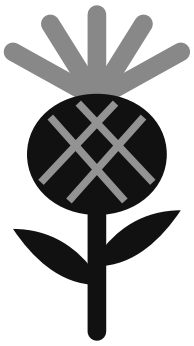
REAL-LIFE PHYSICS

Electricity

Teacher guide

For the Higher Physics workbook



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Blewis
LEARNING

Using the workbooks

The Higher Physics workbook for **Electricity** 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. Use low-voltage supplies only and never open mains equipment; connect electrolytic capacitors the right way round, within their voltage rating, and discharge them safely after use.

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 develop the skills needed for the assignment and for questions on experimental work in the exam; the learn pages and check-ups build 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: Peak and r.m.s. values

Time	One 55-minute period in pairs: about 25 minutes of readings (five settings, three repeats) and the graph in class or for homework.
Kit per group	Low-voltage a.c. supply (variable 2 to 12 V, or a signal generator at 50 Hz with a power amplifier), oscilloscope (or a data-logging scope), digital multimeter on its a.c. range, 12 V lamp or a 100 Ω, 2 W resistor as the load, leads.
Prep	Check that the meter reads true r.m.s. or is accurate for sine waves. Set the oscilloscope to d.c. coupling, 2 V/div (then 5 V/div above about 5 V r.m.s.) and 5 ms/div, with the trace centred.
Expected results	A straight line through the origin with gradient close to 1.41 (sample data: 1.41).
Level	H plans the test, finds means, random and scale-reading uncertainties and the largest percentage uncertainty, draws a best-fit line and interprets the gradient.

Safety and inclusion

- Low-voltage supplies only. Learners never connect the oscilloscope, meter or any lead to the mains. Lamps get hot.
- All roles can be done seated: adjusting the supply, reading the meter, reading the oscilloscope or recording.
- Risk assess for your own class and follow your employer's policies and SSERC guidance.

Common problems

- **Trace drifting:** use the trigger control or re-centre the zero line before each reading.
- **Reading peak-to-peak by mistake:** remind learners to measure from the centre line, or halve the peak-to-peak value.
- **Meter on the d.c. range:** it reads about zero for a.c.

No lab, no time, or a learner absent?

The sample results let learners complete the means, graph, uncertainty and evaluation without the practical.

Assessment link

Good practice for the assignment: repeated readings, scale-reading and random uncertainties, a graph with a gradient and a referenced comparison.

Answers: Topic 1

Topic 1: Monitoring and measuring a.c. (Higher)

1 Peak and r.m.s. values

1 $V_{peak} = \sqrt{2}\ V_{rms} = \sqrt{2} \times 6.0 = 8.5$ V.

2 $I_{peak} = \sqrt{2}\ I_{rms}$, so $2.4 = \sqrt{2} \times I_{rms}$ and $I_{rms} = 2.4 \div \sqrt{2} = 1.7$ A.

3 $V_{peak} = \sqrt{2} \times 230 = 325.3$ V, which is about 325 V.

2 Reading an oscilloscope

1 (a) 3 div × 2 V/div = 6 V. (b) one wave covers 5 div: T = 5 × 1 ms = 5 ms = 0.005 s. (c) f = 1 ÷ 0.005 = 200 Hz. (d) $V_{rms} = 6 \div \sqrt{2} = 4.2$ V.

2 Peak = 3.5 × 0.2 = 0.70 V. T = 4 × 10 ms = 40 ms = 0.040 s, so f = 1 ÷ 0.040 = 25 Hz.

3 The uncertainty in reading the screen is about the same whatever length you measure, so it is a smaller fraction (percentage) of a longer time. Dividing the time for several waves by the number of waves gives a more precise period.

3 Comparing a.c. and d.c.

1 $V_{rms} = 9.0$ V (the d.c. that gives the same power). $V_{peak} = \sqrt{2} \times 9.0 = 12.7$ V, about 13 V.

