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Introduction

Key Points

- Positive charge and mass concentrated in nucleus at atom's center.
- Volume of nucleus $\approx 10^{-15}$ times volume of atom.
- Atom is mostly empty space.
- Chapter covers nuclear size, mass, stability, radioactivity, fission, fusion.

Solved Examples

Practice Set

- Q1: What fraction of an atom's volume is occupied by its nucleus?
  - A) 10^{-10}
  - B) 10^{-15}
  - C) 10^{-5}
  - D) 10^{-20}
- Q2: The nucleus contains
  - A) Only electrons
  - B) Protons and neutrons
  - C) Only protons
  - D) Electrons and neutrons
- Q3: Which phenomenon is NOT related to the nucleus?
  - A) Radioactivity
  - B) Fission
  - C) Chemical bonding
  - D) Fusion

Answer Key

- Q1: B - Nucleus volume is about 10^{-15} times the atom's volume.
- Q2: B - Nucleus contains protons and neutrons (nucleons).
- Q3: C - Chemical bonding involves electrons, not nucleus.

Memory Aids

- Remember: Atom = mostly empty, nucleus tiny but dense.
- 10^{-15} volume ratio is key fact.
- Nucleus = protons + neutrons only.

Atomic Masses and Composition of Nucleus

Atomic Mass

- Average atomic mass = weighted average of isotopes' masses.
- 1 amu = $\frac{1}{12}\times$ mass of carbon-12 atom = 1.660539×10^{-27} kg.
- 1 amu = 931 MeV/c² (energy equivalent).

Composition of Nucleus

- Nucleons = protons + neutrons.
- Atomic number Z = number of protons.
- Mass number $A = Z + N$ (protons + neutrons).
- Nuclear mass = total mass of protons and neutrons.
- Nuclide notation: ${}^{A}_{Z}X$, where X = element symbol.

Properties of Nucleons

- Proton (p): charge +e, mass ~1 amu, rest energy ~938 MeV.
- Neutron (n): charge 0, mass ~1 amu, rest energy ~940 MeV.

Name	Symbol	Charge	Mass	Rest energy
Proton	p	$+e$	1.007276 u	938.28 MeV
Neutron	n	0	1.008665 u	939.57 MeV

Solved Examples

- Ex 1: Calculate mass of nucleus with 6 protons and 6 neutrons.
  - Mass $= (6 + 6) \times 1 \text{ amu} = 12 \text{ amu}$

Practice Set

- Q1: 1 amu equals
  - A) 1.660539×10^{-27} kg
  - B) 1.992647×10^{-26} kg
  - C) 931 MeV/c²
  - D) Both A and C
- Q2: Atomic number Z is
  - A) Number of neutrons
  - B) Number of protons
  - C) Sum of protons and neutrons
  - D) Number of electrons
- Q3: Nuclide notation ${}^{A}_{Z}X$ means
  - A) A = atomic number, Z = mass number
  - B) Z = atomic number, A = mass number
  - C) A = number of protons, Z = number of neutrons
  - D) X = neutron symbol

Answer Key

- Q1: D - 1 amu = 1.660539×10^{-27} kg and 931 MeV/c².
- Q2: B - Atomic number is number of protons.
- Q3: B - Z is atomic number, A is mass number.

Memory Aids

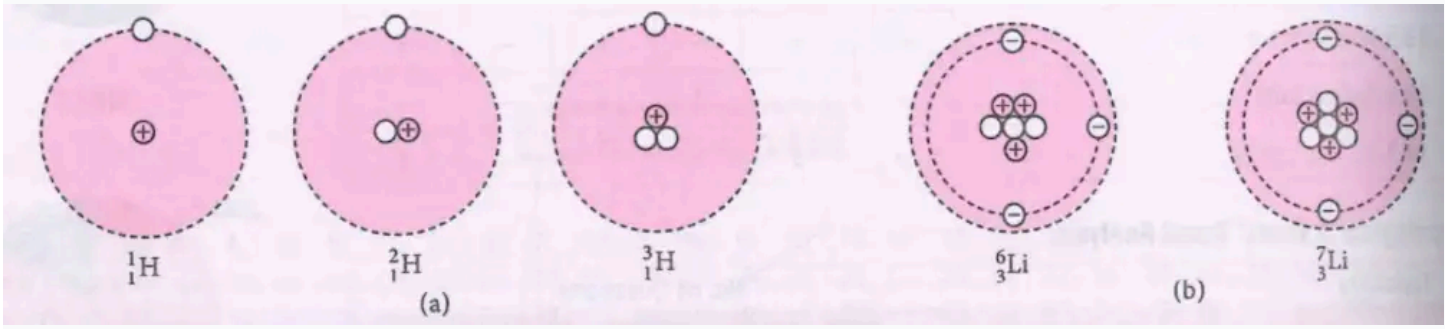
- 1 amu = mass of ${}^{12}C$ atom / 12.
- Atomic number = protons; Mass number = protons + neutrons.
- Nuclide notation: ${}^{A}_{Z}X$.

Isotopes Isobars Isotones and Isomers

Isotopes

- Same atomic number Z, different mass number A.
- Examples: Hydrogen isotopes - ${}^{1}H$, ${}^{2}H$, ${}^{3}H$.

- Lithium isotopes - ${}^{6}Li$, ${}^{7}Li$.



Isobars

- Same mass number A, different atomic number Z.
- Examples: ${}^{3}_{1}H$ and ${}^{3}_{2}He$, ${}^{37}_{17}Cl$ and ${}^{37}_{16}S$.

Isotones

- Same number of neutrons, different atomic number Z.
- Example: ${}^{37}_{17}Cl$ and ${}^{39}_{19}K$.

Isomers

- Same atomic number and mass number but different energy states.

Solved Examples

- Ex 1: Identify isotopes among ${}^{6}Li$ and ${}^{7}Li$.
  - Same $Z = 3$, different $A = 6, 7 \rightarrow$ isotopes.

