LIGHT SHAPE ISOMERS IN THE CCT CHANNEL?

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INTRODUCTION

In our previous publications devoted to the collinear cluster tri-parttition (CCT) of the low excited nuclei [1, 2] we have discussed the role of scattering medium in the registration of the CCT products. This decay mode has been called by us "collinear cluster tri-partition" (CCT) in view of the observed features of the effect, that the decay partners fly apart almost collinearly and at least one of them has magic nucleon composition. Briefly, even if initially two CCT partners fly in the same direction perfectly collinearly they get some angular divergence after passing the scattering medium on the flight pass due to the multiple scattering. Thanks to such effect they can be registered independently in the "stop" mosaic detector. Actually even thin backing of the radioactive source provides the observable effect.

EXPERIMENTS AND RESULTS

In order to increase the effect additional absorbers (metal foils) were introduced just after the source at the distance of approximately 1 mm. The layout of the experiments (Ex1, Ex2 and Ex4) is presented in Fig. 1.

The geometry of the source unit is shown in detail in Fig. 2. Additional absorber foil was placed at 1 mm distance from the Cf source. Typical fission fragment overcomes such distance approximately for 0.1 ns.

Ternary events were analyzed. It means that three fragments were really detected in coincidence in three different silicon detectors. For the sake of convenience, the FFs from such events are labeled as M_1, M_2 and M_3 in an order of decreasing masses in the ternary event. Mass distribution for ternary events from mosaics D1and D2 is shown in Fig. 3. The total mass of two heavier fragments M_1+M_2 is plotted vs. the mass of the lighter fragment M_3. As can be inferred from the figure in all the events where the lightest fragment corresponds to the knocked out Ti ions (M_3 is around 48 amu) we observe missing mass of fission fragments. It is very astonishing fact.

Really, if the elastic Rutherford scattering of one of the fission fragments (FF) took place on the Ti foil the total mass M_1+M_2 should lie in the vicinity of the mass of the mother system namely 252 amu (taking into account emitted neutrons, approximately four in mean and experimental mass resolution).

Similar result was obtained in Ex2 (Fig. 4) where twice more thicker Ti absorber was used. Some points in the expected region for the events resulted from the elastic scattering (dashed oval) can be traced back to random coincidences alpha-FF.

Unfortunately, the quality of the SBD detectors, namely essential effective "dead" layer on the surface, did not let us to reconstruct correctly the masses of the FF hitting the mosaics D3 and D4 at large angles in relation to the symmetry axis of the setup. In the revised version of the spectrometer only PIN diodes were used and the position of the mosaics was changed (Fig. 5).

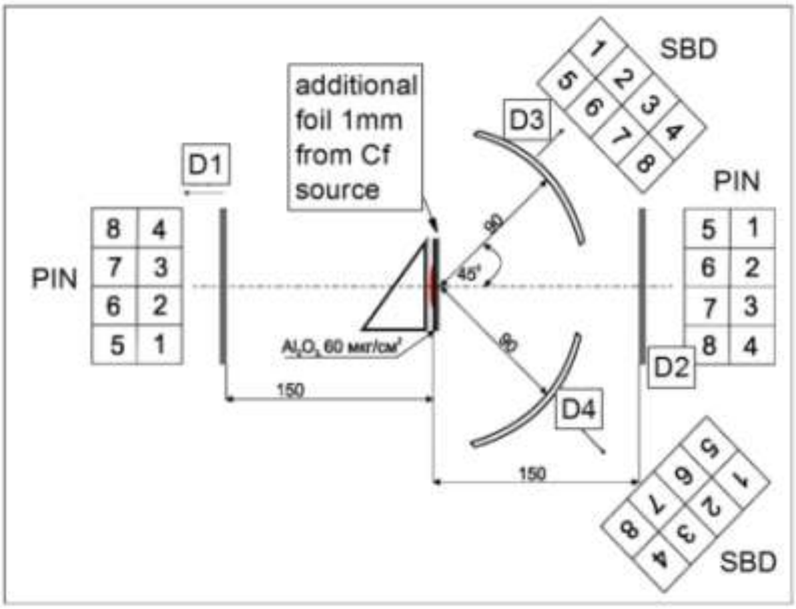


FIGURE 1. Layout of the setup used in two first experiments aimed at studying of an influence of an additional absorber on the characteristics of the CCT products. D1 and D2 are the mosaics of PIN diodes. Mosaics D3 and D4 are based on the surface-barrier detectors (SBD). All in all 32 silicon detectors were used. Micro-channel plates based timing detector (in the center) gives "start" signal while silicon detectors provide signals for measuring of both time-of-flight (TOF) and energy (E) of the fragments. Thus the mass of each fragment detected can be estimated using these two parameters.

