COMPLEMENTARY CHEMISTRY COURSES
SEMESTER - I
15U1CPCHE1: GENERAL CHEMISTRY
(Common to Physical sciences and Life sciences)

NUCLEAR CHEMISTRY

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Contents

- Stability of Nucleus:- binding energy, magic number, packing fraction, n/p ratio.
- Radioactivity: natural radioactivity, induced radioactivity, fertile and fissile isotopes, units of radioactivity.
- Nuclear Reactions: fission and fusion, chain reactions, disposal of nuclear wastes.
- Applications: Reactors – conventional and breeder, energy generation, radiocarbon dating, medical, agricultural and industrial applications.

NUCLEAR CHEMISTRY

Nuclear chemistry is the subfield of chemistry dealing with radioactivity, nuclear processes, and transformations in the nuclei of atoms.

Nuclear stability

- Binding energy
- n/p ratio
- Magic number
- Packing fraction

Radioactive Decay

- **Radioactive decay**
  - the process by which an unstable atomic nucleus loses energy (in terms of mass in its rest frame) by emitting radiation
  - such as
  - *alpha particle*
  - *beta particle with neutrino or only a neutrino in the case of electron capture, or a gamma ray or electron in the case of internal conversion*

Kinetics

Radioactive decay law

- If N radioactive nuclei are present at time t and if no new nuclei are introduced into the sample, then the number dN decaying in a time dt is proportional to N and so

$$\lambda = -\frac{(\frac{dN}{dt})}{N}$$

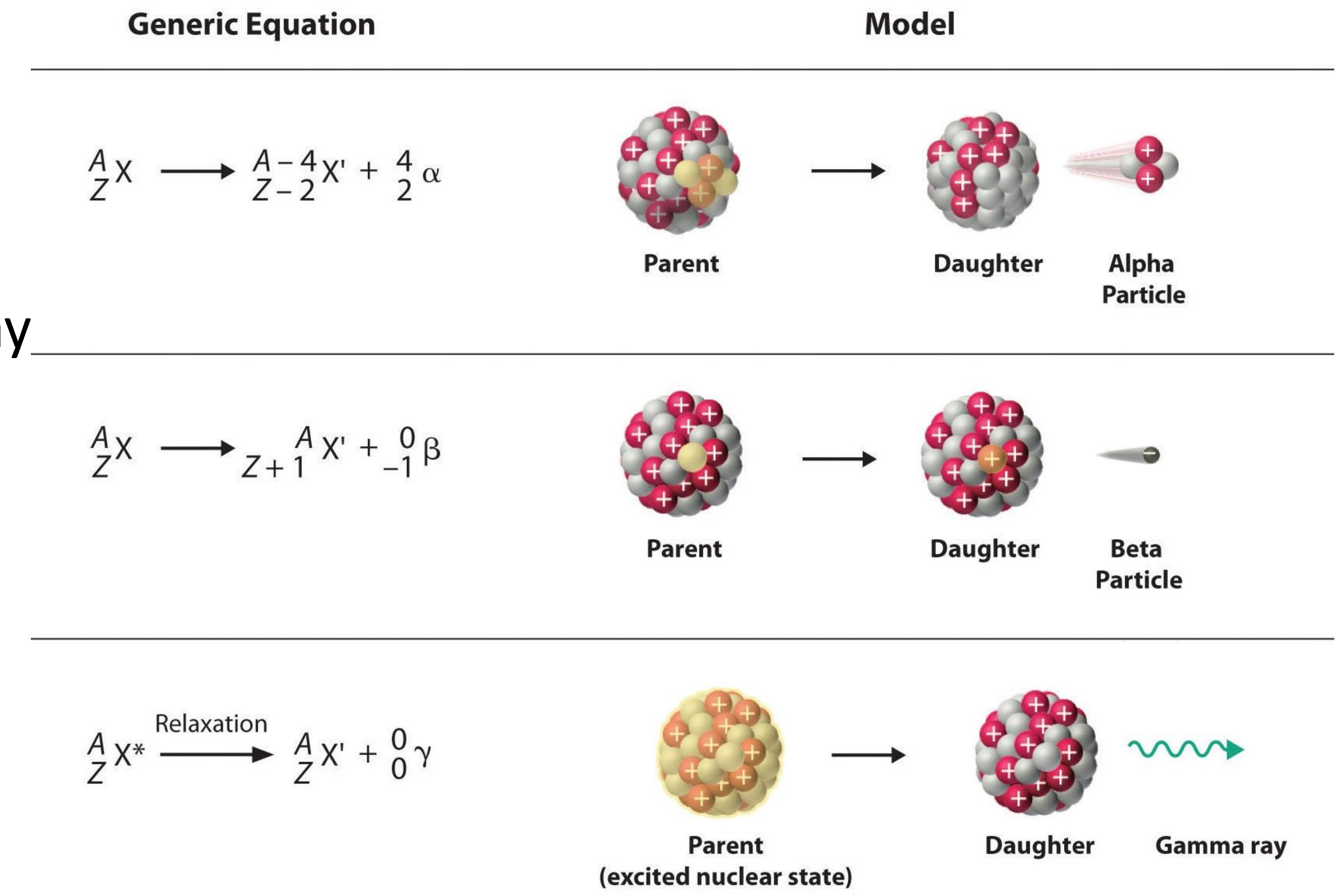
Integrating, we get the ***exponential law of radioactive decay.***

