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THEORETICAL STUDY OF DECAY RATES OF NEWLY SYNTHESIZED SUPER HEAVY ELEMENT

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ABSTRACT

We have studied half lives and penetration probability for even-even nuclei having atomic number 106 to 118.The frequency have been calculated using classical methods. The penetration probability was estimated by modifying the Gamow's theory of alpha decay by varying the potential and it was found to be in a very good agreement with the experimental half-lives. The half-lives for alpha decay can be mainly determined by penetration probability. We have seen that in simple spherical symmetric potential there is a discontinuous jump of the potential which tends to be not physical because the force there becomes infinite. In this present work the square well model is modified by smoothing the potential well inside the nucleus to the top of the coulomb barrier at the outer side of the potential well which we will call as S-potential. The pre-formation factor was calculated from experimental alpha decay energies and half-lives. The theoretical explanation was experimentally proved by Geiger-Nuttall law. The S-potential (Smoothened) gives a better match with the experimental data.

KEYWORDS: Half-lives, super heavy nuclei, pre-formation factor, penetration probability.

1. INTRODUCTION

Tunneling offers to authenticate the theory of quantum mechanics by explaining many phenomena such as alpha decay, molecular bonding and field emission and has resulted in applications such as scanning tunneling microscopes. George Gamow (Russia,USA, 1904-1968)(1) discovered the alpha decay of atomic nuclei which was well explained by tunneling effect. This was one of the strong evidence for the success of quantum mechanics (2).An alpha particle is emitted from heavy nucleus as a discrete particle that can be referred as; some tightly bound assembly of two neutrons and two protons pre-existed in the nucleus. The particles with proton number greater than 82 (Z>82) comes under the category of heavy elements (3). Superheavy elements (SHE) refers to elements beyond atomic number 100(Z>100) which refers to all trans-uranium series. The trans-actinides elements begin with Rutherfordium (atomic nos-104).SHE was created during 20th and 21st century through the bombardment of elements in the particle accelerator. They were made artificially and have no practical purpose because of their short –lives, which cause them to decay after a very short time ranging from few minute to few milliseconds. The detailed alpha decay studies provide the access to the basic properties of SHE –their masses, energy level, half-lives, spins, moments and emission rates. It is a powerful tool to explore the nuclear structure and also very important aspects of reaction mechanism (resonance tunneling).Detailed experimental and theoretical studies of SHE can reveal new decay modes and complex nuclear structure. The detailed analysis of nuclei properties can help to elaborate and improvise the theoretical approach which may used to predict new Radioactive properties of unknown species such prediction can be made with a fair degree of confidence and this may help in the preparation and identification of new SHE. The alpha particle is emitted from the parent nuclei through quantum mechanical tunneling along with the daughter nuclei. In this model; the decay constant λ is considered as the product of: assault frequency *n*, the pre-formation factor P_0(4) and penetration probability *P*.The estimation of pre-formation factor was the most challenging aspect of α-decay, so that nucleus structure and its decay can be explained in a better way. P_0 is extracted from the experimental values of half-lives and the penetration probability which is calculated by S-model which is explained below. In this present work the square well model is modified by smoothen the potential well inside the nucleus to the top of the coulomb barrier at the outer side of the potential well which we will call as S-potential.

2. MODEL

We have already studied the detailed analysis of the simple spherical symmetric potential (5).We have seen that in simple spherical symmetric potential there is a discontinuous jump of the potential which tends to be not physical because the force there becomes infinite. The modification was made in the model by smoothing the jump of the atom from the bottom of the potential well inside the nucleus to the top of the coulomb barrier outside the well and we call it S-potential. The modified model is sketched and shown in Fig.1 below.

