REAL-LIFE PHYSICS

Waves and Radiation

Teacher guide

For the National 5 Physics workbook



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Blewis LEARNING

Using the workbooks

The National 5 Physics workbook for **Waves and Radiation** has five topics. Every topic has learning pages, a practical the learner plans and evaluates (with uncertainties), a brain break and an exam-style check-up.

PRACTICALS

Learners plan each investigation (variables, prediction, kit, risk, method), take repeat readings, work out averages, draw graphs with their own scales, and write conclusions and evaluations.

PRACTICAL SAFETY

Every practical has a Stay safe table and a teacher note with hazards, adapted versions and common problems. The Stay safe tables and these notes are a starting point, not a complete risk assessment: the teacher or school must risk assess every practical for their own learners, room and kit before use, following their employer's policies and national guidance (in Scotland, SSERC). Always check learners' care plans and medical information. Activities with flames or microbes are teacher demonstrations, with example results provided.

NO LAB, NO KIT, OR A LEARNER ABSENT

Each practical includes example results so learners can still complete the results, graph, conclusion and evaluation.

EVIDENCE

The practicals give evidence for the experiment and investigation outcome; the learn pages and check-ups give evidence for knowledge and problem solving. The skills tracker at the back of each workbook can be signed off as you go. Always check the latest course documents and your centre's arrangements.

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TEACHER NOTES

Practical 1: Frequency and wavelength in a ripple tank

Time	One 50-minute lesson in threes. Five frequencies with three readings each takes about 25 minutes if learners photograph the pattern.
Kit per group	Ripple tank with lamp and straight dipper on a variable-frequency motor, low-voltage supply, white paper under the tank, ruler, phone or tablet camera (a stroboscope app helps).
Prep	Level the tank and use about 5 mm of water. Check the motor frequency setting against a slow-motion video count. Put towels round the tank.
Expected results	Wavelength falls as frequency rises; $f \times \lambda$ is roughly constant at about 0.2 to 0.3 m/s for shallow water. Projected patterns are magnified by the lamp: measure with a ruler in the water, or use a ruler on the paper and note it is a scaled value.
Diffraction	Place two barriers to make a gap; show a wide gap and a gap about one wavelength wide. Learners sketch the patterns.
Level	N5 plans the test, repeats readings, finds a mean and random uncertainty, draws a graph with their own scales and evaluates.

Safety and inclusion

- Water and electricity: use the tank's low-voltage lamp; only the supply's plug is on the mains, and it is kept well away from the tank. Mop spills at once.
- The lamp gets hot. Keep fingers away from the motor and dipper.
- All roles can be done seated. A learner who finds the ruler readings hard can take the photographs or record.
- Risk assess before use, following your employer's policies and SSERC guidance.

Common problems

- **Pattern blurred:** use a stroboscope or a still photo.
- **Measuring one wavelength:** always measure several and divide.
- **Uncertainty:** learners divide the range by the number of readings, not by 2.

No lab, no time, or a learner absent?

The sample results let learners complete the means, uncertainties, speeds, graph, conclusion and evaluation without doing the practical.

Assessment link

Develops the skills used in the assignment: raw data in a table with units, means and uncertainties, graphs, comparing with a reference value, and evaluation.

Answers: Topic 1

Topic 1: Wave properties and diffraction (N5)

1 Describing waves

1 Transverse, e.g. water waves, light, radio, any electromagnetic wave. Longitudinal: sound.

2 It carries more energy.

3 3.2 × 0.50 = 1.6 m

2 Wave calculations

1 $\lambda = \frac{v}{f} = \frac{340}{850} = 0.40$ m

2 $f = \frac{N}{t} = \frac{18}{45} = 0.40$ Hz; $T = \frac{1}{f} = \frac{1}{0.40} = 2.5$ s (or $T = \frac{45}{18} = 2.5$ s)

3 $v = \frac{d}{t} = \frac{96}{32} = 3.0$ m/s; $f = v / \lambda = \frac{3.0}{7.5} = 0.40$ Hz

3 Diffraction

1 Curved (nearly semicircular) wavefronts beyond the gap, spaced the same distance apart as the incoming wavefronts.

2 Long-wave radio has a long wavelength, so it diffracts a lot over the hill. TV signals have a short wavelength, so they diffract very little and do not reach the house behind the hill.

