Answers to examination-style questions

Answers	Marks	Examiner's tips
1 (a) (i) 94 protons	1	This is the proton number *Z*.
(ii) 145 neutrons	1	Number of neutrons is found from (nucleon number – proton number) $= (A - Z) = 239 - 94$
(iii) 93 electrons	1	A neutral atom would have 94 electrons (= number of protons *Z*). This ion has a charge of $+e$ ($+1.6 \times 10^{-19}$ C), showing that there is **one** electron missing.
(b) isotopes have same number of protons (or the same *Z*) but a different number of neutrons (or nucleons, or a different *A*)	1 1	You need to remember how isotopes are defined.
2 (a) (i) $\mathrm{u\,\bar{d}}$	1	All mesons consist of a quark-antiquark combination. π^+ has a charge of $+e$, so u ($+\frac{2}{3}e$) together with $\bar{\mathrm{d}}$ ($+\frac{1}{3}e$) give the correct charge as well as the combination.
(ii) X is a neutron its quark composition is udd	1 1	The positive pion accounts for the charge of +e previously carried by one proton, but has only about 15% of the rest mass of a proton. To conserve charge and mass, X has to be a neutron (which has no charge, and a mass similar to that of a proton).
(b) Y is a muon neutrino *Any one property*: negligible rest mass, zero charge, very little interaction of any kind	2 2	The π^+ meson has a similar rest mass to the muon. Neutrinos were always considered to have zero rest mass, but recent experiments have suggested that they may have a small mass.
3 (a) $\pi^- + \mathrm{p} \rightarrow \mathrm{n} + \pi^+ + \mathrm{K}^-$	1	All that is required is to translate the words of the question into symbols.
(b) *charge* : $(-1) + 1 \rightarrow 0 + 1 + (-1)$ *baryon number* : $0 + 1 \rightarrow 1 + 0 + 0$ *lepton number* : $0 + 0 \rightarrow 0 + 0 + 0$ *Comment* : all conservation checks are correct so the transformation is permitted	1 1 1 1	Show the steps of your checks in an organised way, making it clear which particles your numbers represent. In this answer they are written in the order of those in the answer to **(a)**. Don't forget to comment on the conclusion you reach from your checks.

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4 **(i)** $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{207 \times 9.11 \times 10^{-31} \times 3.0 \times 10^{6}}$	1	The mass of the muon is 207 times the electron rest mass, m_e, which is listed in the Data Booklet as 9.11×10^{-31} kg.
$= 1.2 \times 10^{-12}$ m	1	
(ii) $\frac{m_\pi}{m_\mu} = \frac{135}{106} \left(\text{i.e. } \frac{134.972 \text{ MeV}}{105.659 \text{ MeV}}\right)$	1	Mass and energy are equivalent quantities, so the ratio of rest **masses** is the same as the ratio of rest **energies**. The rest energies of these particles are also given in the Data Booklet.
$= 1.28$	1	
(iii) particles having the same de Broglie wavelength must have the same momentum	1	Once you have realised that two particles having the same de Broglie wavelength must have the same momentum, **(iii)** is quite straightforward. You found the ratio of their masses in **(ii)** above.
$\therefore m_\pi v_\pi = m_\mu v_\mu$ $v_\pi = \frac{v_\mu}{(m_\pi / m_\mu)} = \frac{3 \times 10^6}{1.28} = 2.3 \times 10^6 \text{ m s}^{-1}$	1	
5 **(a)** *Photoelectric emission is*: the emission of electrons from a metal surface when electromagnetic radiation (or ultraviolet radiation, or light) is incident upon it	1	Electrons can be released from metal surfaces by other means, such as thermionic emission – in which case heating is responsible.
Two observations and explanations: • there is a threshold frequency – photon energy depends on frequency – with waves electrons would be expected at all frequencies • emitted electrons have a maximum kinetic energy – explained by photoelectric equation $E_{K\,(max)} = hf - \phi$ – waves should produce no limit on energy • emission starts immediately no matter how low the intensity – provided photons have enough energy electrons are emitted – with waves of low intensity there should be a delay	6	Although the question asks you to **explain** how two observations support the particle theory rather than the wave theory, you obviously firstly need to identify the observations. Any two of these three observations would satisfy the requirements of the question. In each case you get one mark for stating the observation and up to two marks for showing how the particle theory explains what the wave theory could not explain.
(b) **(i)** work function $\phi = hf - E_{K\,(max)}$ $= (1.1 \times 10^{-18}) - (4.8 \times 10^{-19})$ $= 6.2 \times 10^{-19}$ J	1	ϕ is found by subtracting the maximum electron kinetic energy from the photon energy.
(ii) from $E_K = \frac{1}{2} m_e v_{max}^2$, maximum speed of electrons $v_{max} = \sqrt{\frac{2 \times 4.8 \times 10^{-19}}{9.11 \times 10^{-31}}}$ $= 1.03 \times 10^6 \text{ m s}^{-1}$	1	In order to find the de Broglie wavelength associated with an emitted electron you need both the mass of the electron (which comes from the Data Booklet) and its maximum speed. Its speed is found from the kinetic energy, which you are given in the question.
de Broglie wavelength $\lambda = \frac{h}{m_e v_{max}} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.03 \times 10^6}$	1	
$= 7.1 \times 10^{-10}$ m	1	