Practice Set

- Q1: Isotopes have
  - A) Same mass number, different atomic number
  - B) Same atomic number, different mass number
  - C) Same number of neutrons, different atomic number
  - D) Same atomic and mass number, different energy

- Q2: Isobars are atoms with
  - A) Same atomic number, different mass number
  - B) Same mass number, different atomic number
  - C) Same number of neutrons, different atomic number
  - D) Same atomic and mass number, different energy
- Q3: Isotones have
  - A) Same atomic number, different mass number
  - B) Same mass number, different atomic number
  - C) Same number of neutrons, different atomic number
  - D) Same atomic and mass number, different energy

Answer Key

- Q1: B - Isotopes differ in mass number but have same atomic number.
- Q2: B - Isobars have same mass number but different atomic number.
- Q3: C - Isotones have same neutron number but different atomic number.

Memory Aids

- Isotopes: Same Z, different A.
- Isobars: Same A, different Z.
- Isotones: Same N, different Z.
- Isomers: Same A and Z, different energy.

Size of the Nucleus

Nuclear Size

- Volume of nucleus $\propto$ number of nucleons (mass number A)
- Formula: $\frac{4}{3}\pi R^3 \propto A$ or $R \propto A^{1/3}$
- Radius: $R = R_0 A^{1/3}$, where $R_0 = 1.2 \times 10^{-15}$ m

Nuclear Density

- Different elements have different A, so nuclei have different sizes
- Density formula: $\rho = \frac{\text{mass of nucleus}}{\text{volume of nucleus}}$

- $\rho = \frac{A \times 1 \text{ amu}}{\frac{4}{3}\pi R^3}$
- Using radius formula: $\rho = \frac{A \times 1.66 \times 10^{-27}}{\frac{4}{3}\pi R_0^3 A} = \frac{1.66 \times 10^{-27}}{\frac{4}{3}\pi R_0^3} = 2.29 \times 10^{17} \text{ kg/m}^3$
- Density is constant for all nuclei, independent of A
- Density is maximum at nucleus center and decreases towards edges; no sharp boundaries
- High density (~10^{17} kg/m³) indicates nucleus is highly compact

Solved Examples

Ex 1: Calculate the radius of a nucleus with mass number $A = 64$.

- Use $R = R_0 A^{1/3}$
- $R = 1.2 \times 10^{-15} \times 64^{1/3} = 1.2 \times 10^{-15} \times 4 = 4.8 \times 10^{-15}$ m

Ex 2: Find the nuclear density using $R_0 = 1.2 \times 10^{-15}$ m.

- $\rho = \frac{1.66 \times 10^{-27}}{\frac{4}{3}\pi (1.2 \times 10^{-15})^3} = 2.29 \times 10^{17}$ kg/m³

Practice Set

- **Q1:** The radius of a nucleus with mass number 27 is:
  - A) 3.6×10^{-15} m
  - B) 1.2×10^{-15} m
  - C) 2.4×10^{-15} m
  - D) 4.8×10^{-15} m
- **Q2:** Nuclear density is approximately:
  - A) 10^{10} kg/m³
  - B) 10^{17} kg/m³
  - C) 10^{5} kg/m³
  - D) 10^{3} kg/m³
- **Q3:** If the radius of a nucleus doubles, its volume changes by a factor of:
  - A) 2
  - B) 4
  - C) 6
  - D) 8

Answer Key

- **Q1:** A) 3.6×10^{-15} m — Using $R = R_0 A^{1/3} = 1.2 \times 10^{-15} \times 27^{1/3} = 3.6 \times 10^{-15}$ m
- **Q2:** B) 10^{17} kg/m³ — Nuclear density is constant and very high (~2.29×10^{17} kg/m³)
- **Q3:** D) 8 — Volume $\propto R^3$, doubling radius increases volume by $2^3 = 8$

Memory Aids

- Radius $R = R_0 A^{1/3}$ (cube root relation)
- Density constant $\approx 2.3 \times 10^{17}$ kg/m³ for all nuclei
- Volume $\propto A$, density independent of mass number
- High density means nucleus is very compact

Mass-Energy Equivalence

Key Concepts

- Mass is a form of energy; can convert mass to energy and vice versa.
- Einstein's relation: $E = mc^2$, where E is energy (J), m is mass (kg), $c = 3 \times 10^8\, m/s$.
- Energy from mass conversion can appear as kinetic or other energy forms.

Solved Examples

- **Ex 1:** Calculate energy equivalent of 1 g mass.
  - Convert mass: 1 g = 0.001 kg
  - Use $E = mc^2 = 0.001 \times (3 \times 10^8)^2 = 9 \times 10^{13}$ J

Practice Set

- Q1: Energy equivalent of 2 g mass is?
  - A) 1.8×10^{14} J
  - B) 1.8×10^{13} J
  - C) 9×10^{13} J
  - D) 3×10^8 J
- Q2: If mass decreases by 0.5 kg, energy released is?

    - A) 4.5×10^{16} J
    - B) 4.5×10^{17} J
    - C) 1.5×10^{17} J
    - D) 1.5×10^{16} J
- Q3: Which is true about mass-energy equivalence?
    - A) Mass can be fully converted to energy
    - B) Energy can be converted to mass
    - C) Both A and B
    - D) Neither A nor B

Answer Key

- Q1: A; $E = 0.002 \times (3 \times 10^8)^2 = 1.8 \times 10^{14} J$
- Q2: B; $E = 0.5 \times (3 \times 10^8)^2 = 4.5 \times 10^{16} J$
- Q3: C; Mass and energy are interchangeable as per $E = mc^2$

