HIGH-ENERGY γ-RAY EMISSION STUDIES WITH JANOSIK SET-UP IN ^{20}Ne+^{12}C at 5.2 MeV/u*

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Statistical emission of high-energy photons in heavy-ion reactions ^{20}Ne+^{12}C $\rightarrow ^{32}$S at 5.2 MeV/u and ^{19}F+^{12}C $\rightarrow ^{31}$P at 4.4 MeV/u has been studied and the Giant Dipole Resonance strength functions in ^{32}S and ^{31}P at excitation energy of 58 and 55 MeV have been extracted. Possible isospin and deformation splitting of the GDR are discussed. The derived isospin mixing coefficient for ^{32}S states at 58 MeV excitation is presented.

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1. Introduction

The giant electric dipole resonance (GDR) built on the ground states of the light ($2s$–$1d$) shell nuclei is known to be considerably fragmented. In addition to configurational splitting resulting from inner and outer shell excitation, isospin splitting has been postulated for these nuclei. It was found that for light- and medium-mass nuclei with neutron excess, *i.e.* $T = T_z = (N - Z)/2 \neq 0$, in which valence neutrons and protons fill the same major shells, a splitting of the GDR built on the ground states originates from isospin effects [1]. The GDR splits into two components having

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isospin $T_{>} = T + 1$ and $T_{<} = T$, respectively. The two components are separated in energy by the combined symmetry energy of all particles and holes, which participate in the dipole excitation. This displacement energy is approximately given by $\Delta E = E_{>} - E_{<} = 60(T + 1)/A$ MeV, and the fractional strength distribution among the components is $S_{<} = \frac{T}{(T+1)}(1 + \frac{c}{T})$ and $S_{>} = \frac{1}{(T+1)}(1 - c)$, where $c = \frac{3T}{2A^{2/3}}$ is the correction due to Pauli blocking [1]. Thus for self-conjugate nuclei with $T = 0$ only the $T_{>} = T + 1$ component should be observed.

Moreover, the identification of the GDR splitting proposed above is not the only one possible. Substantial static deformation has been also observed for these nuclei, thus a splitting of the GDR into two components is also expected as a result of a dipole excitation built on the deformed state. The energies of the dipole vibrations along the two semiaxes a and b can be calculated from the formula $E_b/E_a = 0.911\ (a/b) +\ 0.089$, based on the hydrodynamic model.

It is interesting to study the GDR built on the excited states in these nuclei, at nuclear temperature $T \approx 2$ MeV, where we expect the shell effects to vanish and the isospin to be nearly conserved. Thus, we have started the project devoted to the high-energy γ-ray ($E_\gamma = 5$–50 MeV) emission in the ^{20}Ne+^{12}C and ^{19}F+^{12}C heavy-ion collisions at projectile energy of $E_{\mathrm{proj}}/A = 5$–10 MeV/u. The purpose of this work is to investigate the properties of hot, fast rotating compound nuclei around ^{32}S and to extract information on the Giant Dipole Resonance (GDR) built on excited states in those systems as a function of the effective nuclear temperature. We have chosen the ^{32}S as a compound nucleus in which we have populated the GDR by the isospin $T = 0$ entrance channel. The attempt to take advantage of the isovector nature of electric dipole radiation in order to extract the degree of isospin mixing in ^{32}S at high excitation is discussed.

The ^{32}S nuclei in the ground state are deformed with $\beta = 0.31$ and the prolate shape [2]. It has been theoretically predicted that the superdeformation is expected for ^{32}S and nearby mass nuclei [3]. According to the predictions of the Rotating Liquid Drop Model (RLDM) [4] and in agreement with experimental observations [5,6], light- and medium-mass nuclei can be formed in fusion reactions at high angular momenta, near the limit of compound nucleus formation, with a very elongated triaxial "Jacobi" shapes. The phase transition in which the nuclear shape changes from oblate to triaxial and nearly prolate may be studied in statistical decay of those nuclei through the GDR strength function [5,6]. In order to search for the shape changes of ^{32}S, these compound nuclei have been formed with the spin distribution extending above the critical angular momentum predicted for the oblate — triaxial transition.

2. Experimental data

Measurements of the ^{20}Ne+^{12}C $\rightarrow^{32}$S reaction at 5.2 MeV/u and 9.5 MeV/u and ^{19}F+^{12}C $\rightarrow^{31}$P reaction at 4.4 MeV/u have been undertaken using the cyclotron beams at the Heavy-Ion Laboratory of Warsaw University. The energy spectra and angular distributions of the γ-rays emitted in the reactions studied have been measured with the multidetector JANOSIK set-up [7]. High-energy γ-rays have been separated from neutron-induced events by the measured time-of-flight. High-energy γ-ray spectra have been calibrated with the ^{244}Cm/^{13}C source as well as with monoenergetic lines at 4.44 MeV and 15.1 MeV from ^{11}B+D reaction at 19.1 MeV energy of the ^{11}B beam. Spectra at three angles $\theta_{\rm lab}$ =60°, 90° and 120° have been normalized to the summed multiplicity (larger than 2) of low-energy γ-rays measured by the multiplicity filter and then transformed to the compound nucleus center-of-mass frame. We have also measured energy spectra and angular distributions of light charged particles by two Si telescopes placed in the vacuum chamber around the target. These measurements should allow to determine contributions of different processes in the mechanism of the studied reactions at several projectile energies.

