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ENGINEERING PHYSICS

Radhakrishnan S, Ph.D.

Department of Science and Humanities

ENGINEERING PHYSICS

Unit II : Quantum Mechanics of simple systems

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Class #16

- Radioactive alpha decay
- Nuclear surface potential
- Alpha decay as a case of barrier tunneling

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Unit I : Review of concepts leading to Quantum Mechanics

- ***Suggested Reading***

    1. ***Concepts of Modern Physics, Arthur Beiser, Chapter 5***
    2. ***Learning Material prepared by the Department of Physics***

- ***Reference Videos***

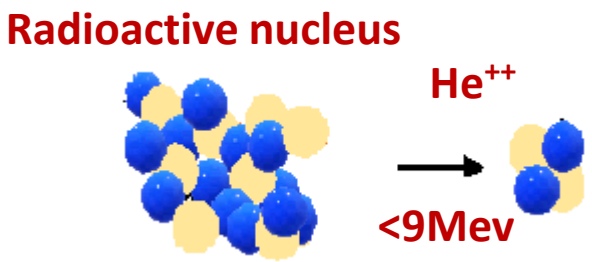
    1. ***Video lectures : MIT 8.04 Quantum Physics I***
    2. ***Engineering Physics Class #15***

Radioactive alpha decay

Alpha particles are He nuclei with 2 protons and 2 neutrons

alpha particles are emitted from a radioactive nucleus with energies of the order of 8 MeV

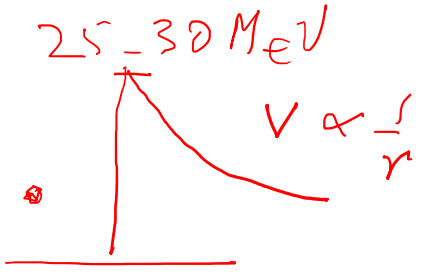
The half life of different radioactive nuclei differ vary vastly in time scales varying from 10^{-9} seconds to 10^{16} years



Radioactive Nuclear decay

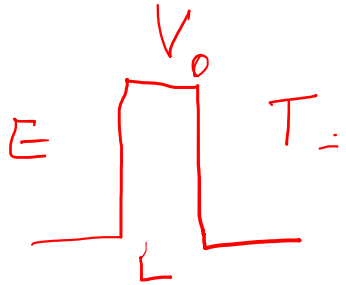
Backscattering experiment reveal existence of a coulomb barrier at the nuclear surface

The potential barrier at the nuclear surface $\approx 20 - 30\ MeV$



The alpha particle emission with energy < 9MeV from the nucleus overcoming a potential barrier of 20-30 MeV

….. A case of barrier tunneling



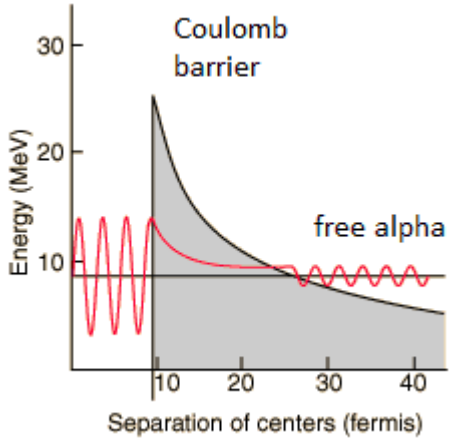


Image courtesy : Hyperphysics

Radioactive Nuclear decay

The tunneling co-efficient for alpha particles can be estimated as $T \cong e^{-2\alpha L}$

L is the distance from the nuclear surface $\approx 20 - 30\ pm$

V_o *is the coulomb barrier at the nuclear surface* $\approx 25\ MeV$

and E *is the energy of the alpha particle* $\approx 5 - 8\ MeV$

$\alpha = \sqrt{\frac{2m(V_o - E)}{\hbar^2}}$ *with m equal to the mass of the* He^{++}

The transmission co-efficient evaluated for a rectangular barrier does not give correct estimations of the radioactive lifetime of atoms.

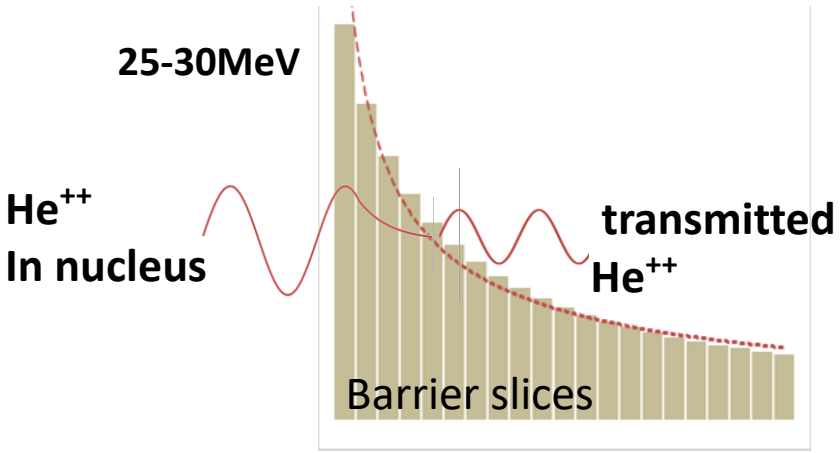
Radioactive alpha decay

An alternate way of looking at the potential barrier is to slice the barriers into n equal widths say Δr but of varying heights

$$V(r) = \frac{2(Z-2)ke^2}{r}$$

The transmission coefficients of each of the slices are estimated as $T_1, T_2, T_3 \ldots T_n$ with a constant E and a variable V.

The effective tunneling probability $T_{eff} = T_1 \times T_2 \times T_3 \ldots\ldots \times T_n$



Radioactive Nuclear decay

Since the potential is a function of r *the decay constant is also a function of* r *given by* $\alpha = \sqrt{\frac{2m(V(r)-E)}{\hbar^2}}$

The tunneling probability for alpha particles can be estimated as $T \cong e^{-2\int \alpha\, dr}$ *integrated between the nuclear surface and the* r

alpha particles modeled to be in a state of constant motion with a very high kinetic energy

frequency of approach to the nuclear surface = the velocity of the particle divided by the diameter of the nucleus

Radioactive Nuclear decay

Frequency × tunneling probability = probability that an alpha particle is emitted out of the nucleus in unit time

The decay time of a nucleus can be estimated from this tunneling probability

The inverse of this probability is then the mean lifetime for alpha decay of the radioactive nucleus.

A calculation of the half life of $^{212}Po_{84}$ yields a value of 0.25 micro seconds which is very close to the experimentally observed values of 0.30 micro seconds

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Class #16 …….. Quiz….

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Radioactive alpha decay ……

1. The Coulomb potentials at the nuclear surfaces are of the order of 20 to 30 MeV
2. Alpha particles with 10 MeV energy can penetrate the coulomb potential at the surface of a nucleus
3. The decaying coulomb potential can be divided into a series of rectangular potentials of small width Δr
4. The transmission co-efficient can be estimated as the product of the transmission co-efficients of the individual rectangular potentials.
5. Barrier tunneling is can explain all alpha decay problems with high accuracy

THANK YOU

Radhakrishnan S, Ph.D.

Professor, Department of Science and Humanities

sradhakrishnan@pes.edu

+91 80 21722683 Extn 759