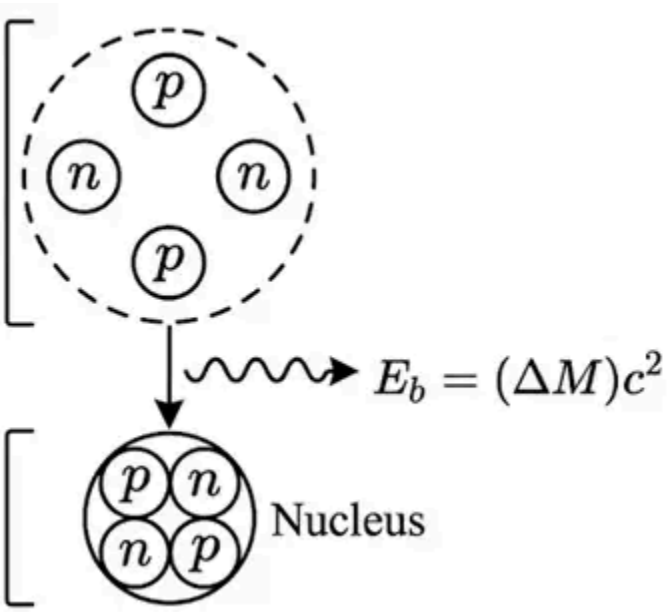
Memory Aids

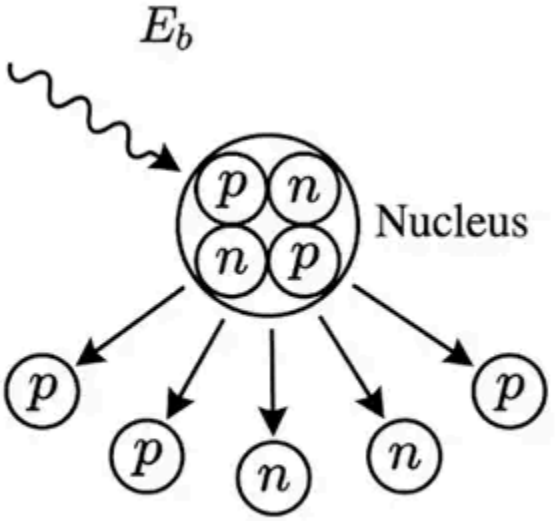
- Remember: $E = mc^2$ means mass times speed of light squared.
- Mass-energy conversion is huge energy for small mass.

Nuclear Binding Energy

Key Concepts

- Binding energy E_b holds nucleons (protons + neutrons) in nucleus.
- Mass defect $\Delta M = [Zm_p + (A - Z)m_n] - M$, where Z = protons, A = mass number, m_p, m_n = proton/neutron mass, M = nucleus mass.
- Binding energy formula: $E_b = \Delta M c^2 = ([Zm_p + (A - Z)m_n] - M)c^2$.
- Binding energy per nucleon: $\Delta E_{bn} = \frac{E_b}{A}$ (average energy to remove one nucleon).
- Energy released when nucleons bind; energy absorbed when nucleus splits (fission).





Solved Examples

- **Ex 1:** Calculate binding energy if $Z = 2$, $A = 4$, $m_p = 1.0073\,u$, $m_n = 1.0087\,u$, nucleus mass $M = 4.0026\,u$.
  - Mass defect $\Delta M = (2 \times 1.0073 + 2 \times 1.0087) - 4.0026 = 0.0288\,u$
  - Convert to kg: $1u = 1.66 \times 10^{-27} kg$
  - $\Delta M = 0.0288 \times 1.66 \times 10^{-27} = 4.78 \times 10^{-29} kg$
  - Binding energy $E_b = \Delta M c^2 = 4.78 \times 10^{-29} \times (3 \times 10^8)^2 = 4.3 \times 10^{-12} J$

Practice Set

- Q1: Mass defect is difference between?
  - A) Mass of nucleons and nucleus
  - B) Mass of electrons and nucleus
  - C) Mass of protons and neutrons
  - D) Mass of atom and nucleus
- Q2: Binding energy per nucleon is?
  - A) $E_b \times A$
  - B) $\frac{E_b}{A}$
  - C) $E_b + A$
  - D) $E_b - A$
- Q3: Which nucleus is most stable?
  - A) Hydrogen (A=1)
  - B) Iron (A=56)
  - C) Uranium (A=238)
  - D) Helium (A=4)

Answer Key

- Q1: A; Mass defect is difference between total nucleon mass and nucleus mass.
- Q2: B; Binding energy per nucleon = total binding energy divided by mass number.
- Q3: B; Iron has highest binding energy per nucleon, most stable nucleus.

