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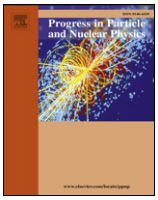

Review

Study of SHE at the GSI-SHIP

S. Hofmann *,[1]

GSI Helmholtzzentrum für Schwerionenforschung, Germany
Goethe Universität, Frankfurt am Main, Germany

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ABSTRACT

An overview of present experimental investigation of superheavy elements is given. Using cold fusion reactions which are based on lead and bismuth targets, relatively neutron deficient isotopes of the elements from 107 to 113 were synthesized at GSI in Darmstadt, Germany, and/or at RIKEN in Wako, Japan. In hot fusion reactions of ^{48}Ca projectiles with actinide targets more neutron rich isotopes of the elements from 112 to 116 and even 118 were produced at FLNR in Dubna, Russia. Recently, part of these data, which represent the first identification of nuclei located on the predicted island of SHEs, were confirmed in two independent experiments. The data are compared with theoretical descriptions.

1. Introduction and status of experiments

For the synthesis of heavy and superheavy elements (SHE) fusion-evaporation reactions are used. Two approaches have been successfully employed. Firstly, reactions with medium mass ion beam impinging on targets of stable Pb and Bi isotopes (cold fusion). These reactions have been successfully used to produce elements up to $Z = 112$ at GSI [1] and to confirm these experiments at RIKEN [2,3] and LBNL [4]. Recently, a number of neutron deficient odd element isotopes were produced in a combination with ^{208}Pb target and odd element projectiles [5,6] at LBNL. Using a ^{209}Bi target the isotope ^{278}113 was synthesized at RIKEN [2]. Secondly, reactions between lighter ions, especially with beams of ^{48}Ca, and radioactive actinide targets (hot fusion) have been used to produce more neutron rich isotopes of elements from $Z = 112$ to 116 and 118 at FLNR [7]. Recently, the results of two of these reactions, $^{48}\text{Ca} + {}^{242}\text{Pu}$ and $^{48}\text{Ca} + {}^{238}\text{U}$ were confirmed in independent experiments [8–10]. Fig. 1 summarizes the data as they are presently known or under investigation.

Besides the discovery of the existence of these high-Z elements, two more important observations emerged. Firstly, the expectation that half-lives of the new isotopes should lengthen with increasing neutron number as one approaches the island of stability seems to be fulfilled. Secondly, the measured cross-sections for the relevant nuclear fusion processes reach values up to 5 pb, which is surprisingly high. Furthermore, they seem to be correlated with the variation of shell-correction energies, as predicted by macroscopic–microscopic calculations [11,12].

2. Nuclear structure and decay properties

The calculation of the ground-state binding energy provides the basic step to determine the stability of SHEs. In macroscopic–microscopic models, the binding energy is calculated as sum of a predominating macroscopic part (derived from the liquid-drop model of the atomic nucleus) and a microscopic part (derived from the nuclear shell model). This way,

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* Corresponding address: GSI Helmholtzzentrum für Schwerionenforschung, Germany.
E-mail address: S.Hofmann@gsi.de.

[1] Josef Buchmann-Professor Laureatus.

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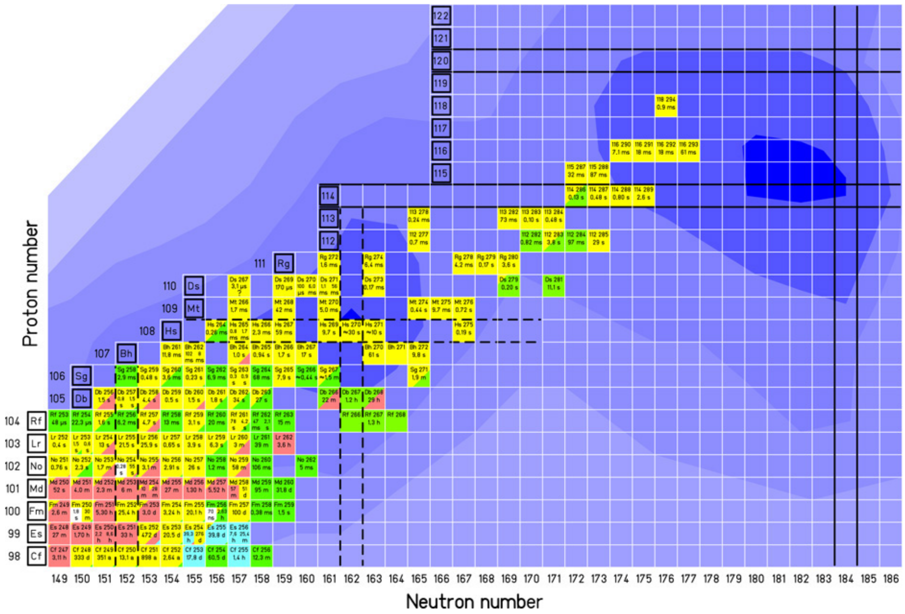

