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RADIATION AND HALF-LIFE

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Specification

Radioactivity and particles

Radioactivity

understand that ionising radiations can be detected using a photographic film or a Geiger-Muller detector

explain the sources of background radiation

understand that the activity of a radioactive source decreases over a period of time and is measured in becquerels

understand the term ‘half-life’ and understand that it is different for different radioactive isotopes

use the concept of half-life to carry out simple calculations on activity

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Detecting radioactivity

Radioactivity can be detected using **photographic film** or a **Geiger counter**.

Radiation badge containing photographic film

Geiger tube and counter

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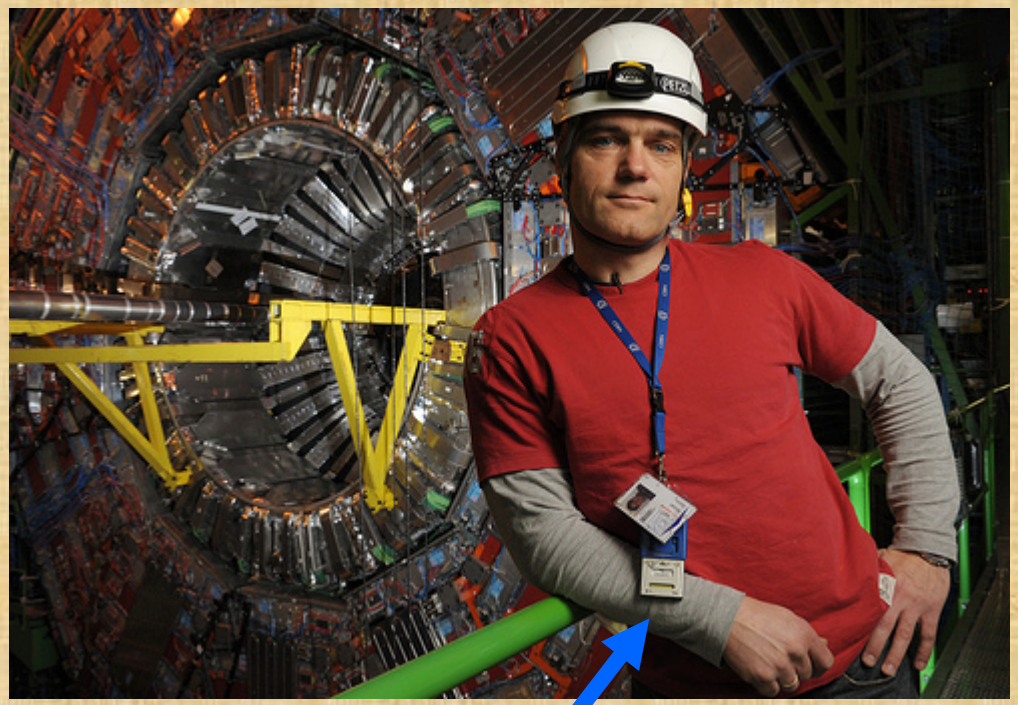
Radiation badges

Photographic film darkens on exposure to radiation and light.

Light cannot penetrate the badge but ionising radiation can.

Darkening of the film indicates that a person has been exposed to too much radiation.



