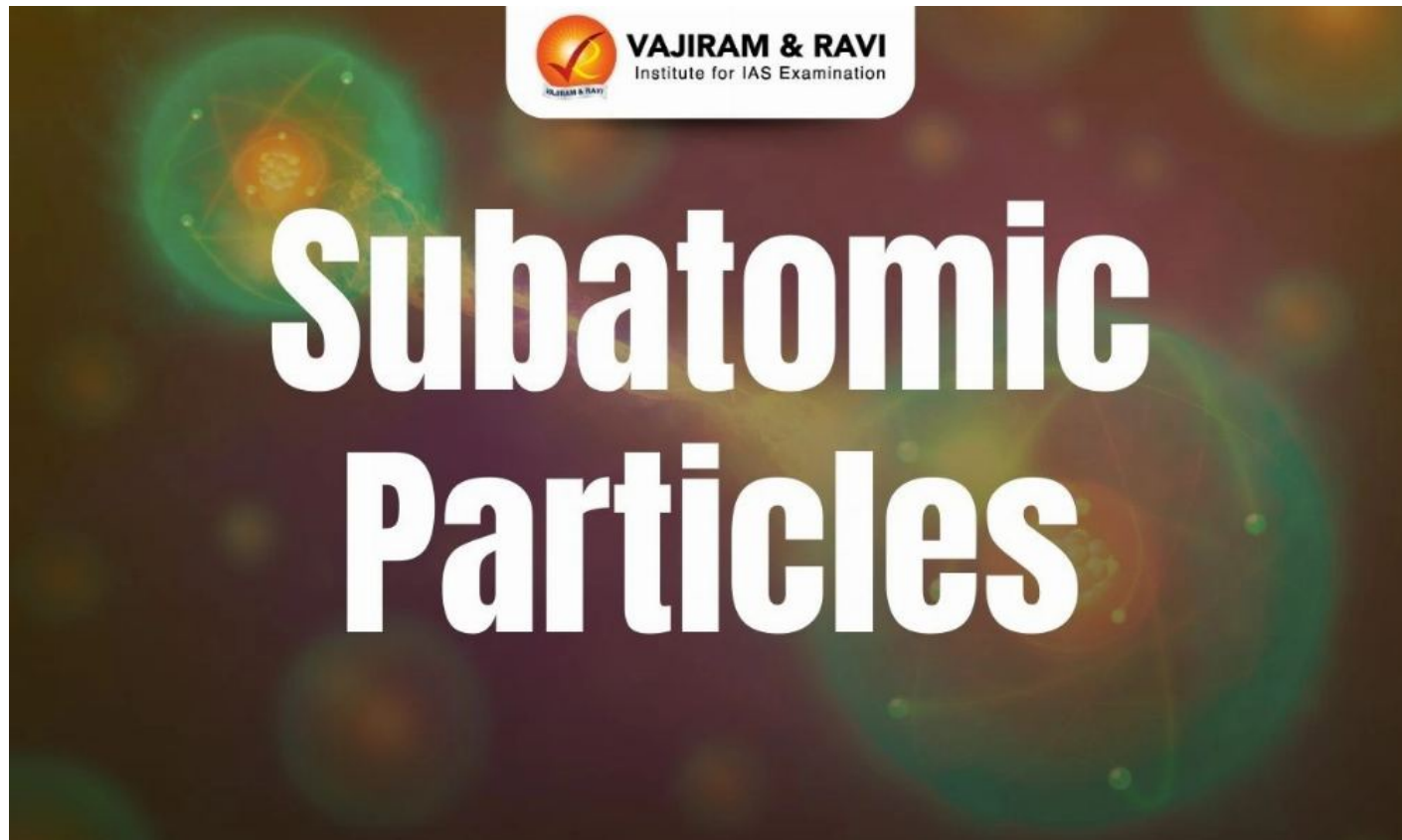


Subatomic Particles

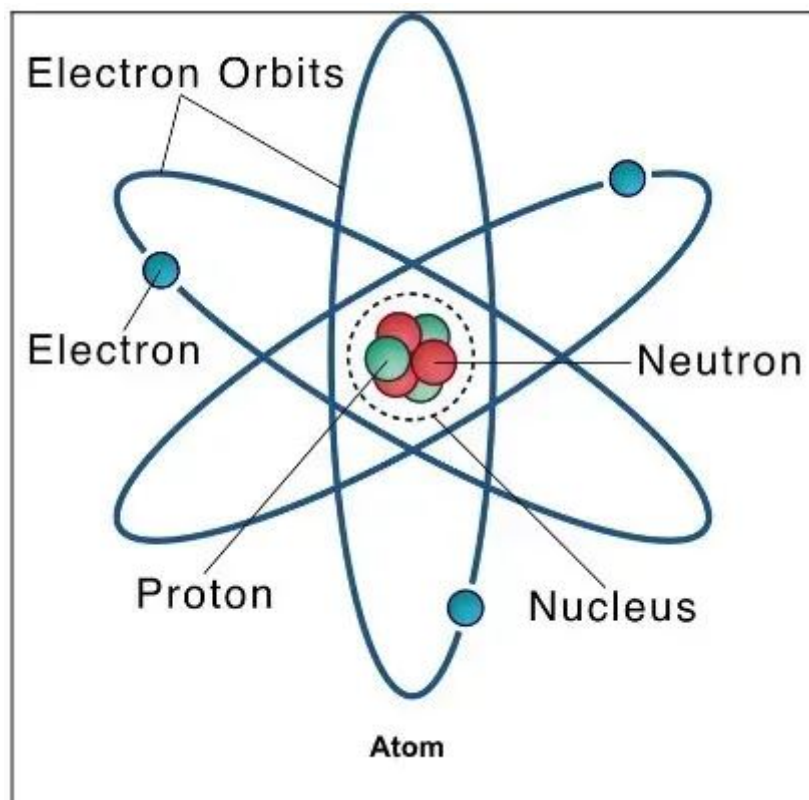
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Subatomic Particles are the particles inside an atom. They are **self-contained units of matter or energy** and are the fundamental constituents of all matter. Initially, the atom was considered to be the fundamental particle which constitutes all the matter. However, with later experiments and discoveries, it was revealed that the atom is itself constituted of several particles such as **Electrons, Protons and Neutrons**. Further research in particle physics revealed that even protons and neutrons are **composite particles**, made up of some other **subatomic elementary particles**.