3. Data analysis and results

Final analysis of the measured angular distributions of γ-rays and charged particles, which should allow to conclude on the character of their emission, is still in progress. It is however expected that at the low projectile energies about 5 MeV/u compound nuclei are formed by complete fusion only and the γ-ray emission is mostly of the statistical character. If so, then the least squares fitting of the statistical model calculations to the experimental high-energy γ-ray spectrum should allow to extract the GDR parameters by using the CASCADE code. With this assumption we have obtained preliminary values of the parameters for the GDR populated in the ^{19}F+^{12}C reaction. Calculations include the isospin, the experimental value of fusion cross-section, level densities given by the Reisdorf's parameterization, and a spin-dependent moment of inertia in agreement with the RLDM. The GDR parameters have been treated as free parameters in the fitting. The quality of the fits with double Lorentz function representing the GDR strength function (see Fig. 1, left bottom) was better than for a single Lorentzian.

The extracted preliminary GDR parameters are: $S_1 = 0.40\pm .04$, $E_1 = 16.7 \pm .1$ MeV, $\Gamma_1 = 3.7 \pm .4$ MeV, $S_2 = 0.57 \pm .05$, $E_2 = 21.0 \pm .2$ MeV, $\Gamma_2 = 7.90 \pm .8$ MeV; $S_{\rm tot} = 0.97 \pm .04$, $\tilde{E} = 19.2$ MeV, $S_2/S_1 = 1.43 \pm .2$.

It is well known that the yield of high-energy γ-rays in the statistical decay of self-conjugate nuclei populated by entrance channels with the isospin

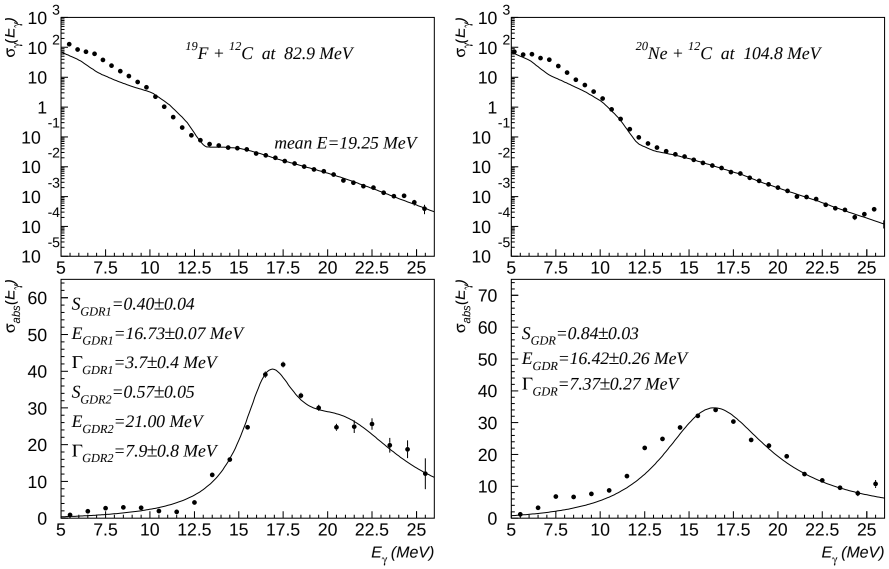

Fig. 1. Measured and fitted gamma-ray spectra (top) and absorption cross-section (bottom) for ^{19}F + ^{12}C reaction at 4.4 MeV/u (left) and for ^{20}Ne + ^{12}C reaction at 5.2 MeV/u (right).

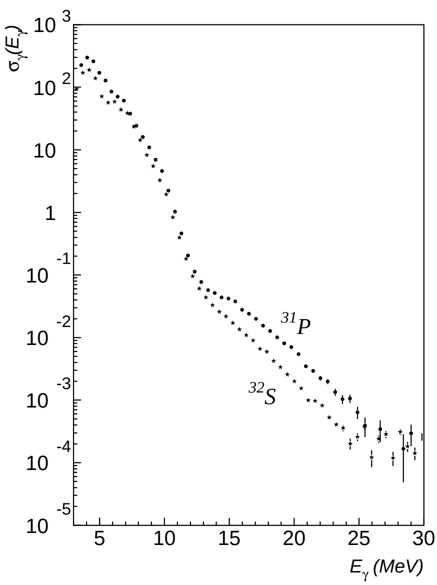

Fig. 2. Comparison of measured γ-ray cross-sections for the ^{20}Ne+^{12}C $\rightarrow ^{32}$S and ^{19}F+^{12}C $\rightarrow ^{31}$P reactions.

