REAL-LIFE PHYSICS

Waves and Radiation

Teacher guide

For the National 4 Physics workbook



C. Blewis

Blewis LEARNING

Using the workbooks

The National 4 Physics workbook for **Waves and Radiation** has ten topics. Every topic has learning pages, a practical the learner plans and evaluates, a brain break and a 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: How fast does a ruler vibrate?

Time	One 50-minute lesson in pairs or threes. Five lengths with three counts each takes about 25 minutes, or less if learners film once and count on playback.
Kit per group	Wooden metre stick, G-clamp, 100 g slotted mass (or a lump of modelling clay) and strong tape, stopwatch, phone or tablet with slow-motion video.
Prep	Check the clamps grip firmly and protect the bench with a folded cloth under the clamp. A slinky for the transverse and longitudinal demonstration on page 1 is very useful.
Expected results	Frequency falls as the overhang increases, from roughly 5 Hz at 40 cm to under 2 Hz at 80 cm with a 100 g mass. Short overhangs are too fast to count by eye: slow-motion video fixes this.
Demonstrations	A slinky stretched along the floor shows both wave types. A ripple tank or a tray of water with a floating cork shows the cork moving up and down while the wave travels on.
Level	N4 plans the test, repeats readings, averages, calculates frequency and draws a line graph with their own scales.

Safety and inclusion

- Only pull the stick down a few centimetres; a snapped or released stick can spring. Eye protection is sensible.
- Tape masses on firmly and stand to the side, not in line with the end of the stick.
- All roles can be done seated. A learner who finds counting hard can operate the video or record results.
- Follow your school and local authority guidance on practical work.

Common problems

- **Counting half vibrations:** one vibration is down and back up again to the start.
- **Overhang measured from the clamp:** measure from the edge of the bench.
- **Amplitude confusion:** learners often measure crest to trough. Stress the middle line.

No lab, no time, or a learner absent?

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

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of using f = N / t in a practical context.

Answers: Topic 1

Topic 1: What is a wave? (N4)

1 Waves carry energy

1 Energy.

2 It moves up and down as the waves pass, but stays in roughly the same place (it does not travel along with the waves).

3 Sound is a **longitudinal** wave. Light is a **transverse** wave. In a transverse wave the particles move at **right angles to** the energy.

2 Parts of a wave

1 A wavelength; B crest; C amplitude; D trough.

2 Amplitude = 2 cm; wavelength = 8 cm.

3 That distance is twice the amplitude. Amplitude is measured from the middle (rest) line to the top of a crest.

3 Frequency

1 $f = \frac{N}{t} = \frac{120}{40} = 3$ Hz

2 $t = 1.5 \times 60 = 90$ s; $f = \frac{N}{t} = \frac{18}{90} = 0.2$ Hz

3 $N = f \times t = 256 \times 5 = 1280$ vibrations

Practical 1: How fast does a ruler vibrate?

Variables: change the overhang length (cm); measure the number of vibrations in 10 s, then work out the frequency (Hz); keep the same: the mass on the end, the stick, how far it is pulled down, the counting time.

Prediction, e.g. the longer the overhang, the lower the frequency, because a longer stick moves more slowly.

Equipment: metre stick, G-clamp, 100 g mass and tape, stopwatch, phone for slow-motion video. Not needed: thermometer, loudspeaker.

Hazards, e.g. the stick snapping or springing back (do not bend it too far, wear eye protection); the clamp or stick falling on feet (clamp firmly, keep the bench clear).

Method key points: clamp the stick firmly to the edge of the bench; measure the overhang from the bench edge to the end; pull the end down the same distance each time and let go; count vibrations in 10 s (film in slow motion and count on playback); repeat 3 times; average; $f = \frac{N}{t.}$

Headings: Overhang (cm), Count 1, 2, 3, Average number, Frequency (Hz).

Sample results: averages 51, 37, 28, 21.7, 17.3; frequencies 5.1, 3.7, 2.8, 2.2, 1.7 Hz.

Graph: overhang (cm) on the x axis, frequency (Hz) on the y axis, a smooth curve falling more slowly as length increases.

Conclusion: as the overhang length increased, the frequency decreased.

Use your graph: about 4.3 Hz (accept 4.1 to 4.5 Hz).

Evaluate: (a) more vibrations are counted, so a miscount of one or a timing error makes a smaller difference. (b) e.g. more repeats; film in slow motion; use the same person to release the stick; measure the overhang carefully from the same point.

Check-up

1 Energy.

2 Transverse: particles move at right angles to the direction of the energy. Longitudinal: particles move back and forth in the same direction as the energy.

3 λ from one crest to the next crest (or trough to trough); A from the middle line to the top of a crest.

4 $t = 60$ s; $f = \frac{N}{t} = \frac{180}{60} = 3$ Hz

5 $N = f \times t = 440 \times 3 = 1320$ waves

TEACHER NOTES

Practical 2: Do waves move faster in deeper water?

Time	One 50-minute lesson in pairs or threes. Five depths with three timings each takes about 25 minutes if the water is added a centimetre at a time.
Kit per group	A shallow plastic tray at least 40 cm long (a plastic storage tray or a large baking tray), 30 cm ruler, jug of water, stopwatch, phone or tablet to film. Towels.
Prep	Put trays on a level bench away from sockets. Start at 1 cm and add water for each new depth, so learners do not need to empty the tray between tests.
Expected results	Speed rises with depth but less steeply as the water gets deeper: about 0.3 m/s at 1 cm and 0.7 m/s at 5 cm. Times are only around a second, so filming and timing on playback gives far better results than a stopwatch.
Demonstrations	Count the seconds between a flash and a bang: a teacher with a clapperboard or two blocks at the far side of the playing field shows the delay clearly.
Level	N4 plans the test, repeats readings, averages, calculates speed and draws a line graph with their own scales.

Safety and inclusion

- Keep water away from sockets and electrical equipment; wipe up spills at once.
- Do not move a full tray: empty it with a jug first.
- All roles can be done seated. A learner who finds timing hard can film, measure depth or record.
- Follow your school and local authority guidance on practical work.

