

Nuclear Physics

These notes are your ultimate revision weapon to revise Nuclear Physics . We've distilled years of previous exam questions (PYQs) into one powerful, concise resource. Everything you need to know, nothing you don't.

- **PYQs, Decoded:** All key concepts from past exams, organized and simplified.
- **Revise in Record Time:** Short, precise, and designed for last-minute review.
- **Focus on What Matters:** Master high-probability topics and boost your confidence.

Nuclear Physics: Particles, Reactions & Fundamental Concepts

1. Sub-atomic Particles & Discoveries

- **Meson:** Discovered by **Hideki Yukawa** (Japan, 1935).
- **Positron:** Discovered by **C.D. Anderson** and **U.F. Hess** (1932). It is the antiparticle of the electron.

2. Challenging Established Theories

- Scientists **Gunter Nimtz** and **Alfons Stahlhofen** claimed that **microwave photons** can travel faster than light, challenging Einstein's theory of relativity.
- **Ernest Rutherford** doubted that nuclear energy could be harnessed, questioning if Einstein's mass-energy equivalence would hold.

3. Nuclear Reactions: Fission vs. Fusion

- **Nuclear Fission:**
 - The process of a heavy atomic nucleus (e.g., Uranium-235) **splitting apart** into smaller fragments.
 - Used in nuclear reactors and atomic bombs.

- **Nuclear Fusion:**
 - The process of two lighter atomic nuclei **fusing together** to form a heavier nucleus.
 - It is the primary source of energy in stars like the Sun.
 - The theory for stellar energy production was explained by **H.A. Bethe** (1938). Stars obtain energy from fusion and gravitational contraction.
- **Clarification:** The breaking apart of a nucleus is **fission, not fusion**.

4. Radioactivity & Properties

- **Definition:** A nuclear property where an unstable nucleus decays, emitting energy and particles (Alpha, Beta, Gamma rays) to become stable.
- **End Product:** The ultimate stable end product of uranium decay is **Lead**.
- **Half-Life Calculations:**
 - **Half-life** is the time for half of a radioactive substance to decay.
 - After 1 half-life: **1/2** remains.
 - After 2 half-lives: **1/4** remains.
 - After 3 half-lives: **1/8** remains.
 - After 4 half-lives: **1/16** remains.
 - If 3/4 has decayed (1/4 remains), it corresponds to **two half-lives**.

5. Radioactive Elements

- Generally, elements with an atomic number **greater than 80** are radioactive.
- **Exceptions:** **Technetium** and **Promethium** are radioactive despite lower atomic numbers.
- **Non-radioactive example:** **Zirconium** (Z=40) is not radioactive.
- **Radioactive examples:** **Astatine** (Z=85), **Francium** (Z=87), and **Tritium**.

Nuclear Technology: Reactors, Components & Types

1. Nuclear Reactor Overview

- A device that initiates and controls a **self-sustaining nuclear chain reaction**.
- Key difference from a bomb: the chain reaction is **controlled**.
- Uses **Uranium-235** or **Plutonium-239** as fuel.

2. Reactor Components & Functions

- **Moderator:**
 - **Function:** To **slow down neutrons** produced by fission to sustain a chain reaction.
 - **Materials:** Heavy Water (D_2O), Ordinary Water, Graphite, Beryllium Oxide.
 - **Graphite** is used specifically to slow neutrons for U-235 fission.
 - **Fast reactors** do not use a moderator.
- **Control Rods:**
 - **Function:** To manage the fission process and prevent the reaction from going out of control by absorbing neutrons.
 - **Materials:** Boron, Silver, Indium, and **Cadmium**.
- **Coolants:**
 - The **Fast Breeder Test Reactor (FBTR)** uses **Liquid Sodium**.

3. Types of Reactors

- **Pressurised Heavy Water Reactor (PHWR):**
 - Manufactured by India's **Nuclear Power Corporation of India Limited (NPCIL)** in 220 MW and 540 MW capacities.
- **Breeder Reactor:**
 - Produces **more fissionable material than it consumes**.
 - A **fast breeder reactor** generates power through **fission**, not fusion.
- **Fusion Reactor (Experimental):**

- The **International Thermonuclear Experimental Reactor (ITER)** aims to demonstrate fusion power.
- **Location:** Cadarache, Southern France.
- **Members:** China, EU, India, Japan, South Korea, Russia, USA.
- **Advantage for India:** Success would allow the building of fusion reactors for power generation.

4. Supporting Instruments

- **Cyclotron:** A particle accelerator for charged particles like protons and deuterons.
- **Scintillation Counter:** Detects radiation by measuring light flashes in a scintillator material.

Nuclear Fuels & Resources

1. Common Nuclear Fuels

- **Uranium-235 (U-235):** The most widely used fuel. Natural uranium must be **enriched** for reactor use.
- **Plutonium-239 (Pu-239):** A primary fuel for power and bombs.
- **Thorium:** Not a fuel itself but can be converted into fissile Uranium-233. It is **more abundant** than uranium.

2. Advantages of Thorium

- **Abundance:** Far more abundant in nature than uranium.
- **Efficiency:** Generates more energy per unit mass of mined mineral.
- **Waste:** Produces less harmful, long-lived radioactive waste and fewer weapons-grade materials.