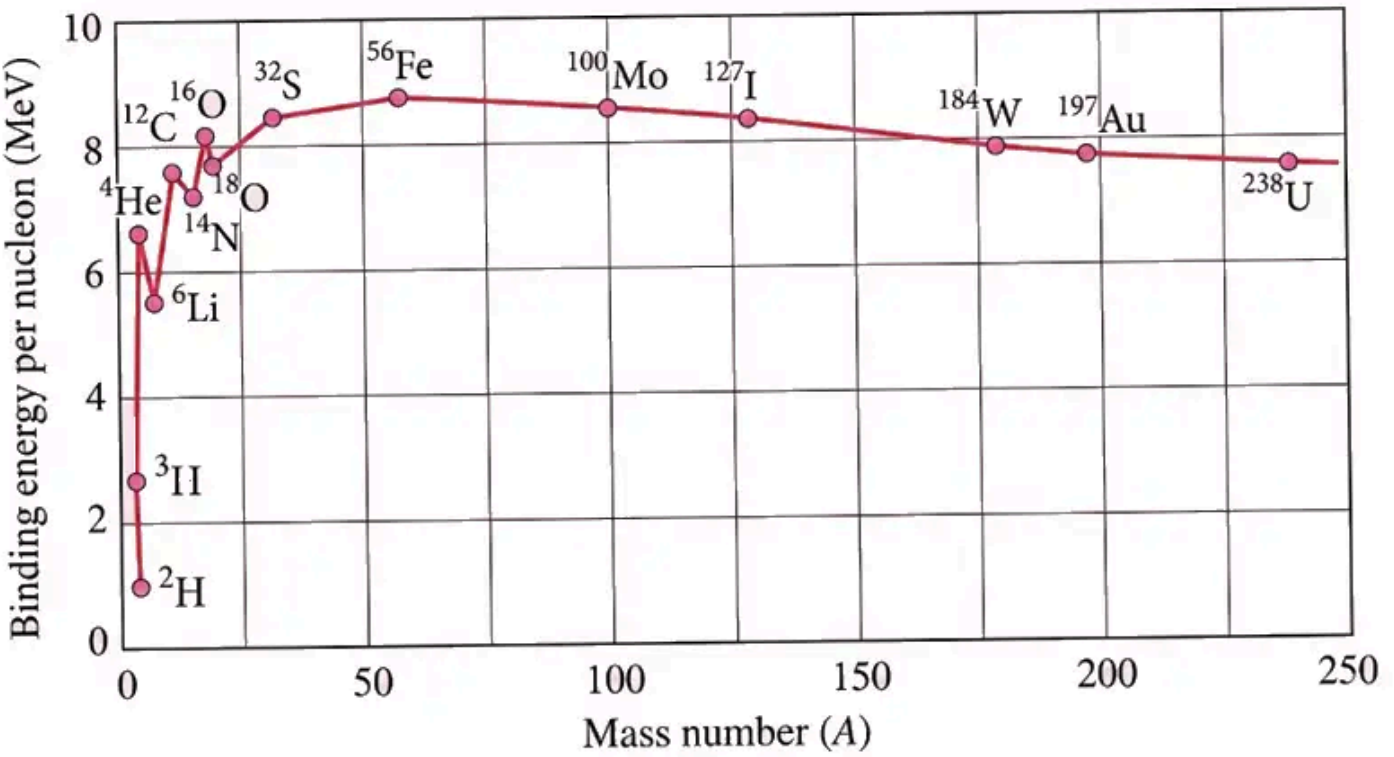
Memory Aids

- Binding energy $E_b = \Delta M c^2$.
- Mass defect = sum of nucleon masses - nucleus mass.
- Higher binding energy per nucleon means more stability.

Binding Energy Curve

Key Concepts

- Binding energy per nucleon E_{bn} vs mass number A graph shows nuclear stability.
- Peak at $A \approx 56$ (Iron), highest stability, $E_{bn} \approx 8.75$ MeV.
- Lighter and very heavy nuclei have lower E_{bn}, less stable.
- Energy release explained by nuclear fission and fusion:
  - Fission: heavy nucleus splits into lighter nuclei with higher E_{bn}.
  - Fusion: light nuclei combine to form heavier nucleus with higher E_{bn}.



Solved Examples

- **Ex 1:** Explain energy release in fission of uranium.
  - Uranium nucleus splits into lighter nuclei with higher binding energy per nucleon.
  - Energy released = difference in total binding energies.

Practice Set

- Q1: Maximum binding energy per nucleon occurs at?
  - A) Hydrogen
  - B) Iron
  - C) Uranium
  - D) Helium
- Q2: Nuclear fission releases energy because?
  - A) Heavy nucleus has lower binding energy per nucleon than fragments
  - B) Heavy nucleus has higher binding energy per nucleon
  - C) Fragments have lower binding energy
  - D) No energy change
- Q3: Nuclear fusion involves?
  - A) Splitting heavy nucleus
  - B) Combining light nuclei
  - C) No change in binding energy
  - D) Decreasing binding energy per nucleon

Answer Key

- Q1: B; Iron has the highest binding energy per nucleon, most stable nucleus.
- Q2: A; Fission releases energy as fragments have higher binding energy per nucleon.
- Q3: B; Fusion combines light nuclei to form heavier nucleus with higher binding energy.