Common problems

- **Ripples bounce back:** time the first crossing only, from the moment the ripple starts.
- **Distance confused:** d is the length of the tray, not the depth.
- **Thunder in kilometres:** remind learners to change km into m before using $d = v\,t$.

No lab, no time, or a learner absent?

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

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of using $v = d / t$ and $v = f \lambda$.

Answers: Topic 2

Topic 2: Wave speed (N4)

1 How fast do waves travel?

1 $v = \frac{d}{t} = \frac{45}{15} = 3$ m/s

2 $d = v\,t = 340 \times 0.6 = 204$ m

3 $t = \frac{d}{v} = \frac{100}{2.5} = 40$ s

2 The wave equation

1 $v = f\,\lambda = 2 \times 1.5 = 3$ m/s

2 $\lambda = \frac{v}{f} = \frac{340}{500} = 0.68$ m

3 $f = v / \lambda = \frac{6}{12} = 0.5$ Hz

3 Thunder and lightning

1 Light travels much faster than sound (300 000 000 m/s compared with about 340 m/s), so the light reaches you almost at once and the sound arrives later.

2 $d = v\,t = 340 \times 3 = 1020$ m

3 $d = 2.04 \times 1000 = 2040$ m; $t = \frac{d}{v} = \frac{2040}{340} =$ 6 s

Practical 2: Do waves move faster in deeper water?

Variables: change the depth of water (cm); measure the time for a ripple to cross the tray (s), then work out the speed (m/s); keep the same: the tray (length), how the ripple is made, the distance travelled, the water temperature.

Prediction, e.g. the deeper the water, the faster the wave.

Equipment: tray, ruler, jug of water, stopwatch, phone to film. Not needed: thermometer, loudspeaker.

Hazards, e.g. spilt water near electrical sockets (keep the tray away from sockets and the phone dry); heavy tray of water (do not lift a full tray, empty it with a jug).

Method key points: measure the depth with a ruler held upright in the water; make the ripple by tapping or lowering a ruler at one end the same way each time; time it from one end to the other (film it and use the timer on playback); repeat 3 times; average; v = d ÷ t with d = length of the tray.

Headings: Depth (cm), Time 1, 2, 3 (s), Average time (s), Speed (m/s).

Sample results: average times 1.60, 1.13, 0.92, 0.80, 0.71 s; speeds 0.31, 0.44, 0.54, 0.63, 0.70 m/s.

Graph: depth (cm) on the x axis, speed (m/s) on the y axis, a smooth curve rising less steeply as depth increases.

Conclusion: as the depth of the water increased, the speed of the waves increased.

Use your graph: about 0.49 m/s (accept 0.47 to 0.51 m/s).

Evaluate: (a) reaction time is about 0.2 s, which is a large part of a time of about 1 s. (b) e.g. film the ripple and time it on playback; use a longer tray so the times are longer; more repeats; measure the depth at several places and average.

Check-up

1 $v = f\,\lambda$: v wave speed (m/s), f frequency (Hz), λ wavelength (m).

2 $t = 1.5 \times 60 = 90$ s; $v = \frac{d}{t} = \frac{90}{90} = 1.0$ m/s

3 $v = f\,\lambda = 0.25 \times 8 = 2$ m/s

4 $d = v\,t = 340 \times 4 = 1360$ m

5 Light from a lighthouse.

TEACHER NOTES

Practical 3: What sets the pitch of a note?

Time	One 50-minute lesson in pairs. Five lengths with three readings each takes about 25 minutes.
Kit per group	Plastic 250 ml measuring cylinder (or a tall narrow bottle or tube), jug of water, tray, ruler, phone or tablet with a free frequency, tuner or spectrum app.
Prep	Test the app first: tuner apps read pitch well for a steady note. Learners may need to practise blowing across the top to get a clear note. Plastic cylinders avoid broken glass.
Expected results	Frequency falls as the air column gets longer: roughly 1200 Hz at 6 cm to about 450 Hz at 18 cm. Some apps jump to a different harmonic; learners should ignore odd readings and repeat.
Demonstrations	Bell in a bell jar with a vacuum pump. Signal generator, loudspeaker, microphone and oscilloscope to show amplitude and frequency changing. Hearing-range test with a signal generator.
Level	N4 plans the test, repeats readings, averages and draws a line graph with their own scales.

Safety and inclusion

- Keep loudspeaker volumes low, especially for the hearing-range test; high frequencies can be uncomfortable. Stop at once if anyone finds a sound unpleasant.
- Bell jar: check the jar for cracks and use a safety screen; implosion is a risk with damaged glass.
- Learners should not share mouthpieces or cylinders without wiping them. Allow rests if blowing makes anyone light-headed.
- Some learners are sensitive to noise: offer ear defenders and a quieter role (measuring or recording). Learners with hearing loss can read the app or watch the oscilloscope trace.
- Follow your school and local authority guidance on practical work.

Common problems

- **Measuring the water instead of the air:** the length that matters is from the water surface to the top.
- **Loudness and pitch mixed up:** taller trace = louder; more waves = higher pitch.

No lab, no time, or a learner absent?

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

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of analysing sound waveforms.

Answers: Topic 3

Topic 3: Sound waves (N4)

1 Sound is a vibration

1 The strings (and the wooden body of the fiddle and the air inside it).

2 We can still see the hammer hitting the bell.

3 Space is a vacuum, with no particles to carry sound, so they cannot hear each other directly. Radio waves can travel through a vacuum.

2 Seeing sound

1 Loudest: Q. Highest pitch: R. Same pitch: P and Q. Lowest frequency: S.

2 Three complete waves across the screen (same number as the fiddle note), but taller than the original trace.

3 The range of hearing

1 Dog, cat and bat.

2 25 000 Hz is above the human range of hearing (about 20 000 Hz) but inside a dog's range.