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6 (i) energy needed = energy difference $= (-2.4 \times 10^{-19}) - (-21.8 \times 10^{-19})$ $= 1.94 \times 10^{-18}$ J	1	The ground state is the $n = 1$ energy level. The required excitation energy is therefore $E_3 - E_1$.
(ii) after collision, kinetic energy of incident electron $= (2.5 \times 10^{-18}) - (1.94 \times 10^{-18})$ $= 5.6 \times 10^{-19}$ J	1	The colliding electron gives 1.94×10^{-18} J of its energy to an orbital electron when it collides with the atom. It then moves away from the atom with a smaller amount of kinetic energy.
(iii) energy difference producing the lowest energy photon corresponds to the transition from $n = 3$ to $n = 2$, for which $\Delta E = 3.0 \times 10^{-19}$ J $\Delta E = \frac{hc}{\lambda}$, from which $\lambda = \frac{hc}{\Delta E}$ $= \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{3.0 \times 10^{-19}}$ $= 6.6 \times 10^{-7}$ m	1 1 1	When it returns to the ground state, the excited electron can do so by either of two routes. The one producing the greatest energy photon is the single stage transition from $n = 3$ to $n = 1$. The alternative (two stage) route takes it from $n = 3$ to $n = 2$, and then from $n = 2$ to $n = 1$, each transition being accompanied by the emission of a photon of the corresponding energy. The smallest energy difference is from $n = 3$ to $n = 2$.
7 (a) (i) speed of electron $= \frac{h}{m_e \lambda}$ $= \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.2 \times 10^{-9}}$ $= 6.06 \times 10^{5}$ m s^{-1}	1 1	Rearrangement of the equation for the de Broglie wavelength, followed by substitution of values for h and m_e from the Data Booklet, leads to this answer.
(ii) kinetic energy $E_K = \frac{1}{2} m_e v^2$ $= \frac{1}{2} \times 9.11 \times 10^{-31} \times (6.06 \times 10^{5})^2$ $= 1.67 \times 10^{-19}$ J	1	You can easily calculate the kinetic energy, but the potential energy is harder. Remember that energy = work = (charge) × (voltage). Since the charge of an electron is negative, so too is its potential energy when it is at a positive potential (+2.8 V).
(iii) potential energy $= eV$ $= -1.6 \times 10^{-19} \times 2.8 = -4.48 \times 10^{-19}$ J total energy $= 1.67 \times 10^{-19} + (-4.48 \times 10^{-19})$ $= -2.8 \times 10^{-19}$ J	1 1	
(b) (i) $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{6.50 \times 10^{-7}}$ $= 3.1 \times 10^{-19}$ J	1	Direct substitution of the values for h, c and the given wavelength are all that is needed.
(ii) the electron can escape from the group of atoms because the energy of the photon exceeds the (negative) total energy of the trapped electron	1 1	The trapped electron must gain at least 2.8×10^{-19} J for it to escape. The photon can pass all of its energy to the electron, which will then escape with 0.3×10^{-19} J of kinetic energy.