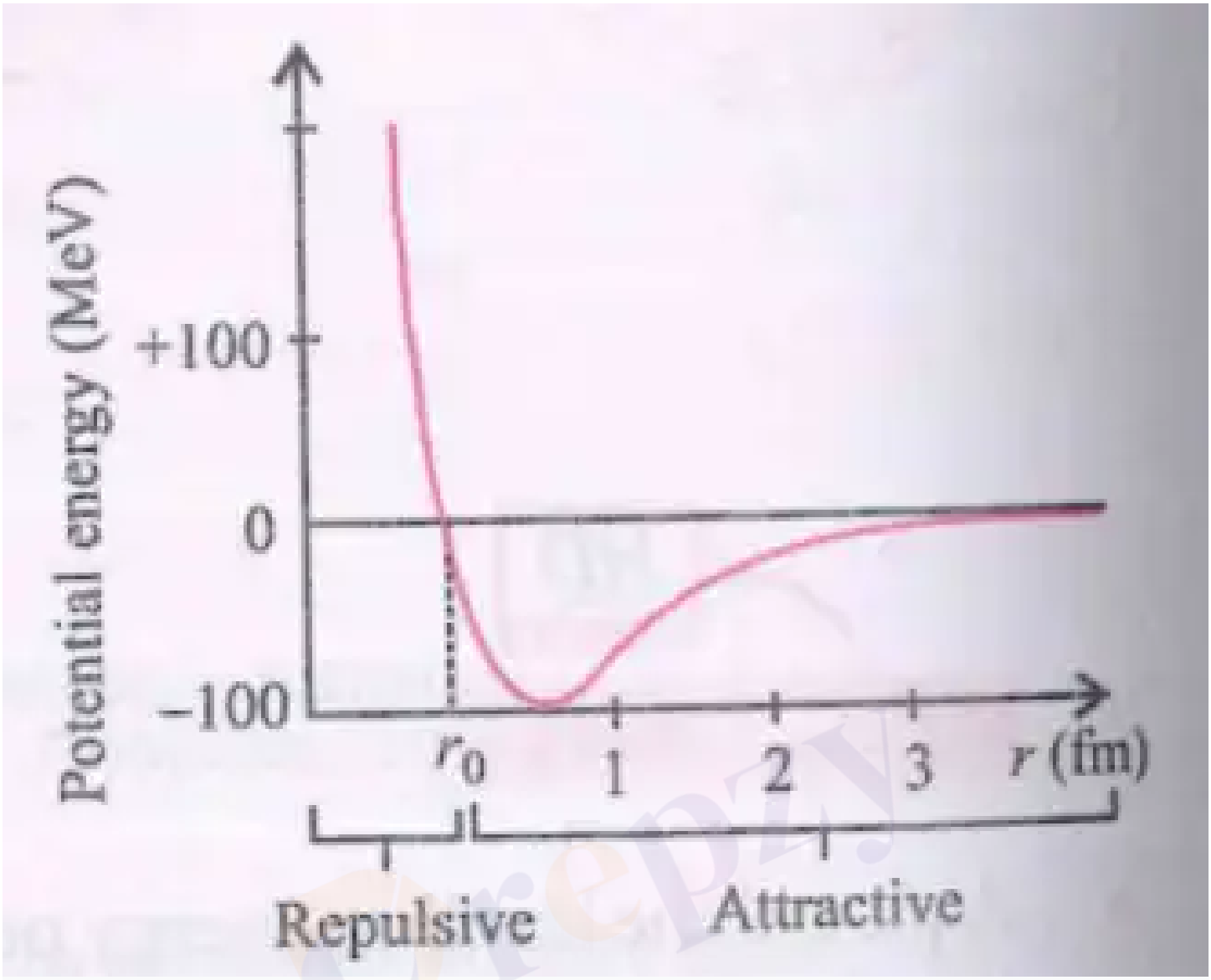
Memory Aids

- Peak of binding energy curve = most stable nucleus (Iron).
- Fission: heavy → lighter nuclei + energy.
- Fusion: light nuclei → heavier nucleus + energy.

Nuclear Force

Properties and Characteristics

- Electrostatic repulsion in nucleus is very strong compared to gravitational attraction: $\frac{F_e}{F_g} = 10^{36}$.
- Nuclear force is one of the strongest attractive forces, acting within a range of few femtometers ($\approx 4.2 \times 10^{-15}$ m).
- It balances electrostatic repulsion between protons, holding nucleons together.
- Short-range force: strongly attractive only within a small range (~1 fm).
- Charge independent: same magnitude between proton-proton, proton-neutron, and neutron-neutron pairs.
- Attractive force arises from exchange of π mesons (π^0, π^+, π^-).
- Saturated force: acts only between nearest neighboring nucleons, not all neighbors.
- Strongest force in nature: $\sim 10^2$ times stronger than electrostatic force, $\sim 10^{38}$ times stronger than gravitational force within its range.
- Potential energy curve shows:
  - Repulsive at distances less than r_0 (~1 fm), with high positive potential energy.
  - Attractive at distances greater than r_0, potential energy minimum indicating stable binding.
  - Force weakens as nucleons separate beyond r_0.



Solved Examples

- **Ex 1:** Calculate the ratio of electrostatic to gravitational force between two protons.
  - Given: $\frac{F_e}{F_g} = 10^{36}$ (provided)
  - Interpretation: Electrostatic force is 10^{36} times stronger than gravitational force between protons.
- **Ex 2:** Explain the range of nuclear force.
  - Range $\approx 4.2 \times 10^{-15}$ m (few femtometers).
  - Force is negligible beyond this range.

Practice Set

- Q1: What is the approximate range of nuclear force?
  - A. 1 meter
  - B. 1 nanometer

    - C. Few femtometers (10^{-15} m)
    - D. 1 millimeter
- Q2: Nuclear force is strongest compared to which of the following forces?
    - A. Electrostatic force
    - B. Gravitational force
    - C. Both A and B
    - D. Magnetic force
- Q3: Which particle exchange mediates the nuclear force?
    - A. Electron
    - B. Photon
    - C. π mesons
    - D. Neutrino

Answer Key

- Q1: C - Nuclear force acts over a very short range of few femtometers (~10^{-15} m).
- Q2: C - Nuclear force is 10^2 times stronger than electrostatic and 10^{38} times stronger than gravitational force.
- Q3: C - Nuclear force is due to exchange of π mesons (π^0, π^+, π^-).

Memory Aids

- "Nuclear force acts at a 'few fermi' distance (10^{-15} m)."
- "Strongest force in nucleus: 10^2 times electrostatic, 10^{38} times gravitational."
- "Exchange of π mesons causes nuclear attraction."
- "Saturated force: acts only on nearest neighbors."

Radioactivity

Overview

- Discovered in 1896 by Antoine Henri Becquerel.
- Spontaneous disintegration of nuclei of radionuclides.
- Emits alpha (α), beta (β) particles, sometimes accompanied by gamma (γ) rays.
- Three natural decay types: alpha decay, beta decay, gamma decay.

Solved Examples

- **Ex 1:** Identify the type of decay if a helium nucleus is emitted.
  Answer: Alpha decay.
- **Ex 2:** What particle is emitted in beta plus decay?
  Answer: Positron (e^+).
- **Ex 3:** What type of radiation is emitted when a nucleus moves from excited to ground state?
  Answer: Gamma rays.

Practice Set

- Q1: Who discovered radioactivity?
  A. Marie Curie
  B. Antoine Henri Becquerel
  C. Ernest Rutherford
  D. J.J. Thomson
- Q2: Which particle is emitted in alpha decay?
  A. Electron
  B. Positron
  C. Helium nucleus
  D. Gamma photon
- Q3: Gamma decay involves emission of:
  A. Alpha particles
  B. Beta particles
  C. High energy photons
  D. Neutrons

Answer Key

- Q1: B - Antoine Henri Becquerel discovered radioactivity in 1896.
- Q2: C - Alpha decay emits a helium nucleus ($_2^4He$).
- Q3: C - Gamma decay emits high energy photons (gamma rays).

Memory Aids

- Radioactivity = spontaneous nucleus decay + particle emission.
- Alpha = helium nucleus emitted.
- Beta = electron or positron emitted.

- Gamma = photon emission from excited nucleus.