T =0, should be strongly inhibited in comparison with the yield from the $T \neq 0$ entrance channels and in nuclei with $N \neq Z$ [9]. The experimental evidence of this effect is shown in Fig. 2 where the measured γ-ray cross-sections for the ^{20}Ne+^{12}C $\rightarrow^{32}$S and ^{19}F+^{12}C $\rightarrow^{31}$P reactions, which populate states with similar excitation energies of 58.3 MeV and 55.1 MeV, are compared.

It might be expected that the GDR built in compound nuclei with similar mass and excitation energy should have very close parameter values. We have then planned to use parameters of the GDR built in ^{31}P in statistical model calculations for ^{20}Ne+^{12}C $\rightarrow^{32}$S reaction, and to obtain the degree of isospin mixing in ^{32}S from comparison of statistical model calculations with the measured γ-ray spectrum. Statistical model calculations for the ^{19}F+^{12}C reaction were found to be insensitive to isospin mixing. However, the fitting of the ^{20}Ne+^{12}C $\rightarrow^{32}$S reaction data with double Lorentz function representing the GDR strength function in ^{31}P appeared to be impossible. The high-energy GDR component is not present in these data. Fits have been then performed with a single Lorentzian, by choosing the starting parameters as $S_{\rm tot} = 1$, $E = 16.7$ MeV, $\Gamma = 7.7$ MeV, and searching for the best value of the isospin mixing coefficient. Preliminary GDR parameters: $S_{\rm tot} = 0.84 \pm .03$, $E = 16.4 \pm .3$ MeV, $\Gamma = 7.4 \pm .3$ MeV (see Fig. 1, right bottom) and the isospin mixing coefficient $\alpha^2 = 0.03 \pm 0.02$ were derived.

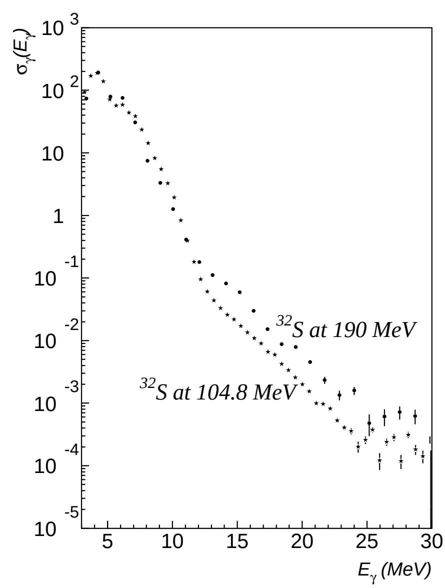

Fig. 3. Comparison of measured γ-ray cross-sections for the ^{20}Ne+^{12}C $\rightarrow^{32}$S reactions at 5.2 MeV/u and 9.5 MeV/u.

The value of α^2 might be compared with the $\alpha^2 = 0.032 \pm 0.029$ obtained for ^{28}Si at excitation energy of about 60 MeV [10].

The γ-ray spectrum for the $^{20}\mathrm{Ne}+^{12}\mathrm{C} \rightarrow ^{32}\mathrm{S}$ reaction at 9.5 MeV/u was also measured in a test experiment with small statistics and is shown in Fig. 3 together with the data at 5.2 MeV/u.

4. Conclusions

The nature of the GDR splitting in ^{31}P might be discussed by taking into account the isospin and deformation effects. The GDR built on the $T = 1$ states in ^{31}P should have two components with an energy separation $\Delta E = 2.9$ MeV and the predicted strengths $S_< = 0.38$ and $S_> = 0.62$. In the experiment we have found the energy difference of the two fitted components equal to 4.3 MeV, and the GDR mean energy to be 19.2 MeV. The GDR built on the $T = 0$ states in ^{32}S should have only a single $T = 1$ isospin component, as it is observed in our experiment, but it should appear at the GDR mean energy, *i.e.* around 19 MeV. If we assume existence of the isospin mixing at high excitation in ^{32}S, we may consider that the GDR may be also built on the admixture of $T = 1$ states and would have the $T = 0$ and $T = 2$ components [11]. The separation of 5.6 MeV between those components, and the strengths of 0.43 and 0.57 for $T = 0$ and $T = 2$ components, respectively, were predicted for the GDR built on pure $T = 1$ state. Thus the $T = 0$ component should be observed around 16 MeV.

On the other hand both studied nuclei should exhibit some deformation which will presumably influence the GDR splitting. The measured $a_2(E_\gamma)$ angular distribution coefficient should soon give us information about the deformation of the nuclei in which the GDR is built. Experiments at 9.5 MeV/u will be continued in order to observe the evolution of the GDR in nuclei studied with increase in nuclear temperature.

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