COMPOUND-ELASTIC SCATTERING IN ELASTIC SCATTERING OF 5.45 MeV *PROTONS ON NICKEL ISOTOPES*

G. F. TIMOSHEVSKIĬ, R. A. VANETSIAN, A. P. KLYUCHAREV, and E. D. FEDCHENKO

Physico-technical Institute, Academy of Sciences, Ukrainian S.S.R.

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A method for calculating the differential cross section for compound-elastic scattering is described. Differential cross sections for elastic scattering of 5.45-MeV protons by Ni^{58} and Ni^{60} isotopes are calculated by employing the complex potential of the optical model. Experimental data in which compound-elastic scattering is taken into account are compared with optical model calculations and satisfactory agreement is obtained.

THE elastic scattering of nucleons by atomic nuclei is successfully described with the aid of the optical model of the nucleus. However, the simple premises on which this model is based cannot yield a detailed description of the scattering process, and the calculations do not always agree with the experimental data.

Our calculations of the elastic scattering of 5.45-MeV protons [1] using the optical model of the nucleus have shown that satisfactory agreement between calculation and experiment is obtained for those nuclei, which have a (p, n) reaction threshold below the energy of the primary protons, that is, for Cr^{53}, Co^{59}, Ni^{64}, Cu^{65}, and Zn^{68}. For those nuclei whose (p, n) reaction threshold exceeds this energy or is close to it, the cross section for elastic large-angle scattering increases greatly and these experimental data cannot be reconciled with experiment. Such nuclei include Cr^{52}, Ni^{58}, Ni^{60}, Ni^{62}, and Zn^{64}. This is apparently due to the contribution of elastic scattering via production of a compound nucleus (compound-elastic scattering) to the measured intensity of the scattered protons, inasmuch as such an effect is not accounted for by the optical model.

In the present paper we attempt to exclude the compound elastic scattering by Ni^{58} and Ni^{60}, whose (p, n) reaction threshold is 9.46 and 7.03 MeV, respectively. The first to take account of this effect were Preskitt and Alford [2] in an optical-model analysis of the elastic scattering of protons by chromium and iron with natural isotopic composition in the 3.49—6.42 MeV range.

The equation for the cross section of compound-elastic scattering can be written in the form

$$\sigma_{ce} = \sigma_c \Gamma_{ce} / (\Gamma_{ce} + \sum_i \Gamma_i + \Gamma_n + \Gamma_\gamma + \Gamma_\alpha), \qquad (1)$$

where σ_c is the cross section for the production of the compound nucleus, and Γ_{ce}, Γ_i, Γ_n, Γ_γ, and Γ_α are the widths for the decay of the compound nucleus via elastically-scattered protons, inelastically scattered protons, and the widths for decay via (p, n), (p, γ), and (p, α) reactions, respectively.

At 5.45 MeV the decay of the compound nucleus via (p, γ) and (p, α) reactions has low probability and we have neglected the possibility of the decay via these channels in the calculations. If the (p, n) reaction channel is closed, then, in accordance with (1), the compound nucleus will decay by emission of elastically and inelastically scattered protons. To simplify the calculations we assume that the residual nucleus following the emission of the inelastically scattered proton is in a state with only the first level excited.

In the nuclear reaction model proposed by Feshbach, Porter, and Weisskopf [3], the differential cross section for compound elastic scattering of protons by a nucleus with zero spin is given by

$$\sigma_{ce}(\theta) = \sum_{l,L} \frac{\sigma_c^l W(l)}{8\pi(2l+1)} [Z^2(l, l+{}^1/_2, l, l+{}^1/_2; {}^1/_2 L) + Z^2(l, l-{}^1/_2, l, l-{}^1/_2; {}^1/_2 L)] P_L(\cos\theta), \qquad (2)$$

where $\sigma_c^l = \pi\lambda\!\!\!^{-2}(2l+1)T_l(E)$ is the cross section for the production of the compound nucleus, $T_l(E)$ is the penetrability, and $W(l)$ is the relative probability of the decay of the residual nucleus via partial channels with orbital angular momentum l. $W(l)$ is given by

$$W(l) = T_l(E) \Big/ \sum_{p,q,s} T_p(E_q'). \qquad (3)$$

The sum is taken over the orbital angular momenta, the possible final states of the system, and the channel spins.

