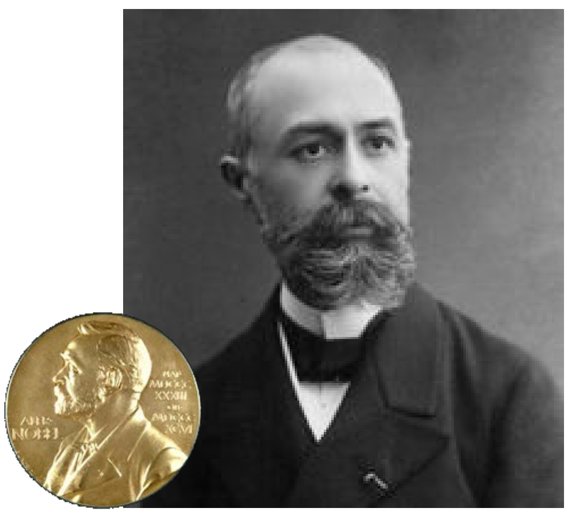
Chapter 12 –Radioactivity

Course Content

- Principle of Radioactivity
  - Definition of radioactivity decay
  - Half-life
- Types of Radiation
  - Alpha, beta and gamma
- Isotopes
  - Definition
  - Applications

Radioactivity History

- In 1896, Henri Becquerel discovered, almost by accident, that uranium can blacken a photographic plate, even in the dark.
- Uranium emits very energetic radiation - it is radioactive.



Henri Becquerel (1852-1908)

In 1903, he shared the Nobel Prize in Physics with Pierre and Marie Curie "in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity".

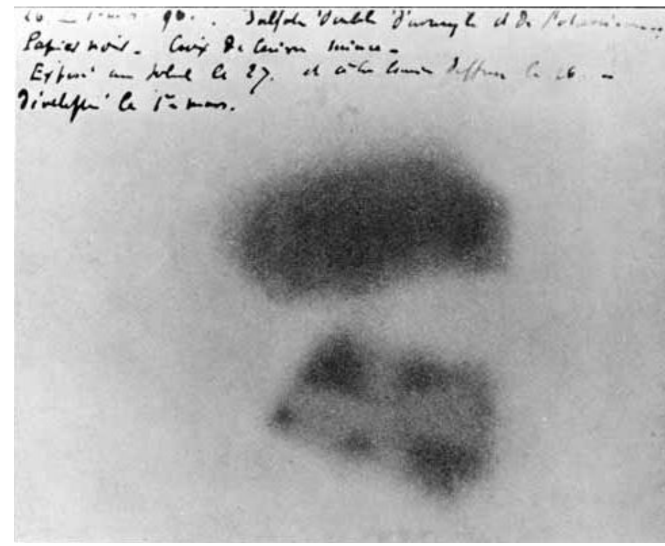


Image of Becquerel's photographic plate which has been fogged by exposure to radiation from a uranium salt.

- Then Marie and Pierre Curie discovered more radioactive elements including polonium and radium.
- She used the word radioactivity to describe the property of certain substances to give off invisible “radiations” that could be detected by films.
- Scientists soon realised that there were three different types of radiation.
- These were called alpha (α), beta (β), and gamma (γ) rays from the first three letters of the Greek alphabet.

Marie Curie (1867-1934)

Pierre Curie (1859-1906)

