Half-lives and the random nature of radioactive decay

6.4.2.3 · Physics · revision notes

What half-life means, how it links to the random nature of radioactive decay, and how to find a half-life from a graph or data. At Higher tier you also work out the net decline, as a ratio, after a number of half-lives. Expect graph reading and 2 to 4 mark calculations.

Key facts

- Half-life: time for the number of unstable nuclei in a sample (or its count rate) to halve
- Number of half-lives = time passed ÷ half-life
- Grade 7+ only Fraction left after n half-lives = $\left(\frac{1}{2}\right)^n$; net decline = $1 - \left(\frac{1}{2}\right)^n$ of the original
- Radioactive decay is random: you cannot predict which nucleus decays or when
- Fraction left after 0, 1, 2, 3, 4 half-lives: 1, 1/2, 1/4, 1/8, 1/16
- Subtract the background count rate before finding a half-life

Notes

Random decay

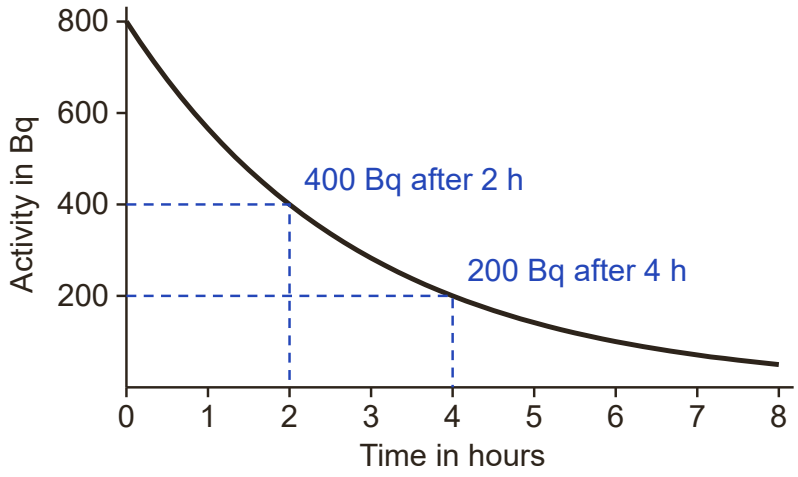
- Radioactive decay is **random**. You cannot predict which nucleus in a sample will decay next, or when a particular nucleus will decay.
- But a sample contains a huge number of nuclei, so the fraction that decays in a given time is predictable. That is why each isotope has its own fixed half-life.

Half-life

- The **half-life** of a radioactive isotope is the time it takes for the number of nuclei of the isotope in a sample to halve.
- It is also the time it takes for the count rate (or activity) from a sample containing the isotope to fall to half its initial level.
- After each half-life the activity halves again, e.g. 800 Bq → 400 Bq → 200 Bq → 100 Bq after 3 half-lives.
- Number of half-lives = time passed ÷ half-life.

Finding the half-life from a graph

- Choose a starting value on the curve that is easy to halve, e.g. 600 Bq, and read the time.
- Find where the activity is half that value (300 Bq) and read that time.
- The difference between the two times is the half-life. Repeat from another starting value and take the mean.



The activity halves every 2 hours (800 → 400 → 200 Bq), so the half-life is 2 hours.

- If the readings include background radiation, subtract the background count rate first.

Net decline as a ratio Grade 7+ only

- After n half-lives, the fraction of the original nuclei (or activity) that remains is $\left(\frac{1}{2}\right)^n$
- The net decline is the amount that has gone: $1 - \left(\frac{1}{2}\right)^n$ of the original.
- Example: after 3 half-lives, $\left(\frac{1}{2}\right)^3 = \frac{1}{8}$ remains, so the net decline is $\frac{7}{8}$ of the original, a ratio of 7 : 8.
- A question may instead ask for the ratio of the amount left to the amount at the start: after 5 half-lives this is 1 : 32.

How to answer each type of question

Define half-life and random decay 1 to 2 marks Grade 5

1. Half-life: 'the time taken for the number of unstable nuclei (or the count rate) to halve'.
2. Random: 'cannot predict which nucleus will decay next, or when'.