Engineer at CERN wearing a radiation badge

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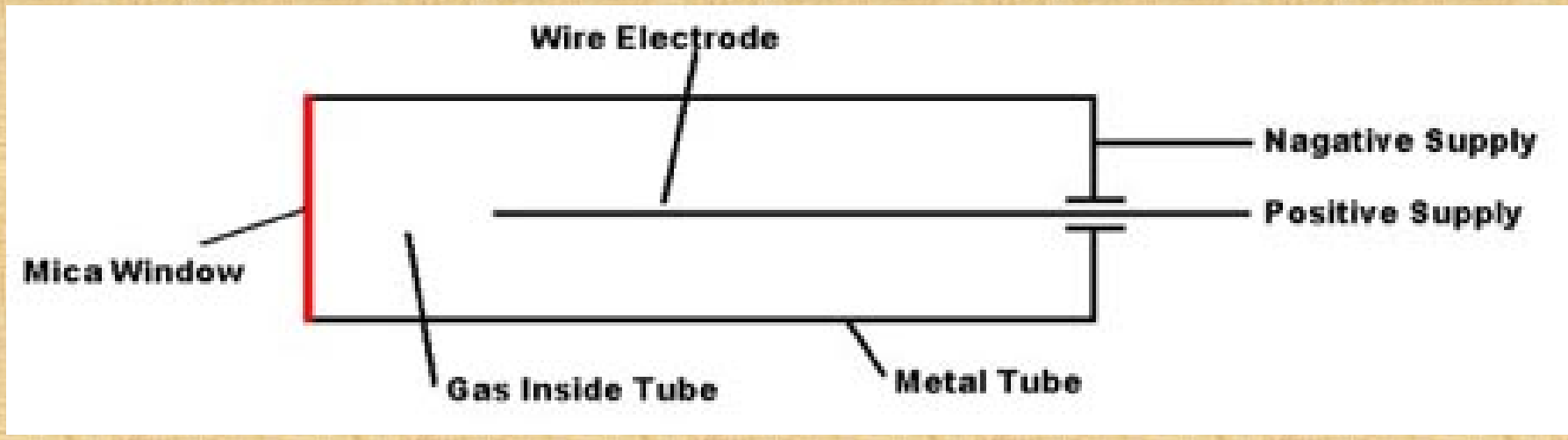
The Geiger tube



Radiation produces ions in a **low pressure gas** between a central positively charged electrode and the outer negatively charged tube. A pulse of current then flows that is registered by the counter.

The thin **mica window** allows the least penetrating radiation (alpha) to enter the tube. Gamma radiation and most beta can enter through the sides of the metal tube.

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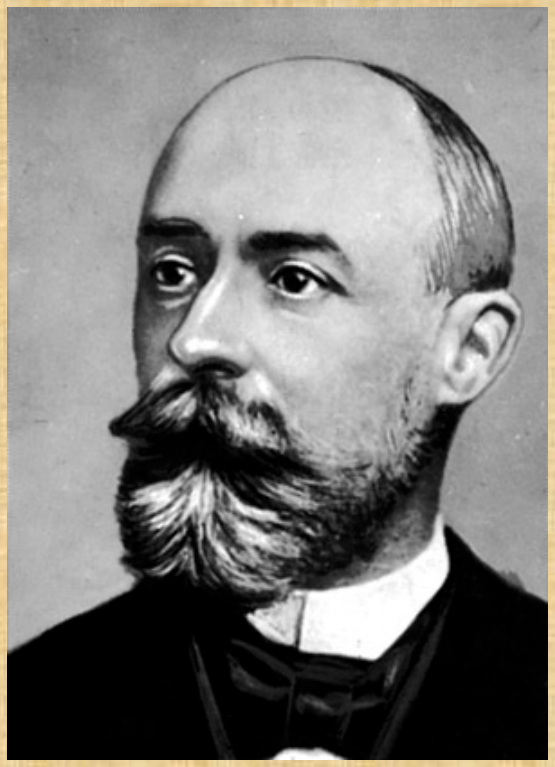
Activity

The activity of a radioactive source is equal to the number of decays per second.

Activity is measured in **bequerels (Bq)**

1 becquerel
= 1 decay per second



Henri Becquerel discovered radioactivity in 1896

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Question 1

A radioactive source undergoes 72 000 decays over a ten minute period.

What is its average activity in becquerels?

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Question 1

A radioactive source undergoes 72 000 decays over a ten minute period.

What is its average activity in becquerels?

Activity in becquerels equals decays per second.

72 000 per 10 minutes

= 72 000 / 10 per minute

= 72 000 / (10 x 60) per second

= 72 000 / 600

= 120 per second

Activity = 120 becquerel

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Question 2

A radioactive source has an activity of 25 Bq.

How many decays would be expected over a 3 hour period?

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Question 2

A radioactive source has an activity of 25 Bq.

How many decays would be expected over a 3 hour period?

Activity is 25 Bq

= 25 decays per second

= (25 x 60) = 1500 decays in one minute

= (1500 x 60) = 90 000 decays in one hour

= (90 000 x 3) decays in 3 hours

Number of decays in 3 hours = 270 000

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Background radiation

Background radiation is low-level ionising radiation that is produced all of the time.

