

1. D [1]
2. C [1]
3. B [1]
4. B [1]
5. (a) **Use of sensor**
 Event happens very quickly OR cannot take readings fast enough (1)
 Sampling rate: 50+ samples per second (1) 2
- (b) Initially the temperature is low so current is high
 Resistance of filament increases as temperature increases
 Current falls to steady value when temperature is constant
 Maximum heating is when lamp is switched on / when current is highest
 Filament breaks due to melting caused by temperature rise Max 4 [6]
6. The answer must be clear, use an appropriate style and be organised in a logical sequence. (QWC)
 Reference to $I = nqvA$ (1)
For the lamp
 Increased atomic vibrations reduce the movement of electrons (1)
 Resistance of lamp increases with temperature (1)
For the thermistor
 Increased atomic vibrations again reduce movement of electrons (1)
 But increase in temperature leads to a large increase in n (1)
 Overall the resistance of the thermistor decreased with increase in temperature. (1) Max 5 [5]
7. (a) Voltmeter is across resistor should be across cell (1) 1

- (b) (i) **Plot of graph**
 Check any three points (award mark if these are correct) (3)
 Line of best fit 3
- (ii) e.m.f. = [1.36 – 1.44 V] (1) 1
- (iii) Attempt to find gradient (1)
 Answer [0.38 – 0.42 Ω] (1) 2
- (c) Intercept would be twice value above (1) (accept numerical value 2× value (b)(ii))
 Gradient would be twice value above (1) (accept numerical value 2× value (b)(iii)) 2

[9]

8. (a) Diode or LED (1) 1
- (b) (i) Use of $R = V / I$ current between 75 and 90 ignoring powers of 10 (1)
 answer 6.7 – 8.0 Ω (1)
 Example of answer
 $R = 0.60 \text{ V} \div (85 \times 10^{-3}) \text{ A}$
 $R = 7.06 \Omega$ 2
- (ii) Infinite OR very high OR ∞ 1
- (c) **ANY ONE**
 Rectification / AC to DC / DC supply [not DC appliances]
 Preventing earth leakage
 Stabilising power output
 To protect components
 A named use of LED if linked to LED as component in (a)(eg calculator display / torch)
 A voltage controlled switch
 (Allow current in only one direction) 1

[5]

9. (a) Resistivity definition
 Resistivity = resistance \times (1)
 \times cross sectional area / length (1)
 $\rho = RA/l$ with symbols defined scores 2/2
 equation as above without symbols defined scores 1/2
 equation given as $R = \rho l/A$ with symbols defined scores 1/2
 (1st mark is for linking resistivity to resistance with some other terms) 2
- (b) (i) Resistance calculation
 Converts kW to W (1)
 Use of $P = V^2/R$ OR $P = VI$ and $V = IR$ (1)
 Resistance = 53 Ω (1)
Example of answer
 $R = (230 \text{ V})^2 \div 1000 \text{ W}$
 $R = 53 \Omega$ 3
- (ii) Length calculation
 Recall $R = \rho l/A$ (1)
 Correct substitution of values (1)
 Length = 6.3 m (accept 6.2 m) (1)
 ecf value of R
Example of answer
 $l = (52.9 \Omega \times 1.3 \times 10^{-7} \text{ m}^2) \div (1.1 \times 10^{-6} \Omega \text{ m})$
 $l = 6.3 \text{ m}$ 3
- (iii) **Proportion method**
 Identifies a smaller diameter is needed (1)
 Diameter = 0.29 mm (1)
OR
Calculation method
 Use of formula with $l =$ half their value in (b)(ii) (1)
 Diameter = 0.29 mm (1)
 (Ecf a wrong formula from part ii for full credit)
Example of answer
 $d_{\text{new}} = 0.41 \text{ mm} \div \sqrt{2}$
 $d_{\text{new}} = 0.29 \text{ mm}$ 2

[10]

10. (a) **Definition of E.M.F.**
 Energy (conversion) or work done (1)
 Per unit charge (1)
 [work done/coulomb 1/2, energy given to a charge 1/2, energy given to a charge of a coulomb 2/2]
OR **OR**
 $E = W/Q$ (1) $E = P/I$
 Symbols defined (1) Symbols
 defined
 $(E = 1 \text{ J/C scores } 1)$ $(E = 1 \text{ W/A scores } 1)$
 ((Terminal) potential difference when no current is drawn 1/2) 2
- (b) (i) Internal resistance calculation
 Attempt to find current (1)
 Pd across $r = 0.2 \text{ V}$ (1)
 $r = 0.36 \text{ } (\Omega)$ (1)
 [You must follow through the working, I have seen incorrect methods getting $0.36 \text{ } \Omega$]
 Example of answer
 $I = 2.8 \text{ V} \div 5.0 \text{ } \Omega$
 $r = (3.0 - 2.8) \text{ V} \div 0.56 \text{ A} = 0.36 \text{ } \Omega$ 3
- (ii) Combined resistance
 Use of parallel resistor formula (1)
 Resistance = $3.3 \text{ } \Omega$ [accept $3 \frac{1}{3}$ but not $10/3$] (1) 2
- (iii) Voltmeter reading
 (ecf bii)
 Current calculation using 3 V with either $3.3 \text{ } \Omega$ or $3.7 \text{ } \Omega$ (1)
 Total resistance = $3.7 \text{ } \Omega$ [accept 3.66 to $3.73 \text{ } \Omega$]
 OR use of $V = E - Ir$ (1)
 Voltmeter reading = 2.7 V (1)
OR
 Potential divider method, ratio of resistors with $3.7 \text{ } \Omega$ on bottom (1)
 Multiplied by 3.0 V (1)
 2.7 V (1)
 Example of answer
 $R_{\text{total}} = 3.7 \text{ } \Omega$
 $I = 3 \text{ V} \div 3.7 \text{ } \Omega = 0.81 \text{ A}$
 $V_{\text{voltmeter}} = 3.3 \text{ } \Omega \times 0.81 \text{ A} = 2.7 \text{ V}$ 3

- (c) Ideal voltmeter
 Ideal voltmeter has infinite resistance OR extremely high resistance
 OR highest possible R OR much larger resistance than that of
 component it is connected across OR quotes value $> 1 \text{ M } \Omega$ (1)
 Current through voltmeter is zero (negligible) OR doesn't reduce the
 resistance of the circuit OR doesn't reduce the p.d. it is meant to
 be measuring. (1) 2

[12]

11. (a) Circuit diagram
 Potentiometer correctly connected i.e potential divider circuit (1)
 Ammeter in series and voltmeter in parallel with bulb (1)
 (light bulb in series with resistance can score second mark only) 2

- (b) (i) Graph
 $+I, +V$ quadrant; curve through origin with decreasing gradient (1)
 [do not give this mark if curve becomes flat and then starts going
 down i.e. it has a hook]
 $-I, -V$ quadrant reasonably accurate rotation of $+I, +V$ quadrant (1) 2

- (ii) Shape of graph
 As current/voltage increases, temperature of the lamp increases /
 lamp heats up (1)
 Leading to increase in resistance of lamp (1)
 Rate of increase in current decreases OR equal increases in V
 lead to smaller increases in I (1)
 Qowc (1)
 Ecf if a straight line graph is drawn max 3
 R constant (1)
 $V \propto I$ (1)
 Qowc (1) 4

[8]

12. (a) Calculation of adaptor's input
 Recall of: power = IV (1)
 Correct answer [0.01 A] (1)
 Example of calculation:
 power = IV
 $I = P/V = 25 \text{ W} / 230 \text{ V}$
 $= 0.01 \text{ A}$ 2

- (b) (i) Explain why VA is a unit of power
 Power = voltage \times current so unit = volt \times amp **(1)** 1
- (ii) Calculation of efficiency of adaptor
 Use of efficiency equation **(1)**
 Correct answer [24%] **(1)**
 Example of calculation:
 $\text{efficiency} = (0.6 \text{ VA} / 2.5 \text{ W}) \times 100\%$
 $= 24 \% [0.24]$ 2
- (iii) Reason for efficiency less than 100%
 Resistance (accept explanations beyond spec, e.g. eddy currents) **(1)**
hence heat loss to surroundings **(1)** 2
- (c) (i) Calculation of charge
 Recall of: $Q = It$ **(1)**
 Correct answer [4000 C] **(1)**
 Example of calculation:
 $Q = It$
 $= 0.2 \text{ A} \times 6 \text{ h}$
 $= 0.2 \text{ A} \times (6 \times 60 \times 60) \text{ s}$
 $= 4000 \text{ C} (4320 \text{ C})$ 2
- (ii) Calculation of work done
 Recall of: $W = QV$ OR Recall of $W = Pt$ **(1)**
 Correct substitution **(1)**
 Correct answer [13 000 J] **(1)**
 Example of calculation:
 $W = QV$
 $W = 4320 \text{ C} \times 3 \text{ V [ecf]}$
 $= 13\,000 \text{ J} (12\,960 \text{ J})$
 OR
 $W = Pt$
 $W = 0.6 \text{ W} \times 6 \text{ h}$
 $W = 0.6 \text{ W} \times (6 \times 60 \times 60) \text{ s}$
 $= 13\,000 \text{ J}$ 3

[12]

13. (a) Blue light:
Wavelength / frequency / (photon) energy 1

(b) (i) Frequency:
Conversion of either value of eV to Joules
Use of $f = E / h$
Correct frequency range [$4.8 \times 10^{14} - 8.2 \times 10^{14}$ Hz **or** range =
 3.4×10^{14} Hz]
[no penalty for rounding errors]
eg.
 $2 \text{ eV} = 2 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19} \text{ J}$
 $= 6.63 \times 10^{-34} \times f$
 $f = 4.8 \times 10^{14} \text{ Hz}$
 $3.4 \text{ eV} = 3.4 \times 1.6 \times 10^{-19} = 5.4 \times 10^{-19} \text{ J}$
 $f = 8.2 \times 10^{14} \text{ Hz}$ 3

(ii) Diagrams:
Downward arrow from top to bottom level
On larger energy gap diagram 2

(c) (i) Resistivity drop:
Less heating / less energy lost / greater efficiency / lower
voltage needed / less power lost 1

(ii) Resistance:
Recall of $R = \rho L / A$
Use of $R = \rho L / A$
Correct answer [80(Ω)] [allow 80–84 (Ω) for rounding errors]
Eg.
 $R = (2 \times 10^{-2} \times 5.0 \times 10^{-3}) / (3.0 \times 10^{-3} \times 4.0 \times 10^{-4})$
 $= 83 \Omega$ 3

[10]

14. (a) n is (number of) charge carriers per unit volume **or**
number density or (number of) charge carriers m^{-3} **or**
charge carrier density(1)
[allow electrons]
 v is drift speed **or** average velocity **or** drift velocity
(of the charge carriers) (1)
[just speed or velocity scores zero] 2

(b) / A and Q A s or / Cs⁻¹ and Q C (1)
 $n \text{ m}^{-3}$ (1)
 $A \text{ m}^2$ and $v \text{ m s}^{-1}$ (1)
 [If no equation written assume order is that of equation] 3

(c) (i) $n I$ and Q Need all three 1
 (i) Ratio v_A/v_B less than 1 following sensible calculation (1)
 Ratio = $\frac{1}{4}$ // 0.25 // 1:4 (1)
 (ratio 4:1 scores 1)
 [$4v_A:1v_B$ scores 1] 2

[8]

15. (a) Use of $P = IV$ (1)
 Current in lamp A – 2 A (1)
 [0.5 A scores zero unless $24 = I \times 12$ seen for 1st mark] 2
 Example of answer
 $I = P \div V = 24 \text{ W} \div 12 \text{ V}$
 $I = 2 \text{ A}$

(b) (i) Voltmeter reading = 12 V (1) 1
 (ii) p.d. across $R_2 = 6 \text{ V}$ or their (b)(i) minus 6V (1)
 Use of $R = V/I$ (1) conditional on first mark
 R_2

Answer to this part must be consistent with
 voltmeter reading and if voltmeter reading is wrong
 this part has a max 2. If (b)(i) = 15 V then need to see
 If (b)(i) = 6V or less they are going to score zero for this section. 3

(iii) current through $R_1 = 5 \text{ A}$ (1) ecf answers from (a) 1
 Example of answer
 Current through $R_1 = 2 \text{ A} + 3 \text{ A} = 5 \text{ A}$