2 P = I V = 5.2 × 230 = 1196 W, about 1.2 kW.

3 20 V peak-to-peak is a peak of only 10 V, so the r.m.s. value is 10 ÷ √2 = 7.1 V. That gives much less power than 20 V d.c., so the lamp is dimmer.

Practical 1: Peak and r.m.s. values

Variables: change the r.m.s. p.d. (supply setting, read on the meter); measure the peak p.d. on the oscilloscope; keep the same: the load (lamp or resistor), frequency, oscilloscope settings where possible.

Prediction: a straight line through the origin with a gradient of about 1.4 (√2).

Equipment: low-voltage a.c. supply, oscilloscope, a.c. voltmeter, leads, lamp as load. Not needed: light gate, thermometer.

Hazards, e.g. hot lamp (do not touch it while on, let it cool); trailing leads (keep the bench tidy).

Method key points: meter and oscilloscope connected in parallel across the same load; Y-gain chosen so the trace fills most of the screen; five settings, read the peak three times (re-centring the trace each time); find the mean; plot mean peak against r.m.s.

Sample means: 2.0 V: 2.83 V; 4.0 V: 5.67 V; 6.0 V: 8.50 V; 8.0 V: 11.30 V; 10.0 V: 14.10 V.

Gradient of the best-fit line ≈ 1.41 (accept 1.39 to 1.43), very close to √2 = 1.41.

(a) (14.2 − 14.0) ÷ 3 = ±0.067 V, about ±0.07 V, which is 0.5% of 14.1 V. The scale-reading uncertainty (± 0.5 V on 5 V/div, 3.5%) is larger, so it dominates.

(b) e.g. The peak p.d. is directly proportional to the r.m.s. p.d.; the gradient (1.41) shows $V_{peak} = \sqrt{2}\ V_{rms}$ (within the uncertainty).

(c) e.g. use a smaller V/div setting (more divisions for each reading), use the oscilloscope's cursors or measure peak-to-peak and halve it.

Check-up

1 (a) $V_{peak} = \sqrt{2}\ V_{rms}$ (1); $V_{peak} = \sqrt{2} \times 230$ (1); $V_{peak} = 325$ V (1). (b) T = 1 ÷ f = 1 ÷ 50 (1); T = 0.020 s (1).

2 T = 8 × 0.25 ms = 2.0 ms = 0.0020 s (1); f = 1 ÷ 0.0020 = 500 Hz (1).

3 Open-ended (3 marks for a full, correct answer showing good understanding). Points could include: the 230 V on a label is an r.m.s. value, the steady d.c. value that gives the same power; the p.d. rises to a peak of about 325 V twice each cycle; insulation and equipment must be designed for the peak; danger depends on current through the body, which depends on p.d. and resistance; both a.c. and d.c. at mains p.d. can be lethal.

4 $I_{rms} = P \div V_{rms} = 1200 \div 230 = 5.22$ A (1)(1); $I_{peak} = \sqrt{2} \times 5.22$ (1); $I_{peak} = 7.4$ A (1).

TEACHER NOTES

Practical 2: Testing the potential divider rule

Time	One 55-minute period in pairs: about 25 minutes of readings and the graph in class or for homework.
Kit per group	Low-voltage d.c. supply or battery pack (about 6 V), digital voltmeter, decade resistance box (100 Ω to 10 kΩ), a 1.0 kΩ resistor (± 1%), leads.
Prep	Check each resistance box works on the settings used. A high-resistance digital meter keeps the loading effect small.
Expected results	A straight line through the origin with gradient close to V_s (sample data: 5.98 V for 6.00 V).
Level	H plans the test, calculates a derived variable, finds uncertainties, draws a best-fit line and compares the gradient with theory.

Safety and inclusion

- Low-voltage supplies only. Keep the box above 100 Ω so the current stays small; switch off between readings.
- All roles can be done seated: setting the box, reading the meter, recording or calculating.
- Risk assess for your own class and follow your employer's policies and SSERC guidance.

