Introduction to Radiation Measurements

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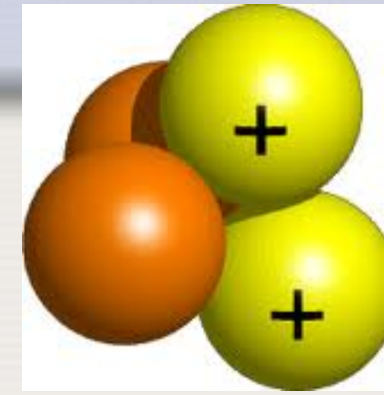
1. Radioactivity

- is a relatively new discovery, being unknown before the end of the nineteenth century.
- X-rays were discovered in 1895 (Roentgen)
- Radioactivity and the electron in 1896 (Becquerel and Thomson) .
- It was soon found that the commonly emitted radiation consisted of three distinct types, called (for simplicity)
- alpha (α), beta (β) and gamma (γ) radiation.

Types

- α-particles are charged He nuclei



- β-rays are fast (energetic) electrons

- γ-rays are electromagnetic radiation of very short wavelength, similar to X-rays
- Note: γ-rays and X-rays
  - γ-rays result from transitions between excited states in the nucleus
  - X-rays result from transitions between atomic levels

Discovery of the Nucleus (Rutherford 1911)

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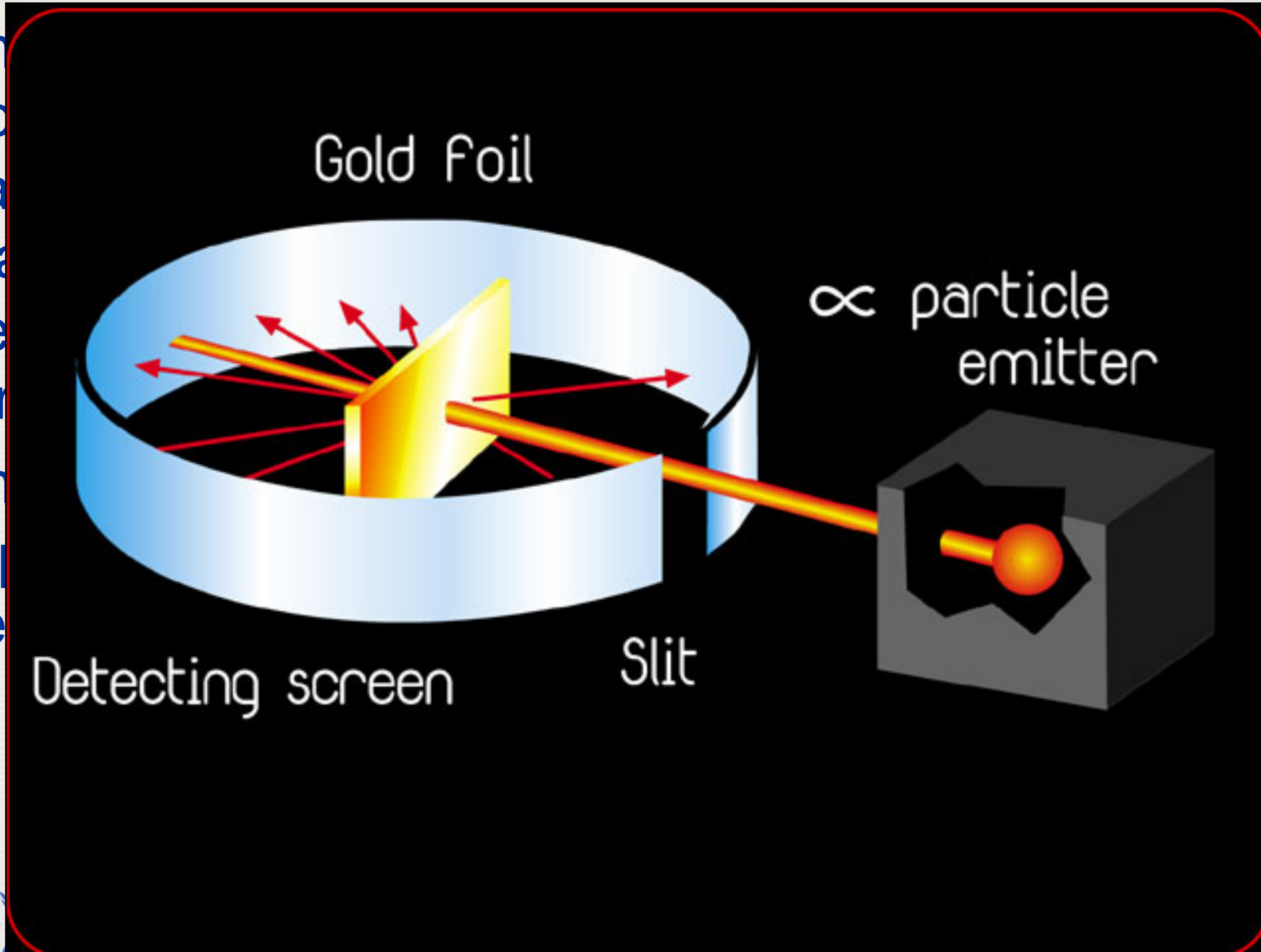