(iv) p.d. across $R_1 = 3 \text{ V}$ (1) ecf (15V minus their (b)(i)) 1
 Example of answer
 p.d. across $R_1 = 15 \text{ V} - 12 \text{ V} = 3 \text{ V}$

(v) R_1 1
 Example of answer
 $R_1 = 3 \text{ V} \div 5\text{A} = 0.6$
 [accept fraction 3/5]

[9]

16. (a) (i) EI (1) 1
 (ii) I^2R (1) 1
 (iii) I^2r (1) 1

(b) $EI = I^2R + I^2r$ **or** $E = IR + Ir$
 ecf Must use values (a)(i)-(iii) 1

(c) I for circuit given by $I_{\text{max}} = E / r$ or substitution of
 5000V into the equation (1)
 (for safety) need I to be as small as possible (1) 3

[7]

17. (a) (i) Calculate maximum current
 Recall of $P = IV$ (1)
 Correct answer [0.49 A] (1)
 Example of calculation:
 $P = IV$
 $I = 5.9 \text{ W} / 12.0 \text{ V}$
 $= 0.49 \text{ A}$ 2

(ii) Show that resistance is about 24 Ω
 Recall of $V = IR$ (1)
 Correct answer to 3 s.f. [24.5 Ω] [no u.e.] (1)
 Example of calculation:
 $R = 12 \text{ V} / 0.49 \text{ A}$
 $= 24.5 \Omega$ 2

- (b) (i) Calculate current
 Use of correct circuit resistance (1)
 Correct answer [0.45 A] (1)
 Example of calculation:
 $I = V / R$
 $= 12 \text{ V} \div (24.5 \text{ } \Omega + 2 \text{ } \Omega)$
 $= 0.45 \text{ A}$ 2
- (ii) Calculate power
 Recall of $P = IV$ and $V = IR$ (accept $P = I^2R$) (1)
 or $P = \frac{V^2}{R}$
 Correct answer [5.0 W] (1)
 Example of calculation:
 $P = I^2R$
 $= (0.45 \text{ A})^2 \times 24.5 \text{ } \Omega$
 $= 5.0 \text{ W}$ 2
- (c) Increase in power available to pump
 e.g. lower resistance in wire thicker wire, panel nearer to motor (1)
 (accept relevant answers relating to panels, e.g. more panels) 1

[9]

18. (i) J C⁻¹
 Potential difference (1)
- (ii) Product of two quantities
 Potential difference (1)
- (iii) Rate of change
 current (1)
- (iv) Base quantity
 current (1)
- (for any part if two answers are given score is zero) 4

[4]

19. (a) (As temperature of thermistor increases) its resistance decreases [Do not credit the converse] (1)
 any TWO
 (slight) decrease in v (symbol, velocity or drift velocity)
 Large increase in n increases [accept electrons/charge carriers for n]
 A, Q and (pd) remain constant (1)(1)
 [ignore any reference to v staying constant] 3
 (n constant, can't score mark for 3,4)

(b) (i) **ammeter** reading decreases (1)
voltmeter reading unaltered (1)
 (ii) ammeter is used to indicate temperature (1)
 (iii) Assumption: ammeter; ideal/ has zero/negligible resistance (1)
 (Reference to meters is zero mark) 4

[7]

20. (a) **Tungsten filament**
 Qowc (1)
 I is not (directly) proportional to V
 Temperature of filament increases/ filament heats up/
 gets hotter as current/pd increases
 [accept bulb or lamp but not wire]
 Links temperature increase to resistance increases
 tungsten filament does not obey Ohm's law/not an
 Ohmic conductor or resistor. (1)(1)(1)
 Any THREE 4

(b) (i) Reading current from graph 1.5 A (1)
 answer 5.3Ω (1)
 (misread current $\rightarrow 0/2$)
 Example of answer
 $V = IR$
 $R = 8.0 \div 1.5 = 5.3 \Omega$ 2

(ii) Addition of two currents (1)
 OR use of $R = V/I$ **and** resistors in parallel formula
 $1.5 + 1.2 = 2.7 \text{ A}$ (1)
 ecf candidates' current from above
 [If you see 2.7 A give 2marks] 2

[8]

21. (a) (i) Use of $P = V^2 / R$ OR $P = IV$ and $V = IR$ (1)
 Total $R = 4.5 \Omega$ (1) 2

Example of answer
 $R = V^2 \div P = 12 \text{ V} \times 12 \text{ V} \div 32 \text{ W}$
 $R = 4.5 \Omega$

(ii) Use of $1/R = 1/R_1 + 1/R_2$ OR $\Sigma R = 1/5R$ (1)
 [OR find total current, divide that by 5 and use $V = IR$]
 Resistance of strip = 22.5Ω (1)
 ecf candidates' R . 2

[common error is to divide by 5 $\rightarrow 0.9 \Omega$ scores 0/2 but
 ecf to next part gives $l = 0.033 \text{ m}$ which will then score 3/3]

(b) $R = \rho l / A$ or correct rearrangement (1)
 Correct substitution (1)
 Length = 0.82 m (1)
 ecf candidates' R 3

Example of answer
 $l = RA/\rho = (22.5 \Omega \times 4.0 \times 10^{-8} \text{ m}^2) \div 1.1 \times 10^{-6} \Omega \text{ m}$
 $l = 0.82 \text{ m}$

(c) See $P = V^2 / R$ OR $P = IV$ leading to increase in current
 or decrease in resistance (1)
 more strips in parallel / material of lower resistivity (1)
 [not greater conductivity] 2

[9]

22. (a) E.M.F. = work done / charge OR energy transferred / charge (1)
 OR power / current
 [There is only one mark here and this is consistent with
 specification but it must not be Joules or coulombs] 1

(b) (i) Use of $V = IR$ (1)
 $I = 2.0 \text{ A}$ (1) 2
 Example of answer
 $I = V / R = 8.0 \text{ V} / 4.0 \Omega$
 $I = 2.0 \text{ A}$

- (ii) Uses p.d. = 4.0 V (1)
 $r = 2.0 \Omega$ ecf their I (1) 2
 Example of answer
 $r = V/I = 4.0 \text{ V} / 2.0 \text{ A}$
 $r = 2.0 \Omega$
- (iii) Use of $P = VI // I^2R // V^2/R$ (1)
 $P = 16 \text{ W}$ ecf their I (1) 2
 Example of answer
 $P = VI = 8 \text{ V} \times 2 \text{ A}$
 $P = 16 \text{ W}$
- (iv) Uses 4V or $2\text{A} \times 2\Omega$ or their $I \times r$ (1)
 see $5 \times 60 \text{ s}$ in an energy equation (1)
 energy = 2400 J (1) 3
 Example of answer
 $E = VI t = 4 \text{ V} \times 2 \text{ A} \times 5 \times 60 \text{ s}$
 $E = 2400 \text{ J}$

[10]

23. (a) (i) Calculate resistance
 Recall of $R = V/I$ (1)
 Correct answer [8.65 Ω] (1) 2
 Example of calculation:
 $R = V/I$
 $R = 2.68 \text{ V} \div 0.31 \text{ A}$
 $= 8.65 \Omega$
- (ii) Show that internal resistance is about 0.4 Ω
 Recall of relevant formula [$V = \varepsilon - Ir$ OR lost volts = $(\varepsilon - V)$] (1) OR
 $\varepsilon = I(R + r)$] including emf
 Correct answer [0.39 Ω] [no ue] [allow ecf if $\varepsilon = I(R + r)$] (1) 2
 Example of calculation:
 $V = \varepsilon - Ir$
 $r = (\varepsilon - V)/I$
 $= (2.8 \text{ V} - 2.68 \text{ V})/0.31 \text{ A}$
 $= 0.39 \Omega$

(iii) Comment on match to maximum power
 Not matched [ecf for R in (a) (i) and r in (a)(ii)] (1)
 Max power when internal resistance = load resistance (1) 2

(b) (i) Show that charge is about 14 000 C
 Recall of $Q = It$ (1)
 Correct answer [14 400 C] [no ue] (1) 2
 Example of calculation:
 $Q = It$
 $= 2 \times 2 \text{ A} \times 60 \times 60 \text{ s}$
 $= 14\,400 \text{ C}$

(ii) Calculate time for which battery maintains current
 Use of $Q = It$ OR use of $W = Pt$ (1)
 Correct answer [46 450 s or 12.9 h] (1) 2
 Example of calculation:
 $t = Q/I$
 $= 14\,400 \text{ C} / 0.31 \text{ A}$
 $= 46\,450 \text{ s}$

(c) Explain effect on efficiency
 $\text{Efficiency} = I^2 R / I^2 (r + R)$ / Efficiency depends on $R / (r + R)$ /
 more heat dissipated in cells / Efficiency is V/I and V decreases (1)
 so efficiency is less (1)
 [Must attempt explanation to get 2nd mark] 2

[12]

24. (a) Circuit:
 Potential divider (1) 1

(b) Relay potential difference:
 4 V (1) 1
 Example:
 $5/15 \times 12 = 4\text{V}$

- (c) (i) Resistance:
 Recall of $R = \rho L/A$ (1)
 Correct substitution of values into formula (1)
 Correct answer [98(Ω)] (1)
 [allow 97 – 98 Ω to allow for rounding errors] [no u.e.] 3
 Example:
 $R = (3.4 \times 10^2 \times 1.44) / (100 \times 0.05)$
 $= 98 \Omega$
- (ii) Combined resistance:
 Use of $1/R_{\text{Tot}} = 1/R_1 + 1/R_2$ (1)
 Correct answer for R [4.8 Ω] (1)
 [allow 4.7 Ω – 4.8 Ω to allow for rounding errors] 2
 $1/R = 1/98 + 1/5$ (or = $1/100 + 1/5$)
 $R = 4.8 \Omega$
- (iii) Relay voltage:
 P.d. across relay with ballast very similar to p.d across
 the relay alone / p.d. = 3.9 V / p.d. lower (slightly) (1) 1
- (iv) Train on track:
 Relay voltage becomes **very** small / zero (1) 1
- (v) Wet ballast:
 Any two–
 • Combined resistance now small / $R_T = 0.45 \Omega$
 • Relay voltage now small / $V = 0.52 \text{ V}$
 • Relay voltage too small to trigger green light /
 signal remains red (1)(1) 2

[11]

25. Tungsten filament bulb

- (a) Resistance
 Use of $P = V^2/R$ or $P = VI$ with $V = IR$ (1)
 answer 960 Ω (1) 2
 Example of answer
 $R = (240 \text{ V} \times 240 \text{ V}) \div 60 \text{ W}$
 $R = 960 \Omega$

- (b) Drift speed
 rearrangement of $I = nAvQ$ (1)
 Use of $Q = 1.6 \times 10^{-19}$ (C) (1)
 answer 0.15/0.148 m s^{-1} (1) 3

Example of answer

$$v = 0.25 \text{ A} \div (3.4 \times 10^{28} \text{ m}^{-3} \times 1.6 \times 10^{-19} \text{ C} \times 3.1 \times 10^{-10} \text{ m}^2)$$

- (c) Explanation
 Qowc (1)
 Any THREE
 - Resistance due to collisions between electrons & ions/atoms/particles
 - (as T increases) ions/atoms/particles have more energy
 - (as T increases) ions/atoms/particles vibrate through larger amplitude /vibrate faster OR amplitude if lattice vibration increases.
 - more chance/increased frequency of collision/interaction
 OR impedes the flow of electrons (1)(1)(1) 4

[9]

26. Emf and Internal resistance

- (a) Derivation
 $E = I(R + r)$ OR $E = IR + Ir$ (1) 1

- (b) (i) Correct working (allow even if evidence of working backwards) (1)

Example of answer

$$E/I = R + r$$

$$\text{Rearranging } R = E/I - r$$

- (ii) Emf
 Attempt to use gradient (1)
 answer 1.5 V (bald answer 1.5 V scores 0/2) (1) 2

- (iii) Power
 From graph find value of $1/I$ when $R = 5 \Omega$ (1)
 Use of $P = I^2R$ (1)
 answer 0.31 (W) (1) 3

Example of answer

$$1/I = 4 \text{ A}^{-1} \rightarrow I = 0.25 \text{ A}$$

$$P = 0.25 \text{ A} \times 0.25 \text{ A} \times 5 \Omega = 0.3125 \text{ W}$$

- (c) Graph
 Intercept at -2 (ohms) (1)
 Graph steeper than original (1)
 Gradient is 3.0 V i.e. line passes through $[10, 27-29]$ [no ecf] (1) 3

[10]

