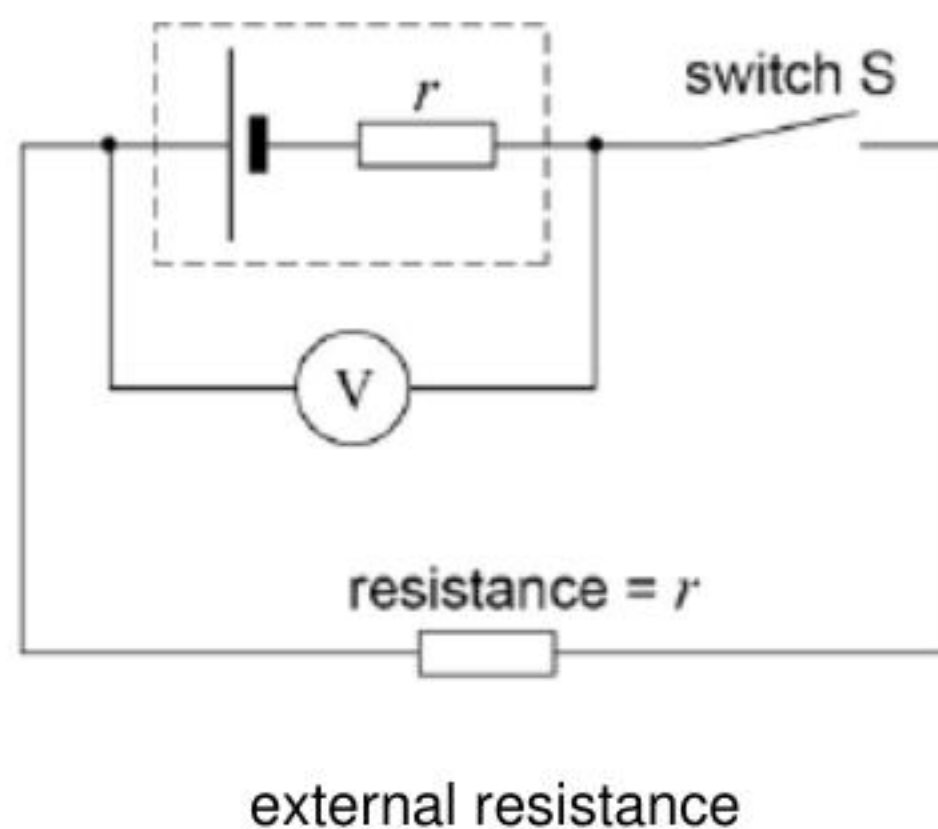


- 1** In the circuit shown, V is a voltmeter with a very high resistance. The internal resistance of the cell, r , is equal to the external resistance in the circuit.



Which of the following is not equal to the emf of the cell?

- | | | |
|----------|---|--------------------------|
| A | the reading of the voltmeter when the Switch S is open | ☐ |
| B | the chemical energy changed to electrical energy when unit charge passes through the cell | ☐ |
| C | twice the reading of the voltmeter when the switch S is closed | ☐ |
| D | the electrical energy produced when unit current passes through the cell | ☐ |

(Total 1 mark)

- 2** A battery is connected to a $10\ \Omega$ resistor and a switch in series. A voltmeter is connected across the battery. When the switch is open (off) the voltmeter reads 1.45 V. When the switch is closed the reading is 1.26 V.

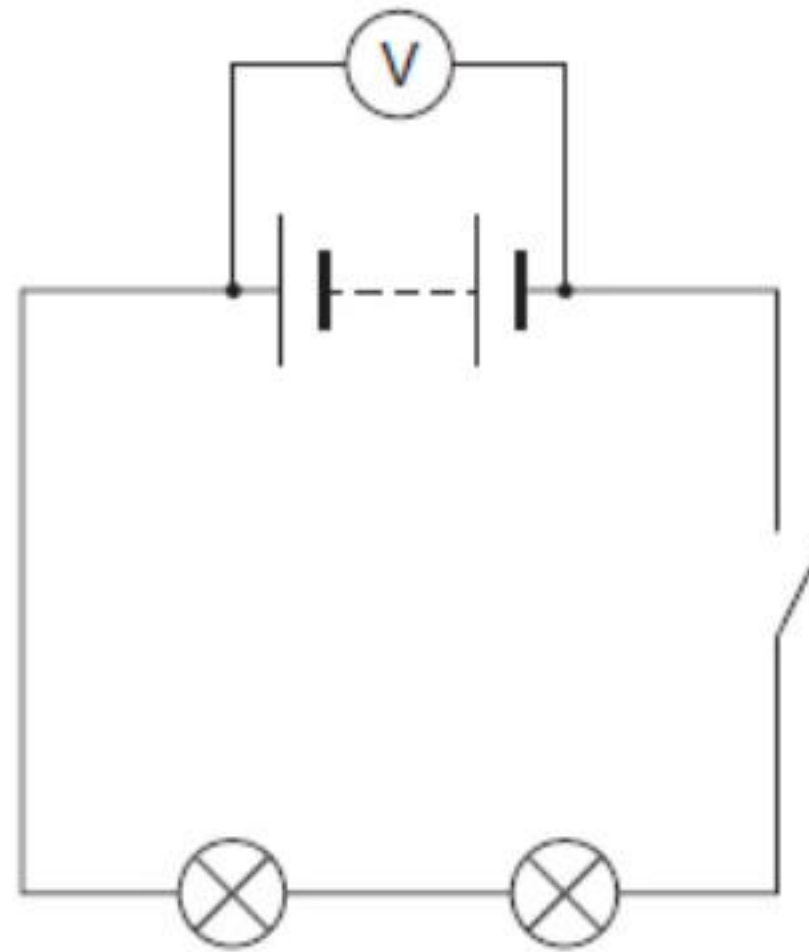
What is the internal resistance of the battery?