Types of Subatomic Particles

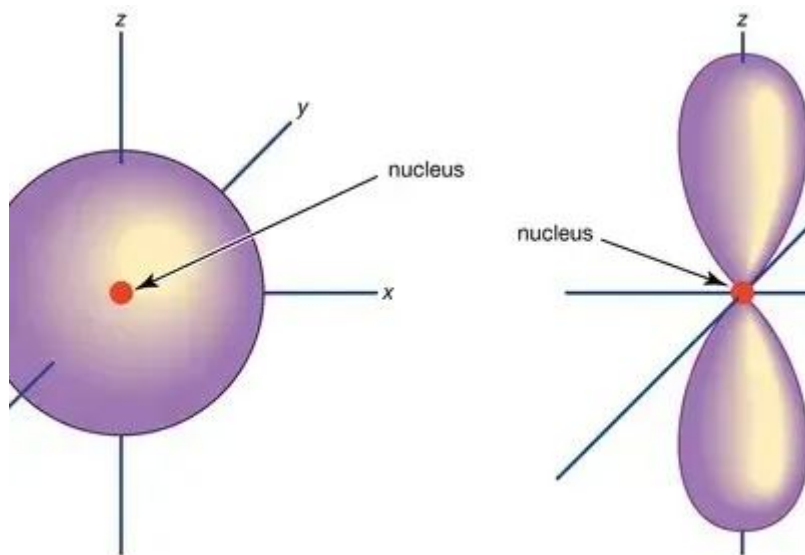
Atoms are considered the basic **building blocks of matter**. It was John Dalton who in 1803 postulated that an atom is indestructible and is the fundamental unit of matter. This was proved wrong by **J.J. Thomson** in 1897.



Electrons

Electrons were discovered by **J.J Thomson** after many experiments involving **cathode rays**. He demonstrated the ratio of mass to electric charge of cathode rays. He confirmed that **cathode rays are fundamental particles** that are **negatively** charged; these cathode rays became known as **electrons**.

