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Specific parameters for some isotopes of copernicium and flerovium

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Abstract

Super heavy elements (SHE) in the periodic table are generally transuranic and transactinide elements having Z > 92. Here, some of the properties of two super heavy elements viz. Copernicium (Cn) and Flerovium (Fl) are discussed. The half life time, transition probability, Gamow's factor, disintegration constant are calculated for these super heavy elements and compared with other values.

Keywords**:** Transition probability, semi empirical mass formula, disintegration constant, tunneling effect

1. Introduction

From the early days of the synthesis of heavier transuranic elements, it was predicted that since such heavy elements did not occur in nature, they would have shorter and shorter half lives. A doubly magic isotope having magic numbers of proton and neutrons would be stabilized against radioactive decay. The doubly magic isotope after lead-208 is flerovium-298 with 114 protons and 184 neutrons. It forms the centre of a so called 'island of stability'. This island of stability centering around elements 112-118 comes just after a 'sea of instability' from elements 101-111. The Flerovium isotopes in it were speculated in 1966 and it's half lives were estimated to be more than a hundred million years.

B. Buck, A. C. Merchant, and S. M. Perez have shown in their paper new look about the α decay of heavy nuclei. Geiger-Nuttall plots of the accurate modern data on partial half-lives for α decay yield very striking linear correlations. Other data on ground-state to ground-state α decays for even-even nuclei with $76 \leq Z \leq 100$ may be accounted for very well by a simple model with fixed parameters [1]. Sigurd Hofmann has explored the island of stability for the super heavy elements**.** Now, a Russian-American collaboration headed by Yuri Oganessian at the Joint Institute for Nuclear Research in Dubna, Russia, announces in Physical Review Letters its latest discovery—a new element with atomic number 117 [2] The simplest of the nuclear models, which imagines the nucleus as a charged liquid drop, predicts that the most stable ones are located in the "valley of stability," the boundaries of which are determined by the interplay between nuclear and electric forces. The root-mean-square (rms) nuclear charge radii of superheavy odd-*A* and odd-odd nuclei are tentatively pursued by the deduction of experimental α decay data. The framework of calculating α decay half-lives is constructed via the combination of the improved two-potential approach with the density-dependent cluster model. In this procedure, the charge distribution of daughter nuclei is determined to exactly reproduce the measured α decay half-lives [3]. Assuming that the α particle is a structureless point particle with two protons and two neutrons, F R Xu et al [4] have calculated a mean-field-type cluster potential based on the Woods-Saxon potential with a folding factor which is to satisfy the quantization condition of a quasi bound cluster state. The folded Woods-Saxon cluster potential has been successfully applied to the calculations of α-particle decay in light and super-heavy nuclei. The standard values of the Woods-Saxon parameters were used without any adjustment. The calculated α-decay widths or lifetimes agree generally with experiment. Such a cluster potential leads to a consistent description of single-particle and cluster motions [4]. S K Patra et al calculated the reaction and the fusion cross-sections of neutron-rich heavy nuclei taking light exotic isotopes as projectiles [5, 6]. Results of neutron-rich Pb and U isotopes are demonstrated as the representative targets and He, B as the projectiles. The Gluaber Model and the Coupled Channel Formalism are used to evaluate the reaction and the fusion cross-sections for the cases considered. Based on the analysis of these cross-sections, we predict the formation of heavy, superheavy and super-superheavy elements through rapid neutron/ light nuclei capture r-process of the nucleosynthesis in astrophysical objects [7].

Physical and Chemical properties of Cn & Fv

Copernicium is an extremely radioactive element first originated in 1966 by the GSI Helmholtz Centre for Heavy Ion Research, Germany which was created in the laboratory. In the periodic table of the elements, it is a d-block transactinide element, extremely volatile even gas at standard temperature and pressure. Its lighter homologues, zinc, cadmium and mercury are entirely different from it. The most notable property is the withdrawing two 6d electrons before 7s ones due to the relativistic effects confirming that Cn is a transition metal [8, 9].

$$\Delta E_n(\text{relativistic}) = - \frac{E_H}{n^3}\alpha^2\left[\frac{1}{l+\frac{1}{2}} - \frac{3}{4n}\right]$$

It is predicted to differ significantly from the lighter group 12 elements. Cn2+ is likely to have a [Rn] $5f^{14}$ $6d^{8}7s^{2}$ electronic configuration. In water solutions it remains in +2 or +4 oxidation states. Cn is able to form metallic bond with copper, palladium, platinum, silver and gold. These bonds are predicted to be only about 15-20 kJ/mol weaker than the analogous bonds with mercury. According to the "Hund's rule'' with the state of higher total angular momentum, the binding energy would be lower. When the total correction (relativistic + spin orbit) is independent of the orbital quantum number, states with same 'n' and 'j' but with different 'l' will remain degenerate.