Practical 1: Frequency and wavelength in a ripple tank

Variables: change the frequency of the dipper (Hz); measure the wavelength (cm); keep the same: depth of water, the same tank, how the wavelength is measured (over 10 waves).

Prediction, e.g. as the frequency increases the wavelength gets shorter, because the speed stays the same and $v = f \lambda$.

Equipment: ripple tank, power supply for the motor, ruler, phone camera, lamp. Not needed: thermometer, balance.

Hazards, e.g. water on the floor (slips: mop up); hot lamp (do not touch); moving motor parts (keep fingers clear).

Method key points: set the frequency on the supply or measure it (count dips with slow-motion video); photograph the pattern with a ruler in the tank; measure across 10 wavelengths and divide by 10; three repeats at each of five frequencies; mean, uncertainty, $v = f \lambda$.

Headings: Frequency (Hz), 10λ 1st, 2nd, 3rd (cm), Mean λ (cm), Speed (m/s).

Sample results: 5 Hz: λ = 4.98 cm (± 0.05 cm), v = 0.25 m/s; 8 Hz: λ = 3.10 cm (± 0.03 cm), v = 0.25 m/s; 10 Hz: λ = 2.50 cm (± 0.03 cm), v = 0.25 m/s; 12 Hz: λ = 2.10 cm (± 0.03 cm), v = 0.25 m/s; 15 Hz: λ = 1.67 cm (± 0.02 cm), v = 0.25 m/s.

Graph: a smooth curve falling steeply then levelling (wavelength inversely proportional to frequency).

Conclusion: as the frequency increased, the wavelength decreased.

9a The speed is about 0.25 m/s every time: the speed depends on the water, not on the frequency.

10a A small error in reading the ruler is shared over ten wavelengths, so the error in one wavelength is ten times smaller. (b) e.g. use a stroboscope or photograph to freeze the pattern; use a ruler with a finer scale; measure more wavelengths.

Check-up

1 The time for one complete wave to pass a point (1).

2 $f = \frac{1}{T} = \frac{1}{0.25} = 4.0$ Hz (1); $v = f \lambda$ (1); $v = 4.0 \times 1.2$ (1); $v = 4.8$ m/s (1).

3 $\lambda = \frac{v}{f}$ (1); $\lambda = 3.0 \times 10^8 \div 198\,000$ (1); $\lambda = 1500$ m (1.5×10^3 m) (1).

4 The waves spread out (diffract) (1) into curved wavefronts with the same wavelength (1).

5 Long-wave radio has a long wavelength so it diffracts round hills (1); TV has a short wavelength so diffracts very little and the hill blocks it (1).

TEACHER NOTES

Practical 2: How does distance affect infrared heating?

Time	One 50-minute lesson in pairs or threes. Five distances × three repeats of 3 minutes is about 45 minutes of heating, so share distances between groups, or use 2 minutes and two repeats.
Kit per group	Bench lamp with a filament or halogen bulb (60 W filament works well), digital thermometer or temperature probe with the tip painted matt black, clamp stand, metre stick, stopwatch.
Prep	Paint the probe tips with matt black paint the day before. Use a PAT-tested lamp and check its leads; learners do not adjust it while it is on, and water is kept away from it. Mark distances on the bench with tape.
Expected results	The rise falls steeply with distance, roughly as 1 ÷ distance², from about 12 °C at 10 cm to under 1 °C at 40 cm with a 60 W lamp. LED lamps give much smaller rises.
Demonstrations	A phone camera shows the infrared LED of a TV remote. A prism and blackened thermometer beyond the red end shows infrared (as Herschel did).
Level	N5 plans the test, repeats readings, finds a mean and random uncertainty, draws a graph with their own scales and evaluates.

