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ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

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It is known, that under certain conditions the scattering of heavy charged particles may be considered in the framework of the theory of multiple Coulomb excitation /1/. The main feature of this process is a rather large magnitude of the elastic and inelastic cross sections, which is due to the large Coulomb interaction H^{c}_{int} of the projectile with the target-nucleus. Therefore each transition is a many-step one and goes through a number of other states of a target-nucleus.

It is clear that the physical picture mentioned above will not change sharply if the projectile energy increases up to and little above the Coulomb barrier. Therefore the bombarding particle trajectories will be close to the Coulomb ones. From this point of view the only thing to be done near the barrier U_B is the inclusion of the nuclear interaction H^{n}_{int}. Indeed, it occurs usually that small deviations (about 10%) of the true potential from the pure Coulomb one near the barrier, the influence of which on the trajectory may be neglected, lead to a large difference (about 80%) between the total H^{c+n}_{int} and the Coulomb H^{c}_{int} interactions. It does not allow one to consider the nuclear interaction in the framework of the first perturbation order only [2], therefore, we shall use the theory of multiple excitation with the total interaction H_{int}^{c+n} instead of the Coulomb one H_{int}^{c} which was employed in ref. [1].

In the sudden approximation the excitation cross section with transition to the state with spin I of an even nucleus is

$$d\sigma = d\sigma_R \cdot P_I^{c+n} , \tag{1}$$

where the excitation probability P_I^{c+n} can be found by means of the amplitude

$$a_{IM} = < I M \mid \exp - \frac{i}{h} \int_{-\infty}^{\infty} H_{int}^{c+n} \, dt \mid 00 > . \tag{2}$$

The nuclear interaction is defined as a derivative of the Saxon-Woods potential and then

$$H_{int}^{c+n} = H_{int}^{c} + H_{int}^{n} = \frac{2\pi}{5} Z_1 e Q_0 \Sigma (\bar{S}_{2\mu}^{c} + N \bar{S}_{2\mu}^{n}) Y_{2\mu}^{*} (\beta a) , \tag{3}$$

where

$$\bar{S}_{2\mu}^{c} = r^{-3} Y_{2\mu} (\theta\phi) , \quad \bar{S}_{2\mu}^{n} = R^{-3} ch^{-2} Z(r) Y_{2\mu} (\theta\phi) ,$$

$$Z = \frac{1}{2} \frac{r-R}{b} , \qquad R = r_0 A^{1/3} . \tag{4}$$

The dimensionless negative (if $W=0$) coefficient $N = N_1 + iN_2 = -\frac{5}{2}\frac{R}{b}\frac{U+iW}{U_B}$ characterizes the "strength" of the nuclear interaction, and in the case $N=0$ there remains only the pure Coulomb term in eq. (3). Introducing then the parametrization of the Coulomb trajectory of the projectile (i.e. $r\theta\phi \to r_c(t)\ \theta_c(t)\ \phi_c(t)$) and using the method of ref.[1] we obtain in the sudden approximation the following result for the excitation probability of rotational band

$$P_I^{c+n}(q_{eff}(\theta)) = (2I+1)\ |\ A_{I0}(\pi, q_{eff}(\theta))|^2 \tag{5}$$

$$A_{I0} = e^{i\frac{2}{3}q_{eff}} \int_0^1 P_I(x)\ e^{-2iq_{eff}x^2}\ dx \tag{6}$$

($P_I(x)$ - is the Legendre polynomial).

The form of A_{I0} is analogous to that given by eq. (5.14) of ref.[1] but now

$$q_{eff} = q_1 + iq_2 = \frac{3}{4}q\,J_{20}^{c+n}(\theta)$$

$$\left(q = \frac{Z_1 e^2 Q_0}{4\hbar\, va^2}\right), \tag{7}$$

where the total orbital integral J_{20}^{c+n} consists of the two parts: the usual Coulomb

$$J_{20}^{c} = \sin^2\frac{\theta}{2} + tg^2\frac{\theta}{2}\left[1 - \frac{\pi-\theta}{2}\ tg\ \frac{\theta}{2}\right] \tag{8}$$

and the nuclear integrals

$$J_{20}^{n} = 4\,\frac{a^2}{R^3}\int_0^\infty d\omega\,[\,ch^{-2}Z(\omega) + 3a^2(1-\epsilon^2)\,r^{-2}(\omega)\,th^2 Z(\omega)]\;\; r(\omega)\,, \qquad (9)$$

Here

$$r(\omega) = a(\epsilon\, ch\,\omega + 1)\,, \qquad a = \frac{Z_1 Z_2 e^2}{m v^2}\,, \qquad \epsilon = \sin^{-1}\frac{\theta}{2}\,.$$