Common problems

- **Voltmeter across the wrong resistor:** check it is across R_2 (the box).
- **Ratio in mixed units:** both resistances must be in kΩ (or both in Ω).
- **Supply p.d. drifting:** measure V_s each time, or use a fresh battery pack.

No lab, no time, or a learner absent?

The sample results let learners complete the derived column, graph, uncertainty and evaluation without the practical.

Assessment link

Good practice for the assignment: a derived variable, a graph through the origin, uncertainties and comparison with theory.

Answers: Topic 2

Topic 2: Current, p.d., power and resistance (Higher)

1 V = I R and power

1 V = I R = 0.50 × 24 = 12 V. P = I V = 0.50 × 12 = 6.0 W (or P = I^2 R = 0.25 × 24 = 6.0 W).

2 P = V^2 ÷ R, so R = V^2 ÷ P = 230^2 ÷ 2000 = 26.45 Ω, about 26 Ω.

3 R = V^2 ÷ P = 230^2 ÷ 60 = 882 Ω, which is about 880 Ω.

2 Series and parallel combinations

1 (a) parallel pair: 1 ÷ R = 1 ÷ 20 + 1 ÷ 20, R = 10 Ω; total = 10 + 10 = 20 Ω. (b) I = 9.0 ÷ 20 = 0.45 A. (c) V = 0.45 × 10 = 4.5 V. (d) the parallel pair has 9.0 − 4.5 = 4.5 V, so I = 4.5 ÷ 20 = 0.23 A (half of 0.45 A).

2 1 ÷ R_T = 1 ÷ 30 + 1 ÷ 30 + 1 ÷ 30 = 0.10, so R_T = 10 Ω.

3 Each new branch gives the current another path, so for the same p.d. more current flows in total, and R = V ÷ I is smaller.

3 Potential dividers

1 V_2 = 3.6 ÷ (1.2 + 3.6) × 6.0 = 4.5 V; V_1 = 6.0 − 4.5 = 1.5 V.

2 V_2 = 0.80 ÷ (2.2 + 0.80) × 9.0 = 2.4 V. As the thermistor gets hotter its resistance falls, so it takes a smaller share of the supply p.d. and V_2 falls.

3 V_1 ÷ V_2 = R_1 ÷ R_2: 2.0 ÷ 4.0 = 470 ÷ R_2, so R_2 = 940 Ω.

Practical 2: Testing the potential divider rule

Variables: change R_2 (resistance box); measure V_2; keep the same: R_1, supply p.d. V_s, same voltmeter and range.

Prediction: a straight line through the origin, gradient equal to V_s (6.0 V).

Equipment: low-voltage d.c. supply, voltmeter, resistance box, 1.0 kΩ resistor, leads. Not needed: ammeter (optional), stopwatch, thermometer.

Hazards, e.g. a very low box setting with R_1 left out overheats the box (check R_1 is in the circuit before switching on); trailing leads (keep the bench tidy).

Method key points: R_1 and the box in series across the supply; voltmeter across the box; check V_s each time; five values of R_2, three readings each (reconnecting the meter between readings); work out the ratio and plot.

Sample results: 0.50 kΩ: mean 1.99 V, ratio 0.333; 1.00 kΩ: mean 2.99 V, ratio 0.500; 2.00 kΩ: mean 3.98 V, ratio 0.667; 3.00 kΩ: mean 4.48 V, ratio 0.750; 5.00 kΩ: mean 4.98 V, ratio 0.833.

Gradient of the best-fit line ≈ 5.98 V (accept 5.9 to 6.0 V).

(a) (4.49 − 4.47) ÷ 3 = ±0.007 V, about ±0.01 V, which is 0.2% of 4.48 V.

(b) Yes: the graph is a straight line through the origin, so V_2 is directly proportional to R_2 ÷ (R_1 + R_2), and the gradient (5.98 V) is close to V_s = 6.00 V.

(c) e.g. the voltmeter draws a small current, so it slightly lowers the p.d. across R_2; or the resistors are within ± 1% of their stated values; or the supply has some internal resistance.