27. Potential divider

- (a) First circuit
 Middle terminal M
 Outer terminals L and K (any order) (1) 1
- (b) (i) P.d across lamp.
 External resistance in circuit is 25 or $(20+5)$ ohms (1)
 See ratio of resistances (denominator larger) $\times 6.0\text{V}$ (1)
 OR current = $6/25\text{ A}$
 answer 4.8 V (1) 3
- (ii) Assumption
 The resistance of the ammeter is zero/negligible. (1) 1
- (c) Second circuit
 See 2 resistors in parallel with supply (1)
 Supply across ends of variable resistor ($10\ \Omega$) (1)
 Fixed resistor across one end and slider (consequent mark) (1) 3

[8]

28. (a) Circuit diagram and explanation
 ammeter and voltmeter shown in series and parallel respectively (1)
 current measured with ammeter and voltage / p.d. with voltmeter (1) 2
- (b) Calculation of resistance
 Recall of $R = V/I$ (1)
 Correct answer [$25.0\ \Omega$] (1) 2
- Example of calculation:
 $R = V/I$
 $R = 3.00\text{ V} \div 0.12\text{ A}$
 $= 25.0\ \Omega$

(c) Calculation of resistance

Recall of $P = V^2/R$ (1)

Correct answer [29.4 Ω] (1)

2

Example of calculation:

$$P = V^2/R$$

$$R = (230 \text{ V})^2 \div 1800 \text{ W}$$

$$R = 29.4 \Omega$$

[Accept calculation of $I = 7.8 \text{ A}$ (1), calculation of $R = 29.4 \Omega$ (1)]

(d) Explanation of difference in values of resistance

At higher voltage value element is at a higher temperature (1)

(resistance higher because) increased lattice ion vibrations impede charge flow (more) (1)

2

[8]

30. (a) Graph scale:
Log scale (1) 1
- (b) (i) Choice of material:
Any 2 of the following:
 - (almost) all of the voltage is dropped across the carbon rod
 - gives the greatest speed variation
 - others need to be longer (to have same resistance as carbon)
 - others need to be thinner (to have same resistance as carbon) (1)(1) Max 2
- (ii) Resistance calculation:
Use of $R = \rho L/A$ (1)
Correct units used for all terms [all in cm or all in m] (1)
Correct answer [1.9 Ω] (1) 3
[allow 1.8 Ω for rounding errors – no u.e]
eg. $R = 1.4 \times 10^{-5} \times 0.4 / 3.0 \times 10^{-6}$
= 1.9 Ω
- (iii) Available voltage:
X – 12 V Y – 0 V (1) 1
- (iv) Effect of connecting wires:
Less voltage available for train set as some wasted across wires (1)
0.5 Ω is (relatively) large % of total resistance, so effect is high / not negligible (1)
or
Calculation of potential difference available now (1)
[9.5 V] [allow 9.5 – 9.6 V]
Significant drop from 12 V (1)
 $V_{xy} = (R_{xy} / R_{Total}) \times V_{supply} = (1.9 / (1.9 + 0.5)) \times 12 = 9.5 \text{ V}$ 2
31. (a) (i) Potential difference = work (done)/(unit) charge
OR Potential difference = Power/current (1) 1

[9]

(ii) $J = \text{kg m}^2 \text{s}^{-2}$ (1)
 $C = \text{A s}$ or $W = \text{J s}^{-1}$ (1)
 $V = \text{kg m}^2 \text{A}^{-1} \text{s}^{-3}$ (1) 3

- (b) Converts 2 minutes to 120 seconds (1)
 Multiplication of $VI\Delta t$ or $V\Delta Q$ (1)
 Energy = 1440 J (1) 3
 Example of answer:
 Energy = $6.0 \text{ V} \times 2.0 \text{ A} \times 120 \text{ s}$
 = 1440 J

[7]

32. (a) $n =$ number of charge carriers per unit volume **OR**
 $n =$ number of charge carriers m^{-3} **OR**
 $n =$ charge carrier density (1)
 $v =$ drift speed/average velocity/drift velocity (of the charge carriers) (1) 2

- (b) n is greater in conductors / n less in insulators. (1)
 [There must be some comparison]
 larger current flows in a conductor. Dependant on having
 referred to n (1) 2
 (statement that n large in conductor and so current large max1)

- (c) (In series), so same current and same n and Q (1)
 v_B greater v_A (1)
 $v_A/v_B = 1/4 // 0.25$ (1) 3

[7]

33. (a) pd = 3.6 V (1) 1
 Example of answer;
 p.d. = $0.24 \text{ A} \times 15 \Omega = 3.6 \text{ V}$

- (b) Calculation of pd across the resistor (1)
 $[6.0 - 3.6 = 2.4 \text{ V}]$
 Recall $V = I_R$ (1)
 I_1 calculated from their pd / 4Ω (1)
 $[\text{correct answer is } 0.60 \text{ A. Common ecf is } 6\text{V}/4\Omega \text{ gives } 1.5 \text{ A}]$ 3
 Example of answer:
 $I_1 = 2.4 \text{ V} / 4.0 \Omega = 0.6 \text{ A}$

- (c) Calculation of I_2 from $I_1 = 0.24$ [0.36 A] (1)
 [allow ecf of their I_1 . common value = 1.26 A]
 Substitution $V = 3.6$ V (1)
 $R = 10$ Ω (1) 3

[7]

34. (a) (i) (- gradient =) $r = 1.95 - 2$ Ω (1)
 $E = 8.9 - 9$ V (1) 2

- (ii) $I = 2.15 - 2.17$ A (1) 1

- (iii) Use of $V = IR$ (1)
 $R = 2.1 - 2.2$ Ω (1) 2

- (b) (i) Battery or cell with one or more resistive component (1)
 Correct placement of voltmeter and ammeter (1) 2

- (ii) Vary R e.g. variable resistor, lamps in parallel (1)
 Record valid readings of current and pd (consequent mark) (1) 2
 [Do not give these marks if the candidate varies the voltage as well]

[9]

35. Area of wire:

- Use of $A = \pi r^2$ (1)
 Correct answer [1.9×10^{-7} (m^2). Allow 1.9×10^{-7} and 2.0×10^{-7} (m^2)](1) 2
 [No u.e.]

e.g.

$$A = \pi r^2 = \pi \times (2.5 \times 10^{-4})^2$$

$$= 1.96 \times 10^{-7} m^2$$

Table + graph:

Length / Area / $\times 10^6 \text{ m}^{-1}$
0.0
0.5
1.0
1.5
2.0
2.5
3.1
3.6
4.0 – 4.1

(1)

First 2 points plotted correctly to within 1 mm (1)
 Rest of points in straight line with origin by eye (1)

3

Resistivity calculation:

Drawn through the origin, ignoring first 2 points (1)

Recall $\rho = R / (L/A)$ [in any form] (1)

Large triangle drawn on graph OR accept the use of a pair of values (1)
 read from the line

[$x > 3 \times 10^{-6} \text{ m}^{-1}$] is required in **both** cases]

[x-axis allowed as bottom of triangle]

Correct answer [$1.2 \times 10^{-7} \Omega \text{ m}$] (1)

[allow $1.1 - 1.3 \times 10^{-7} (\Omega \text{ m})$] [no u.e.]

4

e.g.

$$0.4 / 3.4 \times 10^6 = 1.2 \times 10^{-7} \Omega \text{ m}$$

Anomalous results:

Any two of the following:

- Higher current/lower resistance for shorter lengths/at these points
- At shorter lengths/at these points wire gets hotter
- Non-uniform area/diameter
- Cable / contact resistance
- Sensitivity of meters
- Effect on resistance of any of the above (2)

max 2

[11]

36. (a) (i) Lamp brightness
 Lamp A (1)
 Larger current through it (at 9.0 V)/greater power (1) 2
 (at 9.0 V)/smaller resistance (at 9.0 V)
- (ii) Battery current
 Addition of currents (1)
 Current = 1.88 – 1.92 A (1) 2
- (iii) Total resistance
 R = 9 V/1.9 A or use of parallel formula (1)
 R = 4.6 – 4.9 Ω (1) 2
 [full ecf for their current]
- (b) Lamps in series
 Current same in both lamps/current in A reduced from original value (1)
 Pd across A less than pd across B (1)
 Lamp A has a lower resistance than lamp B (1)
 P = VI or P = RI² (1) Any 2
 Lamp A will be dimmer than B [conditional on scoring ONE of (1) 1
 the above marks]

[9]

37. (a) (i) Resistance
 Use of V/I [ignore 10^x] (1)
 3800 Ω (3784 Ω) (1) 2
- (ii) Resistance of thermistor
 Use $\frac{V_R}{V_{TH}} = \frac{R}{R_{TH}}$ OR 9V/.74mA – R OR (1)
 6.2 V = 0.74 mA × R_{TH}
 8400 Ω [8378 Ω] [substituting 4000 Ω gives 8857 Ω ie 8900 Ω] (1)
 [method 2 substituting 3800 Ω gives 8362 Ω: substituting 4000 Ω 2
 gives 8162 Ω]

(b) Suggestion and Explanation

The milliammeter reading increases (1)

Thermistor resistance 'becomes zero' /Short circuit (1)

Since supply voltage is constant / $I = 9.0 V/R$ (1)

OR

Circuit resistance reduced

3

[7]

38. (a) Definition of E.M.F.

Energy (conversion) or work done (1)

Per unit charge (1)

OR

$$E = W/Q \text{ (1)}$$

Symbols defined (1)

[$E = 1J/C$ scores 1]

OR

$$E = P/I \text{ (1)}$$

Symbols defined (1)

[terminal pd when no current drawn or open circuit scores max 1]

2

(b) Voltmeter calculation

Any attempt to find any current (1)

Attempt to calculate pd across 10Ω resistor (1)

5.77 V

2

OR

Potential divider method; ratio of resistors with 10.4Ω on the bottom (1)

Multiplied by 6.0 V (1)

5.77 V (1)

3

[For either method, an answer of 0.23 V scores max 1]

(c) Second battery added

Voltmeter reading increased (1)

Any two of:

EMF unchanged

Total resistance reduced

current increases or "lost volts" decreases (2)

3

[8]

39. Explanation increase of resistance with temperature

Temperature increase leads to increased lattice vibrations (1)
scattering flowing electrons / increased collisions of electrons. (1) 2

Calculation of resistance at 200 °C

$R = V/I$ [stated or implied] (1)
 $= 7.4 \text{ V} \div 0.19 \text{ A}$
 $= 39 \Omega$ (1) 2

Discuss whether results support hypothesis

No. Resistance is not increasing with temperature. (1) 1

Calculation of mains voltage

$P = V^2 \div R$ (1)
 $V^2 = PR$
 $= 1200 \text{ W} \times 41 \Omega$ [Mark for rearrangement **OR** substitution] (1)
[Accept 39 – 41 Ω] [ecf]
 $V = 220 \text{ V}$ (1)
[Allow $P = I^2R$ (1), 3
calculate $I = 5.4 \text{ A}$ and use in $1200 \text{ W} = 5.4 \text{ A} \times V$ (1), $V = 220 \text{ V}$ (1)]

[8]

40. Resistance calculation

Use of $R = \rho L/A$ (1)
Substitution $R = 1.6 \times 10^{-4} \times 0.02 / (5 \times (10^{-3}) \times 0.02 \times (10^{-3}))$ (1)
 $= 32 \Omega$ (1) 3

Total resistance

Either Section 2 = $\frac{1}{2} \times R_1$ (16 Ω) **OR** Section 3 = $\frac{1}{3} \times R_1$ (10.7 Ω) (1)
Use of $R_{\text{Total}} = R_1 + R_2 + R_3$ (1)
 $R_{\text{Total}} = 58.7 \Omega$ [55 Ω if 30 Ω used as starting point] (1) 3
[ecf if section 3 calculated as $\frac{1}{4} \times R_1 = 56 \Omega$ **OR** 52.5 Ω if 30 Ω used as starting point]

Why thermochromic ink becomes warm

Current produces heat / reference to I^2R

OR

Thermal conduction from conductive ink (1)

1

[Mark for identifying that the heating effect originates in the conductive ink]

Why only thin section transparent

Thinner / section 1 has more resistance (1)

So even a small current will heat it/Power (heating effect) given by

I^2R / current will heat it more (1)

2

[**OR** opposite argument explaining why thicker section is harder to heat]

[9]

41. Circuits

Base unit: ampere OR amperes OR amp OR amps (1)

Derived quantity: charge OR resistance (1)