Example. (a) Define the half-life of a radioactive isotope. (1 mark)
(b) Radioactive decay is random. Explain what this means. (1 mark)

Model answer.

(a) The time taken for the number of unstable nuclei of the isotope in a sample to halve (1)
(b) You cannot predict which nucleus will decay next, or when a particular nucleus will decay (1)

Calculate the activity after a given time

2 marks | Grade 6

1. Work out the number of half-lives: time ÷ half-life.
2. Halve the starting activity that many times, showing each step.

Example. Iodine-131 has a half-life of 8 days. A sample of iodine-131 has an activity of 2400 Bq. Calculate the activity of the sample after 24 days.

Model answer.

24 ÷ 8 = 3 half-lives (1)

2400 → 1200 → 600 → 300 Bq (1)

Determine a half-life from data

3 marks | Grade 7

1. Subtract the background count rate from each reading.
2. Count how many halvings take you from the first value to the second.
3. Divide the time taken by the number of halvings.

Example. A student measures the count rate from a radioactive source. The background count rate is 20 counts per minute.
At the start the measured count rate is 420 counts per minute. After 36 minutes it is 120 counts per minute.
Determine the half-life of the source.

Model answer.

Corrected count rates: 420 − 20 = 400 and 120 − 20 = 100 counts per minute (1)

400 → 200 → 100 is 2 half-lives (1)

Half-life = 36 ÷ 2 = 18 minutes (1)

Higher tier: net decline as a ratio

3 marks | Grade 8

1. Find the number of half-lives, n.
2. Fraction remaining = $\left(\frac{1}{2}\right)^{n}$
3. Net decline = 1 − fraction remaining. Write it as a ratio of the original if asked.

Example. A radioactive isotope has a half-life of 6 hours.
Determine the net decline in the number of radioactive nuclei in a sample after 24 hours. Give your answer as a ratio of the original number of nuclei.

Model answer.

24 ÷ 6 = 4 half-lives (1)

Fraction remaining = $\left(\frac{1}{2}\right)^{4} = \frac{1}{16}$ (1)

Net decline = $1 - \frac{1}{16} = \frac{15}{16}$, a ratio of 15 : 16 (1)

Don’t lose marks

- Thinking that after two half-lives the sample has all gone. A quarter is left.
- Dividing the time by 2 instead of by the half-life to find the number of half-lives.
- Forgetting to subtract the background count rate before finding the half-life.
- Defining half-life as 'half the time it takes for the sample to decay completely'.
- Giving the fraction remaining when the question asks for the net decline, or the other way round.

More tips

Memory tricks

- Halving table: write time and activity in two columns, and halve down the columns until you reach the value you need.
- Calculator: 0.5^n gives the fraction left, e.g. 0.5^4 = 0.0625 = 1/16.
- Sense check: 1 half-life leaves a half, 2 leave a quarter, 3 leave an eighth.
- On a graph, draw lines across to the curve and down to the time axis so the examiner can see your readings.

Exam technique

- Show each halving step, e.g. 2400 → 1200 → 600 → 300, so your method is clear.
- When reading a graph, pick a starting value that is easy to halve and read to the nearest small square.
- Read the question carefully: 'remaining' and 'net decline' are different answers.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 4 — **Define half-life**
The time for the number of unstable nuclei in a sample, or its count rate, to halve.

Grade 5 — **Explain what random decay means**
You cannot predict which nucleus will decay or when, but a large sample decays in a predictable way.

Grade 5 — **Find a half-life from a graph**
Read the time for the activity or count rate to fall to half of any starting value.

Grade 6 — **Calculate activity after whole half-lives**
Halve the activity once for each half-life that passes.

Grade 6 — **Find a half-life from data**
Count the number of halvings in the time given, then divide the time by that number.

Grade 7 — **Correct count rates for background radiation**
Subtract the background count rate from each reading before finding the half-life.

Grade 8 — **Find the net decline as a ratio**
After n half-lives, $(1/2)^n$ of the original remains, so the net decline is the rest (Higher tier).

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