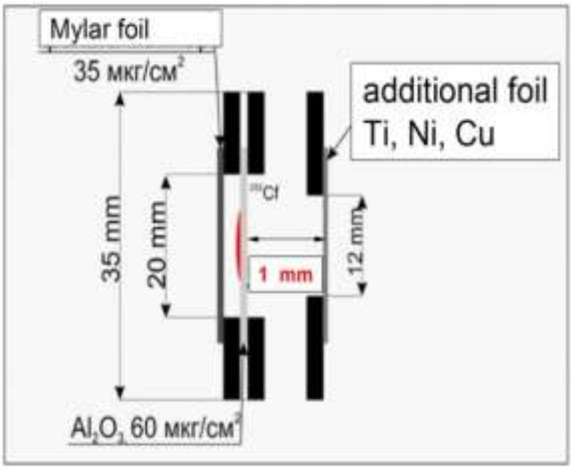


FIGURE 2. ^{252}Cf source and additional foils placed around.

Mass distribution similar to those shown in Fig. 3 and Fig. 4 is presented in Fig. 6. The panel in the figure demonstrates the mass resolution achieved. We can resolve two isotopes of Cu in the natural mixture. The peculiarity of the plot emphasized above confirms in this case as well. Better mass resolution let conclude that the effect of Rutherford scattering being accompanied by the loss of the mass of the scattered fission fragment takes place also in scattering on ^{16}O and ^{27}Al nuclei from the source backing. At the same time at least some part of the FF scattered on the ^{12}C nuclei from the organic foil (Fig. 5) undergo scattering without loss of mass. Corresponding events are marked by the arrow.

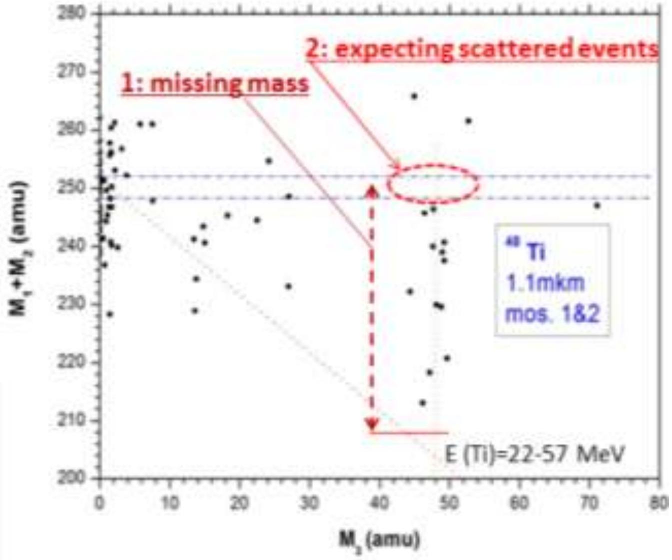


FIGURE 3. Mass distribution for ternary events from Ex1. Ti foil 1.1 mkm thick was used as the additional absorber.

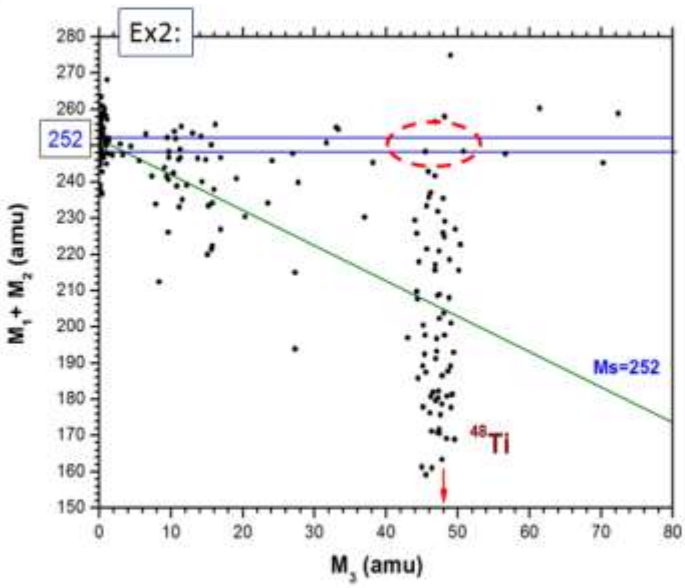


FIGURE 4. Mass distribution from Ex2 for ternary events detected in the mosaics D1 and D2. Ti foil 2.2 mkm thick was used as the additional absorber.