$$N = N_0 e^{-\lambda t}$$

- Where N_0 is the number of nuclei present at time t=0.

RADIOACTIVE DECAY

- Decay series
- Alpha decay
- Beta decay
- Gamma decay



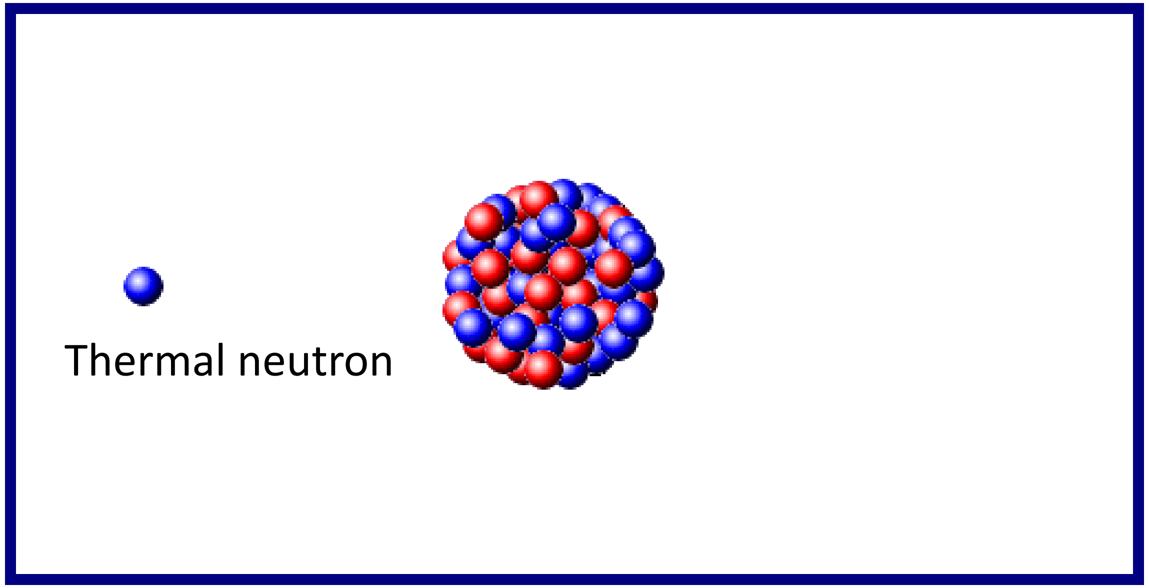
Fusion reactors

- For commercial production of electricity
- Hydrogen fusion reactors
  - Fuel: ${}_{1}^{1}H$- to bring about reactions as those occur in stars

    deuterium, tritium practically used due to the larger reaction cross section and much lower threshold temperature

    ${}_{1}^{2}H + {}_{1}^{3}H \rightarrow {}_{2}^{4}He + n + \gamma$ (energy= 17.6 MeV)
- hurdles on developing a fusion reactor:
  1. attain high temperatures as 20-100 MK (as those in stars)
  2. Confine the reaction in suitable structure

NUCLEAR FISSION REACTION



Nuclear fission is a process in which the nucleus of an atom splits into two or more smaller nuclei as fission products, and usually some by-product particles.

$$ {}_{0}^{1}n + {}_{92}^{235}U \rightarrow [{}_{92}^{236}U] \xrightarrow{85\%} fission\ (e.g.\ {}_{56}^{139}Ba + {}_{36}^{94}Kr + 3\ {}_{0}^{1}n) $$