Derived unit: volt OR volts OR ohm OR ohms (1)

Base quantity: current (1)

4

[If two answers are given to any of the above, both must be correct to gain the mark]

[4]

42. (a) Io and Jupiter: Time taken for electrons to reach Jupiter

$$t = s/v = (4.2 \times 10^8 \text{ m}) / (2.9 \times 10^7 \text{ m s}^{-1}) = 14.48 \text{ s}$$

Correct substitution in $v = s/t$ (ignore powers of ten) (1)

Answer: 14.48 s, 14.5 s [no ue] (1)

2

(b) Estimate of number of electrons

$$Q = ne = It$$

$$n = It/e$$

$$n = (3.0 \times 10^6 \text{ A}) (1\text{s}) / (1.6 \times 10^{-19} \text{ C})$$

Use of $ne = It$ (1)

$$(1.8 - 2.0) \times 10^{25} \text{ (1)}$$

2

(c) Current direction

From Jupiter (to Io) / to Io / to the moon (1)

1

[5]

43. (a) p.d. across 4 Ω resistor
 $1.5 \text{ (A)} \times 4 \text{ (}\Omega\text{)}$
 $= 6 \text{ V (1)}$ 1

(b) Resistance R₂
 Current through R₂ = 0.5 A (1)
 $R_2 = \frac{6 \text{ (V)}}{0.5 \text{ (A)}}$
 $R_2 = 12 \text{ }\Omega \text{ (1)}$ 2
 [allow ecf their pd across 4 Ω]

(c) Resistance R₁
 p.d. across R₁ = 12 – 6 – 4
 $= 2 \text{ V (1)}$
 Current through R₁ = 2 A (1)
 $R_1 = \frac{2 \text{ (V)}}{2 \text{ (A)}} = 1 \Omega \text{ (1)}$
 [allow ecf of pd from (a) if less than 12 V]
 Alternative method
 Parallel combination = 3Ω (1)
 Circuit resistance = 12(V)/2 (A) = 6Ω (1)
 $R_1 = 6 - (3 + 2) = 1 \text{ }\Omega \text{ (1)}$ 3
 [allow ecf of pd from (a) and R from (b)]

[6]

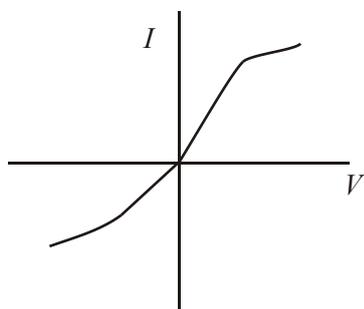
44. (a) Current in filament lamp
 $P = VI$ or correct rearrangement (1)
 2 A (1) 2

(b) (i) Sketch graph

Correct shape for their axes (1)

$-I-V$ quadrant showing fair rotational symmetry (1)

2



(ii) Explanation of shape

(As the voltage/p.d. increases), current also increases (1)

(As the current increases), temperature of lamp increases (1)

(This leads to) an increase in resistance of lamp (1)

so equal increases in V lead to smaller increases in I OR rate of increase in current decreases OR correct reference to their correct gradient (1)

4

[8]

[If a straight line graph was drawn through the origin then (1)(0)(0)(1) for the following:

V is proportional to R
therefore the graph has a constant gradient]

45. (a) (i) Replacement

V_1 (1)

1

(ii) Explanation

[ONE pair of marks]

Resistance: resistance of V_1 [not just the voltmeter] is much larger than 100Ω OR combined resistance of parallel combination is (1) approximately 100Ω

Voltage: p.d. across V_1 is much greater than p.d. across 100Ω OR (1) all 9 V is across V_1

OR

Current: no current is flowing in the circuit / very small current (1)

Resistance: because V_1 has infinite/very large resistance (1)

OR

(Correct current calculation $0.9 \times 10^{-6} \text{ A}$ and) correct pd calculation $90 \times 10^{-6} \text{ A}$ (1)

This is a very small/negligible pd (1)

2

(b) Circuit diagram

(i)  or equivalent resistor symbol labelled $10 \text{ M}\Omega$ (1)



or equivalent resistor symbol labelled $10 \text{ M}\Omega$ (1)

2

[They must be shown in a correct arrangement with R]

(ii) Value of R

$6 \text{ (V)} : 3 \text{ (V)} = 10 \text{ (M}\Omega) : 5 \text{ (M}\Omega)$ / R_{total} of parallel combination is $5 \text{ (M}\Omega)$

$1/5 \text{ (M}\Omega) = 1/10 \text{ (M}\Omega) + 1/R$ OR some equivalent correct (1)
substitution to show working

$R = 10 \text{ M}\Omega$ (1)

3

[8]

46. Explain zeroing of meter
- No resistance when leads touched together/short circuit/calibration for zero error (1) 1
- Show that resistance is about 70 Ω
- $R = V \div I$ (1)
- $= 0.54 \text{ V} \div 0.0081 \text{ A}$
- $= 67 \Omega$ [no ue] (1) 2
- Explain section from passage
- Other currents/voltages/resistances present (1)
- change in current changes reading for resistance (1) 2
- Explain changes in meter reading with temperature increase
- Increased lattice vibrations/vibration of atoms/molecules (1)
- scattering flowing electrons/more collisions (1)
- increased resistance/increase meter reading (1) 3

[8]

47. Circuit diagram
- Ammeter and power source in series (1)
- Voltmeter in parallel with electrodes (1) 2
- [Allow both marks if diagram shows an ohmmeter without a power pack –1 if power pack]
- Calculation of resistance
- Use of area = πr^2 (1)
- $R = 2.7 \times 10^{-3} \Omega \text{ m} \times 5.0 \times 10^{-4} \text{ m/A}$ (1)
- $= 172 \Omega$ (171.9 Ω) (1) 3
- Plotting graph
- Axis drawn with R on y-axis and labelled with units (1)
- Points plotted correctly [-1 for each incorrect] (1)
- Sensible scale (1)
- Curve added passing through a minimum of 4 points (1) 4
- Diameter of hole
- Correct reading from graph = 0.23 mm [Allow 0.22 – 0.26 mm] (1) 1

[10]

48. Temperature calculation

Current = 4.5×10^{-3} A (1)

p.d. across thermistor is 4.2 V (1)

$R_{\text{thermistor}} = 930 \Omega$ ecf their current and pd subtraction error (1)

Temperature = 32 °C – 34 °C [Allow ecf for accurate reading] (1)

4

Supply doubled

Any two from:

- Current would increase / thermistor warms up / temperature increases
- Resistance of thermistor would decrease (1) (1)
- Ratio of p.d.s would change

No OR voltmeter reading / pd across R more than doubles (1)

3

[This mark only awarded if one of the previous two is also given]

[7]

49. Diagram

Labelled wire and a supply (1)

Ammeter in series and voltmeter in parallel (1)

OR

Labelled wire with no supply (1)

Ohmmeter across wire (1)

2

Readings

Current and potential difference OR resistance (consistent with diagram) (1)

Length of wire (1)

Diameter of wire (1)

3

Use of readings

$$R = V/I \text{ OR } \rho = RA/l \text{ (1)}$$

Awareness that A is cross-sectional area (may be seen above and credited here) (1)

Repetition of calculation OR graphical method (1) 3

Precaution

Any two from:

- Readings of diameter at various places /different orientations
- Contact errors
- Zeroing instruments
- Wire straight when measuring length
- Wire not heating up / temperature kept constant (1) (1)

2

[10]

50. Conductor resistance

$$R = \rho l/A \text{ (1)}$$

Correct substitution of data (1)

$$R = 4.3 \times 10^{-2} \Omega \text{ (1)} \quad 3$$

Manufacturer's recommendation

Larger A has a lower R (1)

Energy loss depends on I^2R / reduces overheating in wires (1) 2

[5]

51. Car battery

Voltmeter reading: 12.2 (V) (1) 1

Equation

$$\text{Terminal p.d.} = 12 \text{ V} + (5.0 \text{ A} \times 0.04 \Omega)$$

See 12V (1)

See $5.0 \text{ A} \times 0.04 \Omega$ (1)

Addition of terms (1) 3

Wasted power

$$\text{See } 0.04 \Omega + 0.56 \Omega \text{ OR } 2.8 \text{ V} + 0.2 \text{ V OR } 5 \times (15 - 12) \text{ W (1)}$$

Power = 15 W (1) 2

Efficiency

(same current) $12\text{ V} / 15\text{ V}$ OR $P_{\text{OUT}}/P_{\text{IN}} = 60\text{ W}/75\text{ W}$ (1)

Efficiency = $0.8/80\%$ Efficiency = $0.8/80\%$ (1) 2

Explanation

Any two from:

- Starter motor / to start car needs (very) large current

- $I = \frac{E}{R + r}$

- (E and R fixed) $r_{\text{min}} \Rightarrow I_{\text{max}}$ (1) (1) (1) 2

[10]

52. Circuit diagram

Variable voltage (1)

Includes ammeter and voltmeter (1)

.... in series and parallel respectively (1) 3

[No penalty for LED bias]

Description of current variation in LEDs

Initially, increasing voltage still gives zero current

OR

Current doesn't flow until a specific minimum voltage (1)

Current then increases... (1)

....with an increasing rate of increase (1) 3

Discussion of whether LEDs obey Ohm's law

No (1)

I not proportional to V

OR

R not constant / V/I not constant / R decreases (1) 2

Calculation of resistance of green LED at 1.9 V

$R = V/I$ [Stated or implied] (1)

= $1.9\text{ V} \div 1.46 \times 10^{-3}\text{ A}$

= $1300\ \Omega$ (1) 2

Calculation of power dissipated by red LED at 1.7 V

$$P = IV \text{ [Stated or implied] (1)}$$

$$= 3.89 \times 10^{-3} \text{ A} \times 1.7 \text{ V [do not penalise mA twice]}$$

$$= 6.6 \times 10^{-3} \text{ W (1)}$$

2

[12]

53. Charge

Charge is the current \times time (1)

1

Potential difference

Work done per unit charge [flowing] (1)

1

Energy

$$9 \text{ V} \times 20 \text{ C (1)}$$

$$= 180 \text{ J (1)}$$

2

[4]

54. Number of electrons

$$(-64 \times 10^{-9} \text{ C}) / (-1.6 \times 10^{-19} \text{ C}) = 4.0 \times 10^{11} \text{ electrons}$$

Use of $n = Q/e$ (1)

Seeing $1.6 \times 10^{-19} \text{ C}$ (1)

Answer of 4.0×10^{11} (electrons) (1)

3

[Use of a unit is a ue]

[-ve answer: 2/3]

Rate of flow

$$(6.4 \times 10^{-8} \text{ C}) / 3.8 \text{ s} = 16.8/17 \text{ [nC s}^{-1}\text{] OR } 16.8/17 \times 10^{-9} \text{ [C s}^{-1}\text{]}$$

(6.4) / 3.8 s i.e. use of $I = Q/t$ [Ignore powers of 10] (1)

Correct answer [No e.c.f.] [1.7 or 1.68×10^{-8} or 1.6×10^{-8}] (1)

2

Unit

Amp(ere)/A (1)

1

[6]

55. Explanation of observation

Any two from:

- LED on reverse bias/ R in LED infinite/ LED wrong way round
- so current is zero /LED does not conduct / very small reverse bias current
- since $V = IR$
- $V = 0 \times 1K = 0 \text{ V}$ (1) (1) 2

Explanation of dimness

R_V very large / R_V much greater than R_{LED} (1)
Current very low / pd across LED very small (not zero) (1) 2

Circuit diagram

LED in forward bias (1)
Variation of pd across LED (1)
Voltmeter in parallel with LED alone (1) 3
[LED in series with voltmeter 0/3]

[7]

56. Circuit diagram

Ammeter in series with cell and variable resistor (correct symbol) (1)
Voltmeter in parallel with cell OR variable resistor (1) 2

Power output at point X

Power = voltage \times current (1)
 $= 0.45 \text{ V} \times 0.6 \text{ A}$
 $= 0.27 \text{ W}$ (1) 2

Description of power output

Any three from:

- Current zero; power output zero/small/low
- As current increases power output also increases
- Then (after X) power decreases
- Maximum current; power output zero (1) (1) (1) 3

[Accept reverse order]

e.m.f. of cell

0.58 V (1) 1

Internal resistance

Attempt to use $\frac{\text{"lost volts"}}{\text{current}}$ OR $\epsilon = V + IR$ (1)

$$= \frac{0.58\text{V} - 0.45\text{V}}{0.6\text{A}}$$

= 0.217 / 0.2 Ω (1) 2

[ecf an emf greater than 0.45 V]