Check-up

1 (a) P = I V (1); 24 = I × 12 (1); I = 2.0 A (1). (b) V = I R (1); 12 = 2.0 × R (1); R = 6.0 Ω (1).

2 V_2 = R_2 ÷ (R_1 + R_2) × V_s (1); V_2 = 2.2 ÷ 9.0 × 9.0 = 2.2 V (1).

3 Open-ended (3 marks for a full, correct answer showing good understanding). Points could include: an LDR's resistance increases as light level falls; in a divider with a fixed resistor, the p.d. across the LDR rises as it gets dark; this output p.d. can switch on a transistor or relay that turns on the lamp; a variable resistor sets the light level at which it switches; the lamp must not shine on the LDR.

4 R_T = 5.0 + 5.0 = 10 Ω (1); I = 12 ÷ 10 = 1.2 A (1); P = I^2 R = 1.2^2 × 5.0 = 7.2 W (1).

TEACHER NOTES

Practical 3: The e.m.f. and internal resistance of a cell

Time	One 55-minute period in pairs: about 20 minutes of readings and the graph in class.
Kit per group	One 1.5 V dry cell (zinc-carbon gives a clearer internal resistance than alkaline) in a holder, digital ammeter (0 to 2 A), digital voltmeter, rheostat or decade box (1 to 10 Ω, rated for 1 A), switch, leads. A 1 Ω resistor in series with the cell can be used to model a larger internal resistance.
Prep	Use fresh, undamaged cells. Check rheostats can carry 1 A without overheating.
Expected results	A straight line sloping down: intercept about the e.m.f., gradient −r (sample data: E ≈ 1.55 V, r ≈ 0.40 Ω).
Level	H plans the test, finds means and uncertainties, draws and extrapolates a best-fit line, and finds E and r.

Safety and inclusion

- Use dry cells only; never lithium or other rechargeable cells at high current. Never short-circuit a cell. Switch off between readings; rheostats get hot.
- All roles can be done seated: setting the resistor, reading meters, recording or plotting.
- Risk assess for your own class and follow your employer's policies and SSERC guidance.

Common problems

- **Voltmeter across the resistor, not the cell:** it should be across the cell terminals.
- **Readings drifting:** the cell warms or runs down; take readings quickly and switch off between them.
- **Graph not extended:** E is the intercept at I = 0, so the line must reach the V-axis.

No lab, no time, or a learner absent?

The sample results let learners complete the means, graph, uncertainty and evaluation without the practical.

Assessment link

Good practice for the assignment: a straight-line graph with intercept and gradient, uncertainties, and comparison with data-sheet values.

Answers: Topic 3

Topic 3: Electrical sources and internal resistance (Higher)

1 e.m.f. and internal resistance

1 $I = E \div (R + r) = 9.0 \div 7.5 = 1.2$ A. t.p.d. $V = I R = 1.2 \times 6.0 = 7.2$ V.

2 $E = V + I r$: $6.0 = 5.6 + 0.40\ r$, so $r = 0.40 \div 0.40 = 1.0\ \Omega$.

3 The starter motor draws a very large current, so the lost volts (I r) in the battery become large. The terminal p.d. falls, so the headlights get less p.d. and dim.

2 Open circuit and short circuit

1 The open-circuit reading is the e.m.f., 1.58 V. $I = V \div R = 1.38 \div 3.0 = 0.46$ A. Lost volts = 1.58 − 1.38 = 0.20 V, so $r = 0.20 \div 0.46 = 0.43\ \Omega$.

2 $I = E \div r = 1.5 \div 0.30 = 5.0$ A.

3 A large internal resistance limits the maximum (short-circuit) current to a small value, so even if someone touches the terminals the current through them stays small.

4 increases; decreases.

3 Finding E and r from a graph

1 (a) E = intercept = 2.0 V. (b) gradient = (0.8 − 2.0) ÷ 1.5 = −0.80 V/A, so $r = 0.80\ \Omega$.