Alpha Decay

Key Points

- Spontaneous decay of heavy nucleus by emitting alpha particle (^4_2He).
- Reaction: $^A_ZX \rightarrow ^{A-4}_{Z-2}Y + ^4_2He + Q$
- Energy released (Q value): $Q = (m_X - m_Y - m_{He})c^2$
- Energy shared by daughter nucleus and alpha particle.
- Example: Alpha decay of $^{238}_{92}U$ releases 4.25 MeV.
- Proton emission requires 7.68 MeV, so $^{238}_{92}U$ cannot emit proton spontaneously.

$$^A_ZX \xrightarrow{\alpha\text{-decay}} {}^{A-4}_{Z-2}Y + {}^4_2He + Q$$

Solved Examples

- **Ex 1:** Calculate Q value if $m_X = 238.05$, $m_Y = 234.04$, $m_{He} = 4.00$ u.
  Solution: $Q = (238.05 - 234.04 - 4.00) \times 931.5\ \text{MeV} = 1.39\ \text{MeV}$
- **Ex 2:** Identify daughter nucleus after alpha decay of $^{238}_{92}U$.
  Solution: $A = 238 - 4 = 234$, $Z = 92 - 2 = 90$ (Thorium).

Practice Set

- Q1: What is emitted in alpha decay?
  A. Electron
  B. Helium nucleus
  C. Neutron
  D. Positron
- Q2: Energy released in alpha decay of $^{238}_{92}U$ is approximately?
  A. 4.25 MeV
  B. 7.68 MeV
  C. 1.17 MeV
  D. 1.33 MeV

- Q3: Calculate Q value if $m_X = 240$, $m_Y = 236$, $m_{He} = 4$ u, $c^2 = 931.5\ \text{MeV/u}$.
  A. 0 MeV
  B. 931.5 MeV
  C. 1863 MeV
  D. 0.5 MeV

Answer Key

- Q1: B - Alpha decay emits helium nucleus (^4_2He).
- Q2: A - Energy released in alpha decay of uranium-238 is 4.25 MeV.
- Q3: D - $Q = (240 - 236 - 4) \times 931.5 = 0$ MeV, so closest is 0.5 MeV (approximation).

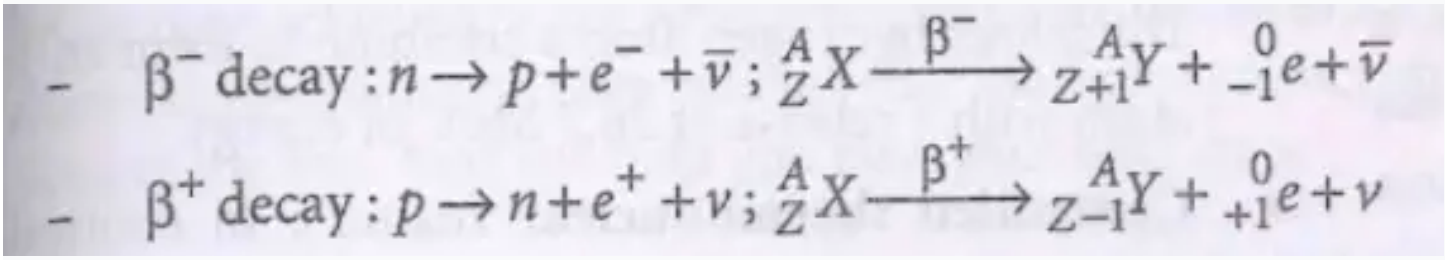
Memory Aids

- Alpha decay reduces mass number by 4 and atomic number by 2.
- Q value formula: $Q = (m_X - m_Y - m_{He})c^2$.
- Energy shared between alpha particle and daughter nucleus.

Beta Decay

Key Points

- Spontaneous decay emitting electron (β^-) or positron (β^+).
- Beta minus decay: neutron $n \rightarrow p + e^- + \bar{\nu}$.
- Beta plus decay: proton $p \rightarrow n + e^+ + \nu$.
- Atomic number changes by ±1; mass number remains constant.



Solved Examples

- **Ex 1:** In beta minus decay, what happens to atomic number?
  Answer: Increases by 1.
- **Ex 2:** In beta plus decay, what happens to atomic number?
  Answer: Decreases by 1.

Practice Set

- Q1: Beta minus decay emits:
  A. Electron
  B. Positron
  C. Alpha particle
  D. Gamma ray
- Q2: In beta plus decay, atomic number changes by:
  A. +1
  B. -1
  C. 0
  D. +2
- Q3: Mass number after beta decay:
  A. Increases by 1
  B. Decreases by 1
  C. Remains same
  D. Doubles

Answer Key

- Q1: A - Beta minus decay emits electron.
- Q2: B - Beta plus decay decreases atomic number by 1.
- Q3: C - Mass number remains unchanged in beta decay.