- **Charge:** **Robert Millikan**, through **oil drop experiments**, found the **value** of the electronic charge.
 - Electrons can abbreviate as **e⁻** and have a **negative charge** that is equal in magnitude to the positive charge of the protons as the atoms are neutral.
 - The charge on an electron is **$1.6020 \times 10^{-19} \text{ C}$** , which is considerably **less** than that of a proton or neutron.
- **Mass:** The mass of an electron is **$9.1 \times 10^{-31} \text{ kg}$** .
- **Location:** Thomson and Rutherford tried to predict the location of electrons but it was Niels Bohr who postulated it most correctly.
 - Electrons revolve around the nucleus of an atom in a circular orbit having fixed energy. After gaining/losing energy, an electron can move to a different orbit of that energy level.
 - Later, after the discovery of quantum mechanics, it was postulated that electrons move randomly around the nucleus and the maximum probability of its finding is called orbital.
 - **Orbitals** can be of various shapes - spherical, dumbbell, double dumbbell, etc.



Protons

Eugene Goldstein in 1886 showed the existence of a positively charged particle in an atom. However, the actual discovery of protons is credited to Ernest Rutherford during his experiment on the scattering of α -particles.

- **Location:** Rutherford postulated that Protons exist in the nucleus and all the charge of the nucleus is due to the presence of protons.
- **Charge:** It is equal to the charge on electrons but positive.
- **Mass:** The mass of a proton is 1.67×10^{-27} kg, around 1840 times the electron's mass.
- **Atomic number:** The atomic number of an element is the number of protons (or electrons) present in an atom of the element.
 - It determines the position of any element in the Modern Periodic Table.

Neutrons

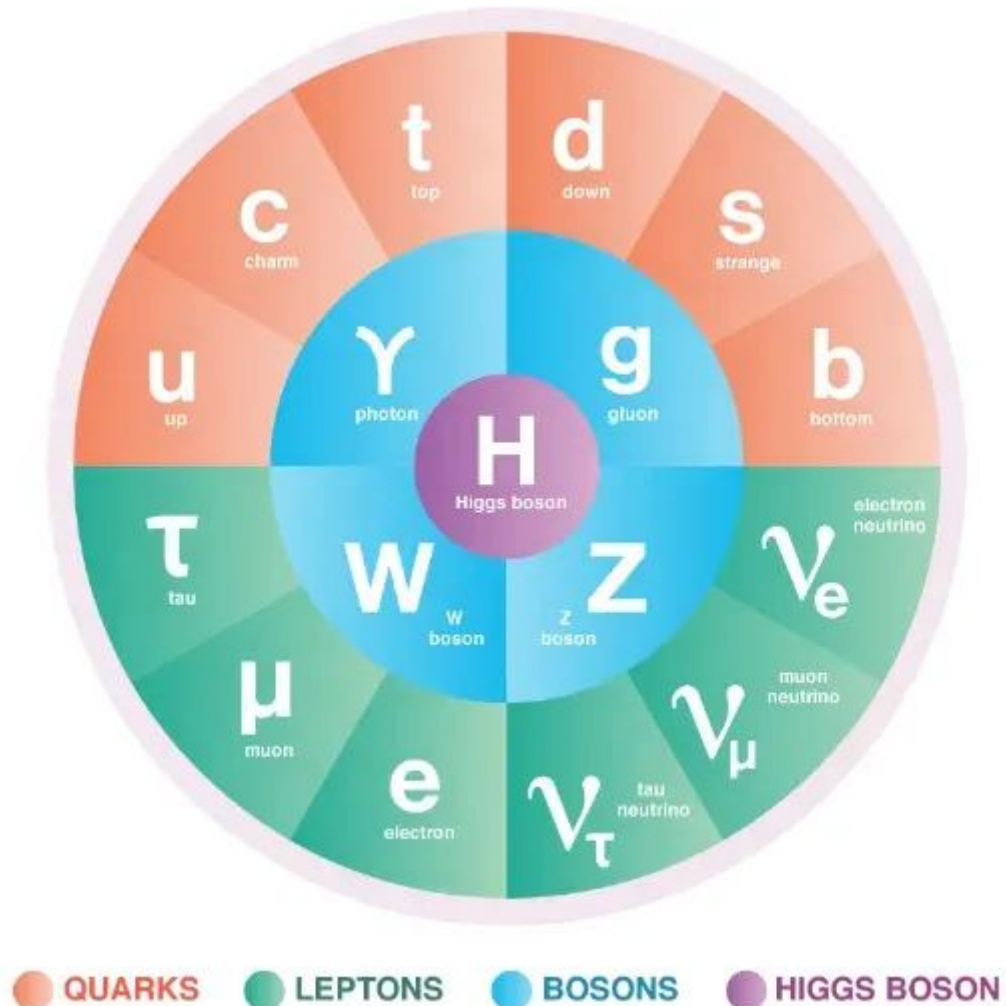
It was inevitable from Rutherford's experiment that there must be a neutral, sub-nuclear particle with a mass closely equal to protons. **James Chadwick** in 1932 discovered the neutrons.

