# 2.2: Nuclear physics tutorial

**Basics:**

The atomic nucleus is the dense region at the center of an atom consisting of protons and neutrons.

In chemistry, we examine chemical reactions, which involve the electron cloud surrounding the nucleus. (Chemical reactions do not involve any changes within the nucleus.)

Nuclear physics examines reactions that take place within the nucleus (ie involving protons and neutrons). (NOTE: **nuclear reactions involve only the nucleus, and not the electrons surrounding the nucleus**)

The study of nuclear physics at Y2 is limited largely to radioactive decay.

**Radioactive decay:**

Radioactive decay is the process by which a nucleus of an unstable atom (too high energy) loses energy by emitting radiation. (Unstable atoms are generally atoms of radioactive isotopes, eg carbon-14)

Remember: isotopes are atoms of the same element (same number of protons) but different number of neutrons

An atom undergoing radioactive decay can emit 3 kinds of radiation:

| | **α (alpha) particles** | **β (beta) particles** | **γ (gamma) rays** |
|---|---|---|---|
| Nature | Helium nuclei, ${}^{4}_{2}He$ | Electrons, ${}^{0}_{-1}e$ | Electromagnetic waves |
| Charge | 2+ | 1- | Neutral |
| Speed | 0.10c | 0.90c | c |
| Penetrating power | Stopped by 1 or 2 sheets of paper | Stopped by 5mm aluminum sheet | Stopped by several centimeters of lead |

Alpha decay (breaking down of unstable nucleus, emitting alpha particle in the process)

$${}^{228}_{90}Th \rightarrow {}^{4}_{2}He + {}^{224}_{88}Ra$$

Beta decay (**the unstable nucleus becomes stable by converting a neutron into a proton and an electron, the electron is ejected from the nucleus at high speed**)

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

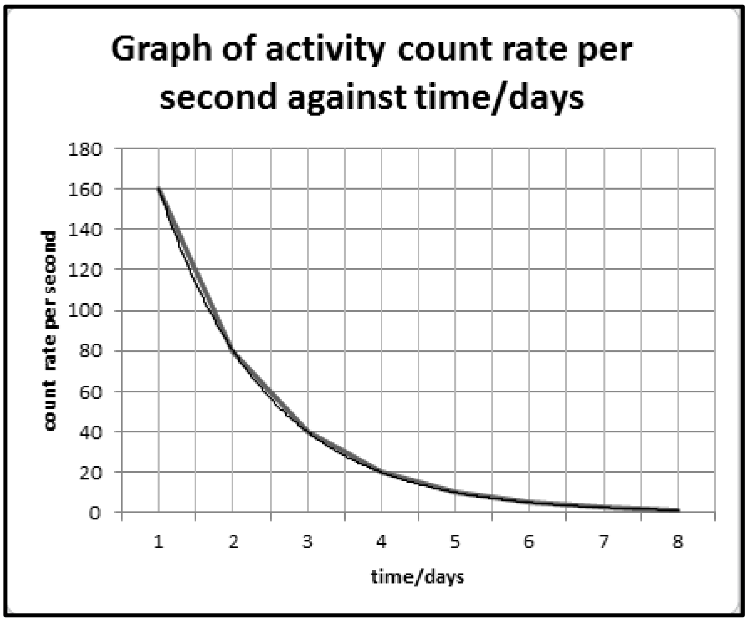
Gamma emission (**after emitting an alpha or beta particle, the remaining nuclei may have surplus energy which is emitted as gamma rays**)

**Half-life**

**The half-life of a radioactive substance is the time taken for half of the nuclei in the sample to undergo radioactive decay**

The amount of nuclei that hasn't decayed can be estimated by measuring the radioactive count rate (activity count rate). This can be done with a **Geiger-Muller counter**.