Safety and inclusion

- Lamps get very hot: no touching while on and for several minutes after. Keep paper and drinks away.
- Do not look directly into bright lamps. Use digital probes rather than glass thermometers if possible.
- All roles can be done seated. A learner who finds reading the thermometer hard can time or record.
- Risk assess before use, following your employer's policies and SSERC guidance.

Common problems

- **Not cooling between tests:** the start temperature creeps up. Wait until it returns to room temperature.
- **Distance measured inconsistently:** measure from the centre of the bulb to the centre of the probe tip.

No lab, no time, or a learner absent?

The sample results let learners complete the means, uncertainties, graph, conclusion and evaluation without doing the practical.

Assessment link

Develops assignment skills: raw data with units, means and uncertainties, a graph with suitable scales, comparing with a reference relationship, and evaluation.

Answers: Topic 2

Topic 2: The electromagnetic spectrum (N5)

1 A family of waves

1 Microwaves (2nd), ultraviolet (5th), gamma rays (7th).

2 Highest frequency: gamma rays. Longest wavelength: radio waves.

3 No. All electromagnetic waves travel at the same speed, 3.0×10^8 m/s in a vacuum. X-rays carry more energy because they have a higher frequency, not because they are faster.

2 Sources, detectors and uses

1 (a) e.g. thermometer (blackened bulb), infrared camera or photodiode (b) GM tube and counter (or photographic film).

2 Ultraviolet. The ink is fluorescent: it absorbs ultraviolet and gives out visible light.

3 Gamma rays carry a lot of energy and are ionising, so they kill cancer cells. The beam must be aimed so it does not damage healthy cells.

4 Radio waves have long wavelengths, travel long distances and diffract round obstacles; X-rays would be absorbed by the air over long distances and are harmful (ionising).

3 Calculations with EM waves

1 $\lambda = \frac{v}{f} = 3.0 \times 10^8 \div (2.45 \times 10^9) = 0.122$ m, so 0.12 m

2 $f = v / \lambda = 3.0 \times 10^8 \div (3.0 \times 10^{-7}) = 1.0 \times 10^{15}$ Hz

Practical 2: How does distance affect infrared heating?

Variables: change the distance from lamp to bulb (cm); measure the temperature rise (°C) in 3 minutes; keep the same: lamp and its power, time, the same thermometer, starting temperature (let it cool back to room temperature).

Prediction, e.g. the temperature rise will be smaller further away, because the infrared spreads out over a bigger area.

Equipment: lamp, thermometer (blackened bulb), metre stick, stopwatch, clamp stand. Not needed: remote control, balance.

Hazards, e.g. hot lamp (do not touch; let it cool); mains lamp (check the lead, keep water away); thermometer breaking if glass (clamp it securely).

Method key points: clamp the thermometer at a measured distance from the bulb centre; record the start temperature; switch on for 3 minutes; record the end temperature; let it cool back to the start temperature; three repeats at each distance; mean and uncertainty.

Headings: Distance (cm), Rise 1, 2, 3 (°C), Mean rise (°C), Uncertainty (°C).

Sample results: 10 cm: 12.5 ± 0.3 °C; 15 cm: 5.6 ± 0.1 °C; 20 cm: 3.2 ± 0.1 °C; 30 cm: 1.4 ± 0.1 °C; 40 cm: 0.8 ± 0.1 °C.

Graph: a smooth curve falling steeply then levelling off.

Conclusion: as the distance increased, the temperature rise decreased, quickly at first and then more slowly.

9a A black surface is a good absorber of infrared, so the bulb heats up more and the readings are bigger and easier to measure.