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8 (a) (i) electromagnetic radiation behaves either as a particle or as a wave	1	Until the discovery of the photoelectric effect, "light" was considered to be waves. Only the photon hypothesis (i.e. particle-like behaviour) could explain the photoelectric effect. Thereafter, electromagnetic radiation had to be considered to have a dual identity.
(ii) photoelectric effect demonstrates the particle behaviour of electromagnetic radiation	1	
(b) (i) work function $\phi = hf - E_{K\,(max)}$ $= (6.63 \times 10^{-34} \times 1.67 \times 10^{15}) - (3.0 \times 10^{-19})$ $= 8.1 \times 10^{-19}$ J	1 1 1	A standard calculation involving a rearrangement of the photoelectric equation. This time you are given the frequency of the incident ultraviolet radiation rather than its wavelength.
(ii) number of electrons released per second is doubled maximum kinetic energy of the released electrons is unchanged	1 1	Each photon still has the same energy, because the frequency is the same. Therefore the maximum kinetic energy of the photoelectrons is unaffected. The intensity is doubled, meaning that the energy arriving per second is doubled. This can only be achieved by doubling the number of photons striking the surface per second. One photon releases one electron, and so the number of electrons released per second is also doubled.
(iii) none of the electrons in the new metal gain enough energy to leave its surface because the energy of an incident photon is now less than the work function of the new material	1 1	For photoemission to occur, an incident photon has to have an amount of energy that is greater than ϕ. Although these photons were able to release electrons when striking the original material, they can no longer do so with the new metal because its work function is greater.
9 (a) *Calculation*: up to 0.50 A the lamp has a constant resistance of 2.0 Ω When $I = 0.50$ A, $V = IR = 0.50 \times 2.0 = 1.0$ V	1	Whilst the current is small the filament does not heat up sufficiently for its resistance to change. The current/voltage characteristic for a constant resistance is a straight line through the origin. As the current increases further the filament temperature increases, causing the resistance to increase. Equal increases in voltage then cause progressively smaller increases in current, so the gradient of the graph decreases.

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Graph to show : • straight line from the origin to the point (1.0 V, 0.50 A) • smooth curve of decreasing slope from this point to the point (12 V, 2.0 A)	**2**	
(b) *Graph to show* : • current is zero between the origin and about +0.6 V • steep rise in current beyond +0.6 V (with voltage not greatly exceeding 1V) • current is zero for all negative voltages	**3**	This is yet another test of your knowledge of the shape of these characteristic curves. A diode conducts in one direction only and conducts increasingly well once the positive voltage is greater than about 0.6 V.
10 (a) (i) $R = \frac{V^2}{P} = \frac{230^2}{60} = 880\ \Omega$	**1**	Combining $P = I\,V$ and $I = V / R$ gives $P = \frac{V^2}{R}$. This allows you to find the resistance, although you could do this in two steps (finding I, and then R). Rearrangement of the resistivity equation leads to the answer in **(ii)**.
(ii) cross-sectional area $A = \pi r^2$ $= \pi \times (8.0 \times 10^{-5})^2 = 2.01 \times 10^{-8}\ \text{m}^2$	**1**	
$\rho = \frac{RA}{L}$ gives $L = \frac{RA}{\rho} = \frac{880 \times 2.01 \times 10^{-8}}{7.0 \times 10^{-5}}$	**1**	
$= 0.253$ m	**1**	
(b) *Relevant points include* : • reference to resistance $R = \frac{\rho L}{A}$ • A is reduced to $(70 / 80)^2$ of the original area • ρ is reduced to (6.4 / 7.0) of the original resistivity • R therefore increases as the filament ages • power decreases to a value less than 60 W because $P = \frac{V^2}{R}$ and V is unchanged	**3**	This type of question may tempt you to try to be vague, but it is much preferable to show that you know some physics. The answer presented here satisfies the requirements of the question very fully. You are not required to calculate the new power, but if you were to do so you would find that $A' = 1.54 \times 10^{-8}\ \text{m}^2$, $R' = 1050\ \Omega$ and the new power would be 50 W.
11 (a) light-dependent resistor	**1**	'LDR' would not be good enough because you are asked for the **full** name.
(b) current $I = \frac{\varepsilon}{R_{total}} = \frac{1.5}{1800 + 2200}$ $= 3.75 \times 10^{-4}$ A	**1**	This pd can be found equally easily from the potential divider equation: $V_{out} = \left(\frac{R_2}{R_1 + R_2}\right) \times V_{in}$ $= \left(\frac{2.2}{1.8 + 2.2}\right) \times 1.5 = 0.83$ V
output pd = pd across 2.2 kΩ resistor = $I\,R$ $= 3.75 \times 10^{-4} \times 2200 = 0.83$ V	**1**	
(c) (i) resistance of LDR increases when light intensity falls	**1**	In **(i)** you have to state the effect and to explain why it happens. Light dependent resistors are made from semiconducting material, whose ability to conduct depends on the amount of energy available to release charge carriers from their bound state in the atoms.
because fewer charge carriers are available when there is less incident energy	**1**	

