DIFFRACTION SCATTERING OF ^{7}Be AND ^{8}B ON ^{12}C TAKING INTO ACCOUNT THE COULOMB INTERACTION

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The differential cross sections for scattering of ^{7}Be and ^{8}B nuclei on ^{12}C nuclei are calculated in the framework of general theory of diffraction interactions of nuclei consisting of two charged weakly-bound clusters. Available experimental data are analyzed.

During the last decade, the significant progress in theoretical description of nuclei consisting of two weakly-bound clusters with only one charged has been achieved in the framework of diffraction approach [1]. As it was shown by calculations, the Coulomb interaction (CI) of charged cluster and target nucleus when taken into account, “fills” the characteristic diffractive minima and significantly improves theoretical description of experimental data. Generalization of the theory to the case of two charged clusters leads to appearing of divergences. The detailed analysis of appearing divergences in diffraction amplitudes taking into account the CI in general case was carried out in ref. [1], where these divergences were shown to be related with not only the CI, but also with small violation of momentum conservation law in diffraction nuclear model [2].

In present paper we focus on the following two-cluster nuclei: ^7Be, consisting of two weakly-bound ^3He and α charged clusters, and ^8B, consisting of p and ^7Be clusters. Our calculations are based on ref. [3], where we obtained general formulas for amplitude and differential cross section of elastic scattering of nuclei within diffraction two-cluster approach. In this approach the charged clusters of incident nucleus are treated as structureless in first approximation, but nevertheless some of their individual properties are taken into account – the mass, the charge, their contribution into radii of nuclear interaction as well as their extent, described by surface diffuseness parameter Δ of target nucleus. We also add two more physical parameters to the profile function, related to the interaction of each cluster of incident nucleus with target nucleus. They are the transparency parameter $\beta \le 1$ ($\beta = 1$ for absolute black, absorbing nucleus) and the refraction parameter γ ($|\gamma| \le 1$), which characterize target nuclear matter with respect to waves of moving cluster, so that in this case the profile function gets additional factor $\beta(1-i\gamma)$. For the sake of simplicity, we assume that the parameters Δ, β and γ are the same for the both clusters, i.e. we have together with r_0 four physical parameters of interaction, whereas in the optical model of nucleus [5] the number of parameters can be significantly larger. Relative motion of the both charged clusters in incident nucleus are described by Hulten wave functions with parameters for ^7Be and ^8B taken from ref. [4, 5].

The amplitude of elastic scattering and diffraction dissociation of incident weakly-bound two-cluster nucleus in nuclear and Coulomb fields of atomic nucleus can be written in the following symmetrical by the both clusters form:

$$i\bar{G}^Z_{\mathbf{u}}(\mathbf{q}) = \left\{ iG_{\mathbf{u}}(\mathbf{q}) + \bar{g}^{(1)}_{\mathbf{u}}(\mathbf{q}) + \bar{g}^{(2)}_{\mathbf{u}}(\mathbf{q}) \right\} e^{2i[\eta_1(R_1)+\eta_2(R_2)]} \quad , \tag{1}$$

where $iG_{\mathbf{u}}(\mathbf{q})$ is the amplitude taking into account only nuclear interaction:

$$iG_{\mathbf{u}}(\mathbf{q}) = \frac{k}{k_1} f_1(q)\,\Phi_{\mathbf{u},0}(-\beta_2\mathbf{q}) + \frac{k}{k_2} f_2(q)\,\Phi_{\mathbf{u},0}(\beta_1\mathbf{q}) +$$
$$+ \frac{ik}{2\pi k_1 k_2} \int d^{(2)}\mathbf{g}\,\Phi_{\mathbf{u},0}(\mathbf{g})\, f_1(|\beta_1\mathbf{q} - \mathbf{g}|)\, f_2(|\beta_2\mathbf{q} + \mathbf{g}|). \tag{2}$$