10a The 10 cm result has the biggest uncertainty (0.3 °C), so its repeats were the most spread out; compared with its mean, the 40 cm result has the largest uncertainty (about 8%). Accept either with a reason. (b) e.g. more repeats; let the thermometer return to the same start temperature; shield from draughts; use a light meter or IR sensor with a finer scale.

Check-up

1 radio, infrared, ultraviolet, gamma rays (1).

2 $\lambda = \frac{v}{f}$ (1); $\lambda = 3.0 \times 10^8 \div (650 \times 10^6)$ (1); $\lambda = 0.46$ m (1).

3 $t = \frac{d}{v}$ (1); $t = 1.2 \times 10^{12} \div (3.0 \times 10^8)$ (1); $t = 4000$ s (4.0×10^3 s) (1).

4 Infrared: thermometer, IR camera or photodiode (1). Ultraviolet: fluorescent material or photographic film (1).

5 Ultraviolet has a higher frequency so carries more energy (it is ionising) (1).

TEACHER NOTES

Practical 3: Angles of incidence and refraction

Time	One 50-minute lesson in pairs. Six angles with three repeats takes about 30 minutes; repeats can be done by moving the ray box away and resetting it.
Kit per group	Ray box with single-slit mask and low-voltage supply, rectangular glass (or acrylic) block, A4 paper, sharp pencil, ruler, protractor.
Prep	Darken the room partly. Check ray boxes give a thin, sharp ray. Acrylic blocks are lighter and less likely to chip than glass.
Expected results	For glass (refractive index about 1.5): i = 10°, 20°, 30°, 40°, 50°, 60° gives r of about 7°, 13°, 19°, 25°, 31°, 35°. The ray leaving the block is parallel to the ray entering.
Extension	Learners can find the refractive index from sin i ÷ sin r and compare it with a book value, as in an assignment.
Level	N5 plans the test, repeats readings, finds a mean and random uncertainty, draws a graph with their own scales and evaluates.

Safety and inclusion

- Ray box lamps get hot: hold by the base and let them cool. Use low-voltage supplies only.
- If a laser is used to demonstrate, it must be a low-power (Class 2 or lower) pointer used by the teacher, never pointed at eyes.
- Keep the floor clear in a darkened room. A learner who finds the protractor hard can mark the rays or record.
- Risk assess before use, following your employer's policies and SSERC guidance.

Common problems

- **Measuring from the surface:** angles must be measured from the normal.
- **Wide, fuzzy ray:** use the narrowest slit and mark the centre of the ray.
- **Block moving:** draw round it first and check it stays on its outline.

No lab, no time, or a learner absent?

The sample results let learners complete the means, uncertainties, graph, conclusion and evaluation without doing the practical.

Assessment link

Develops assignment skills: raw data with units, means and uncertainties, a graph, comparing with a reference value, and evaluating precision.

Answers: Topic 3

Topic 3: Refraction of light (N5)

1 Refraction and ray diagrams

1 X is the angle of incidence; Y is the angle of refraction.

2 Its speed decreases; its direction does not change.

2 Speed, wavelength and frequency

1 $\lambda = \frac{v}{f} = 2.25 \times 10^{8} \div (5.6 \times 10^{14}) = 4.0 \times 10^{-7}$ m

2 The same number of waves must arrive at, and leave, the boundary each second, so the frequency is set by the source and cannot change.

3 (a) speed increases (b) wavelength increases.

3 Drawing refraction diagrams

1 Normal drawn at 90° to the top surface at the point of entry; refracted ray bends towards the normal inside the block; ray leaves the bottom bending away from the normal, parallel to the incident ray; i and r marked between the rays and the normal; arrows on all rays.

2 Away from the normal, because it speeds up as it passes from water (denser) into air (less dense).

3 A ray entering along the normal (at 0°) does not change direction, although it still slows down.

Practical 3: Angles of incidence and refraction

Variables: change the angle of incidence (°); measure the angle of refraction (°); keep the same: the glass block, the colour of light (same ray box and filter), the point where the ray enters.