Radioactive Decay

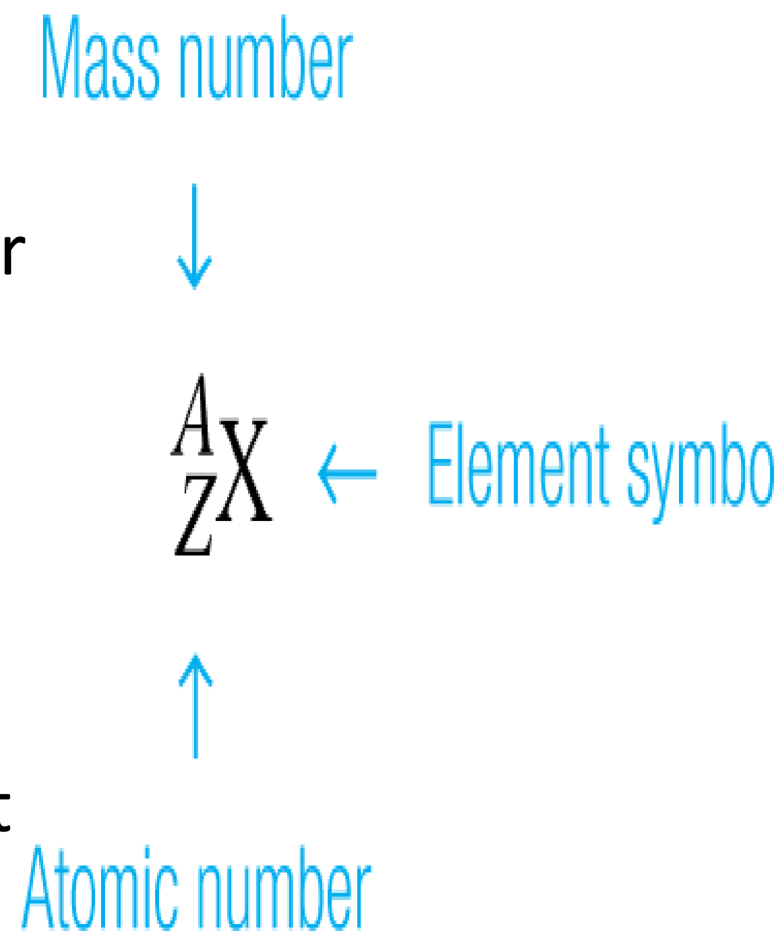
- **Radioactivity** – the spontaneous decomposition or disintegration of a nucleus forming a different nucleus and producing one or more additional particles
- **Radioactive decay** is a process by which the nuclei of a nuclide emit α, β or γ rays.
- In the radioactive process, the nuclide undergoes a **transmutation**, converting to another nuclide.
- **Nuclear Equation** – shows the radioactive decomposition of an element

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

- **Nuclear Forces** – strong nuclear force holds neutrons and protons together to form a nucleus (counters electromagnetic repulsion).

Review of Atomic Terms

- **Nucleons** – particles found in the nucleus of an atom
  - **neutrons and protons**
- **Atomic Number (Z)** – number of protons in the nucleus
- **Mass Number (A)** – sum of the number of protons and neutrons
- **Isotopes** – atoms with identical atomic numbers but different mass numbers
- **Nuclide** – each unique atom