2 $I = E \div r = 2.0 \div 0.80 = 2.5$ A (where the line would meet the I-axis).

3 At 1.0 A, $V = 2.0 - 0.80 \times 1.0 = 1.2$ V. $R = V \div I = 1.2 \div 1.0 = 1.2\ \Omega$.

Practical 3: The e.m.f. and internal resistance of a cell

Variables: change the current (by changing the variable resistor); measure the terminal p.d.; keep the same: the cell, its temperature, the meters and ranges used.

Prediction: a straight line sloping down; the intercept on the V-axis gives E and the gradient gives −r.

Equipment: cell in holder, ammeter, voltmeter, variable resistor, leads and switch. Not needed: oscilloscope, thermometer.

Hazards, e.g. hot variable resistor (switch off between readings); a damaged or rechargeable lithium cell must never be used (risk of fire).

Method key points: ammeter in series with the cell and variable resistor; voltmeter across the cell terminals; five currents from 0.20 A to 1.00 A; switch off between readings; repeat each setting three times; plot and extend the line.

Sample means: 0.20 A: 1.47 V; 0.40 A: 1.39 V; 0.60 A: 1.31 V; 0.80 A: 1.23 V; 1.00 A: 1.15 V.

Best-fit line: intercept ≈ 1.55 V, gradient ≈ −0.40 V/A, so $E \approx 1.55$ V and $r \approx 0.40\ \Omega$ (accept 0.38 to 0.42 Ω).

(a) (1.32 − 1.30) ÷ 3 = ±0.007 V, about ±0.01 V.

(b) e.g. E = 1.55 V and $r = 0.40\ \Omega$.

(c) A current heats the cell and slowly uses its chemicals, which changes E and r during the experiment; short readings keep conditions the same and stop the resistor and leads overheating.

Check-up

1 (a) $E = I (R + r)$ (1); $12.0 = I \times (5.4 + 0.60)$ (1); $I = 2.0$ A (1). (b) $V = I R$ (1); $V = 2.0 \times 5.4$ (1); $V = 10.8$ V (1).

2 $E = V + I r$ (1); $1.5 = 1.2 + 0.60\ r$, so $r = 0.30 \div 0.60 = 0.50\ \Omega$ (1).

3 Open-ended (3 marks for a full, correct answer showing good understanding). Points could include: each extra lamp in parallel lowers the total external resistance; so the current from the battery increases; so the lost volts I r increase and the terminal p.d. (E − I r) falls; the lamps may get dimmer; a battery with smaller internal resistance would show less change.

4 E = 4.5 V (intercept) (1); gradient = (3.0 − 4.5) ÷ 1.5 = −1.0 V A^{-1} (1); $r = 1.0\ \Omega$ (1).

TEACHER NOTES

Practical 4: Charge and p.d. for a capacitor

Time	One 55-minute period in pairs or threes: one person watches the microammeter and adjusts the resistor, one times and one reads the voltmeter.
Kit per group	Low-voltage d.c. supply (12 V), 470 µF electrolytic capacitor rated at 25 V or more, 220 kΩ (or 250 kΩ) variable resistor, or a decade box up to 1 MΩ, microammeter (0 to 200 µA), high-resistance digital voltmeter, stopwatch, 1 kΩ resistor for discharging, switch and leads.
Prep	Mark the + lead of each capacitor clearly. A data logger with current and p.d. sensors makes the readings easier and can replace the stopwatch.
Expected results	Q against V is a straight line through the origin; gradient = C (sample data: 4.7 × 10^{-4} F).
Level	H plans the test, calculates Q = I t, finds uncertainties, draws a best-fit line through the origin and compares C with the labelled value and tolerance.

Safety and inclusion

- Electrolytic capacitors must be connected the right way round and used well below their voltage rating, or they can overheat and burst: eye protection. Use low-voltage supplies only; large or high-voltage capacitors (for example from flash units or microwave ovens) are never used.
- Discharge capacitors through a resistor before handling, never by shorting the leads.
- All roles can be done seated; the timing and recording roles suit learners who find fine adjustment hard.
- Risk assess for your own class and follow your employer's policies and SSERC guidance.