Discovery of the Nucleus (Rutherford 1911)

- The positive charge and almost all the mass of the atom are concentrated in a minute central region of the atom of very high density; this is the nucleus.
  - $d_{Nucleus} \sim 10^{-14}$ m
  - $d_{Atom} \sim 10^{-10}$ m
- The nucleus has a very high density
  - $\rho_{Nucleus} \sim 10^{15}$ kg/m^3 (c.f. $\rho_{Hg} \sim 10^4$ kg/m^3)
- The nucleus of the hydrogen atom is called the **proton**
- The nucleus is surrounded by a strong positive electric field (due to the positively charged protons) which falls off rapidly with distance. Thus the positively charged α-particles will be repelled unless they have enough energy to overcome the repulsion.
- The nucleus consists of positively charged protons and neutral **neutrons**.

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Discovery of the Proton (Rutherford 1919)

- The proton was discovered following bombardment of nitrogen gas by α-particles.
- Scintillations were observed in the detector even when a silver foil was placed between it and the α-particle source. They were also observed even when the range to the detector was made greater than that of the α-particle. The particles causing the scintillation were subsequently identified as protons by measuring their charge and mass.
- There had been a nuclear reaction.
- A reaction, for example, between alphas and a nitrogen atom could and usually would be written as

$$^{14}_{7}N(\alpha,p)^{17}_{8}O$$

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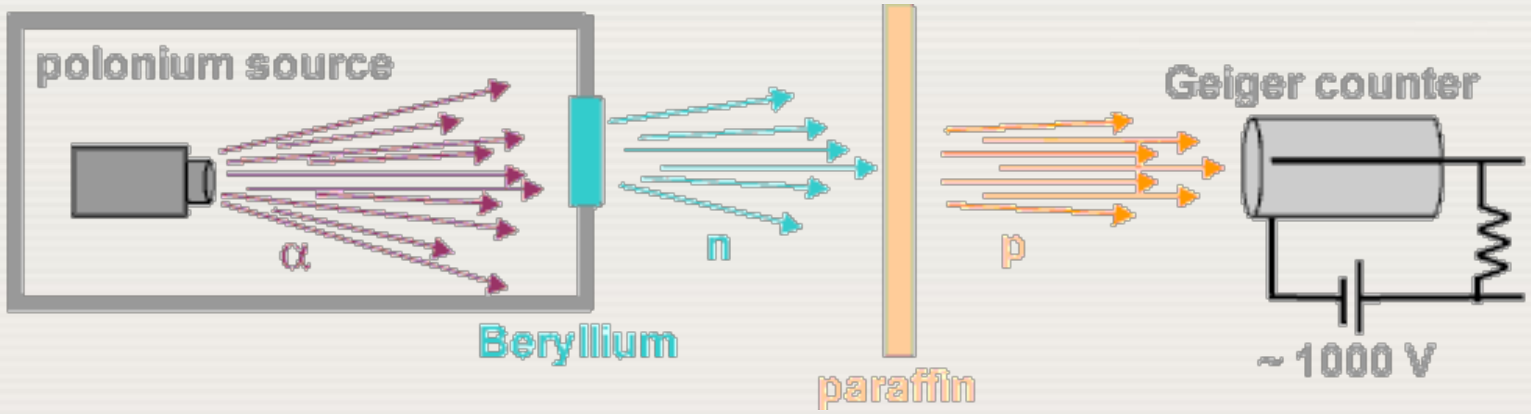
Discovery of the Neutron (Chadwick 1932)

- By bombarding beryllium (Be) with α-particles a very penetrating neutral radiation was observed.
- It was initially thought that this radiation could correspond to very high-energy γ-rays.
- However, in 1932, it was shown that this penetrating radiation could release protons from hydrogen-rich materials such as paraffin wax.
- By measuring the energy of the emitted protons it as finally concluded that the radiation consisted of neutral particles with a mass approximately equal to that of the proton.



