.4[16] and 11.1[6] MeV. The shift in the diffraction picture observed in [6] exceeds the shift for deuterons in our case. It should be noted, however, that the shift is strongly dependent on the energy, inasmuch as at $E_d = 21$ MeV[9] the shift for the Cu isotopes is very small, and evidently depends on the type of bombarding particle.

As in the case of Cr isotopes, a tendency is observed toward a decrease in the cross section of elastic scattering with increase in the number of neutrons.

In conclusion, the authors take this opportunity to express their gratitude to V. N. Medyanik, L. G. Lishenko, and A. V. Nikolaĭchuk for preparation of the isotopic targets, and also to the personnel of the Cyclotron Laboratory for the uninterrupted operation of the apparatus.

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