Isotope review activity

Isotopes

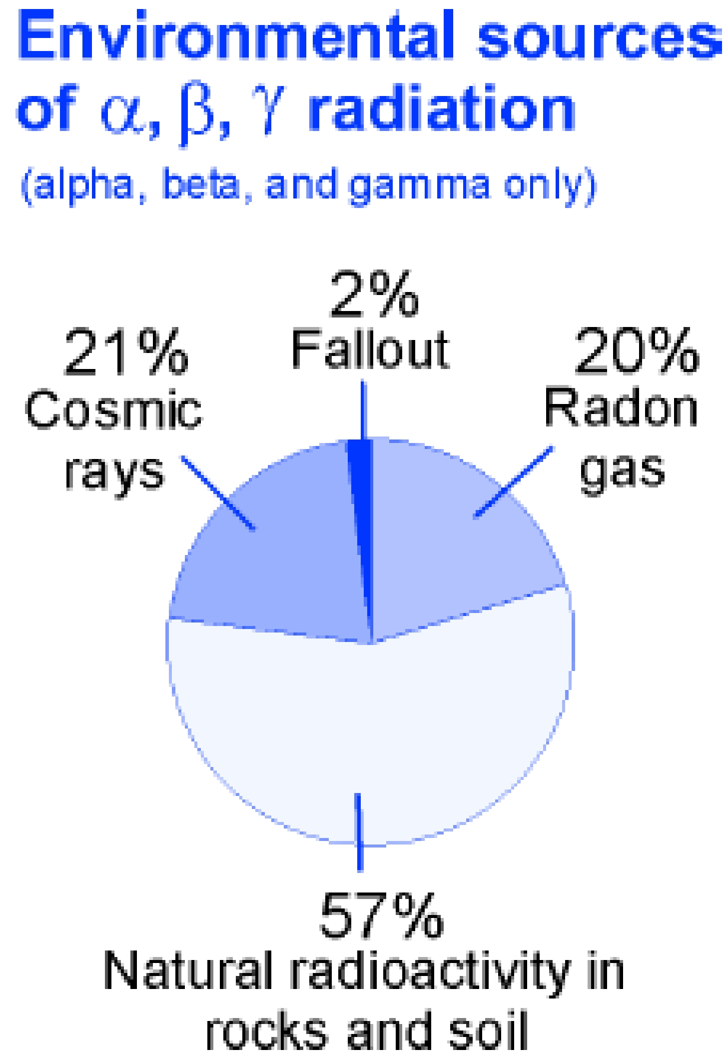
- Most of the isotopes which occur naturally are stable.
- A few naturally occurring isotopes and all of the man-made isotopes are unstable.
- Unstable isotopes can become stable by releasing different types of particles.
- This process is called radioactive decay and the elements which undergo this process are called radioisotopes/radionuclides.

Sources of Radiation

- Ionizing radiation is a natural part of our environment.
- There are two chief sources of radiation you will probably be exposed to:
  - background radiation.
  - radiation from radioisotopes or medical procedures such as x-rays.

Background radiation

- Background radiation levels can vary widely from place to place.
  - Cosmic rays are high energy particles that come from outside our solar system.
  - Radioactive material from nuclear weapons is called fallout.