Most of this radiation occurs naturally but a small amount is due to man-made sources such as nuclear weapon testing.

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Radon gas

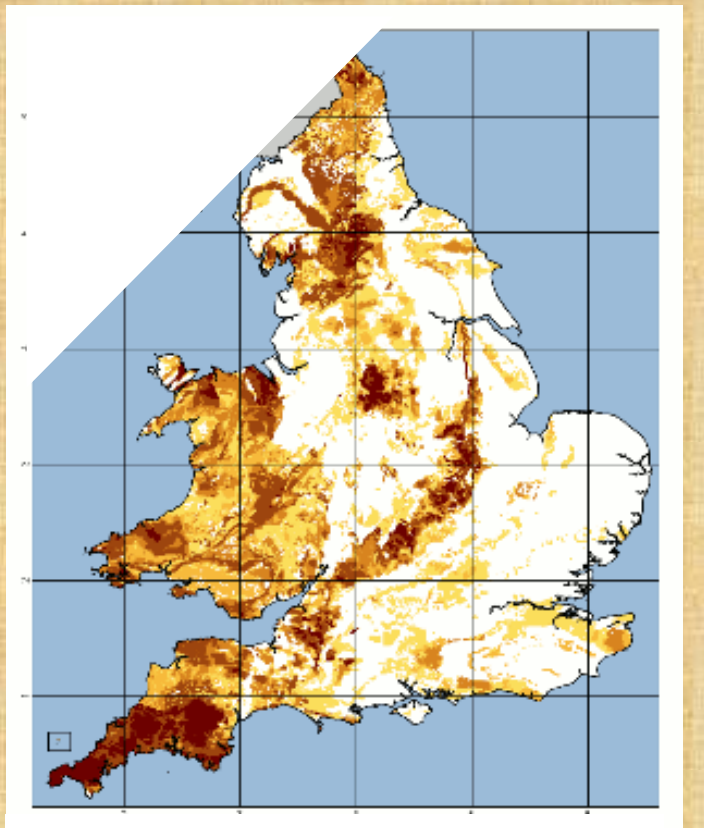
Radon gas accounts for about 50% of natural background radiation.

Two isotopes of radon, radon 222 and radon 220 (also known as thoron) are produced by the radioactive decay of uranium and thorium in the Earth's crust

.

This gas seeps into the atmosphere sometimes building up first inside the basements and foundations of buildings.

Areas containing granite and other igneous rocks, for example Cornwall, have a higher than average amount of background radiation due to radon gas.



Background radiation map of England and Wales

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Cosmic rays

Cosmic rays are a form of natural background radiation produced by the nuclear reactions occurring in stars and exploding stars called supernovae.

These produce high energy particles which continually bombard the Earth.

Our atmosphere gives us good protection from cosmic radiation.

Cosmic radiation is an issue that must be considered in proposed manned space exploration to Mars.

Exposure to cosmic radiation is increased during jet travel

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Internal radiation

Internal radiation is background radiation due to radioactive sources present inside our bodies.

Some of these are from naturally occurring events. An example is carbon 14 that is formed in the atmosphere by the Sun's radiation. This behaves chemically and biologically in the same way as non-radioactive carbon 12.

Others such as strontium 90 are from man-made events such as nuclear weapons testing and accidents. Strontium behaves like calcium in our bodies.

We are all sources of background radiation!

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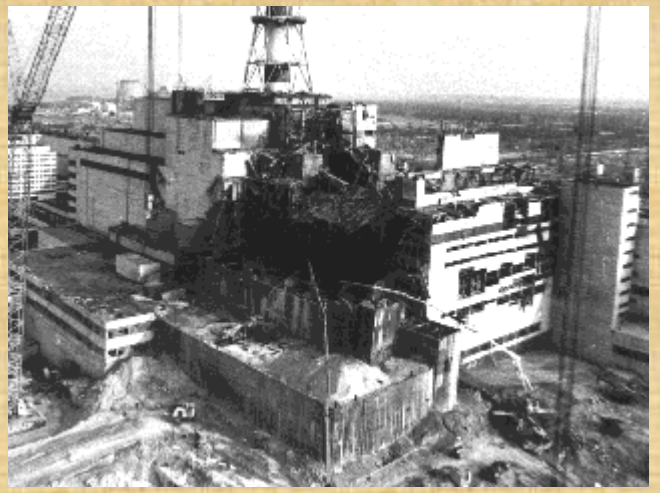
Artificial radiation

Artificial radiation is background radiation due to man-made events or procedures

Some is to due leakage and accidents associated with the generation of electricity using nuclear energy. Some is due to fall-out from nuclear weapon testing.

