Super Heavy Elements:
A new paradigm

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Brief landscape on SHE:

- last element synthesized: Z=118 (Og)
- synthesis method: fusion-evaporation
- isotopes: for each element only a few, usually on the neutron deficient side
- decay modes: SF, alpha decay
- cold fusion (low CN excitation energy) used for synthesis of elements with Z=106-113 has very low cross sections for Z≥112 because of the increasing role of quasifission. Synthesis of Z=113 was done with *cold fusion*: 70Zn+209Bi with a record low cross section of 22 fb. Above Z=113, synthesis was done by *hot fusion* using 48Ca projectiles and highly radioactive trans-uranium targets with “reasonable” life times (hundreds of days).

Foreseen future developments for fusion-evaporation:

- using existing methods and high intensity accelerators (like SHE Factory), try to complete/expand the isotopic chains, especially towards the “center” of the island of stability
- find links (alpha decay chains) to isotopes whose masses are known
- obtain spectroscopic information on already existing isotopes

Limitations:

- Very low cross sections (down to fb region and even below)
- Lack of projectile-target combinations leading to SHE with a “natural” n-p proportion
- Time to reshuffle the nucleons of the two fusing nuclei for making the compound nucleus *shorter than the contact time* of the two reaction partners (see e.g. G.G.Adamian, N.V.Antonenko, W. Scheid Nucl. Phys.A618, 176 (1997))

A new paradigm

Use a two body reaction at energies slightly above the barrier in a collinear geometry (zero degree), with the emission of a high energy alpha particle.

The energy of the light and heavy products are determined only by the *two body kinematics*. In this calculation, the masses are the main ingredient. If the heavy product is excited, the alpha energy will decrease. In this way, measuring the alpha energy one can *control the excitation energy of the heavy product*. For at least 15MeV below the kinematic limit for alphas, *no other reaction mechanisms may provide alphas with such energies* (e.g. evaporation, preequilibrium, clusters, fission, etc.).

The forwardly emitted alpha particle caries away a lot of excitation energy and momentum and constrains the reaction products to stay a *longer time* together.

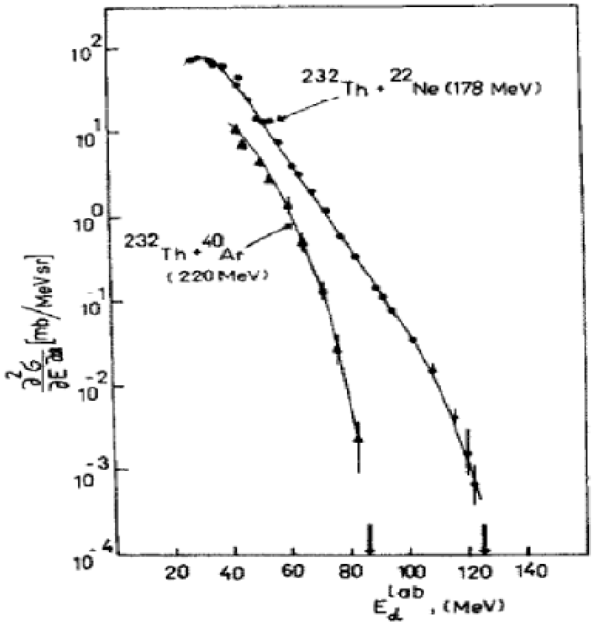
Most of the targets with Z>90 are alpha emitters; for such targets there is a non negligible probability that alphas are *preformed*.

Experimental facts (1)

Till now, there exists measured data with a magnetic spectrometer (MSP144 FLNR) for two systems leading to superheavy elements 106 (Sg) and 110 (Ds), preliminary data:

1) ^{40}Ar(220MeV) + ^{232}Th → ^{4}He + ^{268}Sg

at zero deg.



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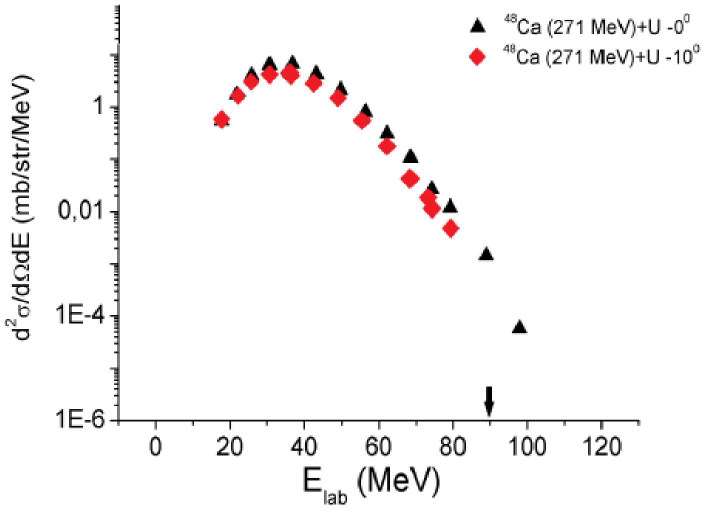
2) ^{48}Ca(271MeV) + ^{238}U → ^{4}He+^{282}Ds

at zero and 10 deg.



