AP5D Electricity: Depth and Exam Drill

AQA 7408 · Calculator allowed · about 125 minutes

Total Marks

Name: ________________________________ Date: ____ / ____ / ______

Answer ALL questions. Show all your working.

1 This question tests core definitions in electricity.

(a) Define the electromotive force (EMF) of a source. (1)

(b) Define the resistivity of a material. (1)

(c) State Kirchhoff's second law. (1)

(Total for Question 1 is 3 marks)

2 This is a quickfire question testing circuit relationships.

(a) State Kirchhoff's first law. (1)

(b) State the base SI unit of resistivity. (1)

(c) Define the volt in terms of energy transferred and charge. (1)

(d) State the equation linking power P, current I and resistance R. (1)

(Total for Question 2 is 4 marks)

3 A wire in a circuit carries a steady current of 0.85 A for 12 minutes.

(a) Calculate the charge that flows through the wire in this time. (2)

(b) Calculate the number of electrons that pass a point in the wire during this time (charge of an electron = 1.60×10^{-19} C). (2)

(Total for Question 3 is 4 marks)

4 A cylindrical graphite rod is used as a fixed resistor. It has length 55 mm and diameter 2.0 mm. The resistivity of the graphite is 6.5×10^{-5} ohm m.

(a) Calculate the cross-sectional area of the rod. (1)

(b) Calculate the resistance of the rod. (3)

(c) Using the equation I = nAvq (where n is the number density of charge carriers, A is cross-sectional area, v is drift velocity and q is charge), explain why the resistance of a typical metal wire increases as its temperature rises. (3)

(Total for Question 4 is 7 marks)

5 A cell of EMF E and internal resistance r is connected in series with a variable resistor. The current I and the terminal potential difference V are recorded for three settings.
I (A): 0.20, 0.50, 0.80
V (V): 1.44, 1.20, 0.96

(a) State the equation relating the terminal pd V, the EMF E, the current I and the internal resistance r. **(1)**

(b) Using the first and third data pairs, calculate the internal resistance of the cell. **(3)**

(c) Calculate the EMF of the cell. **(2)**

(d) Calculate the power dissipated inside the cell (due to its internal resistance) when the current is 0.80 A. **(2)**

(Total for Question 5 is 8 marks)

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6 REQUIRED PRACTICAL. A student investigates the I-V characteristic of a silicon diode. The results are given below.
V (V): 0.00, 0.40, 0.50, 0.55, 0.60, 0.65
I (mA): 0.0, 0.0, 0.1, 0.8, 4.5, 18.0

(a) Describe the shape of the I-V graph for the diode and relate this to its behaviour as a circuit component. **(3)**

(b) Calculate the resistance of the diode at V = 0.65 V. **(2)**

(c) Explain why the diode does not obey Ohm's law, referring to the gradient of the I-V graph. **(2)**

(Total for Question 6 is 7 marks)

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7 A cell of EMF 9.0 V and negligible internal resistance is connected to a resistor R1 = 15 ohm in series with a parallel combination of R2 = 20 ohm and R3 = 30 ohm.

(a) Calculate the combined resistance of R2 and R3 in parallel. **(2)**

(b) Calculate the total resistance of the circuit. **(1)**

(c) Calculate the total current supplied by the cell. **(2)**

(d) Calculate the current through R2. **(2)**

(Total for Question 7 is 7 marks)

8 A thermistor and a fixed resistor of resistance 1.2 kilohm form a potential divider connected across a 6.0 V supply. The output voltage is taken across the fixed resistor. At room temperature the thermistor has a resistance of 3.6 kilohm.

(a) Calculate the output voltage at room temperature. **(3)**

(b) As the temperature rises, the thermistor's resistance falls to 0.80 kilohm. Calculate the new output voltage. **(2)**

(c) Explain, referring to your answers above, how this circuit could be used as the basis of a temperature-operated warning circuit that switches on as temperature rises. **(2)**

(Total for Question 8 is 7 marks)

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9 A student determines the resistivity of a sample of wire. The length is measured as 0.850 ± 0.001 m, the diameter as 0.32 ± 0.01 mm (an average of several micrometer readings), and the resistance as 4.55 ± 0.05 ohm.

