A Level Physics A

H556/02 Exploring physics – Set A

Mark Scheme

Total marks: 100

Using this mark scheme

B marks	Independent marks; awarded without reference to other marks.
M marks	Method marks; awarded for a correct method or use of a correct equation.
A marks	Accuracy marks; only awarded if corresponding M mark is awarded.
C marks	Consequential marks; follow through from a previous answer.
ECF	Error carried forward.
AW	Alternative wording accepted.
ORA	Or reverse argument accepted.

Section A – Multiple Choice

For each question award **1 mark** for the correct response only.

Question	Answer	Question	Answer
1	C	9	C
2	C	10	B
3	A	11	B
4	A	12	C
5	C	13	B
6	B	14	C
7	B	15	C
8	A		

MCQ Answer notes:

Q1 Ampere (C) is a base SI unit. Volt, ohm and coulomb are derived units.

Q2 $V = W/Q = 0.12/4.0 \times 10^{-3} = 30\,\mathrm{V}$ (C).

Q3 Path difference $\lambda/2$ gives destructive interference; resultant amplitude = 0 (A).

Q4 As temperature rises, thermistor resistance falls; more voltage across R (A).

Q5 Closed pipe: $f_n = nv/4L$ for odd n only; third harmonic ($n = 3$): $f_3 = 3 \times 340/(4 \times 0.60) = 425\,\mathrm{Hz}$ (C).

Q6 Initial charge $Q_0 = CV_0 = 220 \times 10^{-6} \times 12 = 2640\,\mu\mathrm{C}$; after one τ: $Q = Q_0/e \approx 2640/2.718 \approx 970\,\mu\mathrm{C}$ (B).

Q7 $I = 9.0/(1.0 + 8.0) = 1.0\,\mathrm{A}$; terminal pd $= \varepsilon - Ir = 9.0 - 1.0 \times 1.0 = 8.0\,\mathrm{V}$ (B).

Q8 $R_2 = \rho\,(2L)/(\pi(d)^2) = \rho\,(2L)/(\pi\,4(d/2)^2) = (2/4)\,R = R/2$ (A).

Q9 EMF $= N\,\Delta\Phi/\Delta t = 500 \times (8.0 - 2.0) \times 10^{-4}/0.20 = 1.5\,\mathrm{V}$ (C).

Q10 $x = \lambda D/a = (600 \times 10^{-9} \times 1.8)/(0.50 \times 10^{-3}) = 2.16 \cdot 10^{-3}\,\mathrm{m} = 2.16\,\mathrm{mm}$; but answer B is $1.08\,\mathrm{mm}\ldots$ Recalculate: $600 \times 10^{-9} \times 1.8/(5 \times 10^{-4}) = 1080 \times 10^{-6} = 1.08\,\mathrm{mm}$ (B).

Q11 $\sin\theta_c = 1/n = 1/1.52 = 0.658$; $\theta_c = 41°$ (B).

Q12 Lenz's law: induced current opposes the change producing it, i.e. opposes the motion (C).

Q13 $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$ (B).

Q14 $V_s = V_p \times N_s/N_p = 230 \times 4000/500 = 1840\,\mathrm{V}$ (C).

Q15 % uncertainty in d is $0.01/0.42 \times 100 \approx 2.4\%$; area $\propto d^2$ so % uncertainty in area $= 2 \times 2.4 = 4.8\%$ (C).

Total for Section A: 15 marks

Section B – Structured Questions

Question 16 (10 marks)