Radioactive tracers are used in industry and medicine and radioisotopes are used to treat cancer.

Overall artificial radiation normally accounts for only a small percentage of background radiation.



The explosion of the Chernobyl power plant in the Ukraine in 19986 placed significant radioactive isotope into the atmosphere.

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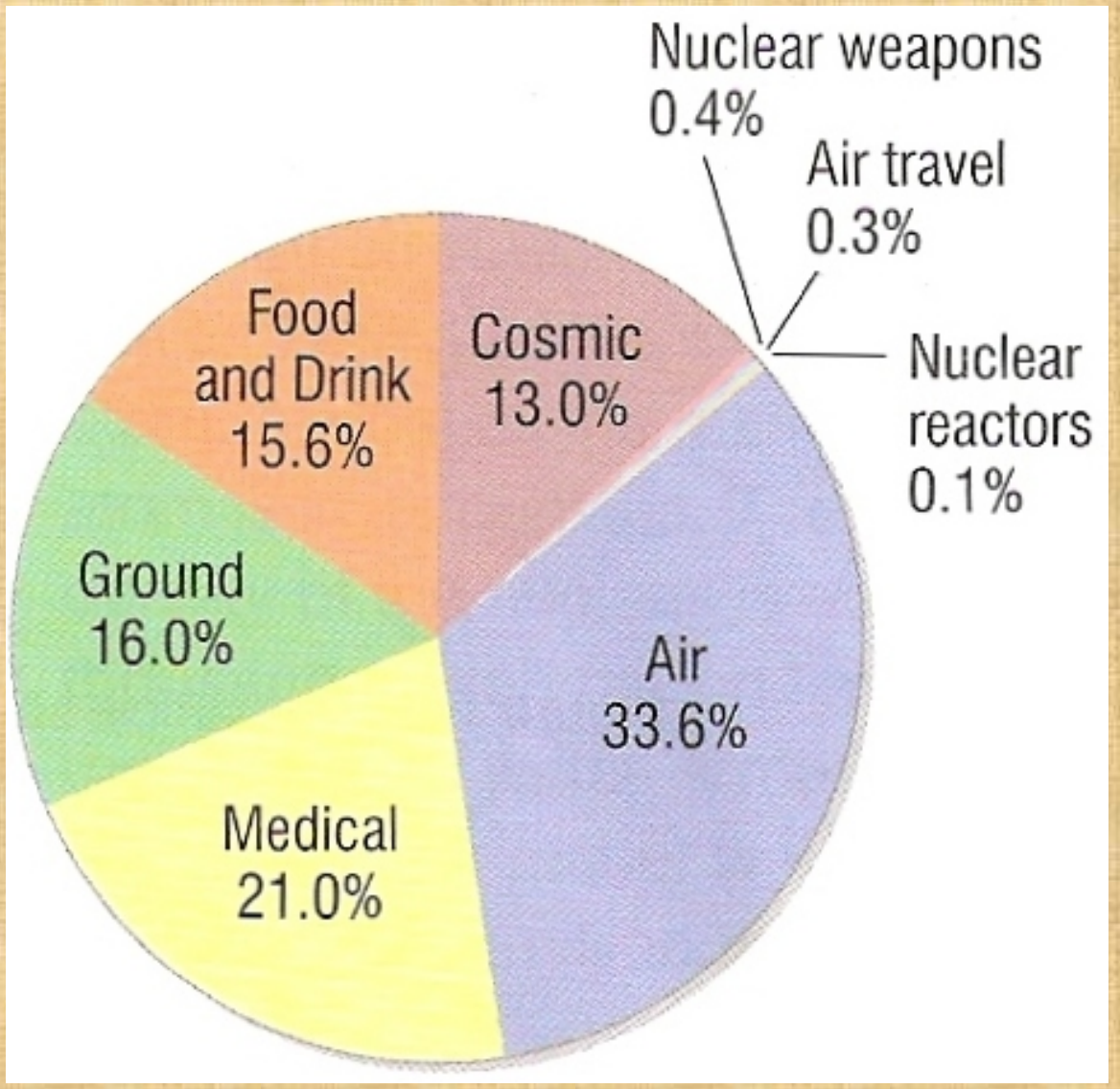
Background radiation pie-chart



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Choose appropriate words to fill in the gaps below:

Radioactivity was first discovered by Henri _____ in 1896 when he noticed that the radiation emitted by an ore of _____ caused the exposure of a _____ plate.