Prediction, e.g. the angle of refraction increases as the angle of incidence increases, but is always smaller, because light slows down in glass.

Equipment: ray box, glass block, protractor, pencil, power supply. Not needed: thermometer, stopwatch.

Hazards, e.g. glass block dropped (chipped edges: handle with care); trailing power leads (keep tidy); low light in the room (keep the floor clear).

Method key points: draw round the block on paper; draw a normal; aim the ray at the point where the normal meets the block; mark the rays with crosses; remove the block, join the crosses; measure i and r from the normal; three repeats at each of six angles; mean and uncertainty.

Headings: Angle i (°), r 1st, 2nd, 3rd (°), Mean r (°), Uncertainty (°).

Sample results: 10°: 6.7 ± 0.3°; 20°: 13.3 ± 0.3°; 30°: 19.7 ± 0.3°; 40°: 25.3 ± 0.3°; 50°: 30.7 ± 0.3°; 60°: 35.3 ± 0.3°.

Graph: a curve through the origin, getting less steep at larger angles.

Conclusion: as the angle of incidence increased, the angle of refraction increased, but it was always smaller than the angle of incidence.

9a About 28° (accept 27° to 29°).

10a A 1° error in reading the protractor is a large fraction of a small angle, and the ray is wide, so its centre is hard to judge. (b) e.g. use a narrower slit or a laser pointer used by the teacher; mark rays with crosses far apart; use a bigger protractor; repeat more times.

Check-up

1 Refraction is the change in speed of a wave when it passes from one medium into another (1).

2 Speed decreases and wavelength decreases (1); frequency stays the same and it bends towards the normal (1).

3 $\lambda = \frac{v}{f}$ (1); $\lambda = 1.9 \times 10^{8} \div (5.7 \times 10^{14})$ (1); $\lambda = 3.3 \times 10^{-7}$ m (1).

4 Normal drawn at 90° to the surface (1); refracted ray bending towards the normal, with arrows (1); angles of incidence and refraction correctly labelled between the rays and the normal (1).

TEACHER NOTES

Practical 4: Where is the background highest?

Time	One 50-minute lesson. Six places with three 1-minute counts each takes about 25 minutes plus moving. Groups can share places and pool results.
Kit per group	GM tube and counter (or ratemeter) with a timer, stand and clamp, stopwatch if needed. No radioactive sources are handled by learners.
Demonstration	Optional absorption demonstration with a sealed beta/gamma source, carried out by the teacher only, following your school's local rules and current SSERC guidance. Sample data are provided, so the demonstration is not required.
Expected results	Typically 15 to 40 counts per minute. Higher near stone, brick and concrete, and in basements where radon can build up. Repeat counts vary by a few counts: a good chance to discuss randomness and uncertainty.
Level	N5 plans the survey, repeats readings, gives each result as mean ± random uncertainty, draws a bar chart and evaluates reliability.

Safety and inclusion

- Keep leads tidy and stay clear of corridors and fire exits.
- Only the teacher handles sealed sources, under local rules: tongs, time, distance, shielding, and a source log.
- All roles can be done seated; a learner can read the counter or record results.
- Follow your school's risk assessment and current SSERC guidance.

Common problems

- **Counter not reset** between counts.
- **Uncertainty**: learners divide by the mean rather than by the number of readings.
- **Corrected count rate**: forgetting to subtract background.

Assessment link

Evidence for handling data, mean and random uncertainty, presenting results and evaluating; good practice for the assignment (comparison with a published background value, referencing).

Answers: Topic 4

Topic 4: Nuclear radiation and dose (N5)

1 Alpha, beta and gamma

1 Alpha. It ionises so strongly that it loses its energy very quickly, so it only travels a few cm in air and is stopped by paper.

2 Beta only. Paper does not change the count, so there is no alpha; a few mm of aluminium stops it, so it is beta, and there is no gamma (gamma would pass through the aluminium).