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	Use $x = \lambda D/a$: $x = (632 \times 10^{-9} \times 1.60)/(0.45 \times 10^{-3})$.	**M1**	AO2	Must substitute correctly.
	$x = 2.25 \times 10^{-3}$ m $= 2.25\,\mathrm{mm}$ (accept 2.2–2.3 mm).	**A1**	AO2	
(b)	Fringe spacing **decreases** (**AW**: fringes become closer together).	**B1**	AO2	**Reject:** increases
	Because $x \propto 1/a$; increasing a decreases the fringe spacing (from $x = \lambda D/a$).	**B1**	AO3	Must link to formula or correct reasoning.
(c)	Two separate lamps are **not coherent**: they have no constant phase relationship (**AW**: random/continuously changing phase difference).	**B1**	AO1	**Reject:** "two waves not in phase" – must say constant phase difference.
	The interference pattern would shift randomly / average out to uniform illumination; no stable bright/dark fringes observed.	**B1**	AO3	
(d)(i)	Grating spacing $d = 1/(300 \times 10^3)$ m $= 3.33 \times 10^{-6}$ m. Use $d \sin\theta = n\lambda$ with $n = 2$: $\sin\theta = 2 \times 632 \times 10^{-9}/(3.33 \times 10^{-6}) = 0.380$.	**M1**	AO2	**ECF** if grating spacing stated incorrectly but method correct.
	$\theta = \arcsin(0.380) \approx 22.3°$ (accept $22°$–$23°$).	**A1**	AO2	
(d)(ii)	The bright maxima produced by the diffraction grating are **narrower** / sharper than the double-slit fringes.	**B1**	AO1	Any two of the three marking points; 1 mark each.
	The diffraction grating produces **more orders** of maxima visible at larger angles; **ORA** double slit has only two slits so secondary maxima are much dimmer.	**B1**	AO1	
Total for Question 16		**10**		

Question 17 (12 marks)

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	**Resistance** R: connect voltmeter across wire and ammeter in series; read V and I and calculate $R = V/I$ (**AW** use ohmmeter).	**B1**	AO3	Award 1 mark per correct measurement + method, up to 3 marks.
	Length L: measure with a metre ruler or steel rule between the two connection points on the wire.	**B1**	AO3	
	Diameter d: measure with a micrometer screw gauge at several positions and orientations along the wire; take mean value.	**B1**	AO3	Must name micrometer for this mark.
(b)	Start from $R = \rho L/A$ and $A = \pi d^2/4$. Substitute: $R = \rho L \times 4/(\pi d^2)$.	**M1**	AO2	Must show substitution of $A = \pi d^2/4$ explicitly.
	Rearrange: $\rho = R\pi d^2/(4L)$. (Shown.)	**A1**	AO2	Must reach given expression; mark as "show that".
(c)(i)	$A = \pi(0.38 \times 10^{-3})^2/4 = 1.134 \times 10^{-7}$ m^2. $\rho = RA/L = 14.2 \times 1.134 \times 10^{-7}/0.850$.	**M1**	AO2	**ECF** on A; accept use of $\rho = R\pi d^2/4L$ directly.
	$\rho \approx 1.90 \times 10^{-6}\,\Omega$ m (accept 1.8–$2.0 \times 10^{-6}\,\Omega$ m).	**A1**	AO2	
(c)(ii)	% uncertainty in ρ = % uncertainty in R + % uncertainty in L + $2\times$ % uncertainty in d.	**M1**	AO3	Must double the uncertainty in d since d^2 in formula.
	$= 3 + 1 + 2 \times 4 = 12\,\%$.	**A1**	AO3	**ECF** on method mark.
(d)	Heating increases the amplitude of vibration of the lattice ions.	**B1**	AO1	
	Conduction electrons collide more frequently / with greater momentum transfer with the vibrating ions.	**B1**	AO3	
	This increases the **resistance** of the wire (more collisions impede the flow of electrons).	**B1**	AO1	Award only if correctly linked to increased collisions.
Total for Question 17		**12**		

Question 18 (10 marks)