Form factors of incident nucleus for elastic scattering and diffractive dissociation are defined as

$$\Phi_{\mathbf{u},0}(\mathbf{g}) = \int d\mathbf{r}\, e^{i\mathbf{g}\mathbf{r}}\, \varphi^*_{\mathbf{u},0}(\mathbf{r})\, \varphi_0(r); \tag{3}$$

$\bar{g}^{(1)}_{\mathbf{u},0}(\mathbf{q})$ and $\bar{g}^{(2)}_{\mathbf{u},0}(\mathbf{q})$ are the contributions of the single and double scattering of two charged clusters to the amplitude $i\bar{G}^Z_{\mathbf{u},0}(\mathbf{q})$ correspondingly, taking into account the CI:

$$\bar{g}^{(1)}_{\mathbf{u},0}(\mathbf{q}) = \frac{k}{k_1} \left\{ \left[ik_1 P_1(q) + f_1(q) \right] e^{-2i\eta_2(R_2)} - f_1(q) \right\} \Phi_{\mathbf{u},0}(-\beta_2\mathbf{q}) +$$
$$+ \frac{k}{k_2} \left\{ \left[ik_2 P_2(q) + f_2(q) \right] e^{-2i\eta_1(R_1)} - f_2(q) \right\} \Phi_{\mathbf{u},0}(\beta_1\mathbf{q}), \tag{4}$$

$$\bar{g}^{(2)}_{\mathbf{u},0}(\mathbf{q}) = \frac{ik}{2\pi k_1 k_2}\int d^{(2)}\mathbf{g}\,\Phi_{\mathbf{u},0}(\mathbf{g})\{-k_1 k_2\, P_1(|\beta_1\mathbf{q}-\mathbf{g}|)\,P_2(|\beta_2\mathbf{q}+\mathbf{g}|)+$$
$$+ik_1 P_1(|\beta_1\mathbf{q}-\mathbf{g}|)\,f_2(|\beta_2\mathbf{q}+\mathbf{g}|)+ik_2 P_2(|\beta_2\mathbf{q}+\mathbf{g}|)\,f_1(|\beta_1\mathbf{q}-\mathbf{g}|)\}. \quad (5)$$

The functions $P_j(q)$ (j=1, 2) can be written in the following convenient for numerical computations form [3]:

$$P_j(q) = \int_0^\infty d\rho\,\rho J_0(q\rho)\left\{e^{2i[\eta_j(\rho)-\eta_j(R_j)]}-1\right\}\left(1+\exp\left(\frac{\rho-R_j}{\Delta}\right)\right)^{-1} -$$
$$-\int_0^{R_j} d\rho\,\rho J_0(q\rho)\left\{e^{2i[\eta_j(\rho_j(\rho)-\eta_j(R_j)]}-1\right\}+ \quad (6)$$
$$+\frac{2in_j}{q^2}\left[\frac{\Gamma(1+in_j)}{\Gamma(1-in_j)}\exp\left(2in_j\ln\frac{2}{qR_j}\right)-qR_j\int_0^1 dx\,J_1(qR_j x)\,e^{2in_j\ln x}\right].$$

The angle dependence of calculated ratio of elastic scattering differential cross section $\sigma(\mathbf{q}) = \left|i\bar{G}_0^Z(\mathbf{q})\right|^2$ to corresponding Rutherford cross section σ_R depending on angle θ (in the center-of-mass reference frame) for the scattering of ^7Be on ^{12}C with the energy $E = 280$ MeV is shown on fig.1. Experimental data are taken from ref. [4, 5]. The solid and dashed lines represent our calculations of the ratio in two cases respectively: 1) the CI is taken into account, and 2) only nuclear interaction is taken into account. Both curves are obtained with the following values of parameters: r_0 = 1.4 fm, $\Delta = 0.25$ fm, $\beta = 0.56$, $\gamma = -0.3$. Taking into account the CI significantly improves the description of experimental data, so that our theory satisfactorily describes data in broad range of angles $1^0 \le \theta \le 10^0$. It seems that in the diffraction model better description of the data for angles $\theta > 10^0$ can be achieved if one takes into account (at least approximately) the structure of ^3He and ^4He clusters forming the ^7Be nucleus. For the comparison in fig.1, the dash-dotted line represents the calculations made using the microscopic optical model [4]. As it was shown in ref. [4], the contribution of inelastic scattering processes, if taken into account, can somewhat improve an agreement with experimental data, especially in the vicinity of minima.