[10]

57. Statement 1

Statement is false (1)

Wires in series have same current (1)

Use of $I = nAev$ with n and e constant (1) 3

[The latter two marks are independent]

Statement 2

Statement is true (1)

Resistors in parallel have same p.d. (1)

Use of Power = V^2/R leading to $R \uparrow$, power \downarrow (1) 3

OR as $R \uparrow$, $I \downarrow$ leading to a lower value of VI 3rd mark consequent on second

[6]

58. Explanation of assumption that voltmeter does not affect values

Voltmeter has very high resistance/takes very small current (1) 1

Current through X

$$4.8 \text{ A} \div 6 = 0.8 \text{ A}$$

OR $48 \text{ V} \div 60 \Omega = 0.8 \text{ A}$ (1) 1

Value missing from E7

$$P = IV$$

$$P = 4.4 \text{ A} \times 53 \text{ V} = 233 \text{ W (1)} \quad 1$$

Description of appearance of lamp X as lamps switched on

Gets dimmer

from table, voltage decreasing / current in X decreasing / power per lamp decreasing (1)

So P decreases (1) 3

Formula for cell C6

$$I = \epsilon / R_{tot} \text{ (1)}$$

$$I = 120 / (15 + B6) \text{ (1)} \quad 2$$

Effect of internal resistance on power

Power has a maximum value (1)

when external resistance = internal resistance (1) 2

[10]

59. Measurement needed

Any three from:

- Resistance
- Distance between probes
- Effective area/cross sectional area

- $R = \rho \frac{L}{A} \text{ (1) (1) (1)}$ 3

Equation of line A

$$\text{Intercept} = -3.5 \text{ (}\Omega \text{ m)} (+/- 0.3) \text{ (1)}$$

$$\text{Gradient} = 1.5 \text{ (}\Omega \text{ mm}^{-1}\text{)} (+/- 0.05) \text{ (1)}$$

So equation is $\rho = 1.5 d - 3.5$ [Or equivalent, e.c.f. allowed] (1) 3

Addition of line

Points correctly plotted (–1 for each error, allow ½ square tolerance) (1) (1)

Line of best fit drawn (1) 3

Best distance

Between 1.90 and 1.99 km (1) 1

[10]

60. Resistance calculations

Evidence of 20 Ω for one arm (1)

$$\frac{1}{R} = \frac{1}{20} + \frac{1}{20} \quad (1)$$

$R = 10 \Omega$ (1) 3

Comment

This combination used instead of a single 10 Ω resistor [or same value as before] (1)

because a smaller current flows through each resistor/reduce heating in any one resistor/average out errors in individual resistors (1) 2

[5]

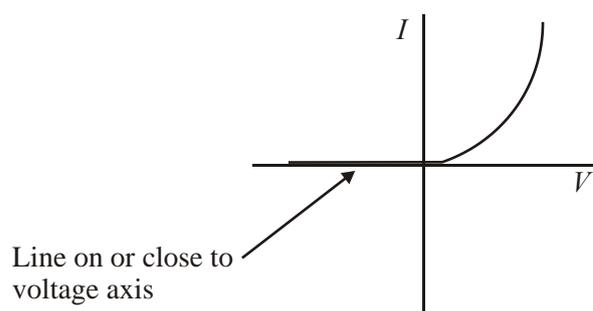
61. Graphs

Diode:

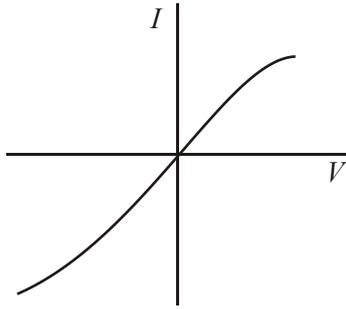
RH quadrant: any curve through origin (1)

Graph correct relative to labelled axes (1)

LH side: any horizontal line close to axes (1) 3



Filament lamp



RH quadrant:

Any curve through origin (1)

Curve correct relative to axes (1)

LH quadrant:

Curve correct relative to RH quadrant (1)

[Ohmic conductor scores 0/3]

3

[6]

62. Circuit

Ammeters and two resistors in series (1)

1

[1 mark circuit penalty for line through cell or resistor]

Cell e.m.f

$E = 150 \times 10^{-6} \text{ (A)} \times 40 \times 10^3 \text{ (}\Omega\text{)}$ total R (1)

Powers of 10 (1)

2

$E = 6.0 \text{ (V)}$

New circuit

Voltmeter in parallel with 25 (k Ω) resistor (1)

1

Resistance of voltmeter

$$\text{(Total resistance)} = \frac{6\text{(V)}}{170 \times 10^{-6}\text{(A)}}$$

$$= (35.3 \text{ k}\Omega) \quad (1)$$

$$\text{(Resistance of II combination)} = 35 - 15 \text{ k}\Omega$$

$$= (20 \text{ }\Omega) \text{ [e.c.f. their total resistance]} \quad (1)$$

$$\frac{1}{20} = \frac{1}{25} + \frac{1}{R_V}$$

$$\frac{1}{R_V} = \frac{5 - 4}{100}$$

$$R_V = 100 \text{ k}\Omega \text{ [108 k}\Omega \text{ if } R_T \text{ calculated correctly]} \quad (1)$$

Alternative route 1:

3

p.d. across 15 kΩ = 2.55 V
(∴ p.d. across ll combination = 3.45 V)
resistance combination = 20 kΩ
→ R_V = 100 kΩ

(1)
(1)
(1)

}
}
}

[7]

Alternative route 2:

3

p.d. across parallel combination = 3.45 V
I through 25 kΩ = 138 μA
→ R_V = 100 kΩ

(1)
(1)
(1)

}
}
}

63. Resistance of strain gauge

State $R = \frac{\rho l}{A}$ (1)

Use of formula (1)

x 6 (1)

$R = 0.13 \Omega$ [ecf their l] (1)

4

$$\left(\begin{array}{l} R = \frac{\rho l}{A} = \frac{9.9 \times 10^{-8} \Omega \text{m} \times 2.4 \times 10^{-2} \text{m} \times 6}{1.1 \times 10^{-7} \text{m}^2} \\ = 129.6 \times 10^{-3} \Omega \\ R = 0.13 \Omega \end{array} \right)$$

Change in resistance

$\Delta R = 0.13 \Omega \times 0.001$

$\Delta R = 1.3 \times 10^{-4} (\Omega)$ [no e.c.f.]

OR

$\Delta R = 0.02 \times 0.001$

$\Delta R = 2.0 \times 10^{-5} \Omega$

0.1% → 0.001 (1)

Correct number for ΔR (1)

2

Drift velocity

Stretching causes R to increase (1)

Any two from:

- Current will decrease
- $I = nAvQ$
- Drift velocity v decreases
- nAe constant (1) (1)

3

[9]

[For R decreasing, max 1:

Any one from:

- I will increase
- $I = nAvQ$
- v will increase
- nAe constant]

64. Resistance in darkness

In the dark $R = 4 \text{ k}\Omega$ (1)

so resistance per mm = $4000 \Omega / 40 \text{ mm} = 100 \Omega(\text{mm}^{-1})$ (1)

2

Resistance of 8 mm length

In the light $R = 200 \Omega$ (1)

so resistance of 8 mm strip = $(8 \text{ mm} / 40 \text{ mm}) \times 200 \Omega [= 40 \Omega]$ (1)

2

Calculations

Resistance of remainder = $32 \text{ mm} \times 100 \Omega \text{ mm}^{-1} = 3200 \Omega$ (1)

1

(i) Total resistance = 3240Ω (1)

Current = $V/R = 1.2 \text{ V} / 3240 \Omega = 3.7 \times 10^{-4} \text{ A}$ (1)

(ii) Across 8 mm, p.d. = $IR = 3.7 \times 10^{-4} \text{ A} \times 40 \Omega$ (1)
= 0.015 V (1)

4

Explanation of why current decreases

Any two points from:

- more of strip is now in the dark
- greater total resistance
- $I = V/R$ where V is constant (1) (1)

Max 2

[11]

65. Resistance of lamps

$$P = \frac{V^2}{R} \quad \text{OR} \quad I = 60/12 = (5 \text{ A}) \quad 1$$

$$R = \frac{12 \text{ V} \times 12 \text{ V}}{60 \text{ W}} \quad \text{OR} \quad R = V/I \quad 1$$

$$R = 2.4 \Omega \quad 1$$

Resistance variation

Lamp A: resistance of A decreases with current increase 1

Lamp B: resistance of B increases with current increase 1

Dim filament

Lamps are dim because p.d. across each bulb is less than 12 V 1

Why filament of lamp A is brighter

Bulbs have the same current 1

p.d. across A > p.d. across B / resistance A > Resistance B 1

OR

power in A > power in B 2

[8]

66. Current in heating element

$$p = VI$$

$$p = \frac{V^2}{R} \quad 1$$

$$I = \frac{500 \text{ W}}{230 \text{ V}}$$

$$R = \frac{230^2}{500} / 105.8(\Omega)$$

$$I = 2.2 \text{ A}$$

$$I = 2.2 \text{ A} \quad 1$$

1

Drift velocity

Drift velocity greater in the thinner wire / toaster filament 1

Explanation

Quality of written communication 1

See $I = nAQv$ 1

I is the same (at all points) 1

(probably) n (and Q) is the same in both wires 1

[8]

67. Resistance of films

$$R = \frac{\rho l}{A} \quad 1$$

$$R = \frac{\rho l}{\omega t} \text{ or } A = \omega t \text{ [consequent on first mark]} \quad 1$$

[i.e. product = ωt]

Resistance calculation

$$R = \frac{(6.0 \times 10^{-5} \Omega \text{m}) \times (8 \times 10^{-3})}{(3 \times 10^{-3} \text{ m}) \times (0.001 \times 10^{-3} \text{ m})}$$

OR

$$R = \frac{(6.0 \times 10^{-5} \Omega \text{m}) \times (8 \text{ mm})}{(3.0 \text{ mm})(1.0 \times 10^{-6} \text{ m})}$$

$$R = 160 \Omega$$

Correct substitution except powers of 10 1

Correct powers of 10 1

Answer 1

Resistance of square film

$$l = \omega \quad 1$$

$$R = \frac{\rho}{t} \quad 1$$

[7]

68. Definition of e.m.f. of a cell

Work/energy (conversion) per unit charge 1

for the whole circuit / refer to total (energy) 1

OR

Work/energy per unit charge 1

converted from chemical to electrical (energy) 1

OR

$E = \frac{W}{Q}$ for whole circuit 1

All symbols defined 1

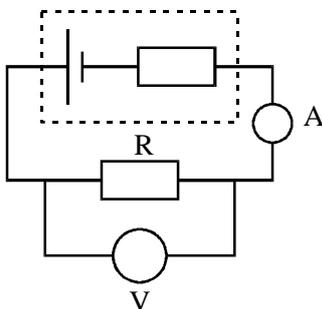
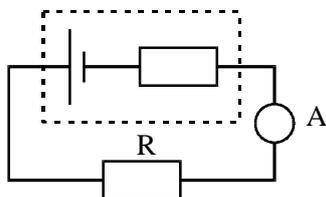
OR

$E = \frac{P}{I}$ for whole circuit 1

All symbols defined 1

[Terminal p.d. when no current drawn scores 1 mark only]

Circuit diagram



R 1

A in series 1

R (can be variable) 1

A and V correct 1

V as shown

Or across R + A

Or across battery

2

[2nd mark is consequent on R(fixed, variable) or lamp]

$r \neq 0 \Omega$ (1)

so $V < E$

OR

Lost volts (1)

across internal resistance (1)

2

Voltmeter reading

0 V [No u.e.] (1)

1

[9]

70. Resistor

(i) $A = \pi r^2 = \pi \times (4.0 \times 10^{-4})^2$ (1)

$= 5.03 \times 10^{-7} \text{ m}^2$ (no u.e) (1)

2

(ii) Recall of $R = \rho l/A$ (1)

Length $l = RA/\rho$

$= 0.12 \times 5.0 \times 10^{-7} / 1.8 \times 10^{-8}$ [substitutions]

$= 3.3 \text{ m}$ (1)

3

Advantage of using iron wire of same diameter

Shorter piece of wire needed (if iron chosen) (1)

1

[6]

71. Unit of current

Amps/ampere (1)

1

Base units of p.d.

