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^{20}Ne+^{12}C REACTION AT 5 AND 9 MeV/A STUDIED AT THE WARSAW CYCLOTRON *

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Two experiments for ^{20}Ne+^{12}C reaction have been performed at projectile energies 5.2 MeV/A and 9.2 MeV/A, respectively, to examine the reaction mechanism as well as to obtain the GDR parameters. Light charged particles were measured at angles in the range of 45°–135° by using Si-ball set-up consisting of 12 triple telescopes. The spectra were measured inclusively as well as in coincidence with γ-quanta. Gamma spectra have been collected at 60°, 90° and 120° with NaI spectrometer.

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1. Introduction

Measurements for ^{20}Ne+^{12}C reaction at 5.2 and 9.2 MeV/A projectile energy have been recently performed in order to examine reaction mechanism and to extract the parameters of Giant Dipole Resonance (GDR) excited in compound nucleus formed.

For light-ion induced reactions at low projectile energies up to about 5–6 MeV/A the only mechanism of a compound nucleus creation is the complete fusion reaction (CF) and the γ-quanta as well as light-charged particle emission is due to purely statistical decay of the compound nucleus (CN). An experiment for ^{20}Ne+^{12}C reaction at 5.2 MeV/A has been performed to confirm the statistical character of γ-quanta and particle emission from the thermalized source.

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At projectile energies above 6 MeV/A, besides complete fusion reaction, also the incomplete fusion reaction (ICF) mechanism occurs and other processes of the bremsstrahlung radiation (BR) and preequilibrium nucleon emission (PREEQ) become significant. The study of the ^{20}Ne+^{12}C reaction performed at 9.2 MeV/A was intended to examine the mechanism of compound nucleus creation (CF, ICF) and additional emission processes (PREEQ, BR). The goal of the present studies was to indicate the importance of all the processes present in the reaction mechanism for the extraction of GDR parameters, especially the width.

2. Motivation

In the incomplete fusion process the light clusters and nucleons are emitted before equilibration of a composite system and they carry away an energy and momentum available in a collision. Thus, in such process and in preequilibrium nucleon emission an equilibrated compound nucleus with the GDR built-in is formed with mass and excitation energy lower than in the complete fusion of the projectile and the target nuclei.

In recent work the ^{18}O+^{100}Mo reaction at 7–12 MeV/A of a projectile energy [1] was studied and the semiempirical formula for the formed compound nucleus excitation energy loss due to incomplete fusion and preequilibrium emission has been proposed. It has been found that the effects of the incomplete fusion, preequilibrium emission and the bremsstrahlung radiation are significant at the projectile energies around 10 MeV/A. Thus it has been suggested that previously published values of the GDR width for Sn and neighboring nuclei, which showed the saturation with increasing excitation energy, require correction. Including the correction for the loss of the average initial excitation energy, mass and charge of the produced compound nuclei, the GDR width does not show the saturation with the increase in the excitation energy, but it is still increasing over the temperature range up to 2.4 MeV [1].

Our studies for ^{12}C+^{58,64}Ni reactions [2, 3] confirmed the importance of all occurring processes but the energy loss estimated on the basis of the semiempirical formula seemed to be too large. In those experiments we have not had the data for the emitted particles measured to estimate the influence of incomplete fusion and preequilibrium emission. Thus it was assumed on the basis of experimental data for other reactions and model calculations [4–6]. To correctly extract the influence of all occurring processes the present experiments have been performed.

3. Experimental set-up and results

Present experiments have been undertaken by using the ^{20}Ne cyclotron beams of 5.2 MeV/A and 9.2 MeV/A energies at the Heavy-Ion Laboratory of Warsaw University. Self-supporting target foils of 2-3 mg/cm^2 of carbon were used. Emitted γ-ray spectra have been collected with NaI(Tl) spectrometer consisting of one NaI(Tl) detector and surrounding shields which suppress the background. The neutron-gamma discrimination achieved by the standard time-of-flight technique with the time resolution of 4.5 ns was good enough to allow for the separation of the events caused by neutron from these caused by γ-quanta. The NaI(Tl) detector was calibrated by using ^{244}Cm/^{13}C source and the 15.1 MeV line from ^{11}B+D resonant reaction.

Light particles were measured with the new Si-ball consisting of 12 triple telescopes placed in a metal sphere at angles in the range of 45°–135° with respect to the beam axis, which allowed for the angular distribution measurement. Each telescope consisted of three silicon detectors: 2 surface barrier detectors of thickness of 10 μm and 130 μm, and one lithium-drifted detector Si(Li) with thickness of 10 mm. They were calibrated using ^{241}Am alpha source.