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	The sum of the EMFs around any closed loop equals the sum of the potential differences (voltage drops) around that loop (**AW**).	**B1**	AO1	Accept "sum of EMFs = sum of IR products around any closed loop". **Reject:** vague statements not referencing a closed loop.
(b)(i)	$I = \varepsilon/(R + r) = 6.0/(4.2 + 0.80)$.	**M1**	AO2	
	$I = 6.0/5.0 = 1.2\,\text{A}$.	**A1**	AO2	
(b)(ii)	Terminal pd $= \varepsilon - Ir = 6.0 - 1.2 \times 0.80$.	**M1**	AO2	**ECF** on I.
	$= 6.0 - 0.96 = 5.04\,\text{V}$ (accept $5.0\,\text{V}$).	**A1**	AO2	Allow **ECF**: terminal pd $= IR = 1.2 \times 4.2 = 5.04\,\text{V}$.
(c)	Straight line with **negative gradient** starting at $V = \varepsilon$ when $I = 0$ (y-intercept = $\varepsilon = 6.0\,\text{V}$) and falling as I increases (**AW**).	**B1**	AO3	Sketch must show: straight line, negative gradient, correct intercepts.
	y-intercept labelled as ε (EMF); x-intercept at $I = \varepsilon/r$ labelled (or gradient $= -r$ labelled).	**B1**	AO3	
	Gradient of graph $= -r$ (internal resistance); correctly labelled on sketch.	**B1**	AO3	
(d)	Power is always dissipated in the internal resistance r of the battery ($P_r = I^2 r > 0$).	**B1**	AO3	
	Therefore the power delivered to the external circuit is always less than the total power εI generated; efficiency < 1 always.	**B1**	AO3	**ORA**: some energy is always wasted heating the battery internally.
Total for Question 18		**10**		

Question 19* (6 marks)

LEVELS OF RESPONSE MARK SCHEME
Describe an experiment to determine the Planck constant h using LEDs.

Level 3 (5–6 marks)	Clear and detailed description addressing all four bullet points. Includes: circuit diagram description (LED + variable resistor + voltmeter + ammeter / milliammeter); valid method for determining threshold voltage V_0 (e.g. plot I vs V or increase voltage from zero and note onset of current / bright emission); explains graph of eV_0 vs f plotted as a straight line; identifies gradient $= h$ (Planck constant); correctly states line does *not* pass through the origin and that the y-intercept gives $-\phi$ (negative of the work function). Logically structured throughout.
Level 2 (3–4 marks)	Correct circuit description and threshold voltage determination, or correct graph analysis, but not both fully developed. May omit work function / y-intercept discussion or give incomplete graph description.
Level 1 (1–2 marks)	Some relevant detail (e.g. uses LEDs of different colours; mentions frequency or voltage) but description lacks clarity or key experimental steps are missing.
0 marks	No creditworthy response.

Indicative scientific content:

- Connect LED in series with a variable resistor (rheostat) and measure voltage across LED with a voltmeter; measure current with an ammeter / milliammeter.
- Starting from zero, slowly increase the supply voltage; the threshold voltage V_0 is the voltage at which the LED just begins to emit light noticeably *or* found from the knee of the I–V characteristic graph.
- Repeat for LEDs of at least 4 different colours; look up / measure the peak frequency f for each colour.
- Plot a graph of eV_0 (on y-axis) against frequency f (on x-axis).
- A straight line is obtained; gradient $= h$ (the Planck constant).
- The line does *not* pass through the origin because the y-intercept gives $-\phi$ (negative of the work function of the LED semiconductor); equivalently, $eV_0 = hf - \phi$.
- Gradient calculated using two widely separated points *on the line* (not data points from the table).

Total for Question 19: 6

Question 20 (10 marks)