In fig. 2, the calculated angular dependencies of the ratio σ/σ_R for elastic scattering of unstable exotic ^8B nucleus on ^{12}C are presented (the binding energy of ^1H and ^7Be clusters is 0.137 MeV [4]) with energy $E = 320$ MeV.

The solid line (taking into account the CI) and dashed curve (without the CI) correspond to the following set of parameters: r_0 = 1.4 fm, $\Delta = 0.3$ fm, $\beta = 1$, $\gamma = -1$. Taking into account the CI slightly shifts maxima and minima towards small angles. The dash-dotted line is taken from the ref. [4] for the comparison. In the vicinity of maxima of calculated ratio of cross sections, there is some agreement with experimental data [4], in general, confirming the existence of the proton halo of ^8B nucleus.

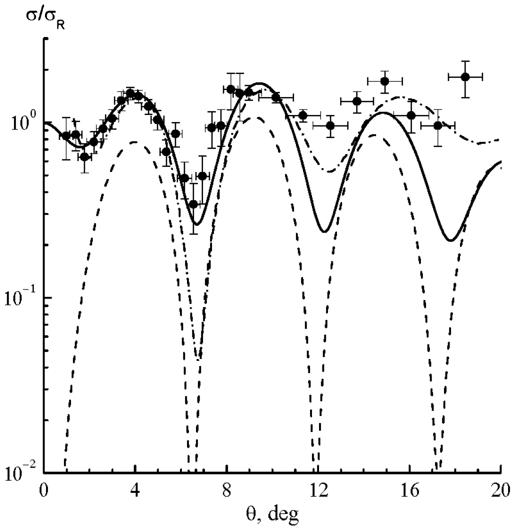

Fig.1

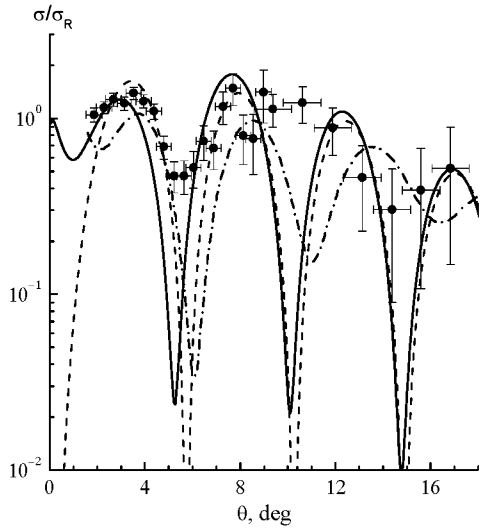

Fig. 2

The contribution of inelastic processes [4, 5] being taken into account, slightly improves an agreement with experiment in the vicinity of minima in both optical and diffraction models, but in contrast to the case with ^{7}Be nucleus (fig.1) it doesn't significantly change the situation for the better. This means, apparently, that for better description of the experiment with ^{8}B in the framework of diffraction model the internal cluster structure of heavy ^{7}Be cluster should be correctly taken into account, i.e. practically it is necessary to use more complicated three-cluster model (p+^{3}He+^{4}He) for ^{8}B.

Finally, we would like to emphasize that the presented theory allows one to calculate cross sections for any nucleus that can be treated as consisting of two weakly-bound clusters (one or both clusters can be charged) and correctly takes into account the Coulomb interaction.

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