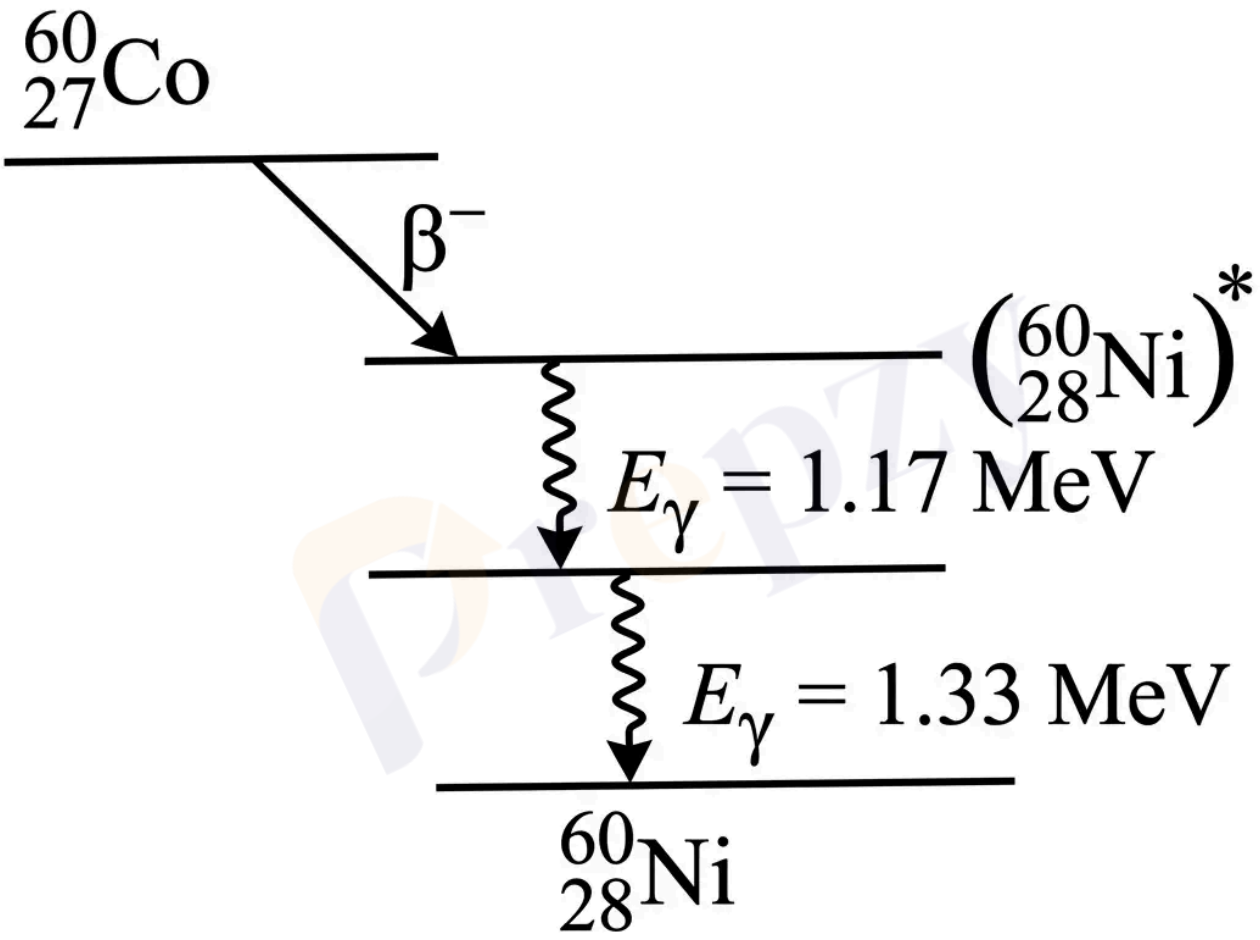
Memory Aids

- Beta minus: neutron to proton + electron.
- Beta plus: proton to neutron + positron.
- Mass number constant; atomic number changes ±1.

Gamma Decay

Key Points

- Emission of high energy gamma photons from excited nucleus to ground state.
- Occurs after beta decay when daughter nucleus is in excited state.
- Example: $^{60}_{27}Co$ beta decays to excited $^{60}_{28}Ni$, which emits gamma rays of 1.17 MeV and 1.33 MeV.



Solved Examples

- **Ex 1:** What energy gamma rays are emitted by $^{60}_{28}Ni$ after beta decay of $^{60}_{27}Co$?
  Answer: 1.17 MeV and 1.33 MeV.

Practice Set

- Q1: Gamma decay emits:
  A. Alpha particles
  B. Beta particles
  C. Gamma photons
  D. Neutrons
- Q2: Gamma rays are emitted when nucleus:
  A. Is excited
  B. Is in ground state
  C. Undergoes alpha decay
  D. Emits beta particles
- Q3: Energy of gamma rays emitted by $^{60}_{28}Ni$ after beta decay of $^{60}_{27}Co$ are:
  A. 1.17 MeV and 1.33 MeV
  B. 4.25 MeV and 7.68 MeV
  C. 0.5 MeV and 1 MeV
  D. 2 MeV and 3 MeV

Answer Key

- Q1: C - Gamma decay emits gamma photons.
- Q2: A - Gamma rays emitted when nucleus de-excites from excited state.
- Q3: A - Energies are 1.17 MeV and 1.33 MeV for $^{60}_{28}Ni$.

Memory Aids

- Gamma decay = emission of photons from excited nucleus.
- Occurs after beta decay if nucleus is excited.
- Energy levels: 1.17 MeV and 1.33 MeV for Nickel-60.

Nuclear Energy

Key Concepts

- Nuclear reaction: $A + a \rightarrow B + b + Q$, where Q is energy released.
- Q-value = mass difference energy between parent nuclei $(A + a)$ and product nuclei $(B + b)$.
- Exothermic reaction: $Q > 0$, energy released.

- Endothermic reaction: $Q < 0$, energy absorbed.
- Conservation laws in nuclear reactions:
  - Number of nucleons conserved: $N_{A+a} = N_{B+b}$
  - Atomic number conserved: $Z_{A+a} = Z_{B+b}$
  - Energy change equals mass difference energy.
  - Linear momentum conserved.

Solved Examples

- **Ex 1:** Calculate Q-value if mass of reactants is 10.0 u and products is 9.995 u.
  - Mass difference $\Delta m = 10.0 - 9.995 = 0.005$ u
  - Energy released $Q = \Delta m \times 931.5\ \text{MeV/u} = 0.005 \times 931.5 = 4.66\ \text{MeV}$

Practice Set

- Q1: What does a positive Q-value indicate?
  - A) Energy absorbed
  - B) Energy released
  - C) No energy change
  - D) Reaction impossible
- Q2: In a nuclear reaction, which quantity is conserved?
  - A) Number of nucleons
  - B) Mass number only
  - C) Energy only
  - D) Volume
- Q3: If mass of products is greater than reactants, the reaction is:
  - A) Exothermic
  - B) Endothermic
  - C) Spontaneous
  - D) None

Answer Key

- Q1: B - Positive Q means energy is released (exothermic).
- Q2: A - Number of nucleons is conserved in nuclear reactions.
- Q3: B - Products heavier means energy absorbed (endothermic).