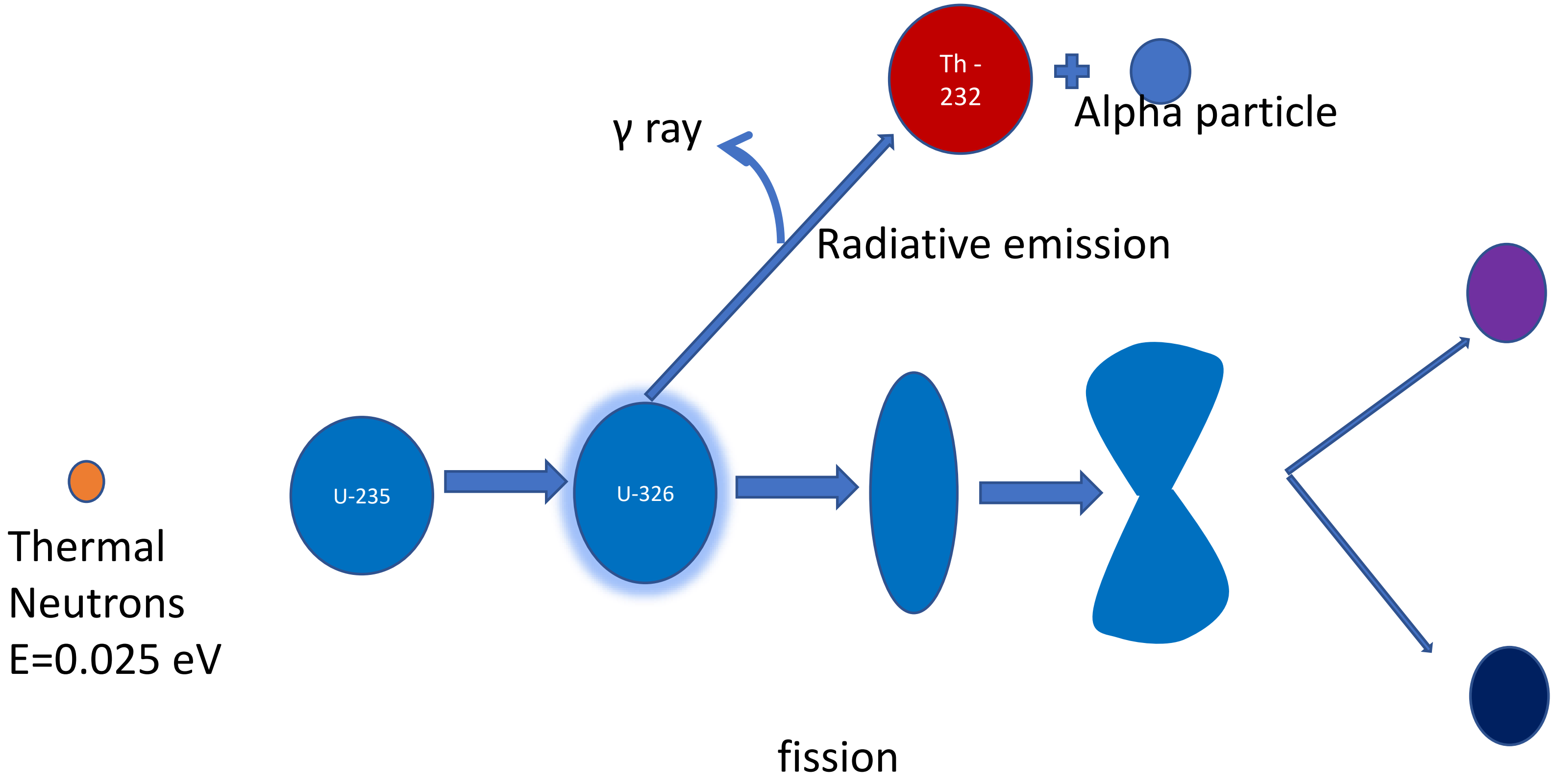
Theory and process

- Explained using liquid drop model
- Nucleus : incompressible liquid whose size is proportional to number of nucleons (A)
- Shape is determined by coulomb force and surface tension
- When excited by neutron capture or other process,
- if excitation energy is not high enough, the nucleus revert back to initial state by radiative decay or by emission of particles such as α.
- If excitation energy is high enough it may undergo fission

$$ {}_0^1n + {}_{92}^{235}U \rightarrow [{}_{92}^{236}U] \xrightarrow{85\%} fission\ (e.g.\ {}_{56}^{139}Ba + {}_{36}^{94}Kr + 3\ {}_0^1n) $$

$$ {}_0^1n + {}_{92}^{235}U \rightarrow [{}_{92}^{236}U] \xrightarrow{15\%} {}_{92}^{236}U + \gamma $$ ***RADIATIVE CAPTURE***