3 The highest frequency we can hear gets lower as we get older; her gran's upper limit is now below 17 000 Hz.

4 Ultrasound (it is above 20 000 Hz).

Practical 3: What sets the pitch of a note?

Variables: change the length of the air column (cm); measure the frequency of the note (Hz); keep the same: the cylinder, how the note is made (blowing the same way), the distance from the phone to the cylinder, the same app.

Prediction, e.g. a shorter air column will give a higher note, because there is less air to vibrate.

Equipment: measuring cylinder and water, ruler, phone with a frequency app. Not needed: stopwatch, tuning fork, thermometer, sound meter.

Hazards, e.g. glass cylinder breaking (use a plastic cylinder or handle with care); feeling dizzy from blowing (rest between notes); sharing a cylinder (each person uses their own, or wipe the top).

Method key points: add water to change the air column; measure from the water surface to the top of the cylinder; blow gently across the top to make a steady note; hold the phone at the same distance; take three readings for each length; average.

Headings: Air column (cm), Frequency 1, 2, 3 (Hz), Average frequency (Hz).

Sample results: averages 1252, 867, 667, 541 and 454 Hz.

Graph: air column length (cm) on the x axis, frequency (Hz) on the y axis; a smooth curve falling steeply at first then more gently.

Conclusion: as the length of the air column increased, the frequency (pitch) decreased.

Use your results: higher (the air column is shorter).

Evaluate: (a) the note is not exactly the same each time (blowing harder or at a different angle), and background noise affects the app. (b) e.g. more repeats; work in a quiet room; hold the phone in a clamp at a fixed distance; measure the air column more carefully at eye level.

Check-up

1 Something must vibrate.

2 A vacuum has no particles to pass the vibrations on.

3 X is louder (bigger amplitude); Y has the higher pitch (more waves, higher frequency).

4 250 Hz, 4000 Hz and 18 000 Hz.

5 $f = \frac{N}{t} = \frac{1650}{5} = 330$ Hz

TEACHER NOTES

Practical 4: How fast is sound?

Time	One 50-minute lesson in groups of three. Five distances with three readings each takes about 25 minutes once the kit is set up.
Kit per group	Two microphones with stands, an electronic (fast) timer or data logger that starts and stops on sound, metre stick, small hammer or wooden block, metal plate or tin lid.
Prep	Check the timer triggers reliably and adjust its sensitivity so classroom noise does not start it. A free two-channel sound recording app on a laptop can be used instead: read the time gap between the two peaks.
Expected results	About 330 to 345 m/s, depending on room temperature and how carefully the distance is measured. Times are 1 to 8 ms for 0.5 to 2.5 m.
Outdoor option	Echo method: stand at least 50 m from a large flat wall and clap. One learner claps in time with the echoes while another times 20 claps; speed = $\frac{2 \times \text{distance} \times 20}{\text{time.}}$ Or time a starting horn across a playing field.
Level	N4 plans the test, repeats readings, averages, changes units, calculates speed and draws a line graph with their own scales.

Safety and inclusion

- Repeated sharp bangs can be uncomfortable: tap firmly, not hard, and offer ear defenders. Some learners are sensitive to sudden noise; warn them before each tap or give them the recording or measuring role.
- Tape down trailing leads. For outdoor work, choose a safe site away from traffic and agree a signal for stopping.
- All roles can be done seated. Learners with hearing loss can read the timer or record.
- Follow your school and local authority guidance on practical work.

Common problems

- **Timer triggered by talking:** work quietly and lower the sensitivity.
- **Milliseconds:** learners must divide by 1000 before using $v = \frac{d}{t.}$
- **Echoes:** learners forget to double the distance to the wall.

No lab, no time, or a learner absent?

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

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of using v = d / t to measure the speed of sound.

Answers: Topic 4

Topic 4: The speed of sound (N4)

1 How fast is sound?

1 $v = \frac{d}{t} = \frac{1020}{3.0} = 340$ m/s

2 $d = v\,t = 340 \times 4.0 = 1360$ m

3 $t = \frac{d}{v} = \frac{85}{340} = 0.25$ s

2 Measuring the speed of sound

1 $v = \frac{d}{t} = \frac{1.50}{0.0044} = 341$ m/s (340.9 m/s)

2 $d = 102 + 102 = 204$ m; $v = \frac{d}{t} = \frac{204}{0.60} = 340$ m/s

3 Sound in solids, liquids and gases

1 $t = \frac{d}{v} = \frac{6000}{1500} = 4.0$ s

2 Steel: $t = \frac{1000}{5000} = 0.20$ s. Air: $t = \frac{1000}{340} = 2.9$ s.

3 The sound travels through the steel and through the air. It is much faster in steel, so that sound arrives first and the sound through the air arrives about 2.7 s later.

Practical 4: How fast is sound?

Variables: change the distance between the microphones (m); measure the time (ms) and calculate the speed (m/s); keep the same: the way the sound is made, the microphones and timer, the line of the microphones with the plate, the room (temperature).

Prediction: the time will double.

Equipment: 2 microphones, electronic timer, metre stick. Not needed: stopwatch, thermometer, loudspeaker. (A hammer and metal plate make the sound.)

Hazards, e.g. trailing leads (tape them down, keep the floor clear); hammer slipping onto fingers (hold the plate on the bench, tap the centre).

Method key points: microphones in a line with the plate, A nearer the plate; measure between the centres of the microphones; reset the timer to zero; tap the plate once; repeat three times for each distance; average; change ms to s; $v = \frac{d}{t}$.

Headings: Distance (m), Time 1, 2, 3 (ms), Average time (ms), Speed (m/s).

Sample results: average times 1.48, 2.95, 4.41, 5.89, 7.35 ms; speeds 338, 339, 340, 340, 340 m/s; average speed about 339 m/s.

Graph: a straight line through (or very close to) the origin.

Conclusion: as the distance increased, the time increased in proportion (doubling the distance doubled the time). The average speed of sound was about 340 m/s.

Compare: within a few m/s of 340 m/s (about 1%).