(a) Calculate the cross-sectional area of the wire. **(2)**

(b) Calculate the resistivity of the wire. **(3)**

(c) Calculate the percentage uncertainty in the resistivity, explaining why the percentage uncertainty in the diameter must be doubled before being combined with the others. **(4)**

(d) State the final result for the resistivity with its absolute uncertainty, to an appropriate number of significant figures. **(1)**

(Total for Question 9 is 10 marks)

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10 A cell has EMF 4.5 V and internal resistance 1.5 ohm and is connected to a variable external resistor R.

(a) Show that the power P delivered to the external resistor R is given by $P = E^2 R / (R + r)^2$, where E is the EMF and r is the internal resistance. **(2)**

(b) Calculate the power delivered to R when R = 1.5 ohm (equal to the internal resistance). **(3)**

(c) Without further calculation, state and explain how the power delivered to R would compare with your answer to (b) if R were changed to 0.50 ohm or to 4.5 ohm. **(2)**

(Total for Question 10 is 7 marks)

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11 A 2.0 kW immersion heater, rated at 230 V, is used to heat 2.5 kg of water in a well-insulated tank. Over 285 seconds (4.75 minutes) of operation, the water temperature rises from 15 degrees C to 65 degrees C. The specific heat capacity of water is 4200 J/(kg degreesC). Evaluate whether all of the electrical energy supplied by the heater is transferred usefully to raising the temperature of the water, using appropriate calculations to support your answer, and discuss possible physical reasons for any discrepancy you find. In your answer, connect the

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Question 1

- (a) **B1** the (total) energy transferred (from chemical or other forms) to electrical energy per unit charge that passes through the source oe
- **(a) Answer: The energy transferred to electrical energy per unit charge that passes through the source.**
- (b) **B1** a property of a material equal to RA/L, the resistance of a sample per unit cross-sectional area per unit length oe
- **(b) Answer: Resistivity is a property of a material, defined by resistivity = RA/L, where R is resistance, A is cross-sectional area and L is length.**
- (c) **B1** the sum of the EMFs around any closed loop in a circuit equals the sum of the potential differences (voltage drops) around that loop oe
- **(c) Answer: The sum of the EMFs around any closed loop equals the sum of the potential differences around that loop.**

Question 2

- (a) **B1** the sum of currents entering a junction equals the sum of currents leaving the junction oe
- **(a) Answer: The sum of currents entering a junction equals the sum of currents leaving it.**
- (b) **B1** ohm metre (ohm m) cao
- **(b) Answer: ohm metre (ohm m)**
- (c) **B1** one volt is the potential difference across a component when one joule of energy is transferred per coulomb of charge that passes through it oe
- **(c) Answer: One volt is the potential difference when one joule of energy is transferred per coulomb of charge passing through a component.**
- (d) **B1** $P = I^2 R$ cao
- **(d) Answer: $P = I^2 R$**

Question 3

- (a) **M1** $Q = I t = 0.85 \times (12 \times 60)$
- (a) **A1** Q = 612 C cao
- **(a) Answer: 612 C**
- (b) **M1** $n = Q / e = 612 / (1.60 \times 10^{-19})$
- (b) **A1** $n = 3.83 \times 10^{21}$ cao
- **(b) Answer: 3.83×10^{21}**

Question 4

- (a) **B1** $A = \pi (1.0 \times 10^{-3})^2 = 3.14 \times 10^{-6}$ m^2 cao
- **(a) Answer: 3.14×10^{-6} m^2**
- (b) **M1** quote $R = \rho L / A$
- (b) **M1** substitute $R = (6.5 \times 10^{-5} \times 0.055) / (3.14 \times 10^{-6})$
- (b) **A1** R = 1.14 ohm cao
- **(b) Answer: 1.14 ohm**
- (c) **B1** as temperature rises, the amplitude of vibration of the (fixed) positive ions in the lattice increases
- (c) **B1** this causes more frequent collisions between the conduction electrons and the vibrating ions
- (c) **B1** so, for a given current, the drift velocity (and hence the ease of electron flow) is reduced, meaning the wire's resistance increases oe
- **(c) Answer: Increased temperature increases the vibration amplitude of the lattice ions, causing more frequent collisions with conduction electrons; this reduces the drift velocity attainable for a given current, so the wire's resistance increases.**

