Historical Introduction to the Elementary Particles

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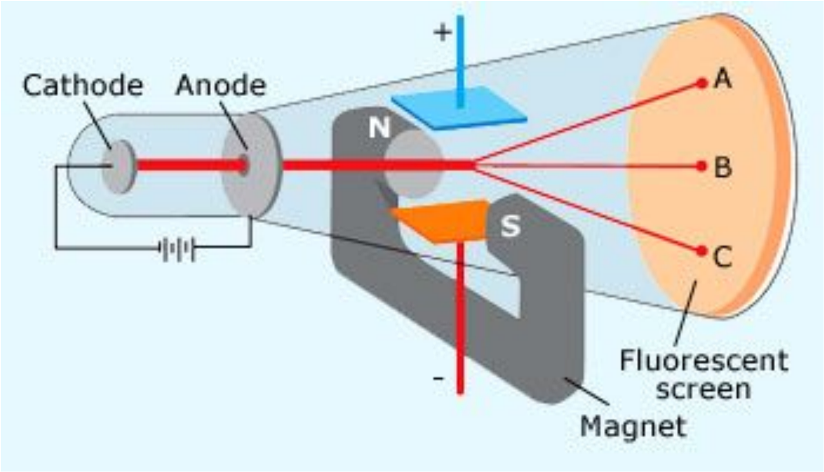
The Classical Era (1897-1932)

- The foundation of atomic theory dates back to ancient Greece (Democritus)
- The true birth of modern elementary particle physics began in **1897** with the discovery of the **electron** by J. J. Thomson
- The foundations were laid through successive discoveries shaping atomic theory

Discovery of Electron (1897)

- **Cathode ray experiments** showed particles with a negative charge.
- Measurement of the **charge-to-mass ratio** indicated a very small mass.
- The term **electron**, first introduced by George Johnstone Stoney (1891), was later adopted.
- Atomic theory



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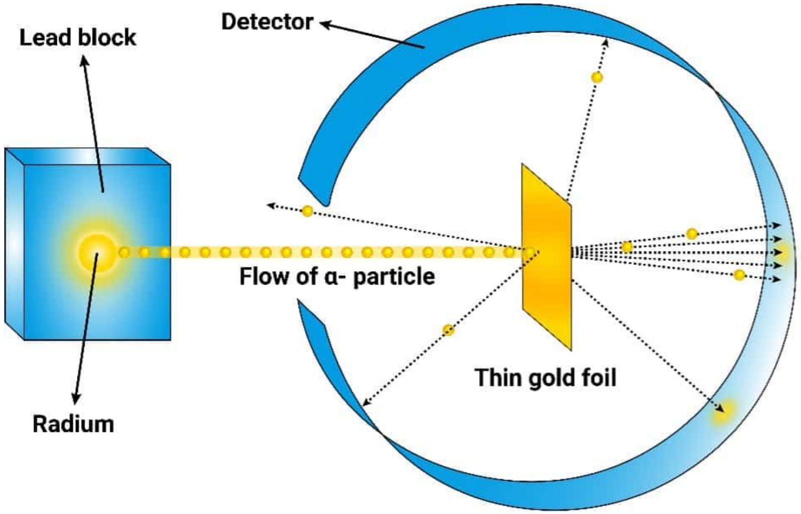
Rutherford's Gold Foil Experiment (1909)

- Alpha particles were expected to pass through a thin gold foil with minimal deflection.
- Some particles were deflected at large angles, indicating a **dense central nucleus**.
- This led to the **nuclear model of the atom**.



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Discovery of Proton & Neutron

- **1917:** Rutherford identified the **proton** as a fundamental particle.
- Concluded Hydrogen nuclei present in other atoms
- **1932:** James Chadwick discovered the **neutron**, resolving inconsistencies in atomic mass calculations. eg(He & Li)
- With electrons, protons, and neutrons, the **classical atomic model** was complete.