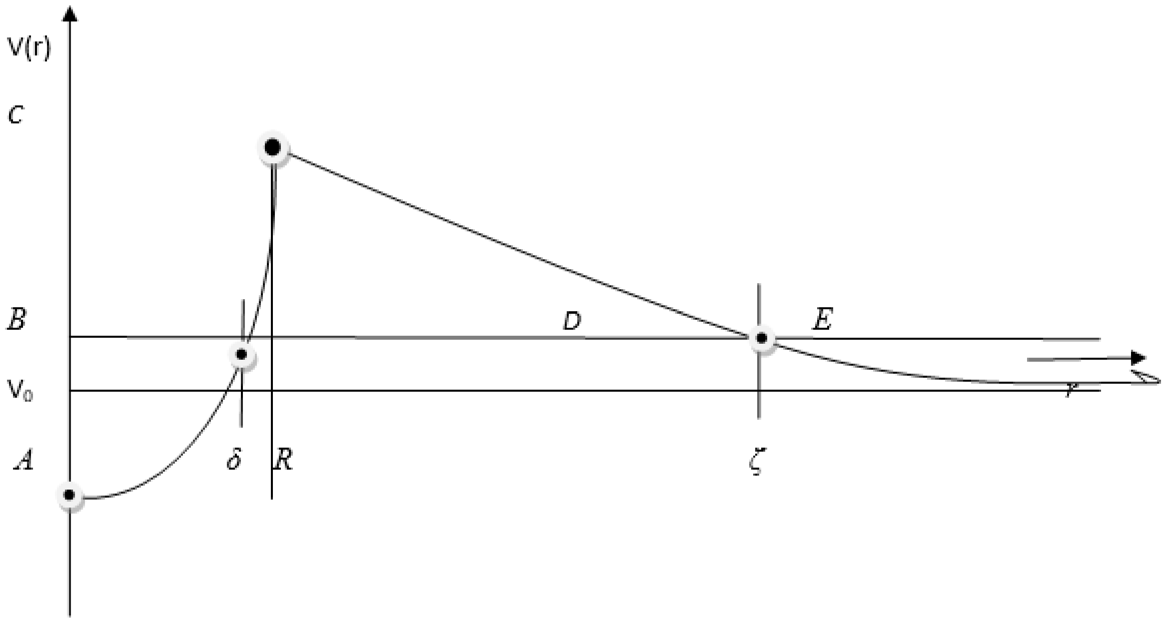

Figure 1: S-Model on the shape of V (r); the inside potential has been assumed to be of the (spherical) harmonic kind

Instead of flat line in the Gamow potential points A and C are joined by a smooth curve BD is joined by a straight line. Point C corresponds to distance R from the origin and point D corresponds to distance ζ from the origin where $\zeta = \frac{2z_1z_2e^2}{E}$.B is a point chosen on the curve AC such that $\delta = \frac{\sqrt{2E/m_c}}{\omega}$ which corresponds to the radius of the cluster nuclei.CD corresponds to a linear drop in the maximum potential at C to cut off potential at D given by ζ corresponding to Q value. This leads to smoothening of the potential in the region AC and removes the abrupt change of potential at distance R. The force is absent on the emitted cluster particle when it is present in the range $0 < r < \delta$ followed by a force of attraction present in the range of $\delta < r < R$. The coulomb repulsive force becomes active outside the barrier where $r \to R$. This approach would be closer to the actual physical process and shall give more accurate results.

The potential function is now:

$$V(r) = \frac{1}{2} m_\alpha \omega r^2 \qquad \delta \leq r \leq R$$

$$= \frac{2Ze^2}{r} R \leq r \leq \zeta$$

The Gamow's factor "G", estimated again was:

$$G = \sqrt{\frac{2m_\alpha}{\hbar^2}} \left[\int_\delta^R dr \sqrt{\left(\frac{1}{2} m_\alpha \omega r^2 - E \right)} \right] + \int_R^\zeta dr \sqrt{\left(\frac{2Ze^2}{r} - E \right)} \text{ ……….. } (1)$$

$$G = \sqrt{\frac{2m_\alpha}{\hbar^2}}\Bigg[\bigg[\frac{R}{2}\sqrt{\frac{1}{2}m_\alpha\omega^2R^2 - E} - \frac{\delta}{2}\sqrt{\frac{1}{2}m_\alpha\omega^2\delta^2 - E} + \frac{E}{\omega\sqrt{2m_\alpha}}ln\left(\frac{\delta m_\alpha\omega^2+\omega\sqrt{2m_\alpha}\sqrt{\frac{1}{2}m_\alpha\omega^2\delta^2-E}}{Rm_\alpha\omega^2+\omega\sqrt{2m_\alpha}\sqrt{\frac{1}{2}m_\alpha\omega^2R^2-E}}\right)\Bigg] +$$

$$\left[\frac{2Z_1e^2\pi^2}{hv_\alpha}\frac{8\pi e}{h}\sqrt{\mu Z_1 r_d}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2 a)}$$