Evaluate: (a) the times are a few thousandths of a second, much less than reaction time, so a stopwatch could not measure them. (b) e.g. more repeats; larger distances so the times are longer; measure the distance carefully between the centres of the microphones; keep the microphones in a straight line with the plate.

Check-up

1 $d = v\,t = 340 \times 1.5 = 510$ m

2 Distance there and back $d = v\,t = 340 \times 2.0 = 680$ m; distance to crags $= \frac{680}{2} = 340$ m

3 Steel, water, air.

4 The particles in a solid are closer together and linked, so vibrations pass from particle to particle more quickly.

5 Light travels much faster than sound (300 000 000 m/s compared with 340 m/s), so the light reaches us almost at once.

TEACHER NOTES

Practical 5: Which material blocks sound best?

Time	One 50-minute lesson in pairs or threes. Five materials with three readings each takes about 20 minutes once the box is set up.
Kit per group	A small buzzer with a battery (or a phone playing a steady tone), a small cardboard box, materials to wrap it in (newspaper, cotton wool, bubble wrap, foam, cloth), tape, scissors, a phone or tablet with a free sound level meter app, a metre stick.
Prep	Install and test the same app on the devices you will use. Check the buzzer gives a steady sound. If possible, give groups separate spaces (corridor, library, store) so they do not hear each other's buzzers.
Expected results	Soft, thick, air-filled materials (foam, cotton wool) reduce the level most; newspaper least. Differences of 5 to 15 dB are typical. Phone apps are not calibrated, so compare results within one device only.
Extension	A sound level survey round the school (corridor at changeover, dining hall, library, music room) makes a good bar chart and links to noise pollution.
Level	N4 plans the test, repeats readings, averages and draws a bar chart with their own scale.

Safety and inclusion

- Keep sound levels low: a buzzer at arm's length is enough. Never hold a sound source against the ear.
- Some learners find loud or sudden sounds distressing. Warn before starting a buzzer, keep tests short, and allow ear defenders or a quieter space.
- Learners with a hearing impairment can read the meter or record; the practical does not depend on hearing the sound.
- Follow your school and local authority guidance on practical work.

Common problems

- **Background noise:** readings jump about. Take readings when the room is quiet and note the background level.
- **Different distances or thicknesses:** mark the phone position with tape, and use one layer of each material.
- **Reading the wrong number:** many apps show a maximum and an average. Use the same one each time.

No lab, no time, or a learner absent?

The sample results let learners complete the averages, bar chart, conclusion and evaluation without doing the practical.

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of sound level measurement and protecting hearing.

Answers: Topic 5

Topic 5: Noise and hearing (N4)

1 Measuring sound level

1 Quietest: the harbour at 6 am (38 dB). Loudest: beside the roadworks (98 dB).

2 Normal conversation (60 dB).

3 Whisper, normal conversation, busy road, jet taking off.

4 Yes: 98 − 65 = 33 dB.

2 Noise pollution and hearing damage

1 Any two, e.g. traffic, aircraft, building sites or roadworks, factories, loud music, alarms.

2 How loud the sound is, and how long you hear it for.

3 Yes. 98 dB is above 85 dB, the level at which workers must wear hearing protection.

4 About 1 hour.

3 Protecting your hearing

1 They cover the ears and absorb sound, so less sound energy reaches the ears and the sound level at the ear is lower.

2 Any two, e.g. use quieter machines; put up a barrier or screen round the drilling; work at times when the café is closed or quiet; take more breaks from the noisiest jobs; keep the café door and windows closed.

3 It has the same shape but is opposite: a crest where the noise has a trough, and a trough where the noise has a crest.

Practical 5: Which material blocks sound best?

Variables: change the material; measure the sound level (dB); keep the same: the buzzer and its loudness, the box, the distance from the phone (30 cm), the thickness of the material, the same phone and app.

Prediction, e.g. foam will be best because it is thick and soft and absorbs sound.

Equipment: buzzer, small box, materials, phone with sound app, metre stick. Not needed: thermometer, stopwatch.

Hazards, e.g. scissors when cutting materials (cut away from the body); trailing wires (keep the bench tidy); a loud buzzer (keep it quiet and away from ears).

Method key points: place the phone 30 cm from the box and measure the distance each time; wrap each material once around the box with the same thickness; keep the room quiet and read the app after a few seconds; repeat 3 times per material; average; include a test with no material.

Headings: Material, Reading 1, 2, 3 (dB), Average sound level (dB).

Sample results: no material 82 dB; newspaper 77 dB; cotton wool 71 dB; bubble wrap 74 dB; foam 66 dB.

Bar chart: materials on the x axis, average sound level (dB) on the y axis with an even scale (e.g. 60 to 85 dB, or from 0), bars of equal width with gaps.

Conclusion: foam reduced the sound level the most (to 66 dB); newspaper reduced it least.

Explain: (a) it is a control, to see how loud the buzzer is without any material, so the effect of each material can be compared. (b) 82 − 66 = 16 dB.

Evaluate: (a) e.g. test in a quiet room or corridor, ask the class to be silent during readings, take a background reading first. (b) e.g. more repeats; use the same thickness of each material; check the buzzer's battery; keep the phone in a clamp at exactly the same place.

Check-up

1 Decibel (dB).

2 60 dB.

3 Loud sounds damage the hair cells in the ear, and these do not grow back. Hearing them for a long time each day over many years adds up to permanent damage.

4 Any two, e.g. wear ear defenders or ear plugs; take breaks; use the drill for less time; use a quieter drill.

5 A microphone picks up the noise, and the headphones make an opposite wave. The two waves cancel out, so less noise is heard.

TEACHER NOTES

Practical 6: How accurate is an echo sensor?

