



## ANS 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

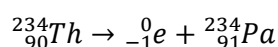
An atom undergoing radioactive decay can emit 3 kinds of radiation:

	<b>α (alpha) particles</b>	<b>β (beta) particles</b>	<b>γ (gamma) rays</b>
Nature	Helium nuclei, ${}^4_2\text{He}$	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)



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**)



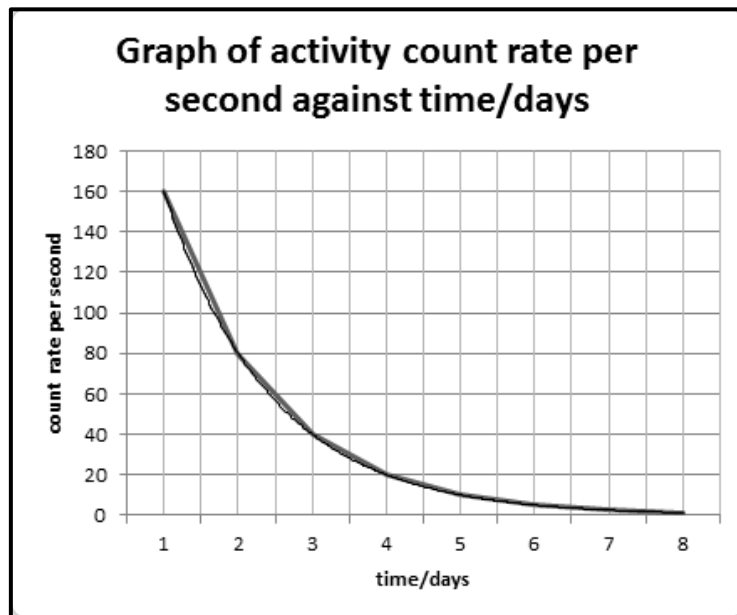
Gamma emission (**after emitting an alpha or beta particle, the remaining nuclei may have surplus energy which is emitted as gamma rays**)

### 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:

Alpha particle/ $\alpha$ -particle/helium nucleus/ ${}^4_2\text{He}$

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



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?

Beta radiation is emitted, it can be stopped by 5mm of aluminum sheet.

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



Question 3:

Tritium,  ${}^3_1\text{H}$ , is a radioactive isotope that undergoes beta decay.

Write out the equation when tritium undergoes beta decay.



Describe the process of 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

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?

By containing the radioactive substance with several centimeters of lead.

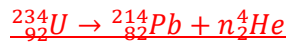
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Question 5:

Uranium-234 decays by emitting a succession of  $\alpha$ -particles to form lead-214. How many  $\alpha$ -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.



$$234 = 214 + 4n$$

$$92 = 82 + 2n$$

$$n = 5$$

Hence each uranium-234 nuclei emits 5  $\alpha$ -particles during decay.

(simpler working is possible)

Question 6:

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

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

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.

\*curved graph should show fall from 1280 to 640 from  $t=0$  to  $t=5600$ , and a fall from 640 to 320 from  $t=5600$  to  $t=11200$

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.

$$1280 \rightarrow 640 \rightarrow 320 \rightarrow 160$$

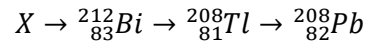
OR

$$160 = 1280 \times \left(\frac{1}{2}\right)^3$$

$$3 \times 5600 = 16800 \text{ yrs}$$

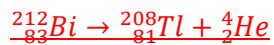
## Question 7:

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



Identify radioactive isotope X:  ${}_{82}^{212}\text{Pb}$

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

$770 \rightarrow 385 \rightarrow 192.5 \rightarrow 96.25 \rightarrow 48.125 \rightarrow 24.0625 \rightarrow 12.03125$  (approx. 12)

OR

$$\underline{12 \approx 770 \times (\frac{1}{2})^6}$$

18 mins = 6 half-lives

1 half-life = 3 mins

## Question 8:

Watch dials are often painted with a compound containing tritium,  ${}^3_1\text{H}$ , 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-eighth as much light,

How many half-lives must pass? 3 half-lives ( $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$ )

How many years must pass? 36.9 years must pass ( $12.3 \times 3$ )

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

The rate at which beta particles are being emitted is very low (half-life is very long, and amount of substance is small)