2 Activity and absorbed dose

1 t = 300 s; $A = \frac{N}{t} = 1.2 \times 10^5 \div 300 = 400$ Bq

2 E = D m = 0.040 × 0.50 = 0.020 J

3 Equivalent dose and staying safe

1 $H = D\, w_R = 2.0 \times 20 = 40$ mSv

2 $\dot{H} = \frac{H}{t} = 3600\ \mu Sv \div 900\ h = 4.0\ \mu Sv/h$

Practical 4: Where is the background highest?

Variables: change the place; measure the count in 1 minute (counts per minute); keep the same: counting time, GM tube and counter, height of the tube above the floor, number of repeats.

Prediction, e.g. highest in the basement or stairwell, because stone gives out radiation and radon gas can collect in low places.

Equipment: GM tube and counter, stopwatch (if the counter has no timer), stand. Not needed: thermometer, loudspeaker (metre stick only to set the height).

Hazards, e.g. trailing leads; blocking a corridor or fire exit; carrying equipment on stairs.

Headings: Place, Count 1, 2, 3 (counts per minute), Mean (counts per minute), Uncertainty (counts per minute).

Sample results (mean ± uncertainty, counts per minute): Science lab 22.3 ± 1.0; Corridor 20.3 ± 1.7; Library 17.3 ± 1.0; Playground 23.7 ± 1.0; Stone stairwell 30.7 ± 1.7; Basement store 37.0 ± 1.3;

Conclusion: the basement store had the highest count rate (37.0 ± 1.3 counts per minute), the library the lowest (17.3 ± 1.0).

Evaluate: radioactive decay is random, so the count varies. Count for longer (e.g. 5 minutes) or take more repeats so the random variation averages out.

Demonstration: corrected count rates 498, 493, 74 and 9 counts per minute. (b) Paper hardly changes the count, so there is no alpha. Aluminium removes most of it, so beta is present. Some still passes through the aluminium and is reduced by lead, so gamma is present too.

Check-up

1 $A = \frac{N}{t}$ (1); $A = 4.8 \times 10^5 \div 120$ (1); $A = 4.0 \times 10^3$ Bq (1)

2(a) $D = \frac{E}{m}$ (1); $D = 1.4 \times 10^{-3} \div 70$ (1); $D = 2.0 \times 10^{-5}$ Gy (1)

2(b) $H = D\, w_R$ (1); $H = 2.0 \times 10^{-5} \times 1$ (1); $H = 2.0 \times 10^{-5}$ Sv (1)

3 $H = \dot{H}\, t$ (1); H = 4.0 × 600 = 2400 µSv (1); H = 2.4 mSv (1); this is a little more than the average UK background of 2.2 mSv per year, so the pilot's yearly dose is roughly doubled (1).

TEACHER NOTES

Practical 5: A dice model of half-life

Time	One 50-minute lesson in pairs or threes. Each run of 8 throws takes about 5 minutes; three runs plus the graph and the real-data question fill the lesson.
Kit per group	100 six-sided dice (or 100 coins, removing heads, which gives a half-life of 1 throw), a large tray with sides. No radioactive sources are handled by learners.
Real data	The decay table is provided, so no demonstration is needed. If you show a real half-life measurement, the teacher alone handles any sealed source, following the school's local rules and current SSERC guidance.
Expected results	The mean number left falls by about one sixth each throw: 100, 84, 70, 58, 48, 40, 33, 28, 23 The half-life is about 3.8 throws. Individual runs vary noticeably, which shows that decay is random.
Level	N5 plans the model, takes three runs, works out mean ± random uncertainty, plots a curve of best fit, finds the half-life twice and evaluates.

Safety and inclusion

- Throw into a tray to stop dice rolling off; pick up dropped dice at once.
- Small dice are a choking hazard for very young children: keep them in the lab.
- Learners with limited fine motor control can count or record while a partner throws.
- Follow your school's risk assessment and current SSERC guidance.