Time	One 50-minute lesson in pairs or threes. Five distances with three readings each takes about 20 minutes once the sensor is working.
Kit per group	An ultrasonic motion or distance sensor with a data logger or laptop (or a micro:bit or Arduino with an HC-SR04 sensor, or a car parking sensor kit), a tape measure or metre sticks, a large flat board (hardboard, a whiteboard or a box lid) and a clamp stand.
Prep	Check the sensor software shows distance in metres, and set it to take single readings. Find a clear stretch of bench or floor at least 3 m long, away from walls and furniture that could give extra echoes.
Expected results	Readings within a few centimetres of the tape measure, usually all slightly high or all slightly low (a systematic error). The graph is a straight line through or very close to the origin. Readings become unreliable close to the sensor (under about 0.2 m) and at long range.
Echo demonstration	Two people 100 m from a large wall can clap and time the echo: a quick way to show d = v t with halving, and to estimate the speed of sound.
Level	N4 plans the test, repeats readings, averages and draws a line graph with their own scales.

Safety and inclusion

- Clamp the board and keep leads taped down. Keep the floor clear where learners walk.
- Ultrasound from these sensors is low power and safe. Some people (and pets) can hear a faint clicking.
- All roles can be done seated. A learner who finds the software hard can measure with the tape or record.
- Follow your school and local authority guidance on practical work.

Common problems

- **Wild readings:** the beam is hitting the bench, a wall or a person. Raise the sensor and clear the space.
- **Forgetting to halve:** in calculations learners often give the there-and-back distance as the depth.
- **Units:** some sensors read in centimetres or millimetres; check before recording.

No lab, no time, or a learner absent?

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

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of using d = v t with echoes.

Answers: Topic 6

Topic 6: Ultrasound and sound technology (N4)

1 What is ultrasound?

1 25 000 Hz and 40 000 Hz.

2 Its frequency is above 20 000 Hz, which is higher than the human ear can detect.

3 Ultrasound does not harm the baby. X-rays could damage the baby's cells.

4 The range of hearing gets smaller with age; older people often cannot hear high frequencies.

2 Echo sounding

1 $d = v\,t = 1500 \times 0.2 = 300$ m there and back; depth = $\frac{300}{2}$ = 150 m

2 $2 \times 45 = 90$ m

3 $d = v\,t = 340 \times 0.02 = 6.8$ m there and back; moth = $\frac{6.8}{2}$ = 3.4 m away

3 Recording and playing sound

1 The microphone changes sound into an electrical signal; the loudspeaker changes an electrical signal into sound.

2 Analogue: vinyl record, cassette tape. Digital: music streaming, CD.

3 e.g. it can be copied and sent around the world without losing quality; it can be stored as a small file and edited easily.

Practical 6: How accurate is an echo sensor?

Variables: change the distance to the board (measured with the tape measure, m); measure the sensor reading (m); keep the same: the board (size and material), the sensor and its position, the angle (sensor pointing straight at the board), where distances are measured from.

Prediction, e.g. the sensor will give almost the same readings as the tape measure, because it times echoes very accurately.

Equipment: ultrasonic sensor, data logger, tape measure, flat board. Not needed: thermometer, loudspeaker, balance.

Hazards, e.g. tripping over the tape or leads (tape leads down, keep the floor clear); the board or sensor falling (clamp them).

Method key points: point the sensor straight at a large flat board; measure from the front of the sensor to the board; set distances of 0.50 m to 2.50 m; take three sensor readings at each distance; average.

Headings: Tape measure distance (m), Sensor reading 1, 2, 3 (m), Average sensor reading (m).

Sample averages: 0.52, 1.02, 1.52, 2.03, 2.54 m.

Graph: a straight line very close to sensor reading = tape distance, slightly above it.

Conclusion: the sensor readings were very close to the tape measure distances, about 2 to 4 cm too big each time.

Explain: e.g. the sensor measures from its inside (the part that sends and receives the pulse), not from its front; or the tape was measured from the wrong point; or the speed of sound set in the sensor is not quite right for the temperature of the room.

Evaluate: (a) a large flat hard surface reflects a strong echo straight back to the sensor; a small or soft object reflects a weak or scattered echo, or the sensor detects something else. (b) e.g. take more readings at each distance; keep other objects and people out of the beam; check the sensor reading with nothing in front; measure from the same point on the sensor each time.

Check-up

1 Sound with a frequency above 20 000 Hz, too high for humans to hear.

2 Any two, e.g. scanning an unborn baby; checking organs or blood flow; cleaning jewellery or dental tools; finding cracks in metal; sonar to find depth or fish.

3 $d = v\,t = 1500 \times 0.12 = 180$ m there and back; depth = $\frac{180}{2}$ = 90 m

4 $d = v\,t = 1500 \times 0.0001 = 0.15$ m there and back; depth = $\frac{0.15}{2}$ = 0.075 m = 7.5 cm

5 An analogue signal can have any value in a range and changes smoothly; a digital signal has only two values, 1 and 0.

TEACHER NOTES

Practical 7: What stops infrared?

Time	One 50-minute lesson. With one TV, run a carousel; with spare IR receivers, groups work in parallel.
Kit per group	TV remote and the TV (or a set-top box, projector or any device with an IR receiver), tape measure, a supply of sheets: printer paper, tissue paper, cotton cloth, thin black plastic bag, kitchen foil. A phone camera to check the remote is working.
Prep	Fresh batteries in the remote. Cut the materials into sheets larger than the front of the remote. Choose a button with a clear effect, such as channel up or volume.
Expected results	Foil blocks infrared completely. Paper lets a surprising amount through, tissue most of all. Thin black plastic often lets infrared through even though it blocks visible light, which makes a good discussion point.
Demonstrations	A prism and a bright ray box or projector show the visible spectrum. A thermometer just beyond the red shows infrared heating; UV beads show ultraviolet beyond the violet.
Level	N4 plans the test, repeats readings, averages and draws a bar chart with their own scale.

Safety and inclusion

- Only the teacher plugs in, moves or adjusts the TV. Keep cables tidy and the TV on a stable stand.
- Never look into a laser or a very bright light source when demonstrating the spectrum.
- All roles can be done seated. A learner who finds counting sheets hard can press the remote or record results.
- Follow your school and local authority guidance on practical work.