Copernicium has no stable isotope. Several radioactive isotopes have been synthesized in the laboratory either by fusing atoms or by decay of heavier atoms. Six different isotopes are reported with atomic masses from 281 to 285 and 277. Among these isotopes, Cn^{283} and Cn^{285} have metastable states. Most of these decay through alpha decay, but some also undergo spontaneous fission.

Density: 23.7gm/cm^3
Structure: hexagonal close-packed crystal
Lattice parameters: a=332 pm and c=540 pm
State: gaseous at room temperature.

Flerovium, the super heavy element is created in the laboratory and has not been observed in nature. The element is named after the Flerov Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research in Dubna, Russia where the element was discovered in 1998 and adopted by IUPAC on May 30, 2012. In the periodic table, it is a transactinide element in the p-block. It is a member of the 7th period and is placed as the heaviest known member of the carbon group.
Electronic configuration: $7s^2 7p^2$
Stability: due to inner pair effect and the effect of tearing of 7p sub shell Fl assumed to be stable
Oxidation states: +4 and +6
Low boiling point, gaseous metal

Island of stability:
Copernicium has 112 protons and 166 neutrons and Flerovium has 114 protons and 184 neutrons which can undergo α-decay process to give the product $^{274}_{112}$Cn.$^{298}_{114}$Fl is having spin J=11/2 with odd parity according to the shell model. After the α-emission the super heavy element goes to the stable form. There are six isotopes of $^{274}_{112}$Cn and two isotopes of $^{298}_{114}$Fl.

2. Calculation of different parameters

Half lives of ^{112}Cn and ^{114} Fl

According to Gamow's theory of α-decay, if the motion of a particle in a neighborhood of a potential barrier is treated wave mechanically it is found that there is a finite probability that the particle can leak through the barrier even though its kinetic energy is less than the height of the barrier. This is known as the 'tunneling effect'. α-decay can be visualized as a process involving the formation of daughter nucleus α-system from the original parent nucleus and the survival of this system as a quasi bound state for a while depends on the life time before it undergoes decay .The decay process is governed by the Schrodinger's equation governing the two body system.

In the centre of mass system, the parent daughter interaction in three dimension having reduced mass μand interacting potential between them as U(r) reduces to the solution of radial Schrodinger equation provided the potential is symmetric [10].The values of fission energy and fission due to the columbic barrier inclusion for symmetric nuclei can be used as inputs for the calculation of cross section [11, 12].
The one-dimensional radial Schrodinger equation is written as

$$\frac{d^2U(r)}{dr^2} + \frac{2\mu}{\hbar^2}[\,E - V(r)]U(r) = 0$$

Where U(r) is the short range attractive nuclear potential.
The WKB approximation can be used to calculate the transmission probability of the particle
T=e^{-2G}

Where G = $\sqrt{\frac{2\mu}{\hbar^2}}\int[V(r) - E]^{1/2}\,dr$

G is known as the Gamow's factor

$$G \cong \sqrt{\frac{2\mu Z_d\, z_\alpha q^2 b}{4\pi\epsilon_0\,\hbar^2}}\left[\,\frac{\pi}{2} - 2\sqrt{\frac{R}{b}}\,\right]$$

Let P_α be the probability of formation of α – particles. They formed from the neutrons and protons in the nucleus [10].

The frequency with which the α-particle hits the wall $\nu = \frac{v}{2R}$

R is the radius of the nucleus and v is the velocity of the α-particle.

$\lambda = P_\alpha \nu T$

$t_{1/2} = \frac{0.693}{\lambda}$

Binding energy

The binding energy is calculated by using the semi-empirical mass formula

$BE = a_v A - a_s A^{2/3} - a_c Z(Z-1)/A^{1/3} - a_a(A-2Z)^2/A + \Delta(A,Z)\,\delta/A^{1/2}$

The term a_v attached to the volume term is known as the co-efficient of volume energy term.

$a_s A^{2/3}$ is known as the surface energy term, a correction to the volume term and strong in nature.

$a_c Z(Z-1)/A^{1/3}$ is known as the coulomb or electrostatic term.

$a_a (A-2Z)^2/A$ is the asymmetry term.

$\delta/A^{1/2}$ is known as the pairing energy term which captures the spin orbit coupling.