The mass distribution M_1−M_2 obtained in Ex4 for the heaviest fragments of ternary events within knocked out Ni ion as a third one is shown in Fig. 7. The points in the vicinity of the line M_1+M_2 = 252 amu are due to the random coincidences of the Ni ions detected in the mosaics D3 and D4 with the FF of binary fission. The counting rate in those mosaics is high enough in accordance with the probability of the Rutherford scattering at big angles. The linear structures observed (to guide the eye they are marked in Fig. 7 by the blue lines) are linked with known magic nuclei. From the methodical point of view it confirms that mass calibration for the masses M_1 and M_2 is unbiased. In principal, negative shift in the mass calibration i.e. incorrect lower values of the sum M_1+M_2 could be the reason of the effect observed.

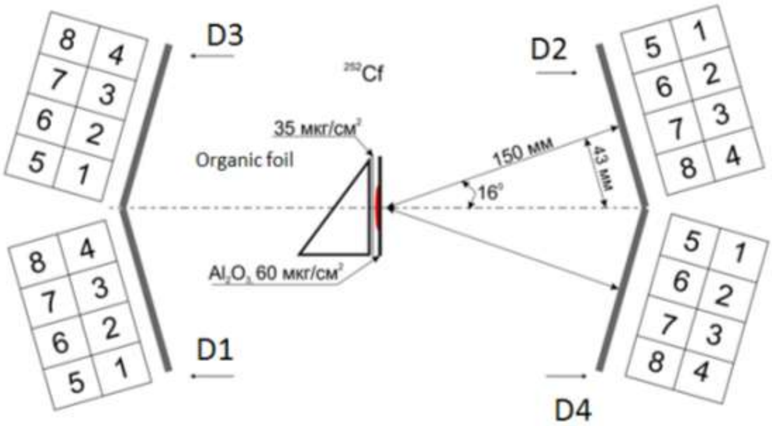


FIGURE 5. Layout of the spectrometer used in Ex3 and Ex4.