Common problems

- **Remote reflects round the sheets:** infrared bounces off walls. Hold the sheets close to the remote and cover its edges.
- **Flat batteries:** check with a phone camera before starting.
- **Order of the spectrum:** learners often swap infrared and ultraviolet. Link "infra" (below) to red and "ultra" (beyond) to violet.

No lab, no time, or a learner absent?

The sample results let learners complete the averages, bar chart, conclusion and evaluation without doing the practical.

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of knowing the members of the electromagnetic spectrum and using d = v t for light.

Answers: Topic 7

Topic 7: The electromagnetic spectrum (N4)

1 A family of waves

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

2 Radio waves.

3 X-rays.

4 No. All electromagnetic waves travel at the same speed, the speed of light (300 000 000 m/s).

2 Light and colour

1 Red, orange, yellow, green, blue, violet.

2 The reading goes up, because infrared lands there. Infrared is absorbed by the thermometer and heats it.

3 e.g. put a material that glows under UV (a security-marked banknote, fluorescent highlighter ink, washing powder) or UV-sensitive beads just beyond the violet; they glow or change colour.

3 As fast as light

1 $t = \frac{d}{v} = \frac{36\,000\,000}{300\,000\,000} = 0.12$ s

2 $d = v\,t = 300\,000\,000 \times 1.28 = 384\,000\,000$ m

3 $t = \frac{d}{v} = \frac{3000}{300\,000\,000} = 0.000\,01$ s.

Practical 7: What stops infrared?

Variables: change the material; measure the largest number of sheets the remote still works through; keep the same: the remote and TV, the distance (2 m), the angle and height of the remote, the button pressed, how the sheets are held.

Prediction, e.g. tissue paper, because it is the thinnest and most open material.

Equipment: TV remote, TV (or another IR receiver), tape measure, phone camera to check the remote is sending. Not needed: thermometer, prism, stopwatch.

Hazards, e.g. the TV being knocked over (keep it on a stable stand, do not lean on it); mains electricity (do not touch plugs or sockets with wet hands; only the teacher moves the TV).

Method key points: remote fixed 2 m from the TV, pointing straight at the receiver; add one sheet at a time in front of the remote; press the same button each time; the largest number of sheets that still changes the channel is recorded; repeat 3 times; average.

Headings: Material, Test 1, 2, 3 (sheets), Average (sheets).

Sample averages: printer paper 14; tissue paper 29; cotton cloth 4.3; black plastic bag 5.7; kitchen foil 0.

Bar chart: materials on the x axis, average number of sheets on the y axis with an even scale (e.g. 0 to 30), equal bars with gaps.

Conclusion: tissue paper let the most infrared through; kitchen foil let none through.

Explain: (a) tissue paper is very thin with tiny gaps between its fibres, so each sheet absorbs or reflects less infrared than a thick, tightly woven cloth. (b) A phone camera can detect infrared, so the LED on the front of the remote shows up as a light on the screen when a button is pressed.

Evaluate: (a) e.g. measure the thickness of each material and compare equal thicknesses, or use a light meter or infrared sensor to measure how much gets through one sheet of each. (b) e.g. more repeats; fix the remote in a clamp so the angle does not change; dim the room lights.

Check-up

1 Radio, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays.

2 Any two: they all travel at the speed of light (300 000 000 m/s); they can all travel through a vacuum; they are all transverse waves; they all carry energy.

3 Ultraviolet.

4 $t = \frac{d}{v} = \frac{1\,500\,000}{300\,000\,000} = 0.005$ s

5 $d = v\,t = 300\,000\,000 \times 0.0001 = 30\,000$ m

TEACHER NOTES

Practical 8: Does a higher SPF block more UV?

Time	One 50-minute lesson in pairs or threes. Each test takes about 2 minutes, plus time for the beads to fade back indoors (5 to 10 minutes), so give each group two sets of beads.
Kit per group	About 20 UV-sensitive colour-change beads, white card, four clear plastic lids or sheets (petri dish lids or cut-up plastic wallets), sunscreens of SPF 15, 30 and 50, gloves or spatulas, stopwatch. A UV torch only if there is no sunshine.
Prep	Use sunlight where possible: it is the safest and most realistic source, and even a bright overcast day works. Store beads in a dark envelope. Check for sunscreen allergies.
Expected results	With no sunscreen almost every bead changes within a minute. Higher SPF means fewer beads change, though a thin smear lets some UV through; a thick, even layer gives the clearest difference.
Level	N4 plans the test, repeats readings, averages and draws a bar chart with their own scale.

Safety and inclusion

- UV torches: use low-power torches sold for this purpose, point them only downwards at the beads, and never shine them into anyone's eyes. The teacher keeps and hands out the torches.
- Gloves or spatulas for sunscreen; wash hands afterwards. Keep sunscreen away from eyes.
- Working outside: keep it short, keep sun protection on, and plan for learners who are sensitive to bright light.
- All roles can be done seated. Follow your school and local authority guidance on practical work.

Common problems

- **Beads have not faded back:** reused beads give low counts. Keep spares in the dark.
- **Different amounts of sunscreen:** the biggest source of unfairness. A pea-sized blob spread with a spatula, or a balance, helps.
- **Ionising confusion:** learners often think all radiation is harmful. Stress that radio, microwaves and visible light at normal strengths are not ionising.

No lab, no time, or a learner absent?

The sample results let learners complete the averages, bar chart, conclusion and evaluation without doing the practical.

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of describing applications, hazards and ways of reducing risk across the electromagnetic spectrum.

Answers: Topic 8

Topic 8: Using EM waves safely (N4)

1 Uses at the low-energy end

1 TV remote: infrared. Microwave oven: microwaves. Wi-fi: radio waves (accept microwaves). Optical fibre: visible light (accept infrared).

2 A person gives out infrared because they are warm. The thermal camera detects infrared, which does not need daylight; an ordinary camera needs visible light.

2 The high-energy end

1 Ultraviolet, X-rays and gamma rays.

2 Gamma rays are ionising and can damage or kill healthy cells too, so the beam must hit only the cancer cells.

3 More.

3 Reducing the risks

1 High risk. e.g. use high-SPF sunscreen and reapply it, wear hats, T-shirts and UV sunglasses, sit in the shade around midday.