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(ii) output pd decreases	**1**	The increased resistance of the LDR causes the current in the 2.2 kΩ resistor to fall (whilst its resistance is unchanged). Using $V = I R$, V_{out} must decrease.
12 (a) wire-wound resistor is **B** thermistor is **C** superconductor is **A**	**2**	The superconductor has zero resistance at low temperature; its resistance then suddenly increases at the transition temperature. The thermistor is made from semiconducting material whose resistance decreases as the temperature increases. 2 marks for getting all three answers correct, 1 mark for getting at least one correct.
(b) cross-sectional area $A = \pi r^2$ $= \pi \times (1.15 \times 10^{-4})^2 = 4.15 \times 10^{-8}$ m^2	**1**	You are presented with two possible hurdles in **(b)**. You have to remember to halve the diameter of the wire before using $A = \pi r^2$, and you have to recall the unit of resistivity.
$\rho = \frac{RA}{L} = \frac{26 \times 4.15 \times 10^{-8}}{1.00}$	**1**	
$= 1.1 \times 10^{-6}$	**1**	
Ωm	**1**	
13 (a) $R = \frac{V}{I} = \frac{2.5}{0.25}$	**1**	These ought to be two very easy marks. When a lamp is working normally it should be operating at its specified voltage and current.
$= 10$ Ω	**1**	
(b) current $I = \frac{\varepsilon}{R_{total}} = \frac{6.0}{R + 10} = 0.25$ A	**1**	Since the lamp is working normally, the current in it (and in all this series circuit) must be 0.25 A.
gives $(R + 10) = 24$ and $R = 14$ Ω	**1**	
(c) $\frac{1}{R_{par}} = \frac{1}{15} + \frac{1}{10} \left(= \frac{5}{30}\right)$	**1**	The first step is to find the resistance of the parallel combination of L and the 15 Ω resistor. The 8.4 Ω resistor is connected in series with this parallel combination.
gives $R_{par} = 6.0$ Ω	**1**	
$R_{total} = 8.4 + 6.0 = 14.4$ Ω	**1**	
(d) total resistance of the first circuit is 24 Ω and that of second circuit is 14.4 Ω	**1**	You are asked to 'explain', but you also have to decide which circuit to choose. It is really only possible to come to this conclusion once you have thought through what is happening in these circuits, and how you can work out an answer. You could calculate the actual powers involved (1.5 W and 2.5 W respectively) but that would be going beyond what is actually expected.
power $P = I V = \frac{V^2}{R}$	**1**	
each circuit has the same voltage applied across it, so the circuit with the greater resistance – the first circuit – dissipates the lower total power	**1**	

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14 (a) $R = \frac{\rho L}{A}$ $= \frac{1.1 \times 10^{-6} \times 3.0}{1.7 \times 10^{-8}}$ $= 194\ \Omega$	1 1 1	The resistivity equation with ρ as subject is given in the Data Booklet. For the first mark you have to rearrange the equation so that R is the subject. Because you are asked to show that R_1 is "about 190 Ω", you should quote all 3 significant figures in the answer.
(b) power $P = \frac{V^2}{R} = \frac{240^2}{194}$ $= 300$ W	1 1	Alternatively, you could work out the current from $I = (V/R)$, and then apply $P = I\,V$ (or $P = I^2R$) to find the power.
(c) (i) power output of R_2 = 2 × power output of R_1 resistance of $R_2 = \frac{1}{2} \times$ resistance of R_1 length of wire in R_2 $= \frac{1}{2}$ of length of wire in R_1 = 1.5 m	1 1 1	Since the total power is now 3× that from R_1 alone, R_2 must dissipate 2× the power from R_1. R_1 and R_2 are connected in parallel and therefore have the same pd across them. The power dissipated = (V^2/R), and this is proportional to $(1/R)$ because V is constant. For the final step, note that R is proportional to L.
(ii) total power output with both elements switched on is 900 W using $P = I\,V$, $I = \frac{P}{V} = \frac{900}{240} = 3.8$ A	1 1	You could use other methods to work this out (such as finding the current in each resistor and then adding the two values).
15 (a) (i) total emf in circuit = 22 − 10 = 12 V	1	In order to charge the car battery, the power supply has to drive charge through it. The two emfs in the circuit are therefore opposing each other.
(ii) from $I = \frac{\varepsilon}{R_{total}}$, $R_{total} = \frac{\varepsilon}{I} = \frac{12}{025}$ $= 48\ \Omega$ total internal resistance = 0.75 + 0.15 $= 0.90\ \Omega$ ∴ resistance of R = 48 − 0.90 = 47.1 Ω	1 1 1	You are told that the initial charging current is 0.25 A. It is important to realise that, even though the emf of the car battery is negative, its internal resistance is still added to that of the power supply when finding the total circuit resistance.
(b) charge $Q = I\,t = 0.25 \times 8.0 \times 3600$ = 7200 C	1	The charge must be in C, so the time must be in s.
16 (a) current $I = \frac{P}{V} = \frac{48}{12} = 4.0$ A	1	The power supply provides current for all eight elements.
(b) (i) current in each element = (4.0/8) = 0.50 A	1	Identical elements must all have the same resistance. Thus the current is divided equally at the junction of the parallel connections.

