NUCLEAR CHEMISTRY

1. Nuclear Fission

Splitting of a heavy nucleus (A > 200) into lighter nuclei with release of large energy (~200 MeV per fission). Example: $^{235}U + n \rightarrow {}^{141}Ba + {}^{92}Kr + 3n$ + energy.

Types of Fission: Controlled (in reactors) and Uncontrolled (in atomic bombs).

2. Nuclear Fusion

Combination of light nuclei to form heavier nuclei with huge energy release, e.g., $^{2}H + {}^{3}H \rightarrow {}^{4}He + n + 17.6$ MeV. Occurs in sun and stars at 10^{7}–10^{8} K.

3. Radio-Analytical Techniques

Technique	Principle	Application
Isotope Dilution	Radioactive isotope mixed with sample; activity measured.	Trace element analysis.
Radiometric Titration	Radioactivity change indicates end point.	Precipitation, complexation titrations.
Tracer Technique	Radioisotope traces reaction path.	Reaction mechanism studies.
Activation Analysis	Irradiation induces radioactivity; γ-rays identify elements.	Non-destructive elemental analysis.

4. Activation Analysis

Sample irradiated with neutrons → nuclei become radioactive → characteristic γ-rays identify elements. Highly sensitive, non-destructive method used in trace and forensic analysis.

5. Decay Modes

Decay Type	Change in Nucleus	Example
α-decay	Mass ↓ by 4, Z ↓ by 2	$^{238}U \rightarrow {}^{234}Th + \alpha$
β^--decay	Neutron → Proton + e^-	$1{}^{4}C \rightarrow {}^{14}N + e^- + \bar{\nu}$
β^+-decay	Proton → Neutron + e^+	$^{22}Na \rightarrow {}^{22}Ne + e^+ + \nu$
Electron Capture	Nucleus captures e^-	$^{40}K + e^- \rightarrow {}^{40}Ar + \nu$
γ-decay	Excited → ground + γ	$^{60}Co^* \rightarrow {}^{60}Co + \gamma$

6. Types of Nuclear Reactions

Reaction Type	Equation / Description	Remarks
Elastic/Inelastic scattering	nucleus + projectile → recoil (+ γ)	Elastic: no energy loss; Inelastic: excitation.

Transmutation	$^{14}N + \alpha \rightarrow {}^{17}O + p$	Artificial change of element.
Photonuclear Reaction	(γ, n), (γ, p)	Induced by γ-rays.
Spallation	High-energy bombardment ejects nucleons	Used in accelerators.
Fragmentation	Heavy ion → multiple fragments	Astrophysical significance.
Fusion	Light nuclei combine	Occurs in stars.

7. Reaction Energetics

Term	Meaning	Remarks / Unit
Threshold Energy	Minimum energy for a reaction.	Depends on mass defect.
Energy Barrier	Coulombic repulsion between nuclei.	Overcome by high KE.
Q-Value	Energy change in reaction.	Positive → exoergic; Negative → endoergic.
Nuclear Cross Section	Probability of reaction.	Unit: barn (10^{-28} cm^2).

8. Fission as a Chain Reaction

Neutrons from one fission cause further fissions. Controlled by moderators (D_2O, graphite) and control rods (Cd, B). Critical mass needed to sustain reaction.

Component	Function
Moderator	Slows neutrons (D_2O, graphite).
Control rods	Absorb excess neutrons (Cd, B).
Coolant	Removes heat (Na, CO_2, H_2O).

9. Nuclear Fuels

Type	Definition	Example
Fissile Isotopes	Undergo fission with slow neutrons.	^{235}U, ^{239}Pu, ^{233}U
Fertile Isotopes	Convert into fissile on neutron absorption.	$^{238}U \rightarrow {}^{239}Pu$; $^{232}Th \rightarrow {}^{233}U$

10. Radiation Hazards

Sources: α, β, γ, X-rays, neutrons. **Effects:** Ionization, DNA damage, burns, mutations. **Units:** Curie (Ci), Gray (Gy). **Protection:** shielding, time reduction, distance maximization.

11. Nuclear Reactors in India

Reactor	Type	Location	Fuel / Moderator
Apsara	Swimming pool type	Trombay	Natural U, water
CIRUS	Heavy water moderated	Trombay	Natural U, D_2O
Dhruva	Research reactor	Trombay	Natural U, D_2O
TAPS-1 & 2	Power reactor	Tarapur	Enriched U, light water
MAPS	Madras Atomic Power Station	Kalpakkam	Natural U, heavy water
KAPS	Kakrapar Power Station	Gujarat	PHWR
Kudankulam	Pressurized water reactor (VVER)	Tamil Nadu	Enriched U, light water

12. Quick Revision Summary

- Fission: Splitting of heavy nuclei → 200 MeV energy.
- Fusion: Combination of light nuclei → high energy.
- Activation Analysis: Neutron activation; γ emission analysis.
- Decay Modes: α, β^-, β^+, EC, γ.
- Q-Value: Energy released or absorbed in reaction.
- Cross Section: Reaction probability (barn).
- Chain Reaction: Fission propagated by neutrons.
- Fissile: Directly fissionable by slow neutrons.
- Fertile: Converts into fissile isotope.
- Reactor Components: Moderator, control rod, coolant.