Question 5

- (a) **B1** V = E - I r cao
- **(a) Answer: V = E - Ir**
- (b) **M1** gradient of V against I = -r = (0.96 - 1.44) / (0.80 - 0.20)
- (b) **M1** gradient = -0.80, so r = 0.80
- (b) **A1** r = 0.80 ohm cao
- **(b) Answer: 0.80 ohm**
- (c) **M1** substitute E = V + Ir using I = 0.20, V = 1.44, r = 0.80
- (c) **A1** E = 1.60 V cao
- **(c) Answer: 1.60 V**
- (d) **M1** use $P = I^2 r = 0.80^2 \times 0.80$
- (d) **A1** P = 0.51 W cao
- **(d) Answer: 0.51 W**

Question 6

- (a) **B1** little or no current flows until the pd reaches a threshold (turn-on) voltage of approximately 0.5-0.6 V
- (a) **B1** above the threshold, the current rises very steeply (rapidly increasing gradient) with only small further increases in pd
- (a) **B1** this shows the diode is non-ohmic (does not obey Ohm's law) and conducts easily in the forward direction only once the threshold pd is exceeded oe
- **(a) Answer: Below about 0.5-0.6 V almost no current flows; above this threshold voltage the current rises very steeply for small further increases in voltage, showing non-ohmic behaviour typical of a forward-biased diode.**
- (b) **M1** $R = V/I = 0.65 / (18.0 \times 10^{-3})$
- (b) **A1** R = 36 ohm cao
- **(b) Answer: 36 ohm**
- (c) **B1** Ohm's law requires current to be directly proportional to pd, i.e. a constant gradient (constant resistance) through the origin
- (c) **B1** the diode's I-V graph has a gradient (1/R) that changes markedly with V (near zero below threshold, very large above it), so its resistance is not constant oe
- **(c) Answer: Ohm's law requires a constant ratio V/I (constant gradient); the diode's gradient changes sharply once past the threshold voltage, so its resistance is not constant and it does not obey Ohm's law.**

Question 7

- (a) **M1** use 1/R23 = 1/20 + 1/30, or R23 = (20 x 30)/(20+30)
- (a) **A1** R23 = 12 ohm cao
- **(a) Answer: 12 ohm**
- (b) **B1** R(total) = 15 + 12 = 27 ohm cao
- **(b) Answer: 27 ohm**
- (c) **M1** I = V/R(total) = 9.0/27
- (c) **A1** I = 0.33 A cao
- **(c) Answer: 0.33 A**
- (d) **M1** pd across parallel section = I(total) x R23 = 0.333 x 12 = 4.0 V, then I(R2) = 4.0/20
- (d) **A1** I(R2) = 0.20 A cao
- **(d) Answer: 0.20 A**

Question 8

- (a) **M1** quote V(out) = V(in) x R(fixed) / (R(fixed) + R(thermistor))
- (a) **M1** substitute V(out) = 6.0 x 1.2 / (1.2 + 3.6)
- (a) **A1** V(out) = 1.5 V cao
- **(a) Answer: 1.5 V**
- (b) **M1** substitute V(out) = 6.0 x 1.2 / (1.2 + 0.80)
- (b) **A1** V(out) = 3.6 V cao
- **(b) Answer: 3.6 V**
- (c) **B1** as temperature rises, thermistor resistance falls, so the output voltage across the fixed resistor increases (as shown by the rise from 1.5 V to 3.6 V)
- (c) **B1** this rising output voltage can be fed to a switching device (e.g. a transistor or comparator) that turns on a warning output (lamp/alarm) once the output voltage exceeds a set threshold oe
- **(c) Answer: As temperature rises the thermistor's resistance falls, so the output voltage across the fixed resistor rises; feeding this rising voltage to a transistor or comparator circuit allows the warning device to switch on once the output exceeds a preset threshold voltage.**