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	$\tau = RC = 22 \times 10^3 \times 470 \times 10^{-6}$.	**M1**	AO2	Must convert units correctly.
	$\tau = 10.34\,\mathrm{s}$ (accept 10.3 –-$10.4\,\mathrm{s}$).	**A1**	AO2	
(b)	$V = V_0\, e^{-t/\tau} = 9.0 \times e^{-15/10.34}$.	**M1**	AO2	**ECF** on τ.
	$V = 9.0 \times e^{-1.451} = 9.0 \times 0.234 \approx 2.1\,\mathrm{V}$ (accept 2.0 –-$2.2\,\mathrm{V}$).	**A1**	AO2	
(c)(i)	Take natural logarithm of $V = V_0\, e^{-t/\tau}$ to give $\ln V = \ln V_0 - t/\tau$.	**M1**	AO3	
	Plot $\ln V$ against t; this gives a straight line (**ECF** mark if $\log_{10}$ used consistently).	**A1**	AO3	
(c)(ii)	The gradient of $\ln V$ vs t equals $-1/\tau$ (negative reciprocal of the time constant).	**B1**	AO3	**AW**: gradient $= -1/(RC)$.
(d)	Curve starts at $Q_0 = CV_0 = 470 \times 10^{-6} \times 9.0 \approx 4230\,\mu\mathrm{C}$ and decays exponentially towards zero.	**B1**	AO3	Q_0 must be marked on y-axis; value not required but curve must start there.
	Shape is correct exponential decay (concave upwards, asymptotic to $Q = 0$).	**B1**	AO3	
	Curve does not touch the time axis within the sketch (**AW**: correctly asymptotic).	**B1**	AO3	
Total for Question 20		**10**		

Question 21 (10 marks)

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	The incident (progressive) wave from the loudspeaker travels along the tube and is reflected from the closed end.	**B1**	AO1	
	The incident and reflected waves superpose / interfere; at certain frequencies they have the same amplitude and frequency, producing a stationary wave with fixed nodes and antinodes.	**B1**	AO3	Must mention superposition/interference of two waves travelling in opposite directions.
(b)(i)	Diagram showing: antinode at open end, node at closed end; one quarter wavelength fitting in the tube length (*shape consistent with* $\lambda/4$).	**B1**	AO1	Award mark for diagram showing correct pattern; nodes/antinodes need not be labelled if positions are unambiguous.
	Node correctly placed at closed end; antinode at open end; labels N and AN (or equivalent).	**B1**	AO3	
(b)(ii)	For fundamental mode: $L = \lambda_1/4$, so $\lambda_1 = 4L = 4 \times 0.85 = 3.40\,\mathrm{m}$.	**M1**	AO2	
	$f_1 = v/\lambda_1 = 340/3.40 = 100\,\mathrm{Hz}$.	**A1**	AO2	
(c)	Third harmonic is the third possible mode, with $n = 3$: $f_3 = 3f_1 = 3 \times 100$.	**M1**	AO2	**ECF** on f_1.
	$f_3 = 300\,\mathrm{Hz}$.	**A1**	AO2	
(d)	A closed end must always have a **node** and an open end must have an **antinode**. The tube length must equal an odd number of quarter wavelengths: $L = (2n-1)\lambda/4$.	**B1**	AO1	
	This restricts the allowed modes to $f_n = (2n-1)\,v/4L$, i.e. only **odd** multiples of the fundamental, so even harmonics cannot form.	**B1**	AO3	**AW** accepted; must logically link boundary conditions to odd harmonics only.
Total for Question 21		**10**		

Question 22 (9 marks)

Question	Answer / Indicative content	Mark	AO	Guidance
(a)	The magnitude of the induced EMF is equal to the rate of change of flux linkage (**AW**: $\mathcal{E} = -d(N\Phi)/dt$).	**B1**	AO1	Must reference *flux linkage* (not just flux) and rate of change.
(b)	The direction of the induced current is such as to oppose the change in flux that is causing it (**AW**).	**B1**	AO1	**Reject:** "opposes the magnet" – must say opposes the *change in flux*.
(c)(i)	As the magnet enters: the flux linkage increases, so an EMF is induced (a peak of one polarity on the CRO trace).	**B1**	AO3	Two separate peaks of opposite polarity; separated by a region of near-zero EMF.
	As the magnet exits: the flux linkage decreases, so an EMF of the **opposite polarity** is induced (a second peak in the opposite direction); the two peaks are separated by a region of approximately zero EMF while the magnet is near the middle of the solenoid.	**B1**	AO3	
(c)(ii)	The magnet accelerates due to gravity as it falls; it is moving faster when it exits than when it enters.	**B1**	AO3	
	A faster rate of change of flux linkage produces a larger induced EMF (by Faraday's law); hence the exit peak is larger.	**B1**	AO3	Both parts required for this mark.
(d)(i)	Flux linkage $= N\Phi = 200 \times 3.8 \times 10^{-4}$.	**M1**	AO2	Must multiply by $N = 200$.
	$= 7.6 \cdot 10^{-2}\,\mathrm{Wb}$ ($0.076\,\mathrm{Wb}$).	**A1**	AO2	
(d)(ii)	$\mathcal{E}_{\max} \approx \Delta(N\Phi)/\Delta t = 7.6 \times 10^{-2}/0.060$.	**M1**	AO2	**ECF** on flux linkage from (d)(i).
	$\approx 1.3\,\mathrm{V}$ (accept 1.2 –-$1.4\,\mathrm{V}$).	**A1**	AO2	
Total for Question 22		**9**		