For $V = IR$ method

Any three from:

- $V = J C^{-1}$
- $C = A s$
- $J = N m$
- $N = kg m s^{-2}$

$[kg m^2 s^{-3} A^{-1}]$

[See $J = kg, m^2 s^{-2}$ (1) (1)]

OR

For $P = VI$ method

- Watt is J s^{-1} / J/s
- $V = \text{J s}^{-1} \text{A}^{-1}$
- $J = \text{Nm}$
- $N = \text{kg m}^2 \text{s}^{-2}$ (1) (1)] (1) (1) (1)

[See $\text{kg m}^2 \text{s}^{-2}$ (1) (1)]

3

[4]

72. Show that resistance is approximately 45Ω

$$R = \frac{\rho l}{A}$$

$$R = \frac{5.5 \times 10^{-5} \Omega \text{m} \times 0.65 \text{m}}{8.0 \times 10^{-7}}$$

$$= 44.7 \Omega \text{ [No u.e.] (1)}$$

[Must see this value and not 45]

Table

Switch X	Switch Y	Resistance of heater/ Ω	
Open	Closed	22.5/22.35	(1)
Closed	Open	45/44.7	(1)
Closed	Closed	15/14.9	(1)

[No u.e.]

3

Calculation of maximum power

$$P = \frac{V^2}{R} \text{ Use of equation with } 15 \Omega \text{ OR their minimum value (1)}$$

$$= 3526 \text{ W}, 3500 \text{ W [full ecf] (1)}$$

2

Explanation of power output fall

As the temperature of the heater increases } resistance (of metals) increases
OR as it gets hotter / hot }

$$\text{Since } V \text{ is constant } P = \frac{V^2}{R} \text{ OR } P = VI \text{ and } V = IR$$

[Then $P \downarrow$ as $R \uparrow$] (1) 2

OR $P \propto \frac{1}{R}$ [so $P \downarrow$ as $R \uparrow$]

[10]

73. Explanation of greater drift velocity

(Electrons have greater drift velocity) in the thinner wire (1)

Any two from:

- Same current in both wires
- Reference to $I = nAQv$
- nQ same in both wires (1) (1)

3

Explanation of higher dissipation of power

(Higher power is dissipated) by the smaller(er)/ low resistor (1)

Any two from:

- Resistors have same p.d. across them
- The small resistor has the largest current [or reverse]
- Power = voltage \times current, OR voltage² \div resistance [NOT I^2R] (1) (1)

3

[6]

74. Circuit diagram

Resistor with another variable resistor/potential divider/variable power pack (1)

Ammeter reading current through resistor (1)

Voltmeter in parallel with resistor (1)

3

Graph labels

Straight line – resistor
Curve – lamp } Both labelled (1)

1

Potential difference

At 0.5 A p.d. = 3.5 V / 3.4 V + 7.8 V / idea of adding p.d. [for same current] (1)

= 11.2 V / 11.3 V (1)

2

[Accept 11.0 – 11.5 V]

Resistance of lamp

$\frac{3.5 \text{ V}}{0.5 \text{ A}}$ [OR their value of p.d. across lamp \div 0.5 A] (1)

= 7.0 Ω (1)

2

[e.c.f. their value]

[8]

75. Meaning of m

$\times 10^{-3}$ (1)

1

Calculation of resistance for reading 3

$R = V/I$ OR $R = 74 \times 10^3 \text{ V} \div 150 \times 10^{-9} \text{ A}$ [ecf for milli] (1)

$R = 4.9 \times 10^5 \Omega$ (1)

2

Calculation of power for reading 4

$P = I \times V$ OR $P = \frac{V^2}{R}$ OR $P = I^2 R$ (1)

= $210 \times 10^{-9} \text{ A} \times 57 \times 10^{-3}$ (1)

2

= $1.2 \times 10^{-8} \text{ W}$

Plotting points on graph

Two correct points (1)

Third correct point (1)

Best fit straight line for points as they appear on student's graph (1)

3

Predicting short-circuit current

Correct from graph, e.g. 450 nA (1)

1

Suggested e.m.f

Correct from graph, or table, 110 mV (1)

1

Explanation of why voltage falls

Cell has internal resistance/ “lost volts” (1)

“Lost volts” = Ir , so lost volts increase as current increases

OR

$V = E - Ir$, so V decreases as I increases (1)

2

[12]

76. Equation to define resistivity

$$\rho = \frac{RA}{l} \text{ (1)}$$

All symbols defined (resistivity, resistance, length, cross-sectional area) (1) (1)

[3 symbols only defined (1)]

3

Resistance meter

Any two from:

- the resistance between the two probes is measured, not the resistivity
- because you cannot measure the cross-sectional area of skin between the probes
- A and l both vary; cannot calculate resistivity (1) (1)

2

Whether results support claims

Yes (1)

Any two from:

- resistance changes with programme content
- least resistance with political programme
- sweat reduces resistance / is a better conductor (1) (1)

3

[8]

77.

Word Equation	Quantity Defined	
Voltage ÷ Current	Resistance	(1)
Voltage × Current	Power	(1)
Charge ÷ Time	Current	(1)
Work done ÷ Charge	Voltage/p.d./e.m.f	(1)

[4]

78. Charge calculation

$$Q = 20\,000 \times 4.0 \times 10^{-4} \text{ s [substitution]}$$

$$Q = 8.0 \text{ C/A s}$$

2

Resistance calculation

$$R = \frac{\rho l}{A}$$

$$= \frac{(1.7 \times 10^{-8} \Omega)(50\text{m})}{(1.0 \times 10^{-3} \text{ m}^2)}$$

$$R = 8.5 \times 10^{-4} \Omega$$

Formula (1)

Correct substitution (1)

Answer (1)

3

Potential difference calculation

$$V = IR$$

$$= (20\,000 \text{ A}) \times (85 \times 10^{-5} \Omega) \text{ [or their value]} \quad (1)$$

$$= 17 \text{ V [Allow full e.c.f]} \quad (1)$$

2

Explanation

For the tree: R or p is larger (1)

1

[8]

79. Networks

First network:	2.5(Ω)	(1)	
Second network:	25 (Ω)	(1)	
Third network:	10 (Ω)	(1)	3

Meter readings

Ammeter:	25 (mA)	(1)	
Voltmeter V ₁ :	25 × 10 OR 50 × 5 [ignore powers of 10]	(1)	
= 0.25 V		(1)	
Voltmeter V ₂ :	50 × 25 [ignore powers of 10]	(1)	
= 1.25 V		(1)	5

[Allow full e.c.f. for their resistance for 2nd network OR their V₁ answer]

[8]

80. Potential difference across resistors

2.0 MΩ:	6.0 V	}	5.99998 V	}	(1)	
		}	OR	}		
4.0 Ω:	0V]	1.2 × 10 ⁻⁵ V]	(1)	2

Second potential divider circuit

p.d. across 45 Ω:

$$\left(\frac{45}{50} \times 6.0 \text{ V}\right) = 5.4 \text{ V} \quad (1)$$

p.d. across diode:

$$(6.0 \text{ V} - 5.4 \text{ V}) = 0.6 \text{ V} \quad (1) \quad 2$$

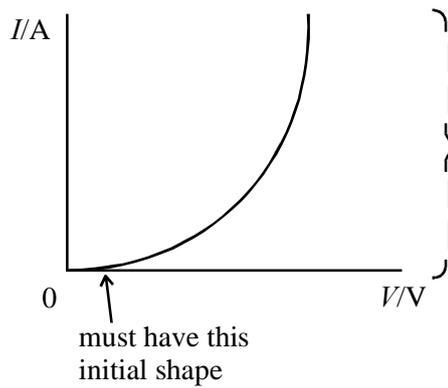
[Allow e.c.f. for 2nd mark if candidate uses

$$\frac{5}{45} \times 6.0 \text{ V} = 0.7 \text{ V for diode}$$

then

$$6.0 \text{ V} - 0.7 \text{ V} = 5.3 \text{ V for } 45 \Omega]$$

Graph



Be leniente here provided generally right shape

(1) 1

[5]

81. Calculation of current

$$P = IV$$

$$I = P/V \text{ (stated or implied) (1)}$$

$$= 0.78 \text{ W} \div 6 \text{ V}$$

$$= 0.13 \text{ A (1)}$$

2

Calculation of resistance

$$P = V^2/R$$

$$\text{OR } R = V/I$$

$$\text{OR } R = (6 \text{ V})^2 \div 0.78 \text{ W}$$

$$\text{OR } R = 6 \text{ V} \div 0.13 \text{ A [ecf] (1)}$$

$$= 46 \Omega \text{ (1)}$$

2

-

Explanation of operation from mains

In series (1)

$$240 \text{ V} \div 40 \text{ lamps} = 6 \text{ V per lamp (1)}$$

2

Explanation of constant brightness of lamps

Current equal – justified, e.g. in series or same V/R or same P/V

1

Statement and explanation of different resistance with ohmmeter

Lower resistance with ohmmeter (1)

Identify lower temperature with ohmmeter [may be implied] (1)

(Lattice) ions'/atoms' vibrations impede electrons/current (1)

[Require interaction]

[Allow converse argument]

3

[10]

82. Explanation of amp hours

Charge = current \times time or $Q = It$ (1)

Amp \rightarrow current and hour \rightarrow time (so amp \times hour \rightarrow charge) (1)

2

Show that charge about 5000 C

Charge = $1.5 \text{ A} \times 1 \times 60 \times 60 \text{ s}$

= 5400 C

1

Calculation of energy stored

$W = QV$ OR $W = Ivt$ (1)

= $5400 \text{ C} \times 3 \text{ V}$ [may use 5000 C]

= 16 200 J [up] (1)

2

-

Show that energy is about 20 000 J

Energy = Ivt (1)

= $0.3 \text{ A} \times 3.1 \text{ V} \times 6 \times 60 \times 60 \text{ s}$

= 20 100 J (20 088 J) (1)

2

Calculation of efficiency

Efficiency = (stored energy/input energy) \times 100%

= $16\,200 \text{ J}$ [allow ecf from 3rd part] (1)

$\div 20\,088 \text{ J}$ [allow 20 000 J from 4th part] (1)

$\times 100\%$

= 80.6% [Accept fractional answers. Allow ecf, but check nos.] (1)

3

[10]

83. Device
 Potential divider or potentiometer 1

Voltmeter reading

A 9.0 V (1)
 B 0 V (1) 2

Diagram

Label X two thirds of the way down from A [Allow e.c.f.] 1

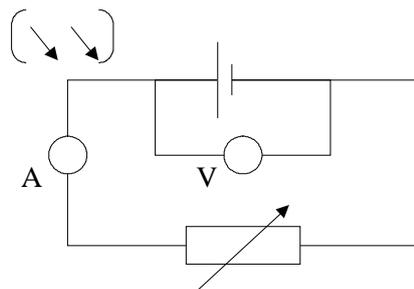
Explanation

Any 3 points from the following:

- lamp in parallel with lowest 1/3 of AB
 - when resistors in parallel, resistance decreases
 - p.d. across lamp reduced to below 3 V
 - current divides
 - no longer enough current to light lamp
- 3

[7]

84. Circuit diagram
 (Variable) resistor symbol (1)
 Voltmeter in parallel with cell/resistor (1)
 Ammeter in series [even if R missing] (1) 3



Maximum power available

Use of $P = IV$ (1)
 Any pair of values which round to 1.4 W (1) 2

Analysis of data

$1000 \text{ W m}^{-2} \quad P = 1.4 \text{ W}$

$100 \text{ W m}^{-2} \quad P = 0.11 \text{ W}$ OR at least one further value of P (1)

Inspection of ratio

[e.g. $100 \div 1000, 0.11 \div 1.4, 1000 \div 1.4$] (1)

Comment based on candidate's result

[e.g. Yes as ratio is similar] (1)

3

Graph

E/V + scale : 2 large squares = 0.05 V (1)

Points (1)

Straight line good fit (1)

$t/^\circ\text{C}$ + scale: 1 large square = 10° (1)

[No penalty if t vs E]

4

Determination of mathematical relationship

Intercept = 0.640 \rightarrow 0.655 (1)

A gradient evaluated (1)

= 2.1 \rightarrow 2.3×10^{-3} (1)

$E = -2.2 \times 10^{-3}t + 0.65$ [e.c.f.] (1)

4

Other axes:

Intercept 290 \rightarrow 310 (1)

Gradient (1)

440 \rightarrow 460 (1)

$t = -450E + 300$ (1)

Determination of light power from the sun

Attempted evaluation of an *area* (1)

= 0.13 \rightarrow 0.17 [-1 if 10^{-6}] (2)

[0.10 \rightarrow 0.20 (1)]

Their answer $\times 4.0 = \dots\dots\dots$ (W) [no u.e.] (1)

4

[20]

85.