- **Location:** Neutrons are **located in the nucleus** along with the protons.
- **Mass:** Along with protons, they make up almost all of the **mass of the nucleus as well as atoms**.
- **Charge:** Neutrons are electrically neutral.
- **Atomic mass:** The total number of protons and neutrons is called the **mass number** or **Atomic mass**.
- **Isotopes:** The variation of neutron number in an element determines the **isotope** of an atom.
 - The ratio of the number of protons and neutrons affects the **stability** of any element.
 - Some isotopes are stable, some are unstable (radioactive).

Fundamental Particles

Subatomic particles can be further divided into elementary (**fundamental**) particles and composite particles (made up of elementary particles).

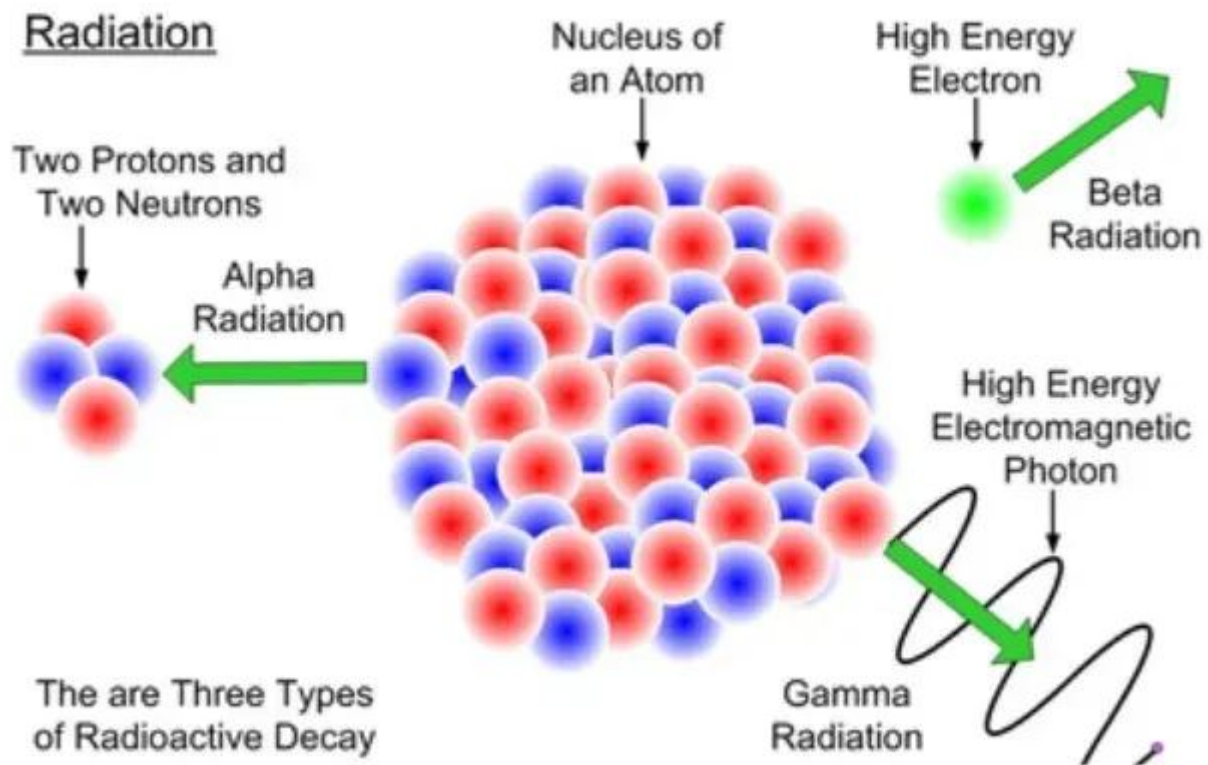
- **Elementary and Composite particles:** The elementary particles are those which can not be broken into smaller ones.
 - Various phases in Particle and Nuclear physics have led to the discovery and definition of various elementary particles.
 - The ones that were once considered as elementary, were later proved to be composite particles.
 - For example, protons and neutrons were once thought of as elementary particles, but are composite particles.



