SCATTERING OF PROTONS WITH ENERGIES BELOW 5 MeV ON Ne^{20}

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The excitation functions for elastic and inelastic scattering of protons by Ne^{20} are measured at an angle of 90° for incident-proton energies between 3.35 and 5.15 MeV. The angular distributions for 3.65, 4.00, 4.15 and 4.35 MeV incident protons are also measured. Variations in the energy dependence of the excitation function and angular distributions indicate the existence of a reaction mechanism involving the formation of a compound nucleus. The data of Heitler et al [7] regarding the sharp increase of the inelastic scattering differential cross section at angles below 50° are not confirmed.

INTRODUCTION

IN one of the investigations at our laboratory [1], in which the excitation functions and the angular distributions of protons scattered elastically and inelastically by Ne^{20} ($Q = -1.63$ MeV) were measured in the energy range 5.20—6.23 MeV, we observed oppositely directed variations in the cross sections of elastic and inelastic scattering with variation of energy. The forms of the angular distributions of inelastic and elastic scattering changed insignificantly with variation of the energy of the incident protons. We have assumed that these results can be explained on the basis of the theory of direct interaction [2-4], which takes into account the connection between the elastic and inelastic scattering channels.

The angular-distribution curves obtained in [5,6] for Ne^{20} at lower incident-proton energies (4.7—5.2 MeV) are similar to our curves, whereas the angular distributions for the inelastic process, measured by Heitler et al [7] at 4.2 MeV, have an entirely different form, characterized by a strong increase of the cross section at small angles. At incident-proton energies below 5.2 MeV, the energy of the inelastically scattered protons is below the Coulomb barrier. As shown in [8,9], in this case we expect the cross section of inelastic scattering in the direct interaction to become insignificant, and the reaction to proceed essentially via formation of a compound nucleus. Taking this into account, the angular distributions obtained in Japan and by Heitler et al at energies below 5.2 MeV can perhaps be explained by assuming that the reaction proceeds via formation of a compound nucleus, in which a small number of levels is excited.

The purpose of the present work was to study the excitation function in the region of lower energies and investigating the conditions under which the curves of the angular distribution for inelastic scattering change their form.

EXPERIMENTAL PROCEDURE

The protons were accelerated in the U-120 cyclotron of the Institute of Atomic Physics in Bucharest. The energy was varied by choosing the corresponding cyclotron parameters (large jumps) and also by introducing aluminum foils in the proton beam (small jumps). The incident proton beam was diaphragmed with the aid of a tantalum collimator with round holes of 4 mm diameter, and entered a cylindrical Faraday chamber after passing through the gas target. The protons scattered by the neon target were registered with a scintillation counter, consisting of a CsI(Tl) crystal 0.4 mm thick and an RCA-5655 photomultiplier. The pulses from the counter were fed to a 400-channel type SA-40 pulse-height analyzer.

The gas-target chamber was a brass cylinder 5 cm high with outside diameter 6 cm and wall thickness 5 mm. It was provided with a special side window 1.2 cm high, covered with a mylar foil 10 microns thick. A brass tube connected the chamber to a special gas-filling unit, consisting of a flask with neon and a mercury manometer.

The gas pressure in the chamber was 100 mm Hg during operation. To determine the solid angle necessary when working with a gas chamber, a collimator was placed in front of the counter, with two rectangular openings.

The differential cross section $d\sigma/d\omega$ in the laboratory system (l.s) at a scattering angle θ was calculated from the formula

$$d\sigma/d\omega = N_p \sin\theta/nNG\,[1 + g(\theta)].$$

Here N_p—number of protons scattered through angle θ; N—number of incident protons; n—number of target atoms per cm^3; $G[1 + g(\theta)]$—geometrical factor of the experiment; G = 2bA/rd, where the values of b, r, and d are shown in Fig. 1, and A is the area of the slot in front of the crystal. The width of the slot is 2a.