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(ii) resistance of each element $= \frac{V}{I} = \frac{12}{050} = 24\ \Omega$	**2**	Resistors connected in parallel have the same pd across each of them. In this case every element has a pd of 12 V across it.
(c) **(i)** when in series, current in each element = 4.0 A	**1**	Power $P = IV$, and to do the same job the rear window heater must give the same heating effect – it still requires a current of 4.0 A to provide 48 W, as the pd is fixed at 12 V.
(ii) total resistance of heater $= \frac{V}{I} = \frac{12}{4.0} = 3.0\ \Omega$	**1**	The total resistance of eight identical elements connected in series is eight times the resistance of one of them.
resistance of each element = (3.0 / 8) = 0.375 Ω	**1**	
(d) if one element fails the whole unit no longer works	**1**	This would not happen if a single element were to fail in the parallel arrangement.
(e) **(i)** ohm metre (**or** Ω m)	**1**	**Not** ohm per metre ($\Omega\ m^{-1}$)
(ii) resistivity $\rho = \frac{RA}{L}$	**1**	Each element has a rectangular cross-section, so the cross-sectional area = width × thickness. Part **(i)** has already tested whether you know the unit, so it wouldn't matter if you got it wrong in the final answer.
$= \frac{0.375 \times 0.12 \times 10^{-3} \times 3.0 \times 10^{-3}}{0.75}$ $= 1.8 \times 10^{-7}$ (Ω m)	**1**	
17 (a) **(i)** distance **AB** represents the emf of the battery	**1**	The battery is not supplying current to the 15 Ω resistor because S_2 is open. The input resistance of an oscilloscope is very high, so it takes negligible current. Therefore the oscilloscope (acting like a voltmeter) is measuring the terminal pd of the battery when on open circuit.
(3.0 divisions) × (2.0 V per division) = 6.0 V	**1**	
(ii) when S_2 is closed the battery provides a current in the 15 Ω resistor	**1**	The battery is no longer in an open circuit. Energy loss resulting from the current in the internal resistance causes the terminal pd to fall.
pd is now lost across the internal resistance of the battery	**1**	
(iii) terminal pd is represented by distance **AC** (2.5 divisions) giving 5.0 V	**1**	This pd is across the battery terminals, but it is also across the external 15 Ω resistor.
current $I = \frac{V}{R} = \frac{5.0}{15} = 0.33$ A	**1**	
(iv) $\varepsilon = IR + Ir$ gives $6.0 = 5.0 + 0.33r$	**1**	IR is the pd across the external resistance, which is 5.0 V from **(iii)**. The current in the complete circuit (including the internal resistance) is 0.33 A.
$\therefore r = 3.0\ \Omega$	**1**	

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(b) **(i)** $V_0 = V_{rms}\sqrt{2} = 5.3\sqrt{2} = 7.5$ V	**1**	An oscilloscope produces a vertical line when the time base is switched off and an ac voltage is applied to the Y-plates. The length of the line represents the peak-to-peak voltage, which is twice the peak voltage.
(ii) *Trace to show*: • a vertical line that is symmetrical above and below the central axis • total length of line = 3.0 divisions	**2**	

Nelson Thornes is responsible for the solution(s) given and they may not constitute the only possible solution(s).