- **Quarks, Leptons and Bosons:** The Standard Model of Particle Physics considers two types of fundamental particles - **Fermions and Bosons**.
 - Fermions are the particles of matter whereas; Bosons are the carriers of fundamental forces and are the reasons for the interconversion and composition of fermions.
 - **Fermions are of two types** - Quarks and Leptons; Quarks interact with strong nuclear force and give rise to composite particles whereas; Leptons do not interact with the strong force.
 - Hadrons are composite particles made up of different combinations of quarks.
 - **Hadrons can be Baryons** (Example - **protons** and **neutrons**) or **Mesons**.
 - **Electron, Muon, Tauon**, and their three **Neutrinos** are leptons.

Radioactive Decay Particles

Radioactive decay occurs in unbalanced atoms called radionuclides due to an unstable nucleus. It causes the emission of **alpha particles**, **beta particles** or **gamma rays**.



- **Alpha particles:** Alpha particles, represented as **He₂⁺** or **α**, are the helium nuclei composed of **two protons and two neutrons**.
 - They originate from the alpha decay process, leading to the **creation of a new element**.
 - The smallest known element exhibiting this phenomenon is **tellurium** at atomic number 52.
- **Beta particles:** Beta decay manifests in two forms - the **emission of electrons (beta particles)** and the **emission of positrons**.
 - A **positron** has the same mass as an electron, with a positive charge, that is, it is an antimatter of the electron.
 - Beta particles are **more penetrating** than alpha particles, potentially leading to **health concerns**.
- **Gamma rays:** Radioactive decay also leads to gamma-ray radiation due to the annihilation of beta particles by positrons (matter with antimatter).
 - They are highly energetic and one of the most dangerous radiations.

Applications of Subatomic Particles

The study and understanding of subatomic particles, which go beyond the traditional protons, neutrons, and electrons, have led to **significant advancements** in various scientific fields.

- **Alpha Particle:**
 - The controlled nature of alpha decay makes it a secure power source for radioisotope generators.
 - They are extensively employed in applications such as artificial heart **pacemakers** and **space** probes.
 - This controlled release of alpha particles ensures a **reliable and safe energy** supply for critical **medical and technological devices**.

- **Beta Particle:**
 - **Positron emission tomography (PET)** relies on the annihilation of positrons with electrons, producing gamma rays.
 - By detecting these gamma rays, PET scans provide detailed images of internal body structures, aiding in medical diagnoses.
- **Hadrons:** Hadrons are popularly utilised by the particle accelerators of the Large Hadron Collider to generate more subatomic particles and study Particle Physics.
 - Higgs Boson was discovered in one of the experiments at LHC.
- **Muons:** Muons are essential in particle physics experiments, serving as probes to study **fundamental forces and interactions**.
 - **Accelerator facilities** use muons to **investigate** the properties of matter at a microscopic level.
- **K-mesons:** K-mesons (composite particles, made of fermions), with **masses greater than protons**, play a role in high-energy particle interactions.
 - Their study aids in unravelling complex processes occurring in **particle accelerators**.
- **Antiproton:** Anti-protons contribute to antimatter studies. They are crucial for understanding the **symmetry between matter and antimatter**.
- **Neutrino and Antineutrino:** Neutrinos and antineutrinos are integral to understanding **nuclear reactions**, especially in the context of **beta decay**.
 - Their detection helps physicists **investigate energy losses in atomic processes**.

Source: <https://vajiramandravi.com/upsc-exam/subatomic-particles/>

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