Observations

The velocities of the heavy residues in the two body reactions are lower than in the case of fusion-evaporation:

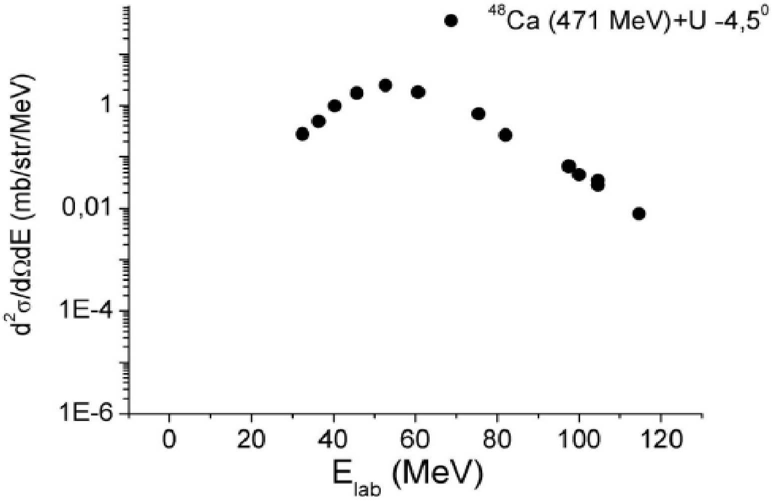
For the first reaction these velocities are respectively 0.39 cm/ns and 0.48 cm/ns. In the second reaction they are 0.468 cm/ns and 0.552 cm/ns.

This difference explains why these residues were not observed in fusion-evaporation reactions (e.g. GSI experiments in the 90's).

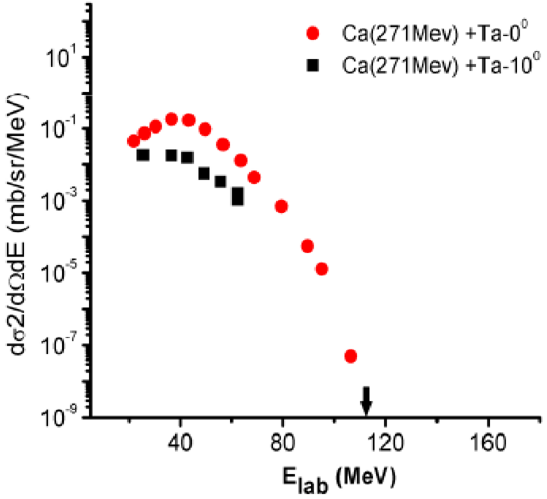
At alpha energies lower that the kinematic limit by more than the neutron separation energy in the heavy residue, this one may evaporate one neutron which leads to a lighter isotope. The production cross section for such an event is at least one order of magnitude higher than at the kinematic limit.

Experimental facts (2)

^{48}Ca(471MeV) + ^{238}U $\longrightarrow$ ^{4}He+^{282}Ds
at 4.5 deg.



^{48}Ca(271MeV) + ^{181}Ta $\longrightarrow$ ^{4}He+^{225}Pa
at 0 and 10 deg.



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Perspectives

A successful *recording the heavy residue* in the above mentioned reactions will open large perspectives for completing the isotopic chains of already discovered SHE. With some technical developments for the coincident measurements alpha-heavy residue, we will have access to the excitation energy of the last one and therefore *spectroscopic studies* will become possible, view the relatively high production cross sections for some projectile-target combinations.

Alpha energies lower than kinematic limit will imply that the heavy residue is excited. This excitation energy may be such as to allow neutron evaporation. In this case, the production cross section will be one order of magnitude or more higher than the one at the kinematic limit!

In parallel, studies of alpha spectra for other interesting combinations like *64Ni+238U (element 118) and especially 64Ni+244Pu (element with Z=120)* are foreseen at the magnetic spectrometer COMBAS in FLNR-JINR Dubna.