2 The patient has one short X-ray when it is needed; the radiographer takes many X-rays every day, so the screen shields them and keeps their total dose low.

3 No. Much of the Sun's ultraviolet passes through clouds, so skin can still burn.

Practical 8: Does a higher SPF block more UV?

Variables: change the SPF of the sunscreen; measure the number of beads (out of 10) that change colour; keep the same: the amount of sunscreen, the type of lid, the time in the UV (2 minutes), the distance from the UV torch or the same sunlight, the number and type of beads.

Prediction, e.g. the higher the SPF, the fewer beads change colour, because the sunscreen blocks more ultraviolet.

Equipment: UV beads, sunscreens of different SPF, clear lids, stopwatch, UV torch (if there is no sun). Not needed: thermometer, TV remote, balance.

Hazards, e.g. sunscreen in the eyes or an allergy to it (wear gloves, wash hands, check for allergies first); sunburn if working outside for a long time (keep tests short, cover skin).

Method key points: spread the same amount of each sunscreen (e.g. one pea-sized blob) evenly over a clear lid; keep the beads in a box or envelope until the start; place the lid over the beads; put them in the sun (or under the torch at a fixed distance) for 2 minutes; count the beads that have changed colour; repeat 3 times with fresh beads that have faded back; average.

Headings: SPF, Test 1, 2, 3 (beads), Average (beads).

Sample averages: SPF 0: 10; SPF 15: 6.3; SPF 30: 3.7; SPF 50: 1.3.

Bar chart: SPF on the x axis, average number of beads changed on the y axis with an even scale (0 to 10), equal bars with gaps.

Conclusion: as the SPF increased, fewer beads changed colour, so less ultraviolet got through.

Explain: (a) It is a control: it shows how many beads change with no sunscreen, so we can see the effect of the sunscreen. (b) Choose a high SPF to block the most UV.

Evaluate: (a) e.g. compare each bead with a colour chart, or have two people agree on each count. (b) e.g. weigh the sunscreen so the same mass is used; use a UV torch at a fixed distance so the UV is the same for every test; make sure the beads have faded fully before reusing them.

Check-up

1 e.g. microwaves: cooking, satellite signals, mobile phones; infrared: heaters, remote controls, thermal cameras; ultraviolet: sterilising, security marks, sunbeds; X-rays: images of bones or teeth, baggage scanners.

2 Gamma rays.

3 Any two: high-SPF sunscreen; hat and clothing; UV sunglasses; stay in the shade; limit time in the sun, especially around midday.

4 X-rays are ionising and can damage cells. They take many X-rays, so the screen shields them and keeps their dose low.

5 Radio and microwaves (at normal strengths).

TEACHER NOTES

Practical 9: Where is the background highest?

Time	One 50-minute lesson. Six places with three 1-minute counts each takes about 25 minutes plus moving between places. Groups can share places and pool results.
Kit per group	GM tube and counter (or ratemeter) with a timer, stand and clamp, stopwatch if the counter has no timer. No radioactive sources are needed.
Prep	Check that each counter works and resets. Choose places with clear differences: a basement or ground-floor store, stone or brick walls, outdoors, a carpeted room upstairs.
Expected results	Typical school background counts are about 15 to 40 counts per minute. Counts vary a lot from minute to minute; differences between places may be small, so a longer counting time helps.
Demonstration	Absorption of alpha, beta and gamma by paper, aluminium and lead can be shown by the teacher with sealed school sources. Radioactive sources are **teacher demonstrations only**, following your school's local rules and national guidance for schools (in Scotland, SSERC). Learners do not handle sources.
Level	N4 plans the survey, repeats counts, averages and draws a bar chart with their own scale.

Safety and inclusion

- Background counting is safe: there is no source. Make sure learners know this, as some may be anxious about radiation.
- Keep corridors and fire exits clear; tidy trailing leads.
- All roles can be done seated. A learner can be timer, reader or recorder.
- Follow your school and local authority guidance on practical work.

Common problems

- **Counter not reset:** counts keep adding up. Reset, or subtract the start reading.
- **Expecting identical repeats:** use this to teach that decay is random.
- **Mixing up "stops" and "reduces":** lead greatly reduces gamma but does not stop all of it.

No lab, no time, or a learner absent?

The sample results let learners complete the averages, bar chart, conclusion and evaluation without doing the practical.

Assessment link

Gives evidence of planning and carrying out an investigation safely, recording and presenting results, drawing a conclusion and evaluating, and of knowledge of background radiation.

Answers: Topic 9

Topic 9: Nuclear radiation (N4)

1 Inside the atom

1 Protons and neutrons.

2 It has unstable nuclei, which give out radiation.

3 Gamma.

4 No. Beta is a fast electron that comes from the nucleus itself, not one of the electrons around the outside.

2 Stopping radiation

1 Paper: stops alpha ✓, beta ×, gamma ×. Aluminium: alpha ✓, beta ✓, gamma ×. Lead: alpha ✓, beta ✓, most gamma ✓.

2 Alpha.

3 Once inside the lungs, nothing (no skin) stops the alpha radiation reaching living cells. Alpha causes the most ionisation, so it can damage or kill cells and cause cancer.

3 Background radiation

1 Radon gas (about half).

2 Natural, e.g. radon, rocks and buildings, cosmic rays, food and drink. Artificial, e.g. medical X-rays and scans, nuclear industry.

3 Granite is naturally radioactive and gives out radon gas, so the count is higher there.

4 To blow radon gas out from under the house so it does not build up indoors.

Practical 9: Where is the background highest?

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

Prediction, e.g. highest in the basement because radon gas from the ground can build up there.

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

Hazards, e.g. trailing leads (tidy them); blocking a corridor or fire exit (set up to the side); carrying equipment on stairs (carry with two hands, one item at a time).