3. Non-Fuel Elements

- **Cadmium:** Used in control rods, not as fuel.
- **Helium, Calcium, Lead, Chromium:** Not used as atomic fuels.
- **Uranium-238 (U-238):** A common but non-fissile isotope, not a primary fuel.

4. Source Minerals

- **Monazite** is the main source of **Thorium**.

Nuclear Weapons

1. Principles of Operation

- **Atomic Bomb:** Based on **uncontrolled nuclear fission**.
- **Hydrogen Bomb (Thermonuclear Bomb):** Based on **uncontrolled nuclear fusion** of hydrogen isotopes (Deuterium and Tritium).

2. Materials and History

- **Material:** Uses **Highly Enriched Uranium (HEU)**, ~90% U-235.
- **Development:** The "father" of the hydrogen bomb is **Edward Teller**.
- **First US Test:** November 1952 at **Eniwetok** in the Marshall Islands.

Indian Nuclear Program & Infrastructure



1. Nuclear Tests

- **Pokhran-I (1974):**
 - Code-named '**Smiling Buddha**'.
 - India's first nuclear weapon test in Pokhran, Rajasthan.
- **Pokhran-II (1998):**
 - Code-named '**Operation Shakti**'.
 - Conducted on May 11th and 13th, 1998, involving five tests.

2. Nuclear Doctrine & Policy

- **Principles:** **No First Use**, **Minimum Credible Deterrence**, and a unilateral moratorium on testing.
- **NPT Stance:** India has **refused to sign the Non-Proliferation Treaty (NPT)**, considering it discriminatory.
- **Safeguards:** India has a safeguards agreement with the IAEA (ratifying an 'Additional Protocol' in 2014), but **only civilian reactors using imported uranium** are under inspection.

3. Nuclear Power in India

- **Status:** The **fourth-largest** source of electricity, contributing about **3%** of total generation.
- **Operator:** All plants are operated by the **Nuclear Power Corporation of India Limited (NPCIL)**.

4. Major Power Plants & Locations

Power Plant	Location	Key Facts
Tarapur (TAPS)	Palghar, Maharashtra	India's first nuclear plant (1969).
Madras (MAPS)	Kalpakkam, Tamil Nadu	First fully indigenous station.
Narora (NAPS)	Bulandshahar, UP	Located in Seismic Zone IV.
Kakrapar (KAPS)	Near Surat, Gujarat	
Rajasthan (RAPS)	Rawatbhata, Rajasthan	
Kaiga	Near Kali River, Karnataka	
Kudankulam (KKNPP)	Tamil Nadu	Largest capacity (2000 MW). Built with Russian collaboration.

5. Research Institutions & Reactors

- **Bhabha Atomic Research Centre (BARC):** Primary facility in **Trombay, Mumbai**.
- **Indira Gandhi Centre for Atomic Research (IGCAR):** Second-largest facility, located in **Kalpakkam**, focusing on fast breeder reactors.
- **Research Reactors:** **Dhruva**, **Purnima**, and **Cirus** are Indian research reactors.

- **Fast Breeder Test Reactor (FBTR):** At IGCAR, operational since 1985, uses Uranium-Plutonium Carbide fuel.

6. Department of Atomic Energy (DAE) Organizations

- **Atomic Minerals Directorate (AMD):** Hyderabad
- **Heavy Water Board (HWB):** Mumbai (First plant in **Trombay, Maharashtra**)
- **Indian Rare Earths Limited (IREL):** Mumbai
- **Uranium Corporation of India Limited (UCIL):** Jaduguda, Jharkhand

7. Other Research Institutes

- **Saha Institute of Nuclear Physics:** Kolkata.
- **Harishchandra Research Institute:** Prayagraj, Uttar Pradesh (Mathematics & Theoretical Physics).

International Nuclear Framework



1. Key Organizations

- **CERN:** The world's largest particle physics lab, located on the **French-Swiss border** near Geneva.
- **International Panel on Fissile Materials (IPFM):** An independent expert group, not an IAEA organ.
- **Nuclear Security Summits:** Focus on securing nuclear materials, but **not held under UN aegis**.

2. Nuclear Non-Proliferation Treaty (NPT)

- **Objective:** Prevent the spread of nuclear weapons (entered force in 1970).
- **Nuclear Weapon States (NWS):** **China, France, Russia, UK, USA** (the only five recognized by the treaty).
- **Key Non-Members:** **India, Israel, and Pakistan** are not parties to the NPT.

3. Nuclear Suppliers Group (NSG)

- **Objective:** Control nuclear exports to prevent proliferation. Established in **1974 in response to India's first nuclear test.**
- **Membership:** 48-member group. **Iran is not a member.**
- **India & NSG:** The NSG ban on India was lifted in 2008. **France** was the first to sign a civil nuclear deal with India afterwards. India seeks membership but has not signed the NPT.

General Science Facts

- **Invention:** The **telephone** was invented by **Graham Bell.**
- **Chemistry:** **Dry ice** is solid carbon dioxide.
- **Scientific Error (Correction):** **Enrico Fermi** was not solely successful in synthesizing transuranic elements; this is often credited to **Glenn T. Seaborg.**

Know More About Nuclear Physics:

- [Nuclear Physics – Old Year Questions](#)
- [Nuclear Physics One Liner Questions & Answers](#)