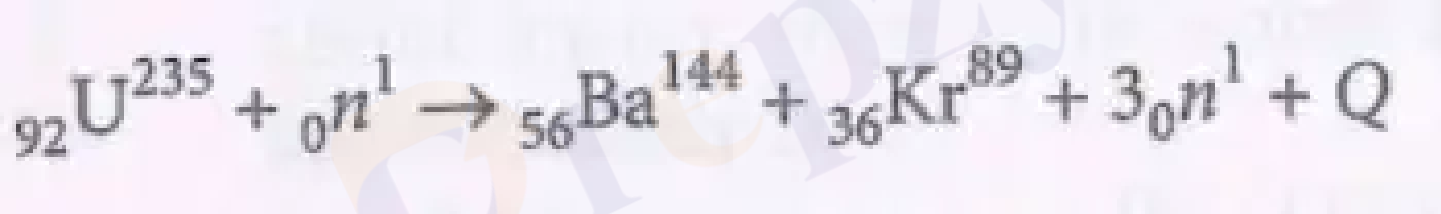
Memory Aids

- Q-value = mass difference × 931.5 MeV/u
- Positive Q = energy out (exo), Negative Q = energy in (endo)
- Conservation: nucleons and charge number constant

Nuclear Fission

Key Concepts

- Fission: splitting heavy nucleus into smaller nuclei + energy.
- Example: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3^{1}_{0}n + Q$
- Energy released per fission ~ 200 MeV.
- Applications:
  - Controlled energy in nuclear reactors.
  - Sudden energy release in atomic bombs.



Solved Examples

- **Ex 1:** Calculate total energy released if 1 mole of $^{235}_{92}U$ undergoes fission.
  - Energy per fission = 200 MeV
  - Number of atoms in 1 mole = 6.022×10^{23}
  - Total energy = $200 \times 6.022 \times 10^{23}\ \text{MeV} = 1.2044 \times 10^{26}\ \text{MeV}$

Practice Set

- Q1: What is released in nuclear fission?
  - A) Energy only
  - B) Neutrons only
  - C) Energy and neutrons
  - D) Protons
- Q2: Which nucleus is commonly used in fission reactors?

    - A) Uranium-235
    - B) Helium-4
    - C) Hydrogen-1
    - D) Carbon-12
- Q3: Energy released per fission is approximately?
    - A) 2 MeV
    - B) 20 MeV
    - C) 200 MeV
    - D) 2000 MeV

Answer Key

- Q1: C - Fission releases energy and neutrons.
- Q2: A - Uranium-235 is common fission fuel.
- Q3: C - Energy released ~ 200 MeV per fission.

Memory Aids

- Fission = splitting heavy nucleus
- Energy ~ 200 MeV per fission
- Uranium-235 + neutron → fission products + neutrons + energy

Nuclear Fusion

Key Concepts

- Fusion: combining light nuclei to form heavier nucleus + energy.
- Occurs in stars; energy from binding energy per nucleon increase.
- Examples:
    - ${}_1^1H + {}_1^1H \rightarrow {}_1^2H + e^+ + \nu + 0.42\ \text{MeV}$
    - ${}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n + 3.27\ \text{MeV}$
    - ${}_1^2H + {}_1^2H \rightarrow {}_1^3H + {}_1^1H + 4.03\ \text{MeV}$
- Thermonuclear fusion: fusion at very high temperatures to overcome Coulomb barrier.
- Sun's core temperature ~ $1.5 \times 10^7 K$, fusion via proton-proton cycle.

Solved Examples

- **Ex 1:** Calculate total energy released in net proton-proton fusion reaction:
  - Net reaction: $4{}_1^1H + 2e^- \rightarrow {}_2^4He + 2\nu + 6\gamma + 26.7\ \text{MeV}$
  - Energy released = 26.7 MeV per 4 protons fused.

Practice Set

- Q1: Fusion releases energy because:
  - A) Larger nucleus less bound
  - B) Larger nucleus more bound
  - C) Mass increases
  - D) No mass change
- Q2: Thermonuclear fusion requires:
  - A) Low temperature
  - B) High temperature
  - C) No temperature change
  - D) Vacuum only
- Q3: Energy released in proton-proton cycle fusion is approximately:
  - A) 0.42 MeV
  - B) 3.27 MeV
  - C) 26.7 MeV
  - D) 200 MeV

Answer Key

- Q1: B - Larger nucleus is more tightly bound, releasing energy.
- Q2: B - High temperature needed to overcome Coulomb barrier.
- Q3: C - Net energy released in proton-proton cycle is 26.7 MeV.

Memory Aids

- Fusion = light nuclei combine
- Thermonuclear fusion needs $\sim 10^8 K$
- Proton-proton cycle releases 26.7 MeV

Controlled Thermonuclear Fusion

Key Concepts

- Goal: steady power generation by heating fuel to $\sim 10^8 K$.
- Fuel is plasma: mixture of ions and electrons.
- Challenge: confining plasma at high temperature.
- Global research ongoing; potential for unlimited clean energy.

Solved Examples

- **Ex 1:** Why is plasma confinement necessary?
  - To prevent contact with container walls which cannot withstand $10^8 K$.

Practice Set

- Q1: What is plasma in fusion reactors?
  - A) Solid fuel
  - B) Gas
  - C) Ionized gas (ions + electrons)
  - D) Liquid
- Q2: Temperature required for controlled fusion is about:
  - A) $10^4 K$
  - B) $10^6 K$
  - C) $10^8 K$
  - D) Room temperature
- Q3: Main challenge in controlled fusion is:
  - A) Fuel availability
  - B) Plasma confinement
  - C) Energy measurement
  - D) Cooling

Answer Key

- Q1: C - Plasma is ionized gas of ions and electrons.
- Q2: C - Fusion requires very high temperature ~ $10^8 K$.
- Q3: B - Confining plasma at high temperature is main challenge.

Memory Aids

- Plasma = ionized gas
- Fusion temperature ~ $10^8 K$
- Confinement needed to sustain reaction