Method key points: place the tube in the same position in each place; reset the counter; count for 1 minute (or longer); repeat 3 times; average.

Headings: Place, Count 1, Count 2, Count 3, Average count (counts per minute).

Sample results (averages): science lab 22.3, corridor 20.3, library 18.3, playground 24.7, stone stairwell 32.7, basement store 36.7 counts per minute.

Bar chart: places on the x axis, average count (counts per minute) on the y axis with an even scale, separate bars of equal width.

Conclusion: the count was highest in the basement store (36.7 counts per minute) and lowest in the library (18.3).

Explain: stone (such as granite) is naturally radioactive, and radon gas from the ground can collect in low, poorly ventilated places such as basements.

Evaluate: (a) radioactive decay is random, so the number of counts changes from minute to minute. (b) e.g. count for longer (5 or 10 minutes) or take more repeats, so the random changes average out.

Check-up

1 Alpha: 2 protons and 2 neutrons. Beta: a fast electron from the nucleus. Gamma: an electromagnetic wave.

2 Alpha.

3 Radiation knocking electrons off atoms, leaving them charged (ions).

4 Any two, e.g. radon gas, rocks and buildings, cosmic rays, food and drink, medical uses, nuclear industry.

5 It ionises atoms in living cells, which can damage or kill the cells or cause cancer.

$\frac{6\,120}{5}$ = 24 counts per minute.

TEACHER NOTES

Practical 10: A dice model of half-life

Time	One 50-minute lesson in pairs or threes. One run of eight throws takes about 10 minutes, so three runs fit easily.
Kit per group	100 small dice (or 100 cubes with one face marked), a tray with sides, a large plastic cup. Coins also work (remove heads); the half-life is then about one throw.
Prep	Count the dice into bags of 100 before the lesson. Pooling class results makes a smoother curve.
Expected results	About one sixth of the dice are removed each throw, so the half-life is close to 3.8 throws. Individual runs scatter around this.
Demonstration	A real decay curve can be shown with published or simulated data, or by the teacher using a suitable sealed source and method permitted under your school's local rules and current SSERC guidance. Any radioactive sources are **teacher demonstrations only**, following your school's local rules and national guidance for schools (in Scotland, SSERC). Learners do not handle sources.
Level	N4 plans the model, repeats runs, averages, draws a line graph with their own scales and reads the half-life from it.

Safety and inclusion

- Small dice are a choking hazard: supervise closely and use larger cubes with any learner who may put things in their mouth.
- Throw into a tray; pick up spills straight away.
- All roles can be done seated. A learner can shake, sort, count or record.
- Follow your school and local authority guidance on practical work.

Common problems

- **Recording dice removed instead of dice left:** the graph should show the number left.
- **Joining points with straight lines:** encourage a smooth curve of best fit.
- **Half-life confusion:** it is the time to halve, not the time for all of it to go.

No lab, no time, or a learner absent?

The sample results let learners complete the averages, graph, half-life, conclusion and evaluation without doing the practical.

Assessment link

Gives evidence of planning and carrying out an experiment safely, recording and presenting results, drawing a conclusion and evaluating, and of using half-life.

Answers: Topic 10

Topic 10: Using radiation safely (N4)

1 Activity and half-life

1 $t = 2 \times 60 = 120$ s; $A = \frac{N}{t} = \frac{12\,000}{120} = 100$ Bq

2 12 hours: 200 Bq; 18 hours: 100 Bq; 24 hours: 50 Bq.

3 400 → 200 → 100 → 50 is 3 half-lives; half-life $= \frac{15}{3} = 5$ days.

2 Half-life from a graph

1 160 Bq.

2 Half of 160 Bq is 80 Bq, reached at 10 minutes, so the half-life is 10 minutes.

3 40 Bq; 2 half-lives.

4 30 minutes (160 → 80 → 40 → 20 is 3 half-lives).

5 The activity falls quickly, so the radiation does not stay in the patient's body for long and their dose is small.

3 Radiation at work

1 Any three: spend as little time near sources as possible; keep her distance (tongs, stand back); use shielding (lead screens, apron, lead-lined containers); wear a dosimeter badge to check her dose.

2 Gamma. It passes through the packet and kills germs without the packet being opened.

3 Fission is a large nucleus splitting into smaller ones; fusion is small nuclei joining to make a larger one. Both release energy.

Practical 10: A dice model of half-life

Variables: change the throw number; measure the number of dice left (not decayed) after each throw; keep the same: start with 100 dice, remove only sixes, throw the same way, the same tray.

Prediction, e.g. the number of dice left will fall by about the same fraction each throw, so it falls quickly at first and then more slowly.

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

Hazards, e.g. dice on the floor (throw into a tray, pick up spills); swallowing small dice (none in mouths, take care with younger learners).

Method key points: shake all the dice in a cup and tip into the tray; remove the sixes ("decayed"); count the dice left and record; put the rest back in the cup and repeat for 8 throws (or until few are left); repeat the whole run 3 times; average.

Row labels: Run 1 left, Run 2 left, Run 3 left, Average left.

Sample averages: 100.0, 83.7, 70.0, 58.3, 48.7, 40.7, 34.0, 28.3, 23.7.

Graph: a smooth curve falling more and more slowly.

Conclusion: as the number of throws increased, the number of dice left decreased, quickly at first and then more slowly.

Half-life: about 3.9 throws (accept 3.5 to 4 throws).

Evaluate: (a) which dice land on a six is random, like decay. (b) Like real decay: random, and the same fraction decays each time so the number left halves in equal "times". Different: real sources have millions of nuclei, decay happens continuously not in throws, and each nucleus has a different chance from a dice.

Check-up

1 $t = 60$ s; $A = \frac{N}{t} = \frac{2400}{60} = 40$ Bq

2 The time it takes for the activity of the source to fall to half.

3 6 hours is 3 half-lives: 1200 → 600 → 300 → 150 Bq.

4 Any two: tracers, radiotherapy, sterilising equipment.

5 Short time; use tongs to keep your distance; lead shielding.

6 Nuclear fission.

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.