Equation (1) shows the estimated decay rate after solving the model using Gamow's theory of alpha decay. Since the penetration probability is given by P = e^{-2G}...(2b)Then the two lines of equation (2) appear to be the correction in decay rate with respect to Gamow's result. In this model the decay constants is defined as the product of the penetration probability, the assaulted frequency and the pre-formation factor. The decay of parent nuclei is the process of pre –born and then their penetrations. In the alpha decay process the parent nuclei is divided into two fragments: the alpha particle and the residual daughter nuclei [5]. Therefore, decay constant is given by,$\lambda = nPP_0$..(3) Where $\boldsymbol{P_0}$ **is known as the Pre-formation factor**.By substituting the value of equation (2) in equation nos.(3) and rearranging we get:

$$ln\lambda=\ln n-2\sqrt{\frac{2m_\alpha}{\hbar^2}}\Bigg[\bigg[\frac{R}{2}\sqrt{\frac{1}{2}m_\alpha\omega^2R^2 - E} - \frac{\delta}{2}\sqrt{\frac{1}{2}m_\alpha\omega^2\delta^2 - E} + \frac{E}{\omega\sqrt{2m_\alpha}}ln\left(\frac{\delta m_\alpha\omega^2+\omega\sqrt{2m_\alpha}\sqrt{\frac{1}{2}m_\alpha\omega^2\delta^2-E}}{Rm_\alpha\omega^2+\omega\sqrt{2m_\alpha}\sqrt{\frac{1}{2}m_\alpha\omega^2R^2-E}}\right)\Bigg]+$$

$$\left[\frac{2Z_1e^2\pi^2}{hv_\alpha} - \frac{8\pi e}{h}\sqrt{\mu Z_1 r_d}\right] + lnP_0\ldots\ldots\ldots\text{(4)}$$

WhereR is the radius of parent nucleus given by: R = $r_oA^{1/3}$ .E is the energy of alpha particle(MeV).W is the angular frequency given by $V_\alpha/2R$ (sec^{-1}).... (5) δ is the radius of daughter nuclei.

The above equation is the expected expression for the decay constant of alpha particles. **Half life** is defined as the time taken by a nucleus to reduce to half of its original values. It can be calculated by the formula: $\lambda=\frac{\ln 2}{T_{1/2}}\ldots..6(a) log_{10}T_{1/2} = log_{10}0.693 - log_{10}\lambda\ldots.6(b)$ The pre-formation factor Po which is present inside the parent nucleus can be extracted by using Eqs 2(a),2(b), 5 and 6(a), in Eq (3).

By using equations (5) and (6) the **decay constants** and **half lives** of different nuclei can be calculated respectively.

3. VALIDITY OF GEIGER - NUTTAL LAW

Gamow's theory can be verified using Geiger-Nuttall law. This law is valid for the radioactivity of all clusters (including α particle). A correlation exists between the decay constant and the alpha kinetic energy such that large decay energies are usually associated with large decay constants (small half lives). A successful effort to express the correlations quantitatively was first made by Geiger and Nuttall [6]in 1911, who found an empirical relation between the alpha particles' range in air and the decay constant. This regularity may be converted into an equivalent relation between the decay constants and alpha energy by use of the range-energy curve for the alpha particles in air. We have calculated the relation of GN law for even-even superheavy elements. This is equivalent Geiger Nuttall law:$\boldsymbol{log_{10}T_{1/2} = \frac{1}{\sqrt{Q}}}$**.......(7)**

This radioactive decay law shows a linear relation between the half-lives of the decaying SHE and their corresponding *Q*-values. In this decay law the penetrability is still a dominant quantity.

4. GRAPHICAL ANALYSIS AND TABULATIONS

Table 1: The first and second columns represent the parent nuclei and the daughter nuclei, respectively. The third and fourth column corresponds to the released energies of different even-even heavy nuclei and the assault frequency. The fifth and sixth columns represents calculated pre-formation factor, penetration probability for S-Model respectively. The seventh and eighth columns correspond to the half lives by experiment and S-Model, respectively. The last two columns represent the logarithmic half-life values (7)