Fission process

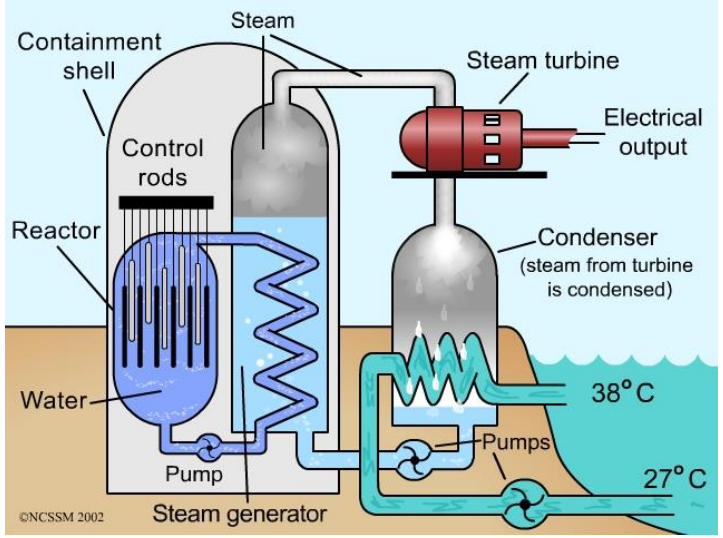


NUCLEAR REACTOR

A nuclear reactor is a system that contains and controls sustained nuclear chain reactions. Reactors are used for generating electricity, moving aircraft carriers and submarines, producing medical isotopes for imaging and cancer treatment, and for conducting research.

The reactor core generates heat in a number of ways:

- The kinetic energy of fission products is converted to thermal energy when these nuclei collide with nearby atoms.
- The reactor absorbs some of the gamma rays produced during fission and converts their energy into heat.
- Heat is produced by the radioactive decay of fission products and materials that have been activated by neutron absorption. This decay heat-source will remain for some time even after the reactor is shut down.



COMPONENTS OF A NUCLEAR REACTOR AND REACTOR CONTROL

1. **Core**: Part of reactor containing fuel elements (fissile U-235, U-233, Pu239 etc.). Fuel elements are made of plates, or rods of Uranium metal or ceramic, which are usually clad in a thin sheath of SS, Zirconium or aluminium to provide corrosion resistance, retention of radioactivity and structural support.
2. **Core moderator**: commonly water (H_2O or D_2O) or graphite is dispersed between the fuel assemblies to moderate or slow down fast neutrons produced during fission.
3. **Control rods**: Made of neutron absorbing materials (B, Cd, Ag and In)upon movement in or out of the core, vary the number of neutrons available for chain reactions.
4. **Reflector:** surround the core to reduce the loss of the neutrons. Graphite, light water and beryllium is used as reflector.
5. **Coolant:** the heat generated as a result of fission is removed by circulation of coolant through the core. Coolant used should have high BP, low MP and should be resistant to corrosion. CO_2, H_2O, molten Na, mercury etc are used as coolant.
6. **Radiation shielding / biological shielding:** for preventing the radiation hazard.

Mainly 2 characteristics of fission reaction are of great importance:

1. Each fission reaction releases large amount of energy
2. Each fission results in an average of 2.5 neutrons (in case of U-235)

- A portion of these neutrons may be absorbed by other fissile atoms and trigger further fission events, which release more neutrons, and so on. This is known as a nuclear chain reaction.
- In nuclear reactors, this chain reaction will proceed in a constant rate by controlling the chain propagation