  - Radioactive radon gas is present in the atmosphere.



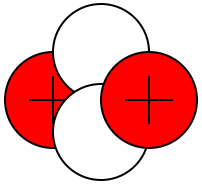
Radioactive Decay

Radioactive decay results in the emission of either:

- an alpha particle (α),
- a beta particle (β),
- or a gamma ray(γ).

Alpha Decay

An alpha particle is identical to that of a helium nucleus.



It contains two protons and two neutrons.

Alpha Decay

- **Alpha-particle production**
- Alpha particle – helium nucleus
  - Examples

$$^{222}_{88}\text{Ra} \rightarrow \, ^{4}_{2}\text{He} + \, ^{218}_{86}\text{Rn}$$

$$^{230}_{90}\text{Th} \rightarrow \, ^{4}_{2}\text{He} + \, ^{226}_{88}\text{Ra}$$

- Net effect is loss of 4 in mass number and loss of 2 in atomic number.

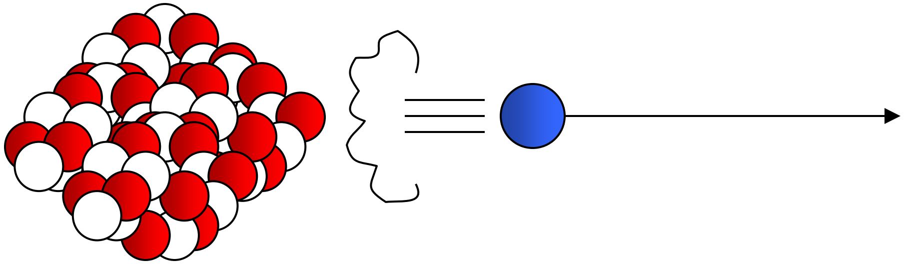
Alpha Decay

$$^{222}_{86}\text{Rn} \longrightarrow \, ^{A}_{Z}\text{Y} + \, ^{4}_{2}\text{He}$$

$$^{222}_{86}\text{Rn} \longrightarrow \, ^{218}_{84}\text{Po} + \, ^{4}_{2}\text{He}$$