	Base unit	Derived unit	Base quantity	Derived quantity	
Mass			✓		(1)
Charge				✓	(1)
Joule		✓			(1)
Ampere	✓				(1)
Volt		✓			(1)

5

[5]

86. Explanation:

As the temperature rises, the resistance decreases (1)

As the resistance decreases, so the ammeter reading/current increases (1)

[No mention of resistance 0/2]

[Current controls temperature → controls R is wrong physics – 0/2]

[If T changes so R changes OR vice versa so I changes 1 mark only]

[Correct static relationship (extremes) 1 mark only]

Reading on milliammeter:

At 20 °C $R = 1.4 \text{ (k}\Omega\text{)}$ (1)

Substitute correctly in $V = IR$ i.e. $6 \text{ V} = I \times 1400 \Omega$ (1)

[Allow their incorrect R ; ignore 10^x] (1)

Milliammeter reading = 0.0043 A OR 4.3 mA [no e.c.f.] (1)

[Accept 4 mA/4.2 mA]

5

[5]

87. Current:

Conversion, i.e. $0.94 \times 10^{-3} \text{ m s}^{-1}$ (1)

Use of $1.6 \times 10^{-19} \text{ C}$ (1)

Answer 3.0 A

$1.0 \times 10^{29} \text{ m}^{-3} \times 0.20 \times 10^{-6} \text{ m}^2 \times 1.6 \times 10^{-19} \text{ C} \times 0.94 \times 10^{-3} \text{ mm s}^{-1}$ (1)

Current = 3.0 A [Accept 2.8 A if 0.9×10^{-3} used.]

3

Resistance:

Recall $R = \frac{\rho l}{A}$ (1)

Substitution:

$$R = \frac{1.7 \times 10^{-8} \Omega \text{ m} \times 4.0 \text{ m}}{0.20 \times 10^{-6} \text{ m}^2} \quad (1)$$

Resistance = 0.34 Ω (1) 3

Potential difference:

Potential difference = 3.0 A \times 0.34 Ω (1)

= 1.0 V (1.02 V)

[Mark for correct substitution of their values or for the answer of 1.0 V] 1

Explanation:

(Increasing resistivity) increases resistance (1)

Leads to a smaller current (1) 2

Comparison:

Drift velocity decreases (in second wire) (1) 1

[Allow $V_1/V_2 = I_1/I_2$]

[Allow e.c.f. answer consistent with their current answer]

[Resistivity up, current down

ρ up, I down / 2 (2nd mark)]

[10]

88. E.m.f.

Use of intercept mentioned/indicated on graph/when $I = 0$ (1)

e.m.f. = 1.5 V (1) 2

Use of graph:

Internal resistance: mention use of gradient/use of numbers/triangle on graph (1)

Internal resistance = 0.5 Ω (1) 2

[Finds r and/or V by substitution, can score answer mark, but NOT method mark]

$$\left[\text{Gradient} = \frac{1.5 - 1.0}{1.0} = 0.5 \Omega \right]$$

They might write gradient = $\frac{1.5}{1.0} = 1.5 \Omega$ OR gradient = $\frac{1.5}{1.2}$ - ignore signs]

Graph:

Negative gradient of a straight line starting anywhere (1)

from (0.0, 3.0) [No e.c.f.] (1)

heading for (1.0, 2.0[1.9 \rightarrow 2.1])/gradient of -1 [Consequent mark] 1 3

Filament lamp: any two of
 if the variable resistor is set to zero [NOT, as R_{VR} down] (1)
 the lamp prevents I from becoming too large (1)
 and overloading/damaging the ammeter (1)
 bulb acting like a fuse OR prevents short circuit (1)
 bulb means there is still resistance in circuit (1)

Max 2

[9]

89. Completion of circuit:

Ammeter and voltmeter used [correct symbols required] (1)

Ammeter in series, voltmeter in parallel (1)

[Do not penalise **variable** resistor in series]

2

Explanation of difference voltages:

Any two from:

- Internal resistance **of cell/battery**
- When current flows, energy transferred to / lost by internal resistance/heating in cell
- Hence voltage across internal resistance/ “lost volts”
- Reduced **terminal** p.d. / $V = E - Ir$ / $E = V + Ir$ (1)

2

-

Show that internal resistance is about 0.6Ω :

$$R = V/I$$

$$= (1.5 - 1.25) \text{ (1)}$$

$$\text{, } 0.4 \text{ A}$$

$$= 0.63 \Omega \text{ [No u.e.] (1)}$$

2

Calculation of resistance of bulb:

$$R = V/I \text{ (1)}$$

$$= 1.25 \text{ V} \div 0.4 \text{ A}$$

$$= 3.1 \Omega \text{ (1)}$$

2

Explanation of lower resistance with ohmmeter:

Identify lower temperature with ohmmeter (1)

Lattice ions’/atoms’ vibrations impede electrons (1)

[Allow converse argument]

2

[10]

90. Explanation of why it is a good approximation:
- Resistance of connecting lead is (very) small (1)
- So $I \times R_{(\text{very}) \text{ small}} = (\text{very}) \text{ small p.d./}e^{-1}\text{s do little work so p.d. small}/r \text{ small}$ (1)
- compared with rest of the circuit so p.d. small
- 2

Circumstances where approximation might break down:

- If current is large **OR** resistance of rest of circuit is small (1)
- [**Not** high voltage/long lead/thin lead/high resistivity lead/hot lead]
- 1

Calculation:

- Use of $R = \frac{\rho l}{A}$ with A attempted \times sectional area (1)
- Correct use of 16 (1)
- Use of $V = IR$ (1)
- 0.036 V (1)
- 4

[10]

91. Number of carriers or electrons per unit volume / per m^3 /carrier density/electron density (1)
- [Not charge density / concentration]
- Drift velocity OR drift speed OR average/mean/net/overall velocity (1) 2
- [Not just velocity; not speed unless drift]
- m^{-3} (1)
- $\text{m}^2 \text{ As m s}^{-1}$ (1)
- Multiply and reduce to A (1) 3

[Base units not needed]
 [Mixed units and symbols could get the third mark]
 [mA = m⁻¹ loses 1 mark]

Metal:

M: n large so there is a current

n : n in metal much larger (1)

Insulator

I: n zero (negligible)/very small so less current (or zero current)

Current in metal is larger (1)

2

[Ignore anything about v . Allow e.g. electron density for n]

[7]

92. Use $R = \rho/l/A$ OR correct rearrangement OR plot $R \rightarrow l$ gradient = ρ/A (1)
 [Symbols or words]

With $A = tw$ (1)

2

$l = RA/\rho$ [Rearrangement mark symbols or numbers] (1)

Use of $A = tw$ (1)

[Correct physical quantities substituted but ignoring unit errors, powers of 10]

= 110 m

[111 m] (1)

3

Reduce width/ w of strip OR use thinner/ t foil [Not reduce A ; not increase T, V, I] (1)

Smaller $w/t/A$ will be less accurate OR have larger error OR larger R will be more accurate (1)

2

[Increase w or t , could give e.c.f. to increased accuracy]

[7]

93. $I^2 R / (\mathcal{E}I - I^2 r) / \frac{(\mathcal{E} - Ir)^2}{R}$ (1)

$I^2 r / (\mathcal{E}I - I^2 r) \frac{(\mathcal{E} - Ir)^2}{R}$ (1)

$\mathcal{E}I$ OR $I^2 R + I^2 r / \mathcal{E}^2 / (R + r)$ (1)

$\mathcal{E}I = I^2 R + I^2 r$ OR $(It = I^2 RT + I^2 rt / \text{their (iii)} = \text{their (i)} + \text{their (ii)})$ (1)

Cancel I (OR I and t) and arrange [only if energy equation is correct] (1)

5

Maximum current occurs when $R = 0$ (1)

$I_{\max} = \varepsilon/r$ (1) 2

OR larger r means smaller I (1 mark)

1 M Ω [Could be underlined OR circled] (1)

It gives the smallest current (1)

[If 100 k Ω this reason: 1 only] 2

[9]

94. No, because V is not proportional to I OR not straight line through origin / (1)
only conducts above 0.5 V / resistance changes 1

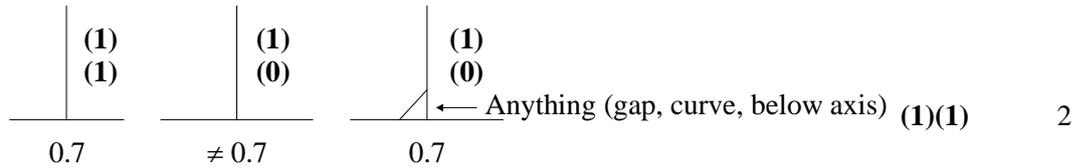
Use of $R = 0.74$ / current from graph (1)

= 9.25 Ω [9.0 – 9.5 Ω] [Minimum 2 significant figures] (1) 2

Calculation of p.d. across R [8.26]	Calculation of total resistance[109 – 115]	Ratio R : ratio V	$E = \Sigma IR$ (1)
$\div I$	– diode resistance [9]	Correct substitutions	Correct substitutions (1)
103 Ω [100 – 106] (1)			

3

[If not vertical line, 0/2]



[Otherwise 0 0]

[8]

95. Potential difference = $\frac{\text{work/energy}}{\text{charge}}$ OR $\frac{\text{power}}{\text{current}}$
- OR in words: work done in moving 1 coulomb of charge between two points. (1) 1
- Unit: volt OR J C^{-1} OR V (1) 1
- Base units: $\text{kg m}^2 \text{A}^{-1} \text{s}^{-3}$ (1)(1) 2
- [2/2 possible even if final answers wrong for recognising that $\text{As} = \text{C}$ $\text{J} = \text{Nm}$]

[4]

96. Current in motor:
- $$I = \frac{P}{V} = 300\,000 \text{ W} / 420 \text{ V}$$
- $$= 714 \text{ A} \quad [\text{allow } 710][\text{no u.e.}] \quad (1) \quad 1$$
- Problem:
- Overheating in wires OR circuit/motor becomes hot
- OR Need thick/large/heavy cables
- OR other sensible comment (1) 1
- Why e.m.f. of battery must be more than 420 V:
- Mention of internal resistance (1)
- Detail e.g. loss of p.d. inside battery when current delivered/ lost volts (1)
- OR equations used correctly 2 marks 2
- Overall efficiency of motor:
- $$\text{K.E. gained} = \frac{1}{2} m v^2$$
- $$= \frac{1}{2} \times 1160 \times 10^2 \text{ J}$$
- $$= 6.64 \text{ M J} \quad (1)$$
- Energy input = $P \times t$
- $$= 300\,000 \times 100 \text{ J}$$
- $$= 30 \text{ M J} \quad (1)$$
- \Rightarrow efficiency = $\text{out/in} \times 100$
- $$= 6.64/30 \times 100 = 22\% \quad (1) \quad 3$$

Reasons for energy losses: (1)

Work (done) against air resistance (1)

Work (done) against friction (1)

Heating in wires of circuit (1)

Heating, in battery (1)

Heating in motor coils (1)

Max 2

OR other sensible comments e.g. sound

[Friction or heat loss scores zero unless detailed e.g. heat due to friction/air resistance ✓ but heat to surroundings ✗]

[9]

97. Why resistance changes:

Wire lengthens OR cross-sectional area OR diameter reduces (1)

Use of $R = \rho l/A$ to explain [R and l , $R \propto 1/A$] (1)

2

Advantage:

A long length of wire OR small area OR multiple stretching (1)

1

Diagram:

Circuit with ammeter in series (1)

voltmeter in parallel (with strain gauge) (1)

OR multimeter across strain gauge (1)(1)

[Multimeter with power supply – 1 only]

Max 2

Resistance:

$$R = \rho l/A$$

$$= 4.9 \times 10^{-7} \Omega \text{ m} \times 0.2 \text{ m} / \pi \times (2 \times 10^{-4} \text{ m} / 2)^2 \text{ (1)}$$

[i.e. area = (1)] (1)

$$= 3.1 \Omega \text{ (1)}$$

3

[8]

98. Threshold wave:

Electron requires certain amount of energy to escape from surface (1)

This energy comes from one photon (1)

Use of $E = hf$ (1)

(So photon needs) minimum frequency (1)

Hence maximum wavelength

OR use of $E = hc/\lambda$ (1)

Max 4

Work function:

$$f = c/\lambda = 3.0 \times 10^8 / 700 \times 10^{-9} \text{ m (1)}$$

$$= 4.28 \times 10^{14} \text{ Hz (1)}$$

$$E = hf = 6.63 \times 10^{-34} \text{ J s} \times 4.28 \times 10^{14} \text{ Hz} = 2.84 \times 10^{-19} \text{ (J) [Allow e.c.f.] (1)}$$

3

Circuit :

Circuit showing resistors only in series (1)

Potentials labelled (1)

[Use of potential divider – allowed]

Resistor values 1: 1: 1 OR 1:2 (1)

Max 2

Suggestion:

Cosmic rays travel more slowly than light (1)

1

[10]

99. Definition of symbols:

n = number of electrons/carriers per unit volume (per m^3)
OR
electron (or carrier) density (1)

v = average (OR drift) velocity (OR speed) (1) 2

Ratio	Value	Explanation
$\frac{n_y}{n_x}$	1	Same material (1) (1)
$\frac{l_y}{l_x}$	1	Connected in series/Kirchoff's 1 st law/conservation of charge/current is the same (1) (1)
$\frac{v_y}{v_x}$	2	A is halved so v double [Accept qualitative, e.g. $A \downarrow$ so $v \uparrow$, or good analogy] (1) (1)

6

[Accept e.g. $n_y = n_x$]

[No e.c.f.]