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2. Properties of Common Radiations

- Properties of α-particles
  - Charge: 2+
  - Mass: 4.0026 amu or 3.7GeV
  - Typical energies: 4 – 6 MeV

- Most α-particle sources produce as of discrete energy in the range 4 to 6 MeV. There is a very strong correlation between the energy of the emitted α and the half-life of the parent isotope; the higher the α energy the shorter is the half-life. This correlation is a consequence of the quantum mechanical tunnelling nature of the α-decay.

2. Properties of Common Radiations

- Properties of α-particles
  - E_α > 6.5 MeV … half-life < few days
  - E_α > 4.0 MeV … barrier penetration very small and half-life gets large
  - Most common α-particle calibration source is ^{241}Am which has a half life of 432.7 years;
  - most of its α-particles have an energy of 5.4857 MeV
  - Range of alpha particles:
    - In air (STP): 3.5 cm
    - In Silicon: 20μm
- α-particles lose energy rapidly when passing through materials, due to being doubly charged.
- α-particle sources must be made thin in order that the α-particles can get out, and also so as to not overly degrade the α-particle energy.

2. Properties of Common Radiations

- Properties of β-particles
  - Charge: -1
  - Mass: 0.0005486 amu or 511 keV
  - Typical energies: Up to a few MeV
- The energy spectrum following β-decay is a continuous energy spectrum with electron energies ranging from zero to a maximum energy, called the end-point energy, which depends on the source. The beta decay process, which can be written as

$$n \rightarrow p^{+} + e^{-} + \upsilon$$

- involves a third particle, the neutrino (υ), which shares the available energy with the electron. The result is a distribution in electron energies up to the maximum endpoint energy. Discrete energy electrons can also be produced following the internal conversion and Auger electron processes. These discrete peaks will be superimposed on the continuous beta decay spectrum.

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2. Properties of Common Radiations

- Properties of β-particles
- Most radionuclides produced following neutron bombardment are β-active. Hence a large variety of beta sources are readily available from reactors.
- **Half-Lives:** A wide range, from thousands of years to very short (<< second).
- **Range:** β-particles have a smaller charge than α-particles and are therefore less ionising (i.e. they lose energy at a lower rate). They are also about 8000 times lighter than α-particles and therefore bounce around a lot more and follow a much more tortuous path in the absorbing materials. They interact with the electrons in the stopping material, i.e. with equal mass particles.
- A crude estimate for the range of β-particles:
  - 2 mm per MeV in low density materials
  - 1 mm per MeV in moderate density materials

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2. Properties of Common Radiations

- Properties of neutrons
  - Charge: 0
  - Mass: 1.008665 amu or 0.932GeV
  - Typical energies: range up to about 10 MeV

- Neutron sources are limited to either spontaneous fission sources or to sources using nuclear reactions where the incident particle triggering the reaction is the product of a conventional decay process.

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2. Properties of Common Radiations

- Properties of neutrons
- **Range:** the neutron is uncharged and therefore is not subject to the Coulomb force and does not cause direct ionisation. Therefore, its stopping (and detection) depends on a 'catastrophic' interaction process, most likely involving the nuclei of the atoms in the stopping material, to produce an ionising radiation, which is then detected. Neutrons reactions almost always produce heavy charged particles (protons or β-particles) or gamma-rays.
- **Typical Range** (in solids): 10^{-1} m
- **Life time:** A neutron decays to a proton plus an electron and a neutrino; the half life is 12.8 minutes.

2. Properties of Common Radiations

- Properties of γ-rays
  - Charge: 0
  - Mass: 0
  - Typical energies: up to a few MeV

- **Range:** As for neutrons, y-ray detection depends on a 'catastrophic' interaction process to produce ionising radiation, this time usually giving electrons. In principle there is no definite range, the number of gammas falling off exponentially with distance, but to a first approximation we can say
- **Typical Range** (in solids): 10^{-1} m.

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2. Properties of Common Radiations