Beta Decay

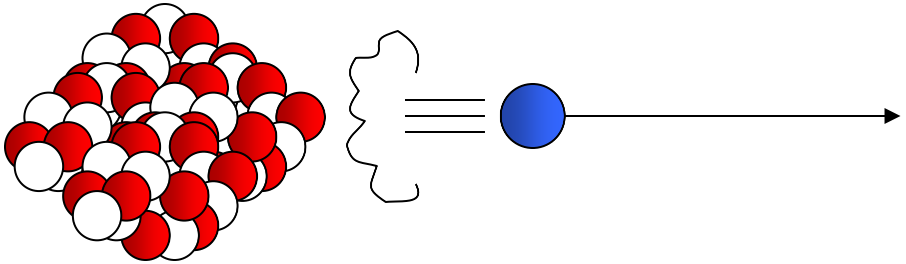
As a result of beta decay, the nucleus has one less neutron, but one extra proton.



The atomic number, Z, increases by 1 and the mass number, A, stays the same.

Beta Decay

As a result of beta decay, the nucleus has one less neutron, but one extra proton.



The atomic number, Z, increases by 1 and the mass number, A, stays the same.

Beta Decay

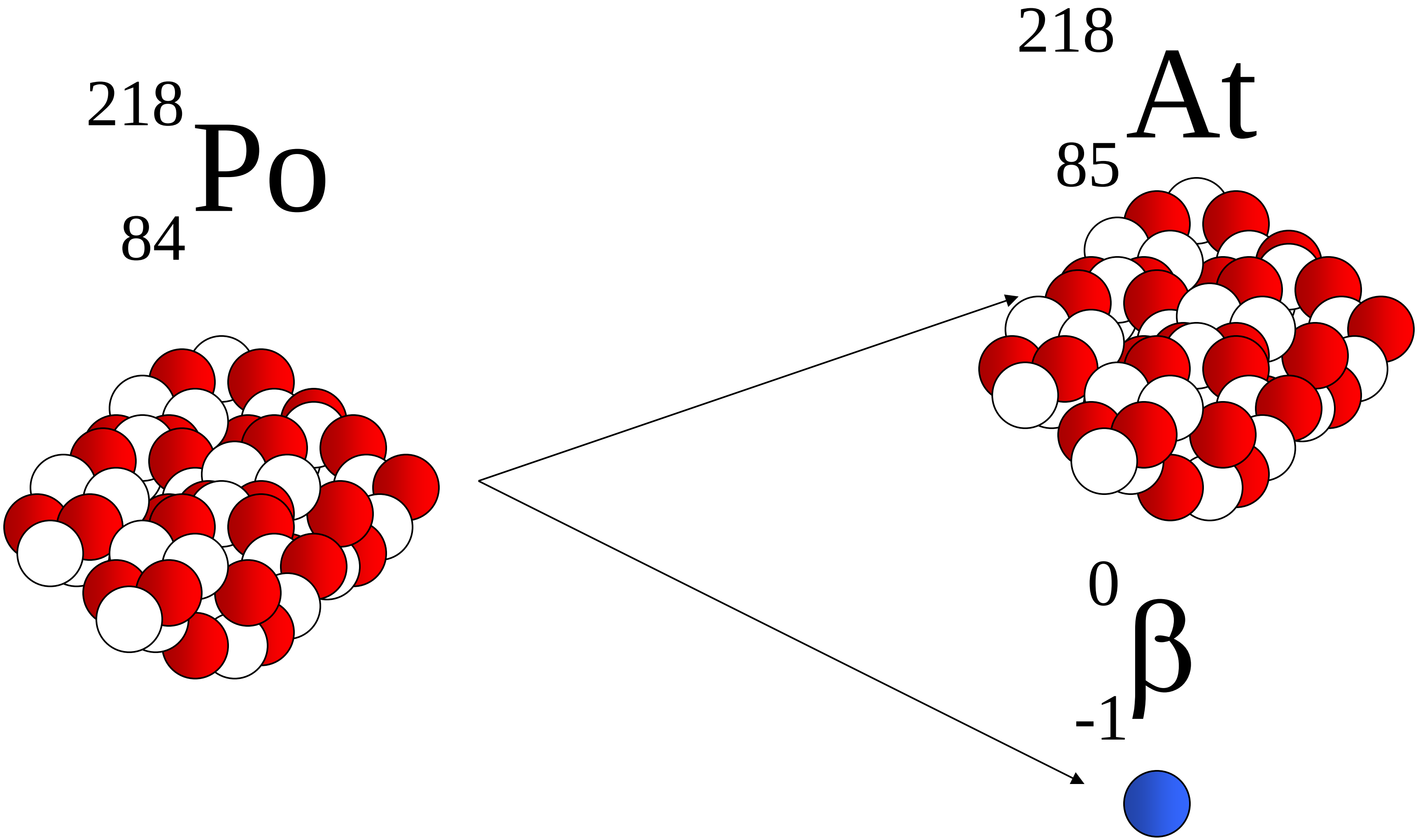
- **Beta-particle production**
  - Beta particle – electron
    - Examples