[NB Mark value first, without looking at explanation. If value correct, mark explanation. If value wrong, don't mark explanation *except*: if $v_y/v_x = 1/2$ or $1:2$, see if explanation is correct physics, and if so give (1). No e.c.f.]

[8]

100. Demonstration that resistance is 0.085Ω :

$$R = \rho l/A \text{ (1)}$$

$$= 1.7 \times 10^{-8} \Omega\text{m} \times 20 \text{ m} / (4.0 \times 10^{-6} \text{ m}^2) \text{ (1)} \quad 2$$

Calculation of voltage drop:

$$V = 37 \text{ A} \times 0.085 \Omega \text{ (1)}$$

$$= 3.1 \text{ V} \times 2 = 6.3 \text{ V} \text{ [Not if } V_{\text{shower}} \text{ then found]} \text{ (1)} \quad 2$$

[Only one conductor, leading to 3.1 V, gets 1st mark]

[Nothing if wires in parallel]

Explanation:

Lower resistance/ $R = 0.057 \Omega$ /less voltage drop/new $V = \frac{2}{3}$ old V (1)

Power dissipated in cable/energy wasted/wire not so hot
OR more p.d./current/power to shower
OR system more efficient (1)

2

[6]

101. Explanation: .

$$I = E/r + R \text{ (1)}$$

1

Appropriate formula for cell E9:

$$C9 * D9 \text{ OR } RI \text{ OR } 1 \Omega \times 4 \text{ A (1)}$$

1

Appropriate formula for cell F 11

$$D11 * E11 \text{ OR } VI \text{ OR } 3 \text{ A} \times 6 \text{ V} \text{ OR } C11 * D11 * D11 \\ \text{OR } RI^2 \text{ OR } 2 \Omega \times (3 \text{ A})^2 \text{ (1)}$$

1

Short circuit current:

$$6 \text{ A (1)}$$

1

Explanation:

r and R in series \rightarrow potential division (1)

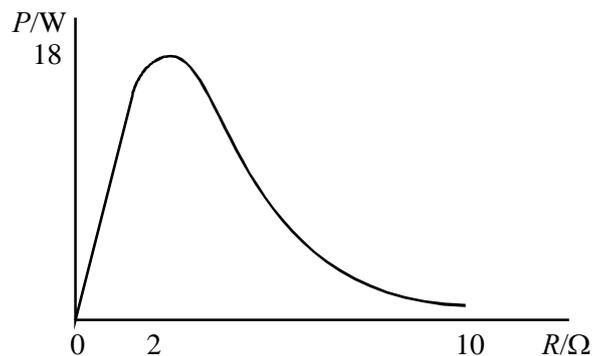
1

as $R \uparrow$, r constant $\rightarrow R$ has greater share of 12 V (1)

1

OR other valid argument

Sketch graph of power against resistance:



18 (1)

2 (1)

Shape including asymptote (1)

3

Comment:

Maximum when $R = r$ (1)

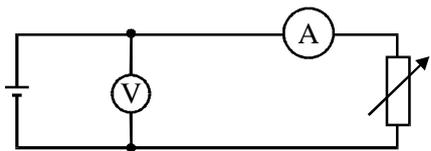
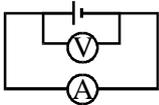
in accordance with maximum power theorem (1)

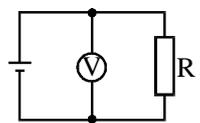
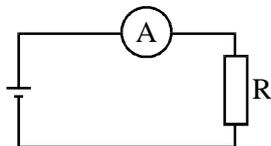
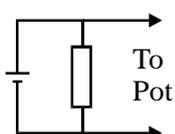
OR $P \rightarrow 0$ as $R \rightarrow \infty$ (1)

Max 2

[11]

102. (a) Mark the method *before* marking the circuit

Suitable circuit				Short circuit option 
What is measured	Set of readings of V and I	V and I	Two sets of V and I	V and I
What is then done	Plot V against I	Record V for open circuit	Substitute in $V = E - Ir$	Record V for open circuit
Finding E and r	$E =$ intercept $r = -$ gradient	$E =$ open circuit voltage r from $V = E - Ir$	Solve simultaneous equations	$E =$ open circuit voltage r from $r = E - Ir$

Suitable circuit			Potentiometer 	
What is measured	V for known R	I for known R	Two sets of I and R	l for known R
What is then done	Record V for open circuit	Record V for open circuit	Substitute in $E = I(R + r)$	l' for open circuit
Finding E and r	$E =$ open	$E =$ open	Solve	E from l'

	circuit voltage r from $E/V = (R + r)/R$	circuit voltage r from $E = I(R + r)$	simultaneous equations	(calibrated) $\frac{l'}{l} = \frac{(R+r)}{R}$
--	--	--	---------------------------	--

Mark other procedures in a similar way

4

[Mark text, then tick for circuit if it does the job described.

If diagram *alone*, ask if it can do the job and give mark if yes]

(b) (i) p.d. across battery:

$$V = E - Ir$$

$$= 12.0 \text{ V} - 3.0 \text{ A} \times 3.0 \text{ } \Omega \text{ (substitution)}$$

$$= 3.0 \text{ V}$$

2

(ii) Straight line from (0,12) to (3,3) (e.c.f.)

1

Current: 2.05 to 2.10 A

1

[8]

[Allow correct intersection of their line (ignore shape), $\pm 0.05 \text{ A}$, of the characteristic with their graph, even if theirs is wrong. A line **MUST** be drawn for the last mark.]

103. Explanation of variation shown on the graph:

More electrons set free. Any one from: as temperature increases; thermal energy/vibration increases/
resistance decreases/current increases

2

Resistance of thermistor:

$$\begin{aligned} V \text{ (across thermistor)} &= 1.20 \text{ V} \\ \text{Resistance ratio} &= \text{voltage ratio} \\ R &= 495 \Omega \end{aligned}$$

or

$$\begin{aligned} I &= 0.80 \text{ V}/330 \Omega \text{ (substitution)} \\ &= 0.002424 \text{ A} \\ V \text{ across thermistor} &= 1.20 \text{ V} \\ R &= 1.20 \text{ V}/0.002424 \text{ A} \\ &= 495 \Omega \end{aligned}$$

or

$$\begin{aligned} I &= 0.80 \text{ V}/330 \Omega \\ &= 0.002424 \text{ A} \\ R_{\text{(total)}} &= 2.0 \text{ V}/0.002424 \text{ A} \\ &= 825 \Omega \\ R &= 825 \Omega - 330 \Omega \\ &= 495 \Omega \end{aligned}$$

3

Explanation:

Thermistor resistance low

Why: thermistor hotter/more current, power, charge carriers

Why v. small: thermistor takes smaller fraction of p.d. *or* ratio of p.d.

3

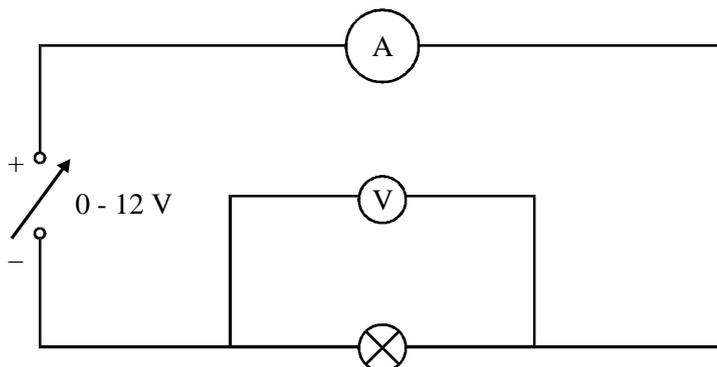
[8]

104. Completion of a correct circuit diagram:

Ammeter in series with lamp and supply [Ignore voltmeter position]

Voltmeter across lamp and ammeter [and maybe with ammeter]

2



Measurements:

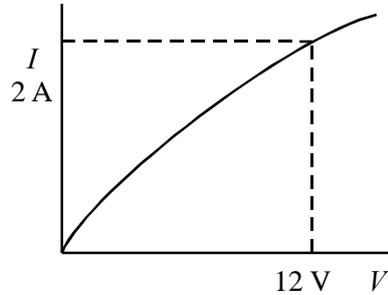
Record voltmeter reading

Record corresponding ammeter reading ["corresponding" may be implied]

Repeat for range of supply voltage settings [or currents]

3

Labelled sketch:



Label axes I and V [with or without units]

Graph line with correct curvature [overlook any tendency of the current value to saturate]

Show 12 V, 2 A correctly [Allow 12 and 2 if units are labelled on axes]

3

[The second mark is lost if axes are not labelled, unless 2 A and 12 V are present, with the units, to make sense of the axes.]

[8]

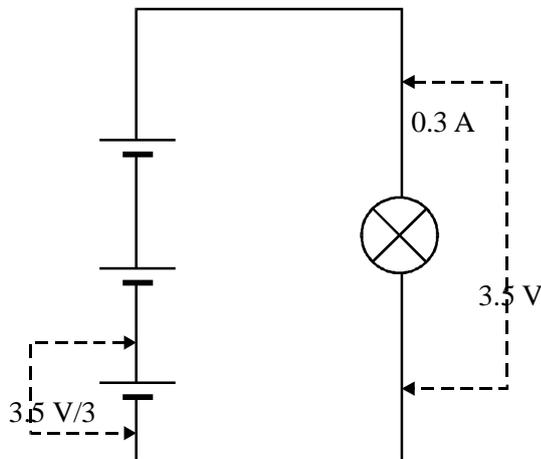
105. Diagram of torch circuit:

The lamp will light

Correct circuit

2

[Circuit showing one cell only is allowed one mark only unless the cell is labelled 4.5 V. If a resistor is included, allow first mark only unless it is clearly labelled in some way as an internal resistance.]



Voltage across each circuit component and current in lamp:
 Either 3.5 V/3 shown across the terminals of one cell or 3.5 V across
 all three cells
 3.5 V shown to be across the lamp
 0.3 A flowing in the lamp [i.e. an isolated 0.3 A near the lamp does not
 score]

3

Calculation of internal resistance of one of the cells:

$$\text{Lost volts} = 4.5 \text{ V} - 3.5 \text{ V} \text{ or } 1.5 \text{ V} - \frac{3.5 \text{ V}}{3}$$

$$\text{or total resistance} = (4.5 \text{ V}) / (0.3 \text{ A}) = 15 \text{ K}\Omega$$

Internal resistance of one cell = $[(1.0 \text{ V}) / (0.3 \text{ A})] \div 3$

$$\text{or } [(0.33 \text{ V}) / (0.3 \text{ A})] \text{ or lamp resistance} = (3.5 \text{ V}) / (0.3 \text{ A}) = 11.7 \Omega$$

$$= 1.1 \Omega \text{ or } = (3.3 \Omega) / 3 = 1.1 \Omega \quad 3$$

[Some of these latter marks can be read from the diagram if it is so
 labelled]

[8]