Common problems

- **Current not constant:** it falls as the capacitor charges, so the resistor must be turned down steadily; practise first.
- **µF not converted:** 470 µF = 470 × 10^{-6} F.
- **Capacitor not fully discharged:** the graph will not pass through the origin; discharge for at least 10 s between runs.

No lab, no time, or a learner absent?

The sample results let learners complete the charge column, graph, uncertainty and evaluation without the practical.

Assessment link

Good practice for the assignment: a derived quantity (Q = I t), a dominant uncertainty, and comparison with a manufacturer's tolerance.

Answers: Topic 4

Topic 4: Capacitors (Higher)

1 Capacitance and charge

1 $C = Q \div V = 3.0 \times 10^{-3} \div 6.0 = 5.0 \times 10^{-4}$ F = 500 µF.

2 $Q = I\,t = 2.0 \times 10^{-3} \times 25 = 0.050$ C. $V = Q \div C = 0.050 \div (4700 \times 10^{-6}) = 10.6$ V, about 11 V.

3 $Q = C\,V = 100 \times 10^{-6} \times 9.0 = 9.0 \times 10^{-4}$ C.

2 Energy stored

1 $E = \frac{1}{2}\,C\,V^2 = 0.5 \times 220 \times 10^{-6} \times 300^2 = 9.9$ J.

2 $E = \frac{1}{2}\,Q\,V$: $0.50 = 0.5 \times 0.020 \times V$, so $V = 50$ V.

3 The plates already hold charge, which repels the new charge being added; the more charge there is, the bigger the p.d. and the more work each extra coulomb needs (work per coulomb = V, which rises as Q rises).

3 Charging and discharging

1 p.d.: starts at its full value and falls, steeply at first then more slowly, towards zero. Current: starts at its largest negative value and rises towards zero (the same shape reflected below the time axis).

2 (a) At the start $V_C = 0$, so all 12 V is across R: $I = 12 \div 10\,000 = 1.2 \times 10^{-3}$ A (1.2 mA). (b) p.d. across R = 12 − 8.0 = 4.0 V, so $I = 4.0 \div 10\,000 = 4.0 \times 10^{-4}$ A (0.40 mA).

3 Use a larger resistance; use a larger capacitance.

Practical 4: Charge and p.d. for a capacitor

Variables: change the charging time (so the charge, $Q = I\,t$); measure the p.d. across the capacitor; keep the same: the charging current (100 µA), the capacitor, the meters.

Prediction: a straight line through the origin; gradient = capacitance.

Equipment: low-voltage d.c. supply, capacitor, variable resistor, microammeter, voltmeter, stopwatch. Not needed: thermometer.

Hazards, e.g. a charged capacitor can give a small shock or spark if its leads are touched (discharge it through a resistor, never by shorting it); trailing leads.

Method key points: all in series with the voltmeter across C; start the stopwatch as the switch closes; keep adjusting the variable resistor so the current stays at 100 µA; read the p.d. every 10 s; discharge through a 1 kΩ resistor and repeat three times; $Q = I\,t$; plot Q against V.

Sample results: 10 s: 2.12 V, $Q = 1.0 \times 10^{-3}$ C; 20 s: 4.25 V, $Q = 2.0 \times 10^{-3}$ C; 30 s: 6.37 V, $Q = 3.0 \times 10^{-3}$ C; 40 s: 8.51 V, $Q = 4.0 \times 10^{-3}$ C; 50 s: 10.63 V, $Q = 5.0 \times 10^{-3}$ C.

Gradient of the best-fit line ≈ 4.7×10^{-4} F, so C ≈ 470 µF (accept 460 to 480 µF).

(a) (8.55 − 8.48) ÷ 3 = ±0.023 V, about ±0.02 V, 0.2% of 8.51 V.