$$^{234}_{90}\text{Th} \rightarrow \, ^{234}_{91}\text{Pa} + \, ^{0}_{-1}\text{e}$$

$$^{131}_{53}\text{I} \rightarrow \, ^{0}_{-1}\text{e} + \, ^{131}_{54}\text{Xe}$$

- Net effect is to change a neutron to a proton.

Beta Decay



Beta Decay

$$^{A}_{Z}X \longrightarrow \,^{A}_{Z+1}Y + \,^{0}_{-1}\beta$$

$$^{218}_{84}Po \longrightarrow \,^{218}_{85}Rn + \,^{0}_{-1}\beta$$

Gamma Decay

- Gamma rays are not charged particles like a and b particles.
- Gamma rays are electromagnetic radiation with high frequency.
- When atoms decay by emitting a or b particles to form a new atom, the nuclei of the new atom formed may still have too much energy to be completely stable.
- This excess energy is emitted as gamma rays (gamma ray photons have energies of ~ 1×10^{-12} J).

Gamma Decay

- **Gamma ray release**
- Gamma ray – high energy photon
  - Examples

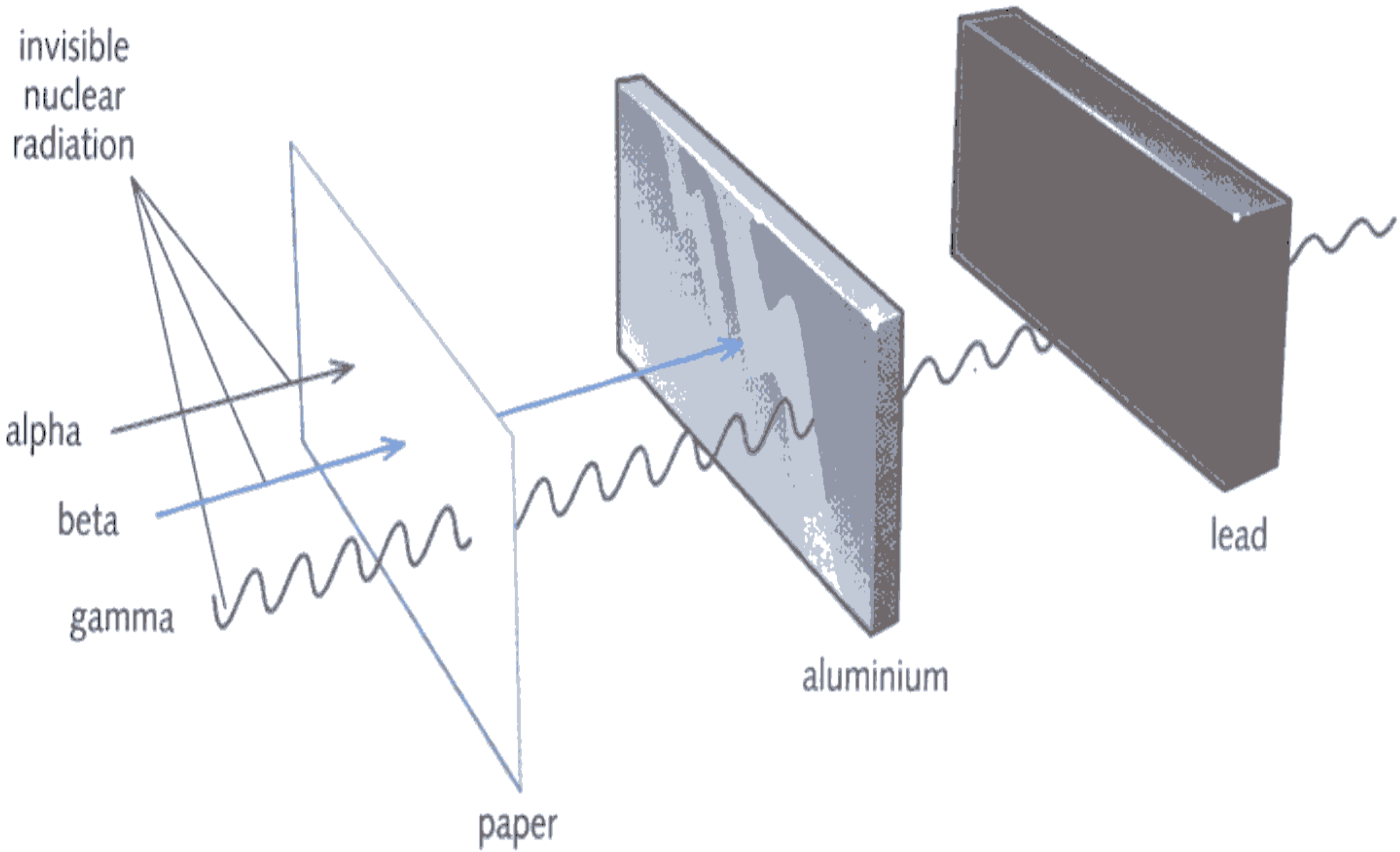
$$^{238}_{92}U \rightarrow \,^{4}_{2}He + \,^{234}_{90}Th + 2\,^{0}_{0}\gamma$$

- Net effect is no change in mass number or atomic number.