$\Delta(A,Z) = \begin{cases} +1 \\ 0 \\ -1 \end{cases}$ [for (A even and Z even), A odd and (A even and Z odd) respectively]

From the binding energy expression, we calculate the energy of the reaction as

$E\alpha$ = B.E. (He) + B.E. (Y) - B.E. (X)

The α-decay process for flerovium is written as

$^{289}Fl_{114} \rightarrow {}^{285}Cn_{112} + {}^{4}He_2$

The calculated values of half life for the isotopes of Cn and Fl are given in table-1. The correlation between various nuclear parameters are shown in Fig.1 to 3.

Table 1. Different parameters for the Isotopes of Cn & Fl

isotopes	E_α in MeV	G	T	ν	$t_{1/2}$ in sec.
$^{277}Cn_{112}$	10.470	23.6044	3.144	1.442	0.15
$^{281}Cn_{112}$	10.003	25.0494	1.747	1.403	2.83
$^{282}Cn_{112}$	9.884	25.4331	8.112	1.393	6.13
$^{283}Cn_{112}$	9.766	25.8261	3.696	1.383	13.56
$^{284}Cn_{112}$	9.646	26.2288	1.652	1.373	70.57
$^{285}Cn_{112}$	9.526	26.6415	7.235	1.362	30.30
$^{292}Fl_{114}$	9.690	26.7436	5.899	1.363	86.19
$^{289}Fl_{114}$	10.045	25.5529	6.383	1.392	7.80