Radioactivity can also be detected using a _____ tube connected to an electronic _____ or rate meter.

Background radiation is mainly due to natural sources of _____ radiation such as from _____ gas that seeps out from rocks in the ground.

WORD SELECTION:

counter radon Geiger photographic

ionising Becquerel uranium

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Choose appropriate words to fill in the gaps below:

Radioactivity was first discovered by Henri _Becquerel_ in 1896 when he noticed that the radiation emitted by an ore of _uranium_ caused the exposure of a _photographic_ plate.

Radioactivity can also be detected using a _Geiger_ tube connected to an electronic _counter_ or rate meter.

Background radiation is mainly due to natural sources of _ionising_ radiation such as from _radon_ gas that seeps out from rocks in the ground.

WORD SELECTION:

counter radon Geiger photographic

ionising Becquerel uranium

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Half-life

The activity of a radioactive sample decreases over time.

The half-life of a radioactive sample is the average time taken for half of the original mass of the sample to decay.

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Half-lives of some radioactive isotopes

Uranium 238 = 4500 million years

Uranium 235 = 704 million years

Plutonium 239 = 24 100 years

Carbon 14 = 5600 years

Strontium 90 = 29 years

Hydrogen 3 (Tritium) = 12 years

Cobalt 60 = 5.2 years

Technetium 99m = 6 hours

Radon 224 = 60 seconds

Helium 5 = 1×10^{-20} seconds

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Example 1 - The decay of a sample of strontium 90

Strontium 90 has a half-life of 29 years.

In 2012 a sample contains 18.2g of strontium 90

The mass of strontium 90 in the sample halves every 29 years.

Year	***Mass of strontium 90 (g)***
2012	**18.2**
2041	**9.60**
2070	**4.80**
2099	**2.40**
2128	**1.20**
2157	**0.60**

When will the mass have fall to 0.15 g? **2215**

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Question 1

At 10am in the morning a radioactive sample contains 80g of a radioactive isotope. If the isotope has a half-life of 20 minutes calculate the mass of the isotope remaining at 11am.

10am to 11am = 60 minutes

= 3 x 20 minutes

= 3 half-lives

mass of isotope = ½ x ½ x ½ x 80g

mass at 11 am = 10g

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Question 2

Calculate the half-life of the radioactive isotope in a source if its mass decreases from 24g to 6g over a period of 60 days.

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Question 2

Calculate the half-life of the radioactive isotope in a source if its mass decreases from 24g to 6g over a period of 60 days.

24g x ½ = 12g

12g x ½ = 6g

therefore **TWO** half-lives occur in 60 days

half-life = 30 days

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Other ways of defining half-life

In terms of activity of a source:

The half-life of a radioactive source is the average time taken for the activity of the source to decrease to half of its initial value.

In terms of the number of nuclei:

The half-life of a radioactive isotope is the average time it takes for half of the nuclei of the isotope to decay into some other isotope.

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Example 2 – The decay of source Z

Source Z decays with a half-life of three hours.

At 9 am the source has an activity of 16000 Bq

The activity halves every three hours.

Time	*Activity (Bq)*
9 am	**16000**
12 noon	**8000**
3 pm	**4000**
6 pm	**2000**
9 pm	**1000**
midnight	**500**

When will the activity have fallen to 125 Bq? **6 am**

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Example 3 – The decay of isotope X

Isotope X decays to Isotope Y with a half-life of 2 hours.

At 2 pm there are 6400 nuclei of isotope X.

Time	*Nuclei of X*	*Nuclei of Y*
2 pm	**6400**	**0**
4 pm	**3200**	**3200**
6 pm	**1600**	**4800**
8 pm	**800**	**5600**
10 pm	**400**	**6000**
midnight	**200**	**6200**

When will the nuclei of isotope X fallen to 25? **6 am**

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Question 3

A radioactive source has a half-life of 3 hours.