To calculate $g(\theta)$ without making any simplifications is a very complicated matter. Assuming that: (1) the beam is filament-like, (2) all the scattered protons passing through the two slots of the collimator strike the crystal perpendicularly, and (3) the distance from any point of the volume bounded by the extreme rays passing through the slots at the crystal is constant and equal to r, we obtain $g(\theta) = 0$. In our case these simplifications introduce an error smaller than 1% for the angle range $20 < \theta < 160°$. If we retain the first two assumptions and discard the third, then $g(\theta)$ can be represented as a series in powers of $\cot^2\theta$. Retaining only the first term of this series, we get*

$$g(\theta) = 2\,\frac{b^2r^2 + a^2(r-d)^2}{r^2d^2}\,\mathrm{ctg}^2\,\theta.$$

In our case the correction to $g(\theta)$ exceeds 1% only for angles in the interval $15° > \theta > 175°$. We also made a calculation in which we dispensed with the second assumption, leaving the first and third. As a result we obtained the expression $g(\theta) = K\cot^2\theta$. A numerical calculation has shown that the use of the second assumption introduces negligibly small errors. We can expect the first assumption to lead to even smaller corrections. In our work we have assumed that $g(\theta) = 0$, but such an approximation must be excluded if we deal with very large or very small angles.

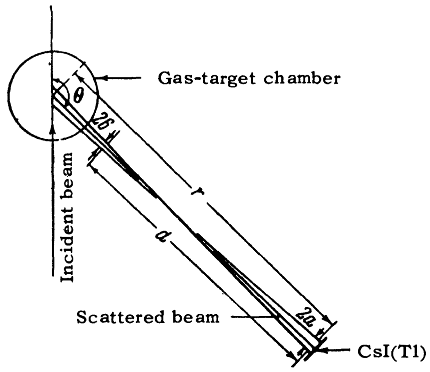


FIG. 1. Diagram of experimental setup: a = 0.5 cm, b = 0.25 cm, r = 24 cm, d = 16 cm.

* ctg = cot.

RESULTS AND THEIR DISCUSSION

Figure 2 shows a typical spectrum of the protons scattered by neon with $\theta_{l.s.} = 90°$ and $E_p = 4.15$ MeV. Such spectra were plotted for all angles and all energies at which the measurements were made.

The excitation functions of the elastically and inelastically scattered protons at a l.s. angle of 90°, measured in the energy range 3.15—5.15 MeV, are shown in Fig. 3. The same figure shows also the excitation functions for energies larger than 5.15 MeV, obtained in one of our earlier investigations [1]. The form of the excitation function of the inelastically scattered protons at energies < 4.7 MeV is similar to the curve obtained by Seward [8] for the case Mg^{24} (Q = −1.37 MeV) up to energies approaching the Coulomb barrier for inelastically scattered protons. Our results agree well with the data obtained by the Japanese group in the energy region 4.6—5.5 MeV. We note also that the cross sections of the elastic and inelastic processes no longer cancel each other at energies below 5.2 MeV, and also that the inelastic scattering cross sections decrease when the energy of the incident protons drop below 4.7 MeV.

The angular distributions of the inelastically scattered protons, which leave the Ne^{20} in the first excited state (Q = −1.63 MeV), are shown in Fig. 4. They correspond to the proton energies indica-

FIG. 2. Amplitude spectrum of protons scattered by neon target at E_p = 4.15 MeV and θ = 90°: 1 – Ne^{20} (Q = 1.63 MeV), 2 – Ne^{22} (Q = −1.28 MeV), 3 – Ne (Q = 0).

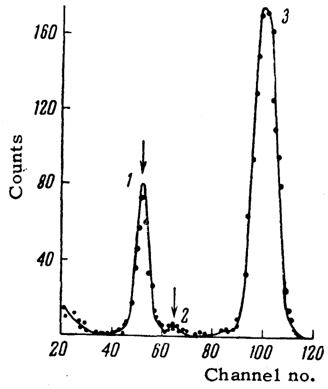
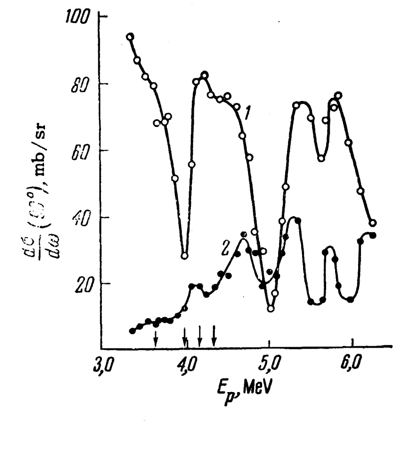


FIG. 3. Excitation functions of protons scattered elastically (curve 1) and inelastically (curve 2) by Ne^{20} at $\theta_{l.s.}$ = 90°.