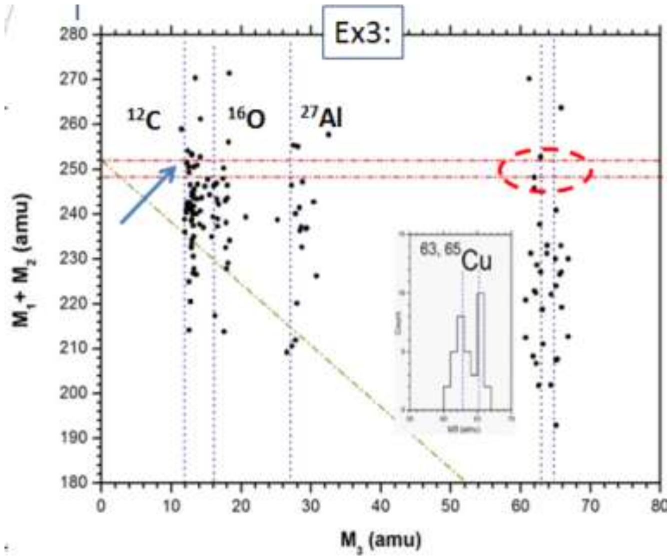


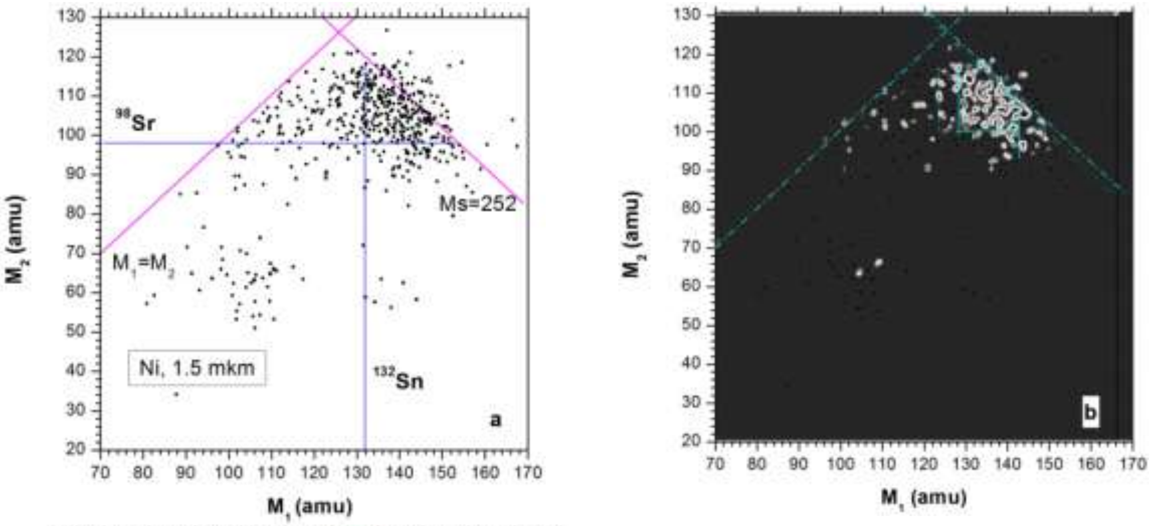
FIGURE 6. Mass distribution for ternary events from Ex3. Cu foil 0.83 mkm thick was used as the additional absorber. The events which are caused by the random coincidences alpha-FF were excluded thanks to the selection on energy E_3. See text for details.

Linear structures similar to those shown in Fig. 7 were observed in our previous experiments at the COMETA setup where only source backing played a role of scattering medium (Fig. 8). There are some differences caused likely by the geometry of the experiments compared but in all the cases we observe very bright manifestation of clustering linked with magic nuclei.

The experimental findings presented above allow us to assume the following:

1. Inelastic impact, at least the frontal one, makes free the constituents of the di-nuclear system (fission fragment) formed in the binary fission.
2. Bearing in mind the distance between the Cf source and the generating foil (~1 mm) the lower limit of the life-time of this di-nuclear system (shape isomer) is about 0.1 ns.
3. Relative probability of elastic Rutherford scattering of fission fragments i.e. taking place without missing mass seems to be much less in our experiments than those in the inelastic

channel. In other words, *the bulk of the fragments from the conventional binary fission are born apparently, as shape-isomers.*



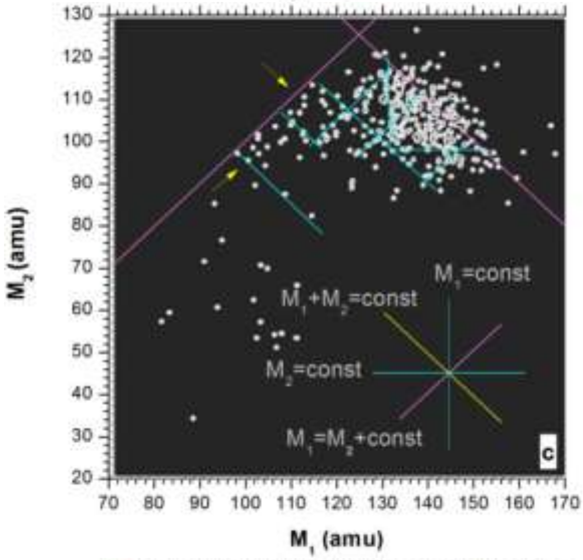


FIGURE 7. Mass distribution for ternary events from Ex4 with the lightest fragment to be the ion knocked out from the Ni foil 1.5 mkm thick (a). All the mosaics (see Fig.1) were taken into account. The same distribution processed by the filter sensitive to the density of the points in the image (b). Rectangular-like structure is vividly seen. By the less "strong' filter more details are revealed (c). Four different directions of the linear structures observed are shown in the bottom of the figure.

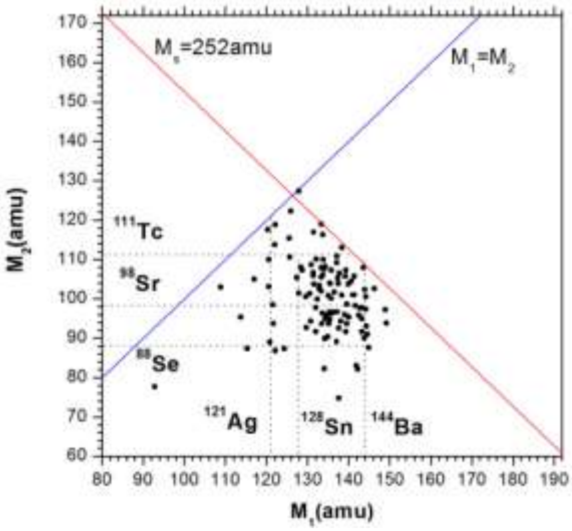


FIGURE 8. Mass distribution for ternary events from the experiment at the COMETA setup. The source backing only played a role of scattering medium.