Absorption of Radiation

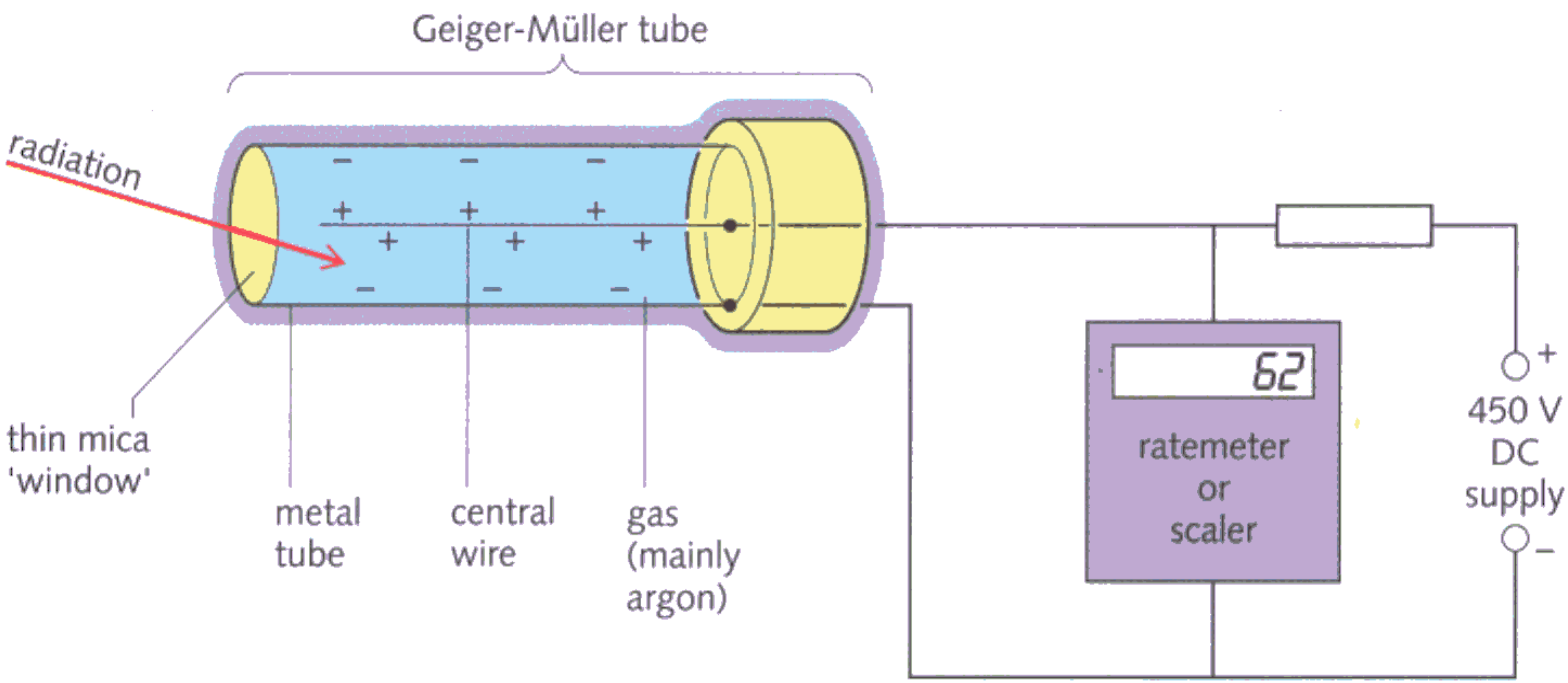
- Alpha (α) – absorbed by 2-3 cm air and thin paper
- Beta (β) – can penetrate paper absorbed by a few mm of metal
- Gamma (γ) – very penetrating absorbed by many cm of lead and metres of concrete

Absorption of Radiation



Detection of Radioactivity

- **Geiger-Muller counter –** instrument which measures radioactive decay by registering the ions and electrons produced as a radioactive particle passes through a gas-filled chamber



Detection of Radioactivity

- **Scintillation counter** instrument which measures the rate of radioactive decay by sensing flashes of light that the radiation produces in the detector

Radioactive Half-Life

- Radioactive decay depends on chance.
- It is possible to predict the average behavior of lots of atoms, but impossible to predict when any one atom will decay.
- One very useful prediction we can make is the half-life.
- The half-life is the time it takes for half of the original sample of radioactive material to decay to half its original

Radioactive Half-Life

- Most radioactive materials decay in a series of reactions.
- Radon gas comes from the decay of uranium in the soil.
- Uranium (U-238) decays to radon-222 (Ra-222).