At 8 am it has an activity of 600 Bq.

What will be its activity at 2 pm?

at 8 am activity = 600 Bq

2 pm is 6 hours later

this is 2 half-lives later

therefore the activity will halve twice

that is: 600 $\Rightarrow$ 300 $\Rightarrow$ 150

activity at 2 pm = 150 Bq

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Question 1 – The decay of substance P

Substance P decays to substance Q with a half-life of 15 minutes. At 9 am there are 1280 nuclei of substance P.

Complete the table.

Time	*Nuclei of X*	*Nuclei of Y*
9 am	**1280**	**0**
9:15	**640**	**640**
9:30	**320**	**960**
9:45	**160**	**1120**
10 am	**80**	**1200**
10:15	**40**	**1240**

How many nuclei of substance X will be left at 11 am? **5**

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Question 4

A sample contains 8 billion nuclei of hydrogen 3 atoms. Hydrogen 3 has a half-life of 12 years. How many nuclei should remain after a period 48 years?

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Question 4

A sample contains 8 billion nuclei of hydrogen 3 atoms. Hydrogen 3 has a half-life of 12 years. How many nuclei should remain after a period 48 years?

48 years = 4 x 12 years

= FOUR half-lives

nuclei left = ½ x ½ x ½ x ½ x 8 billion

nuclei left = 500 million

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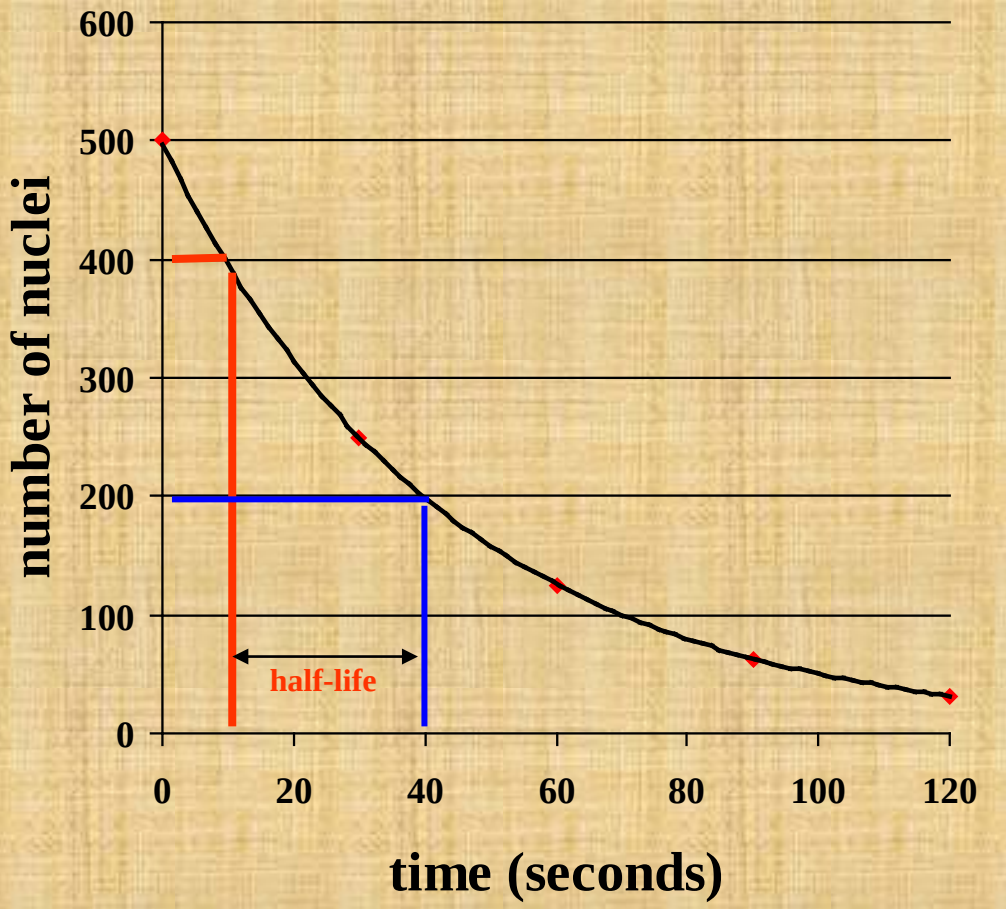
Finding half-life from a graph



The half-life in this example is about 30 seconds.

