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Phys 145 (General Physics)

Chapter 9: Nuclear Physics (part 1)

Week n° 12

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Chapter 9: Nuclear Physics

- **We will learn in this chapter 9:**

- Radioactivity
- Half-Life
- Radioactive Decays

Chapter 9: Nuclear Physics (First part)

- **We will learn in this first part of chapter 9:**

- Radioactivity
- Half-life

Radioactivity

- Ernest Rutherford (1871-1937) inferred the existence of the nucleus in 1911.

- Antoine Henri Becquerel (1852-1908) accidentally made the first observation of a purely nuclear phenomenon in 1896.

  He was the first to discover that uranium (U) is radioactive:
  He left *uranium ore* (يورانيوم خام) in his desk next to photographic paper. When developed the film, he had an image on it from the uranium decaying.
- **Radioactivity** refers to the particles which are emitted from nuclei as a result of **nuclear instability**.

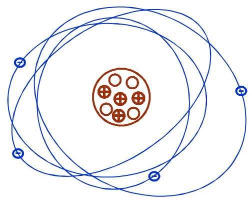
Atoms and nucleus

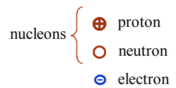
All things around us are **made of atoms**. The atom is the smallest unit of a chemical element, such as copper (Cu) or aluminum (Al), which has the physical and chemical properties of the element.

Atoms have a dense **center called a nucleus**. The nucleus is **surrounded by orbiting electrons**.

Nuclear model of an atom

In this example the atom is beryllium (Be) with 8 nucleons (4 protons+ 4 neutrons) and 4 electrons orbiting the nucleus.





Symbol of a nucleus

- The complete **symbol of a nucleus** contain the **symbol** of the element, the **mass number** and the **atomic number**.

Superscript → Mass number

X

Subscript → Atomic number

$${}^{A}_{Z}X$$

A = number of nucleons (protons + neutrons)

Z = number of protons

N = A – Z = number of neutrons

Number of neutrons = Mass Number – Atomic Number

Isotopes (Example of uranium)

$${}^{235}_{92}U \qquad {}^{238}_{92}U$$

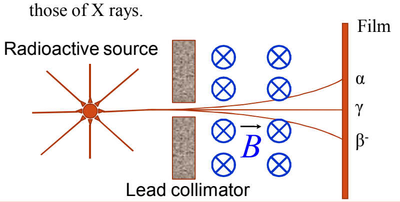
A	235
Z	92
Number of protons	92
Number of neutrons	143

A	238
Z	92
Number of protons	92
Number of neutrons	146

Isotopes of any particular element contain the same number of protons, but different by the numbers of neutrons.

Radioactivity experiment:

- A lead plate can stops most of the radiation from an uranium source, so a plate with a small hole can be used to form a narrow collimated beam of radiation. In the presence of a magnetic field, this beam splits into three components, labeled **alpha** (α), **beta** (β), and **gamma** (γ).
  - Alpha particles are positively charged, they are known to be helium nuclei.
  - Beta particles are negatively charged and are electrons.
  - Gamma are neutral, they are photons whose energies are usually greater than those of X rays.



Radioactivity symbol

Radioactive Decay

Rutherford and Soddy showed in 1903 that when a uranium nucleus emits an alpha particle, it is changed into a thorium nucleus:

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

This is a decay processes (called alpha decay).

Radioactive Decay

- When the atomic nucleus undergoes spontaneous transformation, called ***radioactive decay***, radiation is emitted.
  - If the daughter nucleus is stable, this spontaneous transformation ends.
  - If the daughter is unstable, the process continues until a stable nuclide is reached.
- Most radionuclide's decay in one or more of the following ways:
  - (a) alpha decay,
  - (b) beta-minus (electron) emission,
  - (c) beta-plus (positron) emission,
  - (d) electron capture.

Emission	What?	Penetration
Alpha α	2 protons 2 neutrons	Few cm in air. Stopped by paper
Beta β	electron	1 metre in air. Stopped by thin aluminium
Gamma γ	electromagnetic wave	Few metres of concrete will reduce their energy. Difficult to stop

Half-life

The **half-life** ***T*** is the time it takes for half a radioactive sample to decay. When:

$$N = N(T) = \frac{1}{2} N_0$$

Radioactive decay is a statistical process which depends upon the instability of the particular radioisotope, but which for any given nucleus in a sample is completely unpredictable. The decay process can be described by assuming that individual nuclear decays are purely random events:

If there are N radioactive nuclei at some time t, then the number - ΔN which would decay in any given time interval Δt would be proportional to N and Δt:

$$\Delta N = -\lambda N \Delta t \Rightarrow \frac{\Delta N}{N} = -\lambda \Delta t \Rightarrow N = N(t) = N_o e^{-\lambda t}$$

The proportionality constant λ is called the **decay constant**.

Half-life and decay constant

We have:

$$N(t) = N_o e^{-\lambda t}$$

so:

$$N = N(T) = \frac{1}{2} N_0 = N_0 e^{-\lambda T}$$

$$\frac{1}{2} = e^{-\lambda T} \Rightarrow -\ln(2) = -\lambda T$$

And at the end:

$$\lambda = \frac{\ln(2)}{T} \approx \frac{0.693}{T}$$

Remember that λ is the **decay constant and** ***T*** **the Half-life.**

Video 01 of week 12: Nuclear half-life

Effective half-life

The **effective half-life** T_{eff} is obtained by combining the **biological half-life** T_b and the radioactive or **physical half-life** T (or T_p) according to the formula:

$$\frac{1}{T_{eff}} = \frac{1}{T_b} + \frac{1}{T}$$

Half-lives of some radionuclides used in Medicine			
Nuclide	Organ where concentrated	T (days)	T_b (days)
^{3}H	Total body	4.6x10^{3}	19
^{24}Na	Total body	0.62	29
^{32}P	Bone	14.3	1200
^{42}K	Muscle	0.52	43
^{59}Fe	Blood	46.3	65
^{131}I	Thyroid	8.1	180

Activity

The **activity** *R* of a radioactive substance is defined as the number of radioactive nuclei that disintegrate per second:

$$R = |\Delta N / \Delta t|$$

$$R = \lambda N = \lambda N_o e^{-\lambda t}$$

$$R_o = \lambda N_o$$

$$R(t) = R_o e^{-\lambda t}$$

The SI unit of activity is the Becquerel [Bq]:1 Bq = 1 disintegration/s (dps)

The Curie (Ci) = Activity of 1g of ^{226}Ra. 1 Ci = 3.7 × 10^{10} Bq

Summary of week 12

- **Atoms have a dense center a nucleus surrounded by electrons.**
- **Nucleus contain nucleons that can be neutrons or protons.**
- **A symbol of a nucleus is $^A_Z X$.**
- **The main formulas are:**

$$N(t) = N_o e^{-\lambda t}$$

$$\lambda = \frac{\ln(2)}{T} \approx \frac{0.693}{T}$$

$$\frac{1}{T_{eff}} = \frac{1}{T_b} + \frac{1}{T}$$

Quiz for week 12