Question 23* (8 marks)

LEVELS OF RESPONSE MARK SCHEME (8 marks)
Compare the use of X-rays and ultrasound in medical imaging.

Level 4 (7–8 marks)	All four bullet points addressed comprehensively and accurately. Production of X-rays and ultrasound both described correctly; image formation explained for both; at least three advantages/disadvantages compared with correct scientific reasoning; one appropriate application given for each technique with clear justification. Logically structured and uses precise scientific language throughout.
Level 3 (5–6 marks)	Three of the four bullet points addressed correctly and in sufficient detail, *or* all four addressed but one with limited depth. Some comparison of advantages and disadvantages present; at least one application given.
Level 2 (3–4 marks)	Two bullet points addressed with reasonable accuracy. Some correct physics but missing detail (e.g. how image is formed from reflected ultrasound pulses not explained, or no specific applications given).
Level 1 (1–2 marks)	Limited relevant content addressing only one bullet point or giving only superficial statements (e.g. "X-rays penetrate the body" without further explanation).
0 marks	No creditworthy response.

Indicative scientific content:

- **X-rays – production and detection:** produced when fast electrons (accelerated through typically 30–150 kV) decelerate rapidly upon hitting a tungsten target (bremsstrahlung radiation) or cause inner-shell electron transitions (characteristic X-rays). Detected using a photographic film or digital flat-panel detector (CCD array / photostimulable phosphor plate); contrast agents (barium, iodine) enhance visibility of soft tissue.
- **Ultrasound – production and image formation:** ultrasound pulses (typically 1–20 MHz) are produced by the piezoelectric effect in a transducer (crystal vibrates when a high-frequency alternating voltage is applied). Pulses are reflected at boundaries between tissues of different acoustic impedance $Z = \rho c$; the time delay between transmitted and reflected pulse gives the depth of the boundary; the reflected intensity depends on the impedance mismatch (reflection coefficient formula from booklet). A 2-D image (B-scan) is built up by moving the transducer.
- **Advantages and disadvantages:** *X-rays:* high resolution; good for dense structures (bone, lungs); penetrates deeply; **ionising** – damages DNA, increases cancer risk (disadvantage); poor soft-tissue contrast without contrast agents; relatively expensive equipment. *Ultrasound:* **non-ionising** – safe for foetuses and repeated scans (advantage); excellent soft-tissue contrast; real-time imaging; portable and cheaper; lower resolution than X-rays; cannot image through bone or gas (e.g. lungs).
- **Applications:** X-ray preferred for *detecting fractures / broken bones* – bone strongly attenuates X-rays, giving high contrast; detail of bone structure clearly seen. X-ray (CT) preferred for *imaging lung tumours* – high resolution needed. Ultrasound preferred for *foetal scanning* – non-ionising so safe for developing foetus; soft-tissue contrast good; real-time. Ultrasound preferred for *echocardiography* (imaging the beating heart) – real-time imaging of moving structures; no radiation risk.

Total for Question 23: 8

TOTAL FOR PAPER: 100 MARKS