Common problems

- **Removing the wrong dice** or forgetting to remove them before the next throw.
- **Joining the dots** instead of drawing a smooth curve of best fit.
- **Half-life from a single halving only**: ask for two halvings and compare.

Assessment link

Evidence of modelling, handling data with mean and uncertainty, drawing graphs and extracting a value from a curve, and evaluating; useful practice for comparing with a published value in the assignment.

Answers: Topic 5

Topic 5: Half-life, fission and fusion (N5)

1 Half-life

1 Activity falls from 480 Bq to 240 Bq in 5 days (and 240 to 120 Bq in another 5 days): half-life = 5 days.

2 $\frac{32}{8}$ = 4 half-lives; 720 → 360 → 180 → 90 → 45 kBq.

3 2400 → 1200 → 600 → 300 is 3 half-lives; half-life = $\frac{60}{3}$ = 20 minutes.

2 Choosing a source

1 R: gamma can pass out of the body to be detected outside, and a short half-life (6 hours) means the patient's dose is kept low and it does not stay active for long.

2 Gamma ionises very weakly, so it would hardly ionise the air in the alarm, and smoke would not block it, so the alarm would not detect smoke.

3 Alpha would be stopped completely by the foil, so the count would not change with thickness. Gamma would pass straight through almost unchanged, so small changes in thickness would not be detected.

3 Fission and fusion

1 A large nucleus absorbs a neutron and splits into two smaller nuclei, releasing energy and two or three neutrons.

2 The neutrons released by one fission go on to cause more fissions. It must be controlled (control rods absorb neutrons) or the number of fissions, and the energy released, would increase rapidly.

3 Similarity: both release energy (from nuclei). Difference: fission splits a large nucleus; fusion joins small nuclei (or fusion needs very high temperature; fission uses neutrons).

Practical 5: Dice model of half-life

Variables: change the number of throws; measure the number of dice left; keep the same: starting number of dice (100), type of dice, removing only sixes, throwing all dice each time.

Prediction, e.g. the number left will fall by about the same fraction each throw, so it halves in a fixed number of throws.

Equipment: 100 dice, large tray. Not needed: stopwatch, GM tube, thermometer.

Hazards, e.g. dice on the floor (slips); small dice near young children (choking); leaning over a crowded bench (keep the tray in the middle).

Sample means (throws 0 to 8): 100.0, 83.7, 69.7, 58.0, 48.0, 40.0, 33.3, 27.7, 23.0.

Random uncertainties: 0.0, 1.7, 2.3, 1.7, 1.3, 1.3, 0.7, 1.0, 1.0.

Graph: throw number on the x axis, mean dice left on the y axis, smooth falling curve.

Half-life of the model: about 3.8 throws for 100 → 50 and about 3.8 throws for 50 → 25 (accept 3.5 to 4.5). Theory gives about 3.8 throws.

Evaluate: the dice give random results, just like decay. Use more dice (e.g. 500) or more runs, so the random variation averages out.

Real data: 640 → 320 counts per minute takes just over 3 minutes (between 3 min at 328 and 4 min at 262): half-life about 3.1 minutes (accept 3 to 3.2 minutes).

Check-up

1 $\frac{32}{8.0}$ = 4 half-lives (1); 960 → 480 → 240 → 120 → 60 (1); 60 kBq (1)

2 1200 → 600 → 300 → 150 is 3 half-lives (1); half-life = $\frac{45}{3}$ (1); = 15 minutes (1)

3 It would stay active in the patient for years, giving them a much larger dose. (1)

4 Two small (light) nuclei join to form a larger nucleus (1), releasing energy (1).

About the author

C. Blewis has taught for 17 years, including 10 years in Additional Support Needs (ASN) provision, teaching sciences, maths, PE and more.

In many schools, especially smaller and specialist settings, teachers are often asked to teach outside their own subject. These books are written for them, and for the young people they teach: clear, practical and ready to use from the first lesson.