DISCUSSION

In the frame of the hypothesis put forward there are at least three main questions to be discussed, namely, population of the isomeric states in the FFs in the fission process, survival probability of these states and mechanism of their break-up.

Preformation of the FF of the conventional binary fission in the form of a di-nuclear system (DNS) is very much expected keeping in mind both theoretical and experimental indications known. V.V. Vladimirski was may be the first who postulated that fission probability has noticeable value only if two cluster structures such as magic cores within the light and heavy fragment corresponding to the N = 50 and Z = 50, N = 82 shells are not destroyed. A dumbbell–like configuration consisting of two magic clusters connected by a flat cylindrical neck was considered as a typical shape of the fissioning system. In this case the fragment at the scission point should look like di-nuclear system consisting of the magic core and some part of the neck.

Preformation of two magic clusters in the body of the mother system at the early stage of the descent from the fission barrier was established in the calculations of the potential energy surface in ten dimensional deformation space for some actinides [4]. It takes place in the valley both mass-asymmetric (marked by number 3 in Fig. 9) and symmetric (valley 4) shapes of the fissioning system. Similar calculations let reveal as well three cluster aligned configurations [5, 6]. After first rupture of such configuration di-nuclear system can be also formed. In our work [7] we supposed a fissioning system to be completely clusterised. The fission ways obtained in the frame of the model agree well with those predicted by U. Brosa et al. [8] and experimental findings [9].

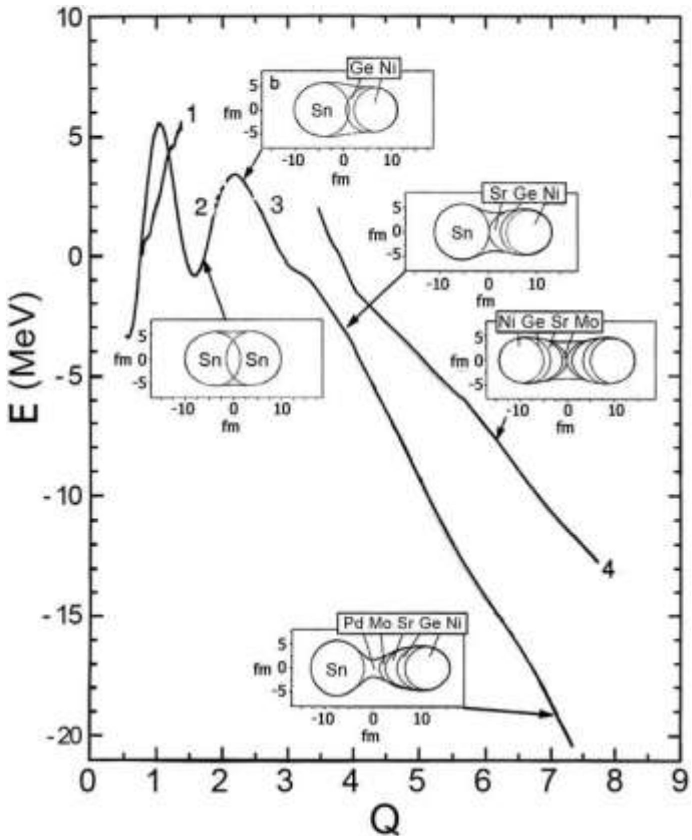


FIGURE 9. The bottoms of the fission valleys as a function of parameter Q (proportional to the quadrupole moment) for ^{246}Cm. The panels depict the shapes of the fissioning system at the points marked by arrows.

From the experimental side, for instance, systematic investigations of the far-asymmetric fission at the mass separator Lohengrin [10] let conclude that "fission is not only determined by the double shell closure in the heavy sphere of the scission point dumbbell configuration around A = 132 (Z = 50, N ≈ 82) but also by the effect of the double shell closure of Z = 28 and N ≈ 50 in the corresponding light sphere".

Survival probability of the DNS is determined by the competition between its possible fusion and fission. Both partial probabilities depend from the DNS excitation energy just after scission of the mother nucleus. An idea concerning the possibility of fusion can be obtained from the driving potential for the typical fission fragment [11] (Fig. 10).