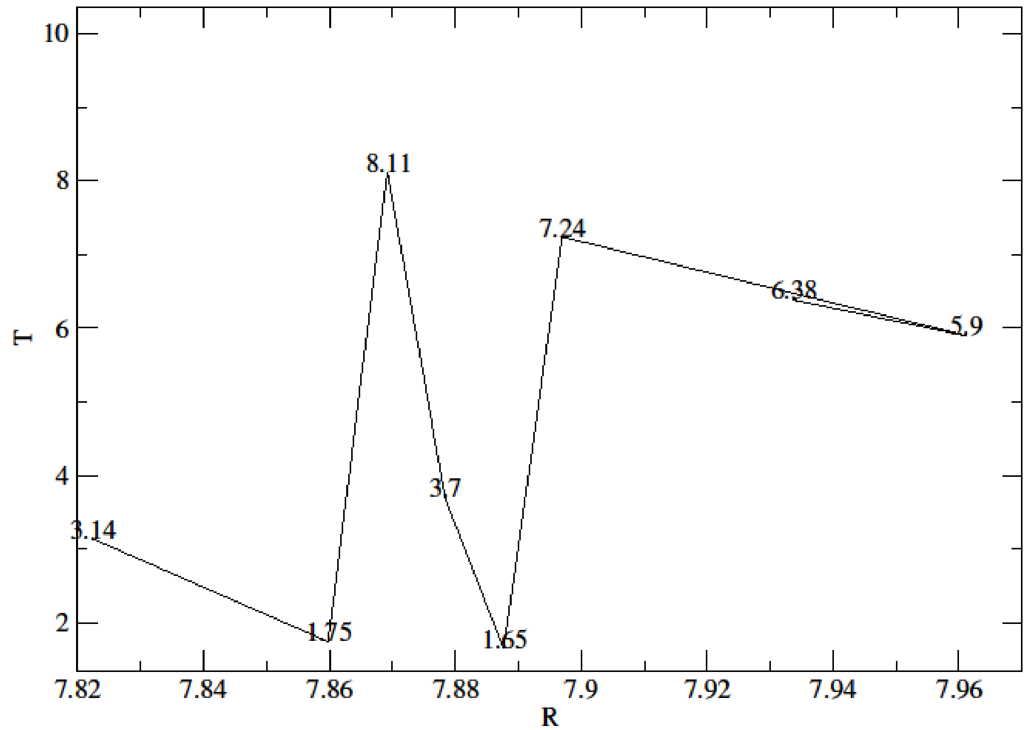

Fig 1 Graph between the T and R (in fermi) for different isotopes of Cn & Fl

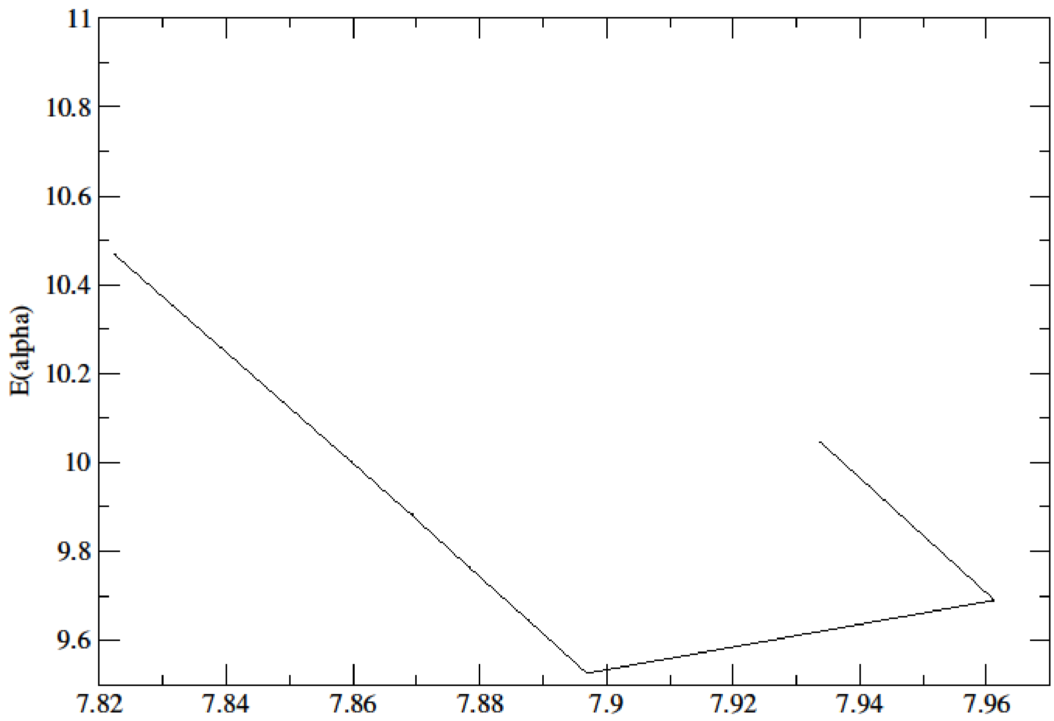

Fig 2 Graph between Eα (in Mev) and R (in fermi) for different isotopes of Cn and Fl

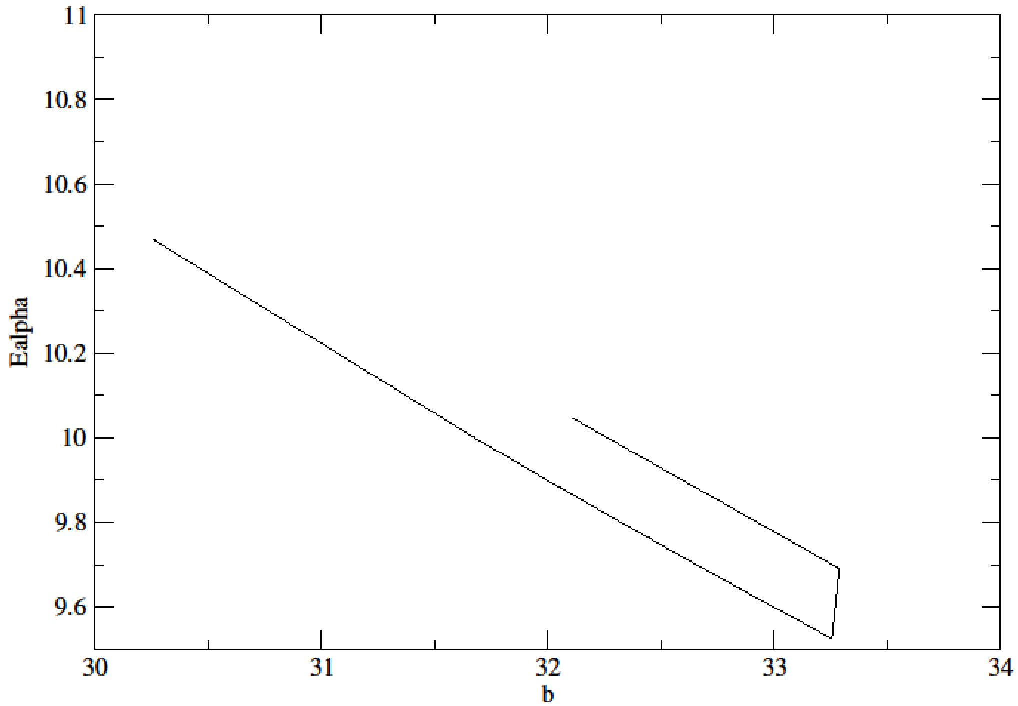

Fig 3 Graph between Eα (in Mev) and b (in fermi) for different isotopes of Cn and Fl

3. Result and Discussions

In the table-1, we see that with increase in atomic mass of different isotopes of copernicium and flerovium, the Gamow factor and the half lives increase. The transition probability shows some abrupt behavior. The binding energy goes in a decreasing fashion with respect to the atomic masses of the superheavy elements. So in order to avoid this discrepancy we have to devise a model by including the coulomb interaction, which is our future plan.

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