Nuclei	Daughter Nuclei	Q_α (MeV)	ν $(\times 10^{21})s^{-1}$	Ln P_0	Ln P	$T_{\alpha\ exp}$ sec	$T_{\alpha\ cal}$ sec	Log $T_{1/2\ exp}$ sec	Log $T_{1/2\ cal}$ sec
$^{294}118$	$^{290}116$	11.81	1.51	1.023	44.859	0.89ms	0.79ms	-3.050	-3.102
$^{292}116$	$^{288}114$	10.66	1.44	3.835	50.660	18ms	16.66ms	-1.744	-1.778
$^{290}116$	$^{286}114$	11.00	1.46	2.312	48.948	7.1ms	13.5ms	-2.148	-1.869
$^{288}114$	$^{284}112$	10.09	1.40	2.095	52.693	0.80s	0.74ms	-0.090	-0.130
$^{286}114$	$^{282}112$	10.33	1.42	2.850	51.643	0.13s	0.12ms	-0.886	-0.920
^{270}Ds	$^{266}110$	11.20	1.52	1.802	43.481	0.1ms	0.092ms	-4.00	-4.036
^{266}Hs	$^{262}106$	10.34	1.46	2.445	47.237	2.3ms	2.14ms	-2.638	-2.669
^{264}Hs	$^{260}106$	10.58	1.48	3.632	46.215	0.25ms	0.23ms	-3.602	-3.638
^{260}Sg	$^{256}104$	9.93	1.44	3.632	46.215	0.25ms	0.23ms	-2.070	-2.102

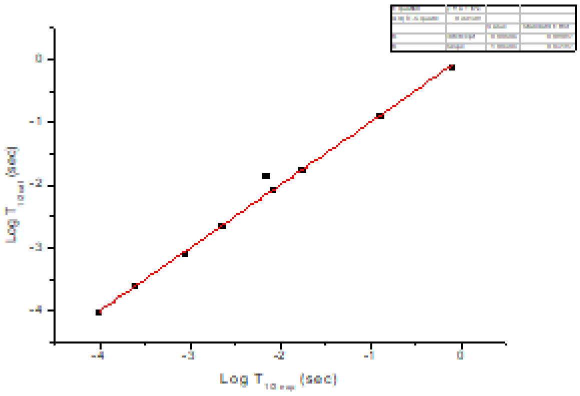

Fig 2:This shows the linearity between the experimental and calculated T1/2 in sec.

Table 2: This table shows the variation of energies of SHE with respect to logarithmic values of half-lives.

Nuclei	Daughter Nuclei	Q_α (MeV)	$Q_\alpha^{-0.5}Z_d$ $(MeV)^{-1}$	Log $T_{1/2\ exp}$ sec	Log $T_{1/2\ cal}$ sec
$^{294}118$	$^{290}116$	11.81	33.768	-3.050	-3.102
$^{292}116$	$^{288}114$	10.66	34.916	-1.744	-1.778
$^{290}116$	$^{286}114$	11.00	34.372	-2.148	-1.869
$^{288}114$	$^{284}112$	10.09	35.259	-0.090	-0.130
$^{286}114$	$^{282}112$	10.33	34.847	-0.886	-0.920
^{270}Ds	$^{266}110$	11.20	32.868	-4.00	-4.036
^{266}Hs	$^{262}106$	10.34	32.964	-2.638	-2.669
^{264}Hs	$^{260}106$	10.58	32.588	-3.602	-3.638
^{260}Sg	$^{256}104$	9.93	33.003	-2.070	-2.102

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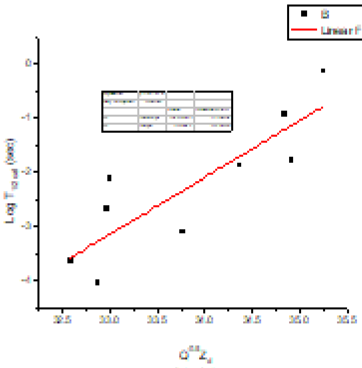

Fig 3:This proves the Geiger-Nuttall law

5. DISCUSSION AND CONCLUSION

Gamow's theory of alpha decay is further modified for the even-even superheavy elements (SHE). We have already studied the detailed analysis of the simple spherical symmetric potential (1). We have seen that in simple spherical symmetric potential there is a discontinuous jump of the potential which is not a physical system as the force becomes infinite at that point. The values of released energies are from the experimental data [8].Finally we modified the potential which we call it as "the S-potential". The model reproduces alpha decay half-lives by keeping the radius constant r_0 at 1.2 fm. Through analyzing and comparing the pre-formation factor, the information of nuclear structure can be provided and thus the half lives can be calculated. The values of the assault frequency *v*, the penetration probability *P* and the pre-formation factor P_0 are listed for SHE in Table 1. The assault frequencies are kept in the magnitude of 10^{21} $s^{-1.}$ Figure 2; we observe that the calculated $LogT_{1/2}$ via our S-potential to be in close agreement to experimental $LogT_{1/2}$ .Table 2 represents the energies of the different nuclei with their corresponding half-lives. A graph is plotted to show the variation of energies and the logarithmic value of half-lives in figure 3.The graph shows a linear nature which proves the validity of Geiger-Nuttall law as shown in eqs 7.

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