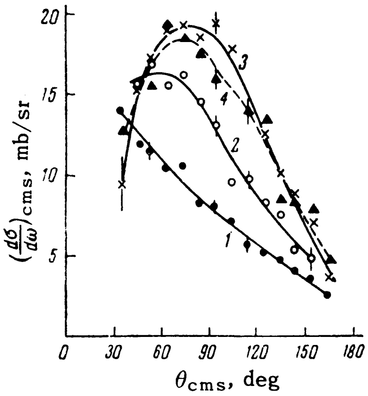


FIG. 4. Angular distribution of protons inelastically scattered by Ne^{20} (Q = −1.63 MeV). Proton energies: curve 1 – 3.65 MeV, 2 – 4.00 MeV, 3 – 4.15 MeV, 4 – 4.35 MeV.

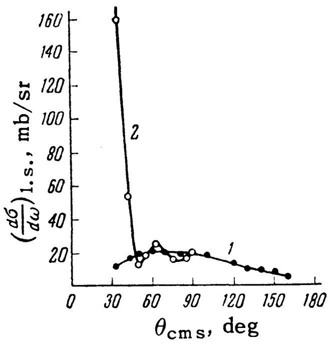


FIG. 5. Comparison of inelastic-scattering curves obtained by us for E_p = 4.15 MeV – curve 1 – and by Heitler et al [7] at E_p = 4.20 MeV – curve 2.

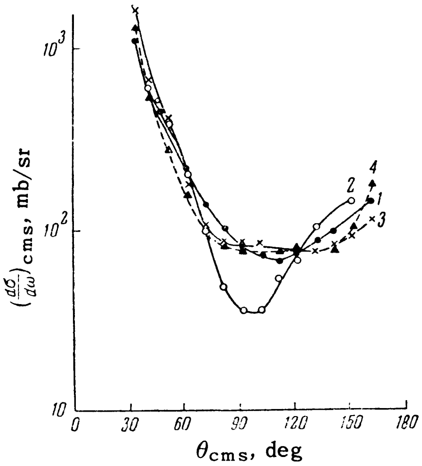


FIG. 6. Angular distribution of protons elastically scattered by Ne^{20}; the markings of curves are the same as in Fig. 4.

ted by the arrows on Fig. 3. The maximum of these curves shifts towards the smaller angles with decreasing energy. Unlike Heitler et al [7], we observed no strong increase in the differential cross sections at angles smaller than 50°. Figure 5 shows the angular distribution corresponding to 4.15 MeV, together with the curve obtained by Heitler et al at 4.2 MeV. The data of Heitler, who did not measure absolute cross sections, were normalized to our data at 90°.

We note incidentally that in our spectra there has appeared a peak, which at certain incident-proton energies and for angles $\theta < 45°$ coincides with the peak of the inelastic scattering for neon. From the shift of this peak over the channels of the multi-channel analyzer with variation of the detection angle we have concluded that it is due to the scattering of protons by hydrogen impurities in the target. These impurities appeared in the neon when the mylar foil covering the chamber window gradually deteriorated under the influence of the incident beam.

The elastic-scattering angular distributions shown in Fig. 6 differ from the curves obtained at higher energy [1,5,6] in the fact that the cross section at large angles is large. Such a behavior can be attributed to the large role of elastic scattering in the formation of the compound nucleus.

The change in the form of the curves of the inelastically scattered protons with variation of the energy can be attributed also to some effects of a compound nucleus in which a limited number of levels is excited. We recall that the angular distribution of inelastic scattering in strong resonance becomes isotropic for 2.72 MeV [10]. We note in conclusion that the data of the present work indicate that at energies of inelastically-scattered protons below the Coulomb barrier, the prevailing mechanism of the (p, p′) reaction is formation of the compound nucleus.

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