$$U^{238} \xrightarrow[\text{4.5 billion years}]{\alpha\text{ decay}} Th^{234}$$

$$Th^{234} \xrightarrow[\text{24 days}]{\beta\text{ decay}} Pa^{234}$$

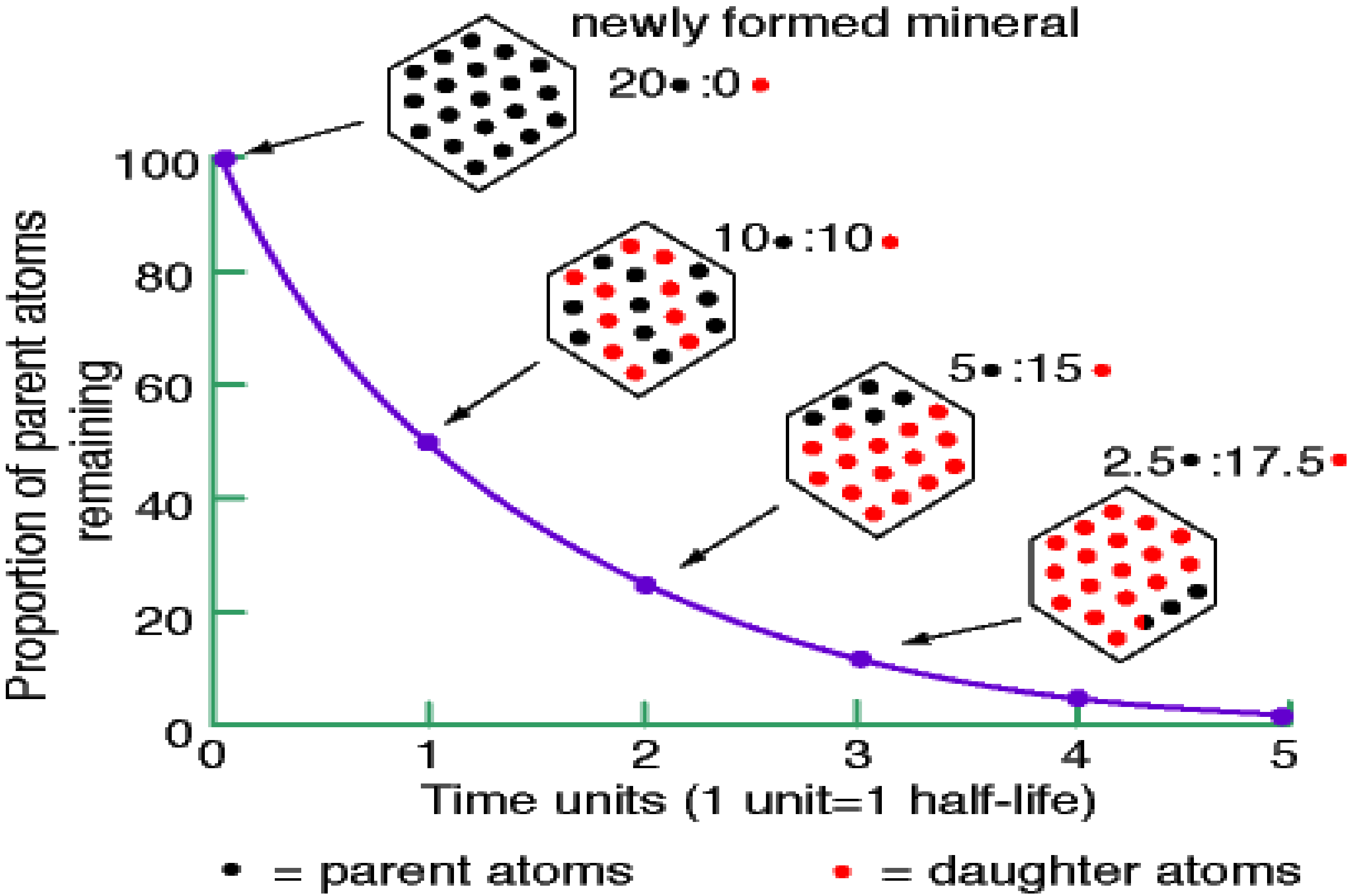
$$Pa^{234} \xrightarrow[\text{6.7 hours}]{\beta\text{ decay}} U^{234}$$

$$U^{234} \xrightarrow[\text{245,500 years}]{\alpha\text{ decay}} Th^{230}$$

$$Th^{230} \xrightarrow[\text{75,000 years}]{\alpha\text{ decay}} Ra^{226}$$

$$Ra^{226} \xrightarrow[\text{1,600 years}]{\alpha\text{ decay}} Rn^{222}$$

Radioactive Half-life



Application of Isotopes

1. Food and Agriculture
   1. Fertilisers
   2. Increasing genetic variability
   3. Food irradiation and preservation
2. Medicine
   1. Sterilization
   2. Treatment of cancer
   3. Diagnosis - Tracers and imaging
3. Carbon dating
4. Smoke detectors

- Note:
  - See Study guide and
  - website: http://www.world-nuclear.org/info/non-power-nuclear-applications/overview/the-many-uses-of-nuclear-technology/