Introduction to the Photon (1900- 1924)

- Unlike other particles, the **photon** was not discovered by a single individual.
- Contributions from **Planck and Einstein** helped establish the concept of quantized light energy.

Planck’s Contribution

- **Ultraviolet Catastrophe:** Classical physics predicted that a blackbody should emit infinite energy at high frequencies, which was clearly incorrect.
- **Max Planck (1900)** solved this by introducing **energy quantization (E = hv)**, assuming radiation is emitted in discrete packets.
- His assumption led to the foundation of quantum mechanics.

Einstein’s Radical Interpretation

- Extended the Idea of Max Planck
- **Photoelectric Effect:** Light behaves as discrete packets (photons) rather than continuous waves.
- **Not Intensity but Frequency**
- **Einstein’s Equation**
- **Significance:** This provided the foundation for quantum mechanics and confirmed the particle-like nature of light.

Millikan & Compton

- **Millikan (1916)** confirmed Einstein's equation but resisted the photon theory.
- **Compton Scattering (1923)** demonstrated photon momentum with the equation:

$$\lambda' = \lambda + \frac{h}{mc}(1 - \cos\theta)$$

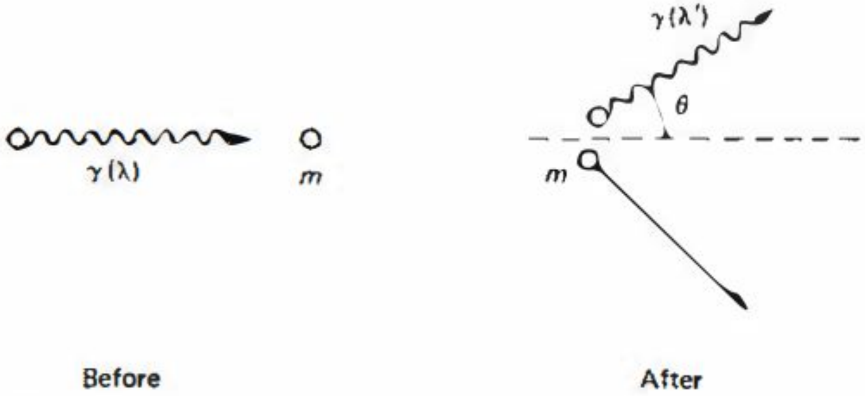

Fig. 1.2 Compton scattering. A photon of wavelength λ scatters off a particle, initially at rest, of mass m. The scattered photon carries wavelength λ' given by Equation 1.4.

Mesons and Strong Force (1934-1947)

- The big question: **What holds the nucleus together?**
- The presence of multiple **positively charged protons** should cause repulsion.
- A powerful but short-ranged force was postulated: the **strong nuclear force**.

Yukawa’s Theory

- **Yukawa (1934)** theorized that a massive particle mediates the strong force, similar to how the photon mediates electromagnetism.
- **Forces are not just fields**: In quantum mechanics, forces arise from the **exchange of particles** rather than continuous fields.
- **Range of the Strong Force**: Given by the equation:

$$\text{Range} \sim \hbar/mc$$

- He predicted a meson with a mass **~300 times the electron’s mass**.
- Anderson & Neddermeyer (1937) discovered a particle with the expected mass in cosmic rays

The Crisis-Something Went Wrong

- Initial cosmic ray discoveries showed **meson-like** particles, but they did not interact as expected.
- These particles had incorrect lifetimes and did not strongly interact with nuclei.

First Resolution- Pion & Muon

Further studies revealed **two different particles**:

- **Pion (π-meson):** The true Yukawa meson, mediating the strong force.
- **Muon (μ-meson):** A separate particle behaving like a heavy electron, unrelated to the strong force.

End of an Early Era

- The discovery of pions and muons refined our understanding of particle interactions.
- This set the stage for further discoveries leading to the **Standard Model of particle physics**.