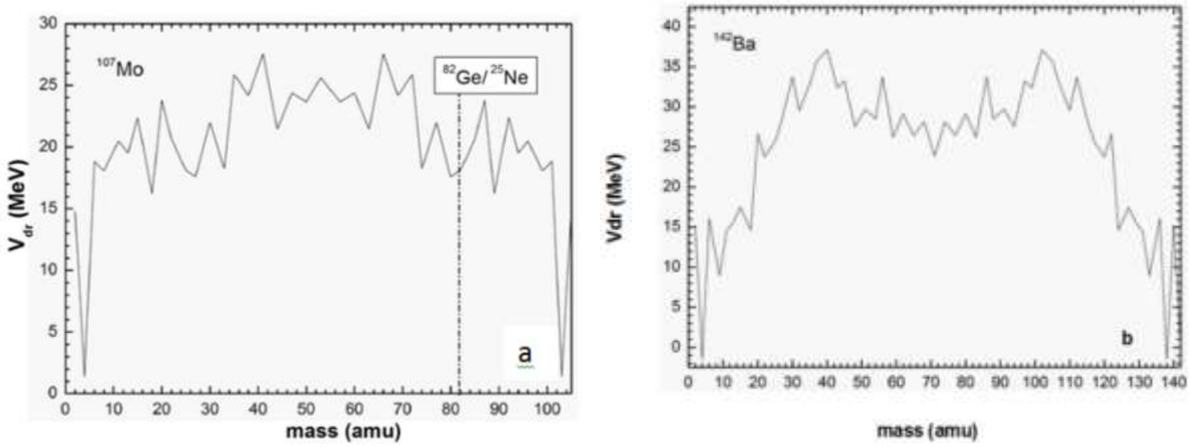


Figure 10. Driving potential of the DNS as a function of the mass of one of the fragments for the ^{107}Mo (a) and ^{142}Ba (b) nuclei.

Driving

$$V_{dr} = B_1 + B_2 + V(R) - B_{in},$$

where B_1, B_2, B_{in} are the nuclear binding energies of the DNS nuclei and the mother system, the nucleus-nucleus potential V(R) incorporates the nuclear and Coulomb potentials. The spin is supposed to be zero for all the nuclei involved. As can be inferred from the figure fusion is preferable at any division of the mother nucleus. At the same time initial DNS representing, for instance, the pair of ^{82}Ge (magic)/^{25}Ne nuclei should overcome essential barrier (up to six MeV) depending on the excitation energy of the DNS on its way to fusion. Comparable barrier preserves the system from fission. Thus, the heights of the barriers let expect the DNS life time at least in the nanosecond range.

We suppose the break-up of the DNS to be the result of it inelastic scattering in the degrading foil. Decreasing of the inter-center distance between the constituents of the molecule during the front impact leads to increasing of interaction energy sufficient to overcome the barrier (Fig. 11).

CONCLUSIONS

1. New mechanism of ternary decay based presumably on the Rutherford break-up of the fragment in the shape-isomeric state is observed.
2. Break-up is only one of the different ways leading to the CCT.

3. The results obtained let us to suppose that the bulk of the fragments from the conventional binary fission are born in the shape-isomeric states.
4. The conclusions above can be regarded as the preliminary ones until further estimation of the life times of the shape isomers under discussion will be obtained.

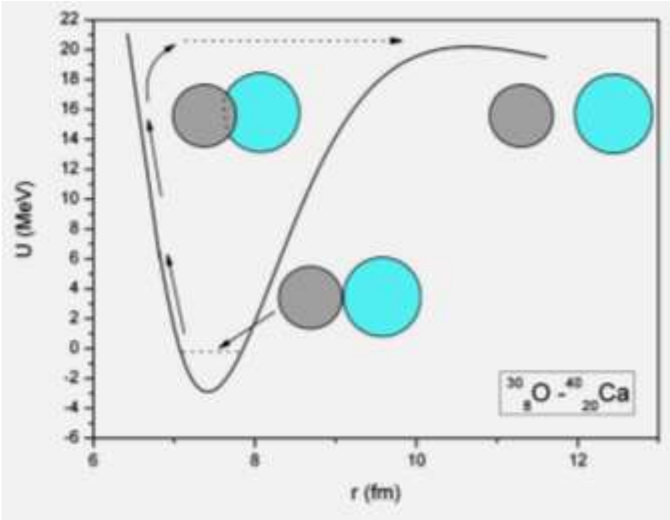


FIGURE 11. Interaction energy of two nuclei as a function of the distance between their centers. See text for details.

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