Fig. 1. Upper end of the chart of nuclei showing the presently (2008) known nuclei. For each known isotope, the element name, mass number, and half-life are given. The magic numbers for the protons at element 114 and 120 and for the neutrons at $N = 184$ are emphasized. The bold dashed lines mark proton number 108 and neutron numbers 152 and 162. Nuclei with that number of protons or neutrons have increased stability. However, they are deformed contrary to the spherical superheavy nuclei. The crossing at $Z = 114$ and $N = 162$ reflects the uncertainty, whether nuclei in that region are deformed or spherical. The background structure in gray shows the calculated shell correction energy according to the macroscopic–microscopic model.

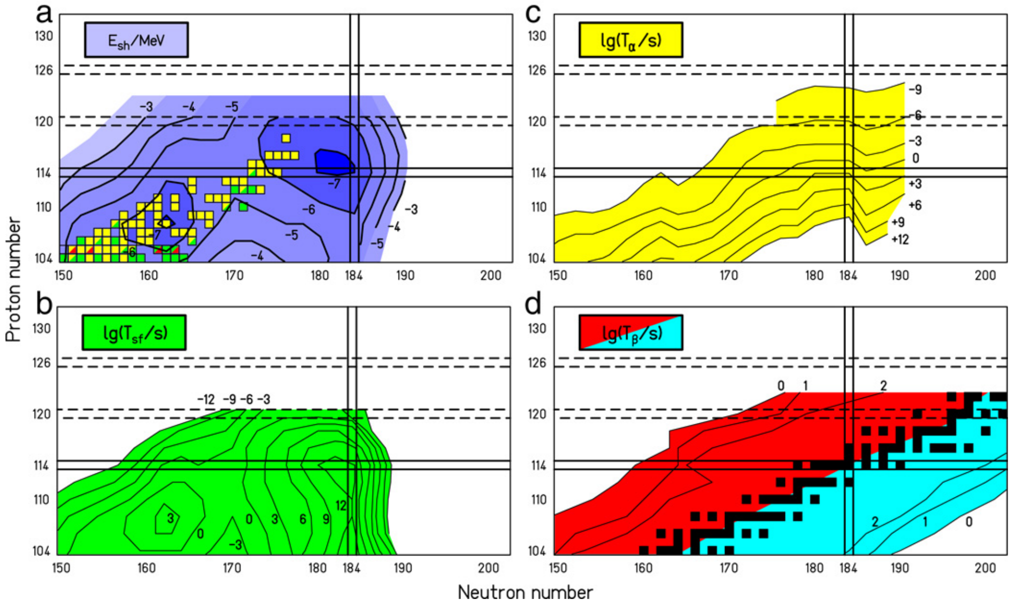

Fig. 2. Shell-correction energy (a) and partial half-lives for SF, α, and β decay (b)–(d). The calculated values in (a)–(c) were taken from Ref. [11,13] and in (d) from Ref. [12]. The squares in (a) mark the nuclei presently known, the filled squares in (d) mark the β stable nuclei.

more accurate values for the binding energy are obtained than in the cases of using only the liquid drop model or the shell model. The shell correction energies of the ground-state of nuclei near closed shells are negative, which results in further decreased values of the negative binding energy from the liquid drop model — and thus increased stability. An experimental signature for the shell-correction energy is obtained by subtracting a calculated smooth macroscopic part from the measured total binding energy.