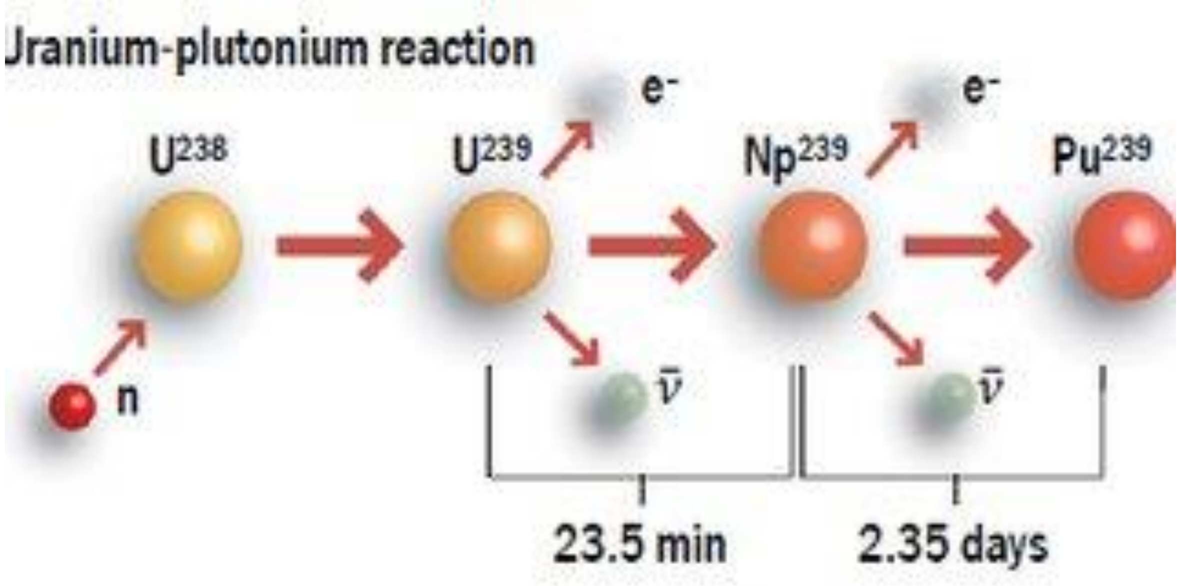
Sustained chain reaction: the key

Breeder Reactor

- A Breeder Reactor is a nuclear reactor that "breeds" fuel.
- Types
  - Fast breeder reactor
  - Thermal breeder reactor

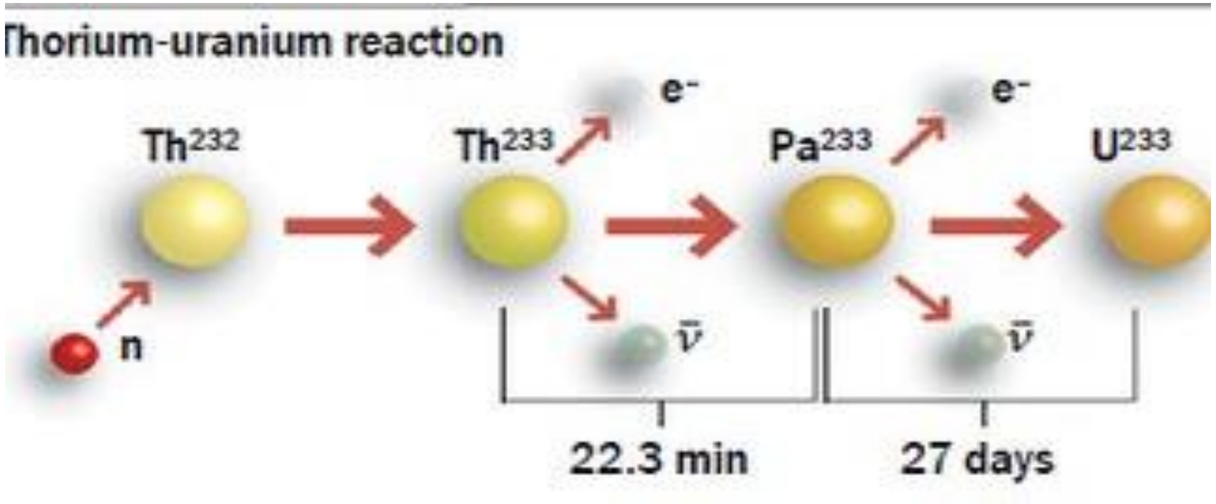
Fast breeder reactor

- convert uranium-238 into the fissionable isotope plutonium-239



Thermal breeder reactor

- converts this isotope into fissionable uranium-233



Fast Breeder Test Reactor

- breeder reactor located at Kalpakkam, India.
- The Indira Gandhi Center for Atomic Research (IGCAR) and Bhabha Atomic Research Centre (BARC) jointly designed, constructed, and operate the reactor.
- The reactor uses a **plutonium-uranium** mixed carbide fuel and liquid sodium as a coolant.


applications
Chemical investigation
Physico-chemical applications
Analytical applications
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Medical application
Agriculture applications
Prospecting of natural resources
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