The Geiger counter detects radiation such as alpha particles, beta particles, and gamma rays. The **count rate** (counts per second, or minutes/days etc) which measures frequency of ionization events being detected, gives an estimate to the amount of radiation being emitted by the substance.




With reference to the graph above, the count rate decreased from 160 to 80 (half its previous value) between 1 and 2 days, so the half-life of the substance is 1 day.

(Note: The time taken for count rate to decrease from 80 to 40, ie half its previous value, is also 1 day. Half-life is constant for the same material, regardless of how much of it is left.)

**Applications of radioactivity**

1. Tracing (for medical scans)
2. Sterilizing (gamma rays)
3. Thickness-control
4. Radiotherapy (gamma rays used to kill cancer cells)

## Practice questions (selected from RI past-year papers)

Question 1:

Uranium, U (nucleon number 238 and proton number 92), decays to thorium, Th (nucleon number 234 and proton number 90), by the emission of an unknown radiation. The count rate of the unknown radiation drops drastically to the background count when a piece of thin paper is placed between the source and a Geiger-Muller counter.

From the information given, specify the type of particle or ray that was emitted: ________________

Complete the missing part in the following equation that shows the decay of Uranium-238:

$$^{238}_{92}U \rightarrow \_\_\_\_\_ + \_\_\_\_\_$$

Question 2:

Carbon-14 is a radioactive isotope of carbon. It decays to form nitrogen.

What radiation is emitted, and how can this radiation be stopped?

______________________________________________________________________________

Using this information, write down an equation for the decay of carbon-14.

______________________________________________________________________________

Question 3:

Tritium, $^{3}_{1}H$, is a radioactive isotope that undergoes beta decay.

Write out the equation when tritium undergoes beta decay.

______________________________________________________________________________

Describe the process of beta decay:

______________________________________________________________________________

Question 4:

Gamma rays are the most dangerous in terms of external exposure by humans. How can humans protect themselves from external exposure to gamma rays?

______________________________________________________________________________

Question 5:

Uranium-234 decays by emitting a succession of α-particles to form lead-214. How many α-particles are emitted by the decay of 1 uranium-234 nuclei? (uranium, U has atomic number 92 and lead, Pb has atomic number 82)

Show your working clearly.

Question 6:

What is meant by the half-life of a nuclide?

______________________________________________________________________________

Carbon-14 has a half-life of 5600 years. A sample of carbon-14 has an initial count rate of 1280 counts/min. Sketch a graph of count rate against time to illustrate the decay of the sample, showing at least 2 half-lives. Label both axes clearly.

A standard sample of living wood gives a carbon-14 count rate of 1280 counts/min. A standard sample of wood from a sunken wreck gives a carbon-14 count rate of 160 counts/min. assuming that the carbon-14 only starts to decay after the tree dies, calculate the age of the sample.

______________________________________________________________________________

______________________________________________________________________________

Question 7:

Radioactive X undergoes beta decay, alpha decay, and finally beta decay successively, as illustrated below:

$$X \rightarrow {}^{212}_{83}Bi \rightarrow {}^{208}_{81}Tl \rightarrow {}^{208}_{82}Pb$$

Identify radioactive isotope X: __________

Write down the equation that best represents the nuclear decay reaction from bismuth-212 to thallium-208.

___________________________________________________________________________

A sample of thallium-208 was placed near a Geiger counter, which was observed to register 770 counts per minute. After 18 minutes, the counter registered 12 counts per minute.

Calculate the half-life of thallium-208

Question 8:

Watch dials are often painted with a compound containing tritium, ${}^{3}_{1}H$, which has a half-life of 12.3 years. When the tritium atom undergoes beta decay, the emitted electron strikes a fluorescent pigment, which then glows.

The tritium-dial watch is giving off a certain amount of light. For the watch to give off one-eight as much light,

How many half-lives must pass? ___________________________________

How many years must pass? ______________________________________

Why do the beta rays emitted by the decay of tritium in the watch pose no health hazard?

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