Now one can make the calculations by means of these equations and compare the obtained results with the experimental data [3] for scattering of α -particles on ^{150}Nd , at an energy of 14–20 MeV and $\theta = 150^{\circ}$. The five theoretical curves, which are shown in Fig.1 and Fig.2, were calculated with the following set of the optical parameters:

	b (fm)	r_0(fm)	U(MeV)	W(MeV)
Curve 1	0,6	1,4	40	0
2	0,5	1,5	40	0
3	0,5	1,5	30	0
4	0,5	1,4	40	0
5	0,5	1,5	40	6

The curve assigned by C corresponds to the pure multiple Coulomb excitation $(V = W = 0)$. In all cases one takes Q_0 = 4,85 barn. U_B = 16,44 MeV.

On the basis of these calculations and from the comparison with experimental results one can draw the following conclusions: i) The inclusion of the nuclear interaction in the energy region near the barrier disturbes sharply the usual picture predicted by the theory of multiple Coulomb excitation. Besides, the inelastic cross section becomes sensitive to the tail of the nuclear interaction much before the elastic one. ii) The excitation probabilities are rather sensitive to the change of the nuclear radius (r_0) and diffuseness (b) parameters and almost insensitive to the depths of V and W (see also ref./3/). Therefore the experimental study of heavy ion scattering at the energy near the Coulomb barrier can give us reliable information on their interaction near the nuclear surface. iii). Finally, it should be noted that an extension of the present method to the region $E \gg U_B$ gives us, as was mentioned earlier/4/, the very quick oscillations of all the curves of P_I^{c+n} . Moreover the inclusion of the absorption parameter (W) can give an unphysical result $P_I^{c+n} > 1$. All these features appear as a consequence of the main restriction of this method that the projectiles move along the Coulomb classical trajectories. Therefore, in principle, it is impossible to take into account the absorption in the course of this movement. However, practically these problems arise at high energy only and for solving them some other method should be used (see for instance ref./5/).

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References

1. K.Alder, A.Winter. Mat. fys. Medd. Dan. Vid. Selsk., 32, no.8 (1960).
2. V.K.Lukyanov. Izv. AN SSSR ser. fiz., 28, 1212 (1964); M.Samuel, U.Smilansky. Phys. Lett., 28B, 318 (1968).
3. O.Nathan, V.Popov. Nucl. Phys., 21, 631 (1960).

4. I.Berson. Tesisi XV Soveschania po Jadernoi Spectroskopii, Minsk, 1965.
5. V.K.Lukyanov, I.Ž.Petkov. Phys. Lett., 15, 149 (1965).

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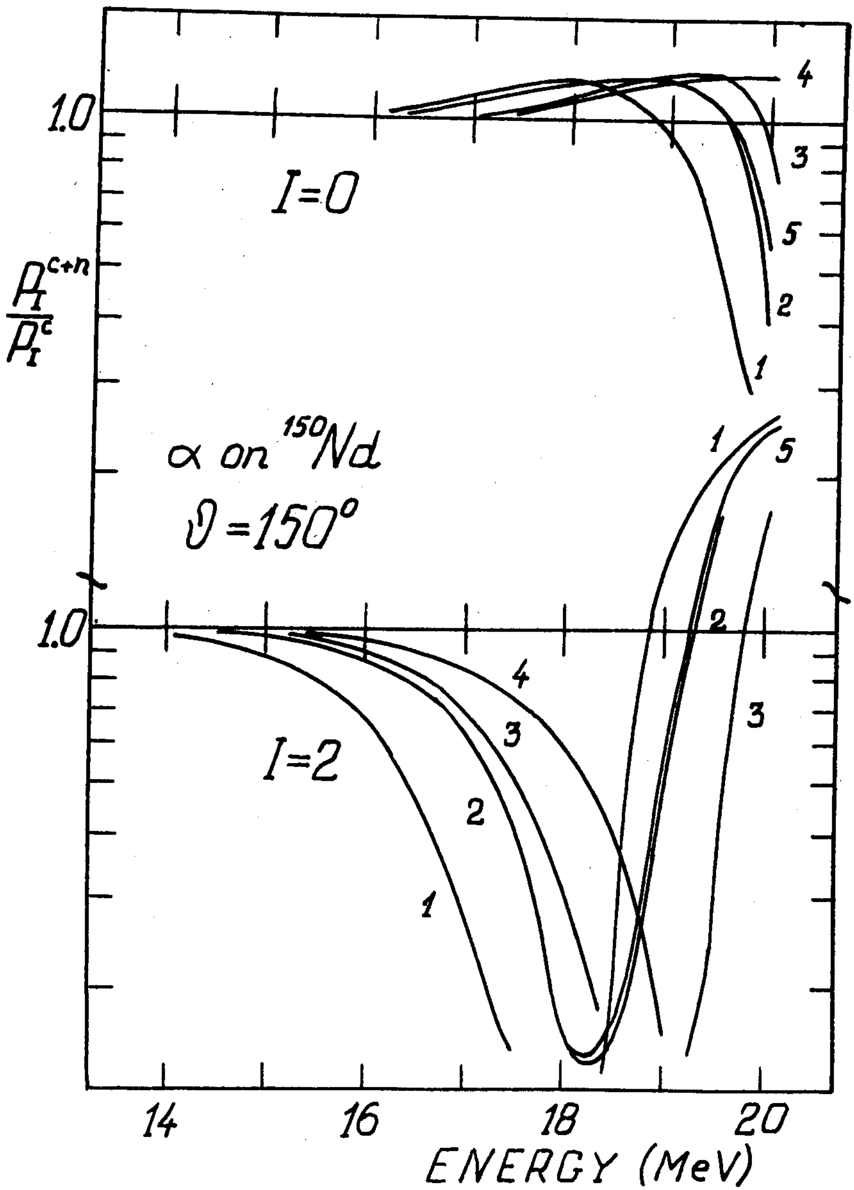