(b) Charge is directly proportional to p.d. (a straight line through the origin); C ≈ 470 µF.

(c) Yes: 470 µF ± 20% is 376 to 564 µF, and the measured value lies well inside this range.

Check-up

1 (a) $Q = C\,V$ (1); $Q = 2200 \times 10^{-6} \times 9.0$ (1); $Q = 2.0 \times 10^{-2}$ C (1). (b) $E = \frac{1}{2}\,C\,V^2$ (1); $E = 0.5 \times 2200 \times 10^{-6} \times 9.0^2$ (1); E = 0.089 J (1).

2 $E = \frac{1}{2}\,C\,V^2$ (1); $E = 0.5 \times 50 \times 10^{-6} \times 400^2 = 4.0$ J (1).

3 Open-ended (3 marks for a full, correct answer showing good understanding). Points could include: a capacitor can be charged very quickly and can deliver energy quickly; but it stores far less energy than a battery of similar size; its p.d. falls continuously, quickly at first, as it discharges, so the light would dim quickly; a battery gives a nearly steady p.d. for a long time; a capacitor could be useful alongside a battery or for a dynamo-powered standlight.

4 $I = V \div R$ (1); $I = 6.0 \div 4700$ (1); $I = 1.3 \times 10^{-3}$ A (1.3 mA) (1).

TEACHER NOTES

Practical 5: Estimating Planck's constant with LEDs

Time	One 55-minute period in pairs: about 20 minutes of readings (five LEDs, three repeats) and the graph in class.
Kit per group	4.5 to 6 V d.c. supply, five LEDs with data-sheet wavelengths, 1 kΩ potentiometer as a potential divider, 220 Ω protective resistor, digital voltmeter, black card tube.
Prep	Label each LED with its wavelength; a pre-built LED board with the protective resistor saves time. Darken the room.
Expected results	V against f is a straight line; gradient about 4×10^{-15} V s, giving h of about 6 to 7×10^{-34} J s (sample data: 6.58×10^{-34} J s).
Level	H plans the test, calculates frequencies, finds uncertainties, uses a gradient with a constant and evaluates a systematic effect.

Safety and inclusion

- Low-voltage supplies only; always include the protective resistor. Some blue and white LEDs are very bright: learners should not stare into them at full brightness.
- Learners with colour-vision deficiency can take the voltmeter or recording role; the colour is not needed to judge "just lit".
- Risk assess for your own class and follow your employer's policies and SSERC guidance.

Common problems

- **Wavelength left in nm:** convert to metres before using f = c ÷ λ.
- **Different people judging:** keep one observer per set of readings.
- **Graph forced through the origin:** the best-fit line usually has a small intercept; only the gradient is used.

No lab, no time, or a learner absent?

The sample results let learners complete the frequencies, graph, uncertainty and evaluation without the practical.

Assessment link

Good practice for the assignment: a derived variable, a gradient used with a constant, a dominant uncertainty and a referenced published value.

Answers: Topic 5

Topic 5: Semiconductors and p–n junctions (Higher)

1 Band theory

1 In a metal the valence and conduction bands overlap, so there are many free electrons that can move and carry current. In an insulator the valence band is full and the band gap is large, so almost no electrons can gain enough energy to reach the conduction band.

2 Heating gives more electrons enough energy to jump the small band gap into the conduction band (leaving more holes), so there are more charge carriers and the resistance falls.

3 A hole is a gap in the valence band where an electron is missing. A nearby electron can move into the hole, leaving a new hole behind, so the hole moves through the material like a positive charge carrier.

4 electrons and holes.

2 Doping and the p–n junction

1 (a) electrons. (b) holes.

2 Forward bias pushes electrons and holes towards the junction, so the depletion layer narrows and charge carriers can cross it: current flows. Reverse bias pulls the carriers away from the junction, widening the depletion layer, so almost no current flows.

3 Each impurity atom that adds a free electron also has one more proton in its nucleus, so doped material is still electrically neutral overall.