If the respective spins of the target and residual nucleus are i and i′, the initial and final orbital angular momenta of the proton are l and l', and the initial and final energies E and E′, then it is convenient to combine the proton and nuclear spins into the initial and final state channel spin:

$$j_{1,2} = i \pm {}^1/_2; \quad j'_{1,2} = i' \pm {}^1/_2.$$

The spin of the compound nucleus level will be denoted by J, and then

$$|J - j| \leqslant l \leqslant J + j; \qquad |J - j'| \leqslant l' \leqslant J + j'.$$

Expression (3) can then be rewritten in the form

$$W(l) = T_l(E) \Big/ \sum_{j', l', q} \varepsilon_{jl'J} T_{l'}(E'_q), \tag{4}$$

where

$$\varepsilon_{j, l'} = \begin{cases} 2, & \text{if } j_1 \text{ and } j_2 \\ 1, & \text{if } j_1 \text{ or } j_2 \\ 0, & \text{if } j_1 \text{ and } j_2 \text{ do not} \end{cases}$$

satisfy the condition $|J - l| \leqslant j \leqslant J + l$.

In calculating the differential cross section for compound-elastic scattering $\sigma_{ce}(\theta)$ and the probability $W(l)$, we evaluated the penetrabilities $T_l(E)$. The potential for the calculation was taken in the form

$$V(r) = V_{\text{Coul}}(r) + Vf(r) + iWg(r), \tag{5}$$

where $V_{\text{Coul}}(r)$ is the potential of the Coulomb field of the nucleus; V and W are the real and imaginary parts of the nuclear potential,

$$f(r) = [1 + e^{(R-R_0)/a}]^{-1}; \qquad g(r) = e^{-[(R-R_0)/b^2]^2};$$

$$R_0 = r_0 A^{1/3}.$$

Figure 1 shows the results of the calculation of the differential cross section of compound-elastic scattering by Ni^{58}. An analogous curve is obtained for Ni^{60}, which we do not present here. Figure 2 shows the experimental data for Ni^{58} and Ni^{60}, the curves calculated from the optical model of the nucleus, and also the points obtained as a result of subtracting from the experimental values of the elastic scattering cross sections the compound elastic scattering cross sections. The results show that account of the compound elastic scattering leads to agreement between the calculated and ex-

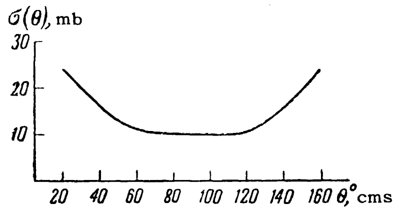

FIG. 1. Differential cross section for compound-elastic scattering, calculated for Ni^{58} with the parameters indicated in Fig. 2.

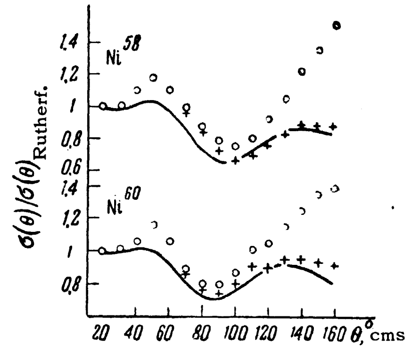

FIG. 2. Results of calculation for Ni^{58} and Ni^{60}: ○ – experimental data; + – experimental data from which the compound elastic scattering is subtracted. Solid curve – results of calculation by optical model with parameters: $r_0 = 1.25 \times 10^{-13}$ cm; $b = 1.2 \times 10^{-13}$ cm; $a = 0.4 \times 10^{-13}$ cm; $V = -57.5$ MeV and $W = -5$ MeV for Ni^{58}. For Ni^{60} we have $W = -6.5$ MeV, and the remaining parameters are the same as for Ni^{58}

perimental curves, starting with scattering angles of 80° and above. The first maximum in the region of the scattering angles of 50°, as in the preceding calculations, cannot be reconciled with experiment. This is possibly connected with the fact that the Gaussian form which we have chosen for the absorption potential is not complete.

We propose to carry out in the future calculations with the absorption potential in the form proposed by Easlea[4], who takes both volume and surface absorption into account.

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