Fig. 1. The energy dependence of the ratios P_I^{c+n}/P_I^{c} obtained with the optical parameters from the table.

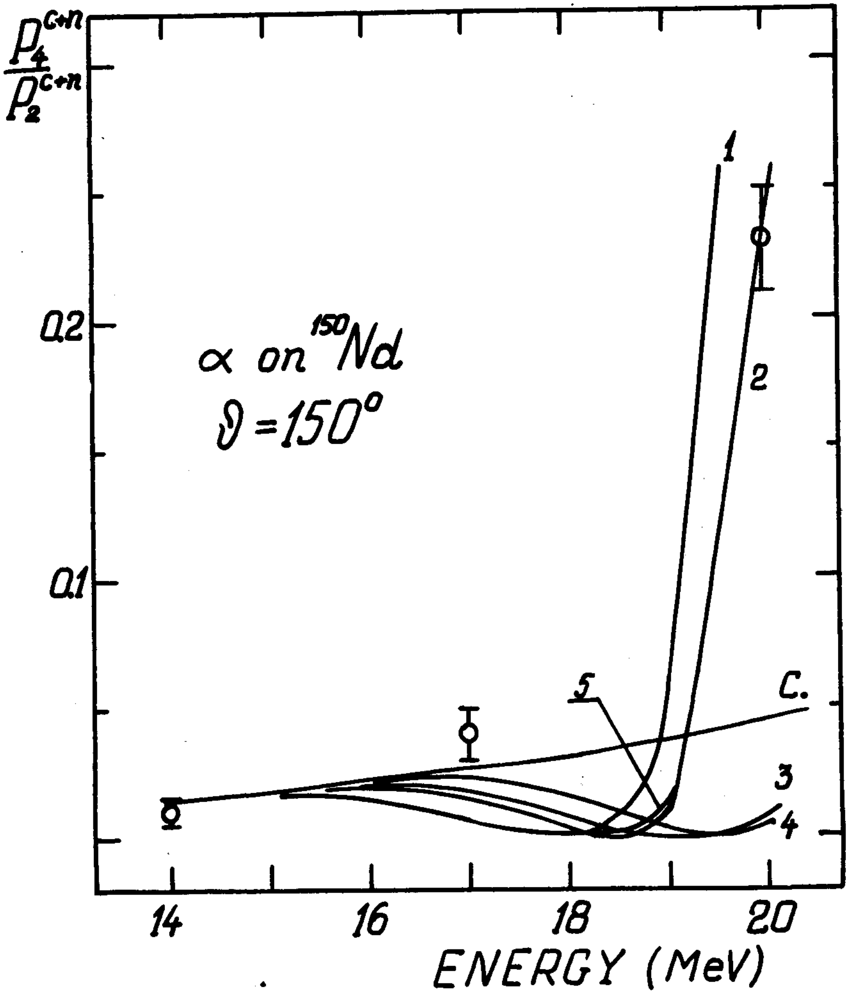

Fig.2. The experimental ratios of the multiple excitation probabilities with transition to the rotational states spin 4+ and spin 2+ and the corresponding theoretical curves as a function of the α -particle energy.