3.1. Results for $^{20}Ne+^{12}C$ reaction at 5.2 MeV/A

The measurements for the γ-quanta and light-charged particles at lower beam energy were inclusive ones. Spectra for γ-quanta, protons (undistinguished from deuterons) and alpha particles have been collected. Spectra for charged particles are presented in Fig. 1. The data are compared to the theoretical calculations performed with CASCADE code which included the effect of isospin, and used the Reisdorf level density description, and a spin-dependent moment of inertia in agreement with the rotating liquid drop model, defining yrast line. Gamma-ray spectrum is well described by the statistical model calculations assuming the purely statistical emission from a formed compound nucleus of ^{32}S of initial excitation energy of 58.3 MeV. GDR parameters are found to be respectively: $E_{\rm GDR}$ = 17.4 MeV, $\Gamma_{\rm GDR}$ = 13.3 MeV, $S_{\rm GDR}$ = 0.9 [7]. However proton and alpha-particle spectra are not well reproduced by reported calculations, especially at forward angles. Particle data collected at each angle were normalized to the number of events collected by monitor placed at 39° with respect to the beam axis and then the spectra were normalized to the theoretical CASCADE calculations. The calculations have been performed in nucleus–nucleus center-of-mass system and then transformed to the laboratory system via Lorentz transformation using LORENT code. Proton spectra have been calculated together with the deuteron spectra and summed (for each angle independently), since the experimental ones have been the sum of protons and deuterons as well (see Fig. 1). The theoretical spectra for alpha particles together with the ^{3}He-particle have also been taken into account (Fig. 1). The differences between the experimental data and theoretical calculations may be caused by non-statistical effects presence or by not well adjusted parameters assumed in the calculations.

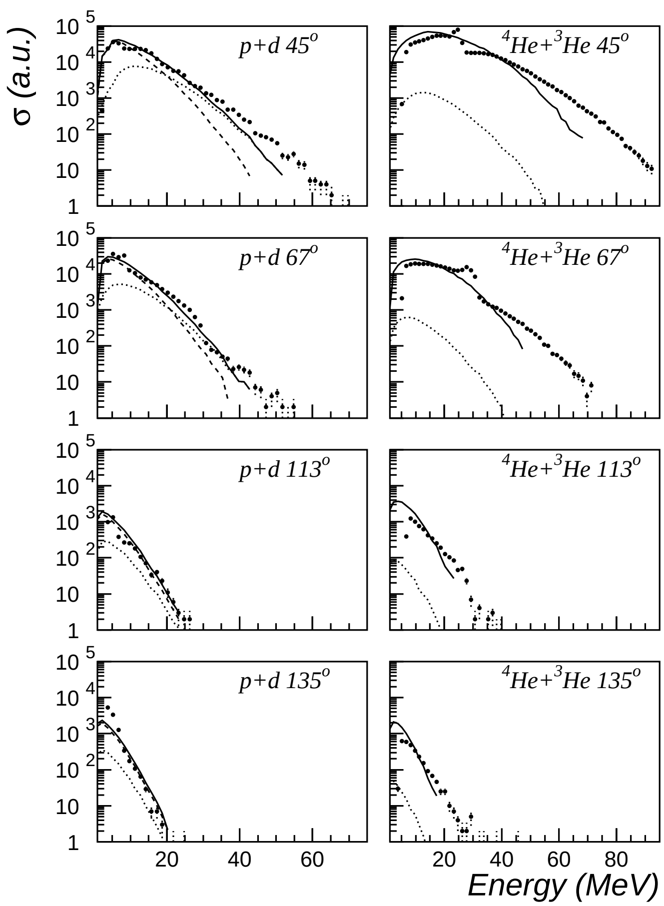

Fig. 1. Proton and alpha particle spectra measured in ^{20}Ne+^{12}C reaction at 5.2 MeV/A. Spectra are compared to the statistical calculations performed with CASCADE code. Straight line — summed spectra for particles: p+d and ^{3}He+^{4}He, dashed line — spectra for p and ^{4}He, dotted line — spectra for d and ^{3}He, respectively.

3.2. Results for $^{20}Ne+^{12}C$ reaction at 9.2 MeV/A

For the higher beam energy particles were measured in coincidence with high energy γ-quanta. Inclusive high-energy γ-ray spectrum for this reaction has been collected in an earlier experiment [7] and exclusive one in the present experiment. The CASIBRFIT code was used to fit the inclusive spectra assuming the influence of preequillibrium emission and incomplete fusion reaction mechanism and the bremmstahlung radiation presence. The γ-ray spectrum was reproduced by these calculations when the decay of the average compound nucleus of ^{30}P at excitation energy of 54.8 MeV was assumed, while in the case of pure complete fusion the ^{32}S would have been formed at 87.8 MeV of excitation energy [7]. It indicates the importance of preequilibrium emission and incomplete fusion reaction mechanism assumption. The particle spectra for protons and alpha particles analyzed in coincidence with γ-quanta of energies $E_\gamma > 7$ MeV collected at 90° are still under analysis now.

4. Conclusions

The measured coincidence data for particles will give information on the average energy of particle measured and probably on the multiplicities of the particles. The information will be helpful to estimate the influence of nonstatistical and nonequlibrium processes in the reaction mechanism. Then the GDR parameters will be extracted by assuming all of the processes present in the reaction. It is still under analysis.

Since in the experiment for Ne+C reaction at 5 MeV/A we have not been able to distinguish between protons and deuterons, the comparison between theoretical calculations and experimental data have been performed here for summed theoretical spectra for both particles. The same procedure have been done for ^{3}He and ^{4}He-particles since the experimental spectra are also the sum for both particles. The difference between the data and the calculations may be the result of non-statistical effects present in the reaction but it may be also caused by not fully appropriate parameters used in the statistical calculations. The analysis is still in progress.

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