A more accurate value can be obtained be repeating this method for a other initial nuclei numbers and then taking an average.

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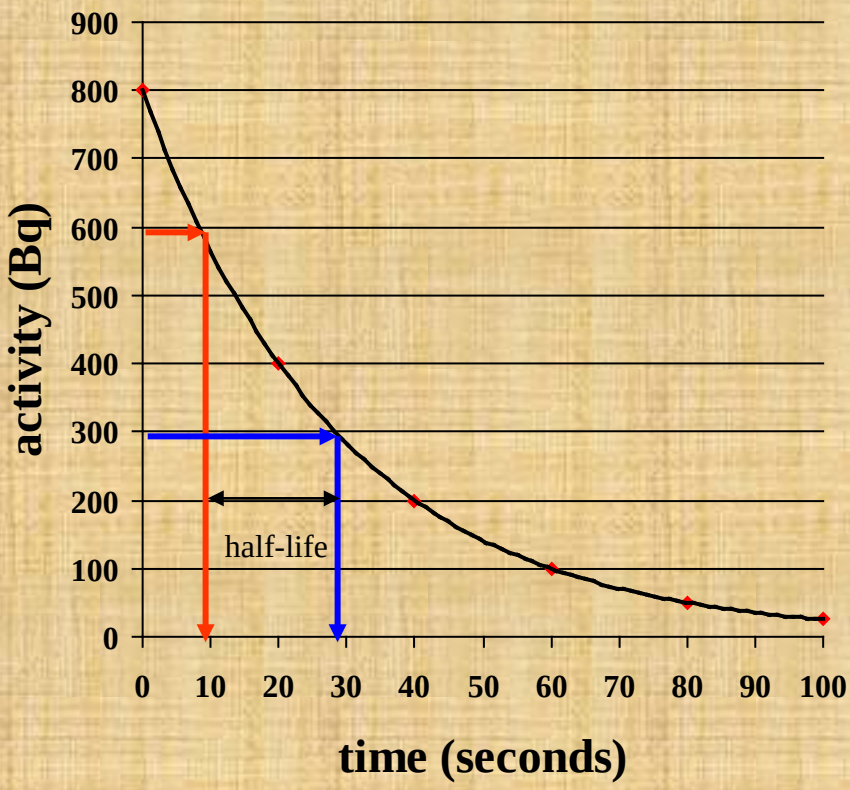
Question 1

Estimate the half-life of the substance whose decay graph is shown opposite.

The half-life is approximately 20 seconds



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Question 2

The mass of a radioactive substance over a 8 hour period is shown in the table below.

Draw a graph of mass against time and use it to determine the half-life of the substance.

Time (hours)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mass (g)	**650**	**493**	**373**	**283**	**214**	**163**	**123**	**93**	**71**

The half-life should be about 2 hours:

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Choose appropriate words or numbers to fill in the gaps below:

The _____ of a radioactive substance is the average time taken for half of the _____of the substance to decay. It is also equal to the average time taken for the _____ of the substance to halve.

The half-life of carbon 14 is about _____ years. If today a sample of carbon 14 has an activity of 3400 Bq then in 5600 years time this should have fallen to _____ Bq. 11200 years later the activity should have fallen to ____ Bq.

The number of carbon 14 nuclei would have also decreased by _____ times.

WORD & NUMBER SELECTION:

5600 nuclei eight half-life 425 1700 activity

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Choose appropriate words or numbers to fill in the gaps below:

The _half-life_ of a radioactive substance is the average time taken for half of the _nuclei_ of the substance to decay. It is also equal to the average time taken for the _activity_ of the substance to halve.

The half-life of carbon 14 is about _5600_ years. If today a sample of carbon 14 has an activity of 3400 Bq then in 5600 years time this should have fallen to _1700_ Bq. 11200 years later the activity should have fallen to _425_ Bq.

The number of carbon 14 nuclei would have also decreased by _eight_ times.