Question 9

- (a) **M1** A = π d^2 / 4 with d = 0.32 x 10^{-3} m
- (a) **A1** A = 8.04 x 10^{-8} m^2 cao
- **(a) Answer: 8.04 x 10^{-8} m^2**
- (b) **M1** quote ρ = RA/L
- (b) **M1** substitute ρ = (4.55 x 8.04 x 10^{-8}) / 0.850
- (b) **A1** ρ = 4.31 x 10^{-7} ohm m cao
- **(b) Answer: 4.31 x 10^{-7} ohm m**
- (c) **M1** percentage uncertainty in L = 0.001/0.850 x 100 = 0.12%; in R = 0.05/4.55 x 100 = 1.10%
- (c) **M1** percentage uncertainty in d = 0.01/0.32 x 100 = 3.13%; since A depends on d^2 (A = π d^2/4), the percentage uncertainty in A (and hence its contribution to ρ) is doubled to 6.25%
- (c) **M1** sum all three contributions: 0.12% + 6.25% + 1.10%
- (c) **A1** total percentage uncertainty = 7.5% cao
- **(c) Answer: 7.5%**
- (d) **B1** ρ = (4.3 ± 0.3) x 10^{-7} ohm m cao (absolute uncertainty = 7.5% of 4.31 x 10^{-7} = 0.32 x 10^{-7})
- **(d) Answer: (4.3 ± 0.3) x 10^{-7} ohm m**

Question 10

- (a) **M1** current in the circuit is I = E/(R+r); power delivered to R is P = I^2 R
- (a) **A1** substituting gives P = $[E/(R+r)]^2$ x R = E^2 R / $(R+r)^2$
- **(a) Answer: P = E^2 R / $(R + r)^2$**
- (b) **M1** substitute P = 4.5^2 x 1.5 / $(1.5+1.5)^2$
- (b) **M1** carry out the calculation: 20.25 x 1.5 / 9.0
- (b) **A1** P = 3.4 W cao
- **(b) Answer: 3.4 W**
- (c) **B1** the power delivered would be lower for both R = 0.50 ohm and R = 4.5 ohm
- (c) **B1** because maximum power is delivered to the external resistor when R equals the internal resistance r (here r = 1.5 ohm); any R above or below this value gives less power transferred to R oe
- **(c) Answer: The power would be lower in both cases, since maximum power transfer to R occurs when R = r (here 1.5 ohm); values of R above or below 1.5 ohm both deliver less power to the external resistor.**

Question 11

- **Level 3** (5-6): Correctly calculates the electrical energy supplied (E = Pt = 2000 x 285 = 570,000 J) and the thermal energy gained by the water (Q = mcT = 2.5 x 4200 x 50 = 525,000 J), correctly compares them to find an efficiency of about 92%, and gives at least two plausible, well-explained physical reasons for the shortfall (e.g. heat capacity of the tank/heating element itself absorbing some energy, heat lost to the surroundings despite insulation, energy used to heat surrounding air/fittings), clearly linking the electrical power equation to the thermal energy equation.
- **Level 2** (3-4): Correctly calculates both the electrical energy supplied and the thermal energy gained by the water (or makes only a minor numerical slip), identifies that not all energy is usefully transferred, and gives at least one reasonable physical reason for the discrepancy, with some link between the electrical and thermal equations.
- **Level 1** (1-2): Attempts one of the two energy calculations, or states qualitatively that some energy is lost without supporting calculation or a valid physical reason.
- **Indicative content:**
  - Electrical energy supplied: E = Pt = 2000 W x 285 s = 570,000 J (0.57 MJ).
  - Thermal energy gained by the water: Q = mcT = 2.5 kg x 4200 J/(kg degC) x (65-15) degC = 525,000 J (0.525 MJ).
  - Efficiency = useful energy output / total energy input = 525,000/570,000 x 100 = about 92%, so not all electrical energy is transferred to the water; about 8% is unaccounted for by the simple water-only calculation.
  - Possible reasons: the heating element and container also have significant heat capacity and must themselves be warmed, absorbing some of the supplied energy; despite insulation, some heat is still conducted/convected/radiated to the surroundings over the 285 s; energy may be used heating trapped air or the tank lid/fittings; the water may not be perfectly uniformly heated (temperature gradients) at the moment of measurement.
  - Linking equations: the electrical power equation P = IV = I^2R gives the rate of electrical energy transfer, which should in principle all appear as thermal energy transferred to the water (Q = mcT) in a perfectly insulated, ideal system; the calculated efficiency shows the real system deviates from this ideal because of the additional heat capacities and loss pathways not included in the simple mcT calculation for the water alone.
  - A valid evaluation must include a numerical efficiency figure derived from both energy calculations, not just a qualitative statement that losses occur.