3 LEDs and solar cells

1 $f = v \div \lambda = 3.00 \times 10^{8} \div (650 \times 10^{-9}) = 4.62 \times 10^{14}$ Hz. $E = h f = 6.63 \times 10^{-34} \times 4.62 \times 10^{14} = 3.06 \times 10^{-19}$ J.

2 $f = E \div h = 3.2 \times 10^{-19} \div (6.63 \times 10^{-34}) = 4.83 \times 10^{14}$ Hz. $\lambda = v \div f = 3.00 \times 10^{8} \div (4.83 \times 10^{14}) = 6.2 \times 10^{-7}$ m (about 620 nm).

3 Photons absorbed at the p–n junction give electrons enough energy to move into the conduction band, creating electron–hole pairs. The junction separates the electrons and holes, so charge builds up on each side and a p.d. is produced (the photovoltaic effect).

Practical 5: Estimating Planck's constant with LEDs

Variables: change the LED (so the frequency of its light); measure the threshold p.d. at which it just lights; keep the same: the viewing conditions (dim room, black tube), the person judging, the protective resistor and meter.

Theory: $e V = h f$, so V against f is a straight line with gradient $h \div e$, so $h = e \times$ gradient.

Equipment: low-voltage d.c. supply, LEDs of known wavelength, variable resistor (as a potential divider) with a protective resistor, voltmeter, milliammeter (optional). Not needed: ray box, stopwatch.

Hazards, e.g. very bright LEDs (do not stare into them at full brightness); hot resistor (switch off between readings).

Method key points: voltmeter across the LED; raise the p.d. slowly from 0 V until the LED just glows, viewed down a black tube in a dim room; repeat three times for each LED; $f = c \div \lambda$.

Sample results: red: 1.82 V, $f = 4.76 \times 10^{14}$ Hz; orange: 1.89 V, $f = 4.92 \times 10^{14}$ Hz; yellow: 1.95 V, $f = 5.08 \times 10^{14}$ Hz; green: 2.21 V, $f = 5.71 \times 10^{14}$ Hz; blue: 2.49 V, $f = 6.38 \times 10^{14}$ Hz.

Gradient $\approx 4.11 \times 10^{-15}$ V s, so $h \approx 1.60 \times 10^{-19} \times 4.11 \times 10^{-15} = 6.58 \times 10^{-34}$ J s (accept 6.3 to 6.9 $\times 10^{-34}$ J s).

(a) $(2.22 - 2.20) \div 3 = \pm 0.007$ V, about ±0.01 V.

(b) percentage difference = 0.8%.

(c) The LED starts emitting before the light is bright enough to see, and different people judge "just lit" differently, so every reading can be shifted the same way. Improvement: use a light sensor or a fixed small current (for example 0.1 mA) to define the threshold, or plot a current–p.d. graph for each LED and extrapolate.

Check-up

1 (a) $v = f \lambda$ (1); $3.00 \times 10^{8} = f \times 450 \times 10^{-9}$ (1); $f = 6.67 \times 10^{14}$ Hz (1). (b) $E = h f$ (1); $E = 6.63 \times 10^{-34} \times 6.67 \times 10^{14}$ (1); $E = 4.42 \times 10^{-19}$ J (1).

2 $E = h f$ (1); $f = 2.8 \times 10^{-19} \div (6.63 \times 10^{-34}) = 4.22 \times 10^{14}$ Hz, about 4.2×10^{14} Hz (1).

3 Open-ended (3 marks for a full, correct answer showing good understanding). Points could include: phosphorus has one more outer electron than silicon, so it gives n-type material with free electrons as majority carriers; but each phosphorus atom is neutral (its extra electron is matched by an extra proton), so the material stays neutral overall; only the number of free charge carriers changes, which lowers the resistance.

4 In forward bias, electrons move from the n-type into the p-type (and holes the other way) (1); electrons in the conduction band fall into holes in the valence band (recombine) (1); the energy lost is emitted as a photon of light, with energy equal to the band gap (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.