- | | | |
|----------|----------------|--------------------------|
| A | $0.66\ \Omega$ | ☐ |
| B | $0.76\ \Omega$ | ☐ |
| C | $1.3\ \Omega$ | ☐ |
| D | $1.5\ \Omega$ | ☐ |

(Total 1 mark)

3

The diagram shows an electrical circuit in a car. A voltmeter of very high resistance is used to measure the potential difference across the terminals of the battery.



- (a) Define potential difference.

(1)

- (b) Explain how and why the voltmeter reading changes when the switch is closed.

(3)

(Total 4 marks)

4

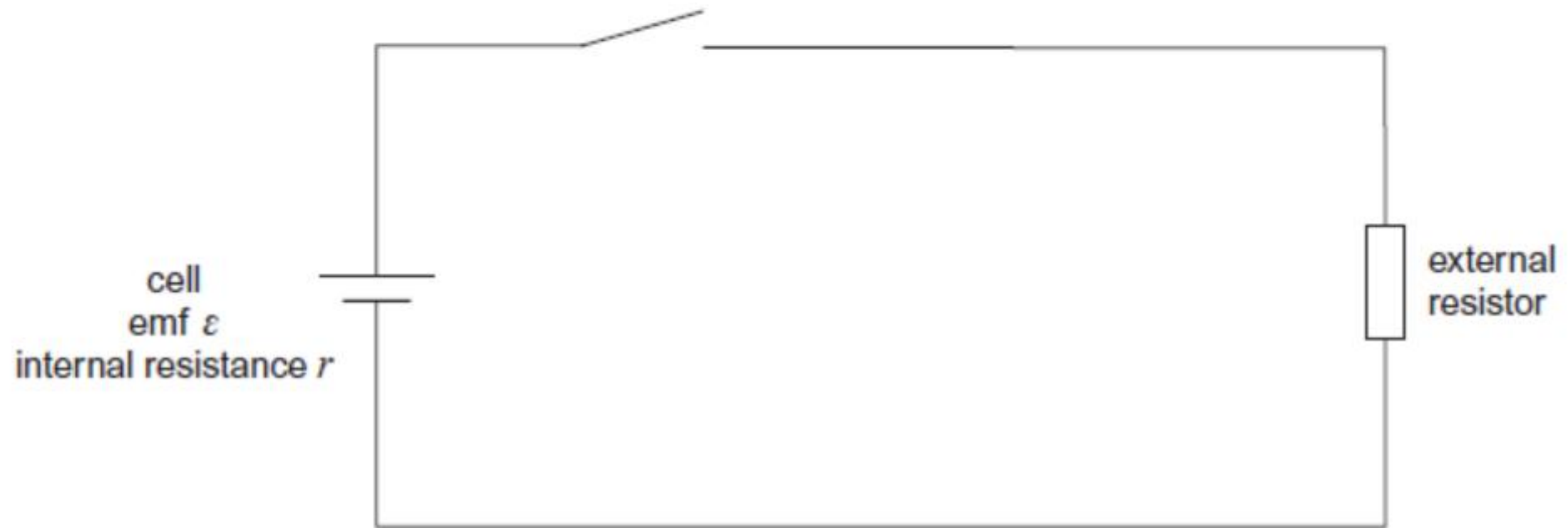
- (a) (i) Describe how you would make a direct measurement of the emf $\mathcal{E}$ of a cell, stating the type of meter you would use.

(1)

- (ii) Explain why this meter must have a very high resistance.

(1)

- (b) A student is provided with the circuit shown in the diagram below.



The student wishes to determine the efficiency of this circuit.

In this circuit, useful power is dissipated in the external resistor. The total power input is the power produced by the battery.

$$\text{Efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

The efficiency can be determined using two readings from a voltmeter.

- (i) Show that the efficiency = $\frac{V}{\varepsilon}$ where ε is the emf of the cell
and V is the potential difference across the external resistor.

(1)

- (ii) Add a voltmeter to the diagram and explain how you would use this new circuit to take readings of $\mathcal{E}$ and V .

(2)

- (c) Describe how you would obtain a set of readings to investigate the relationship between efficiency and the resistance of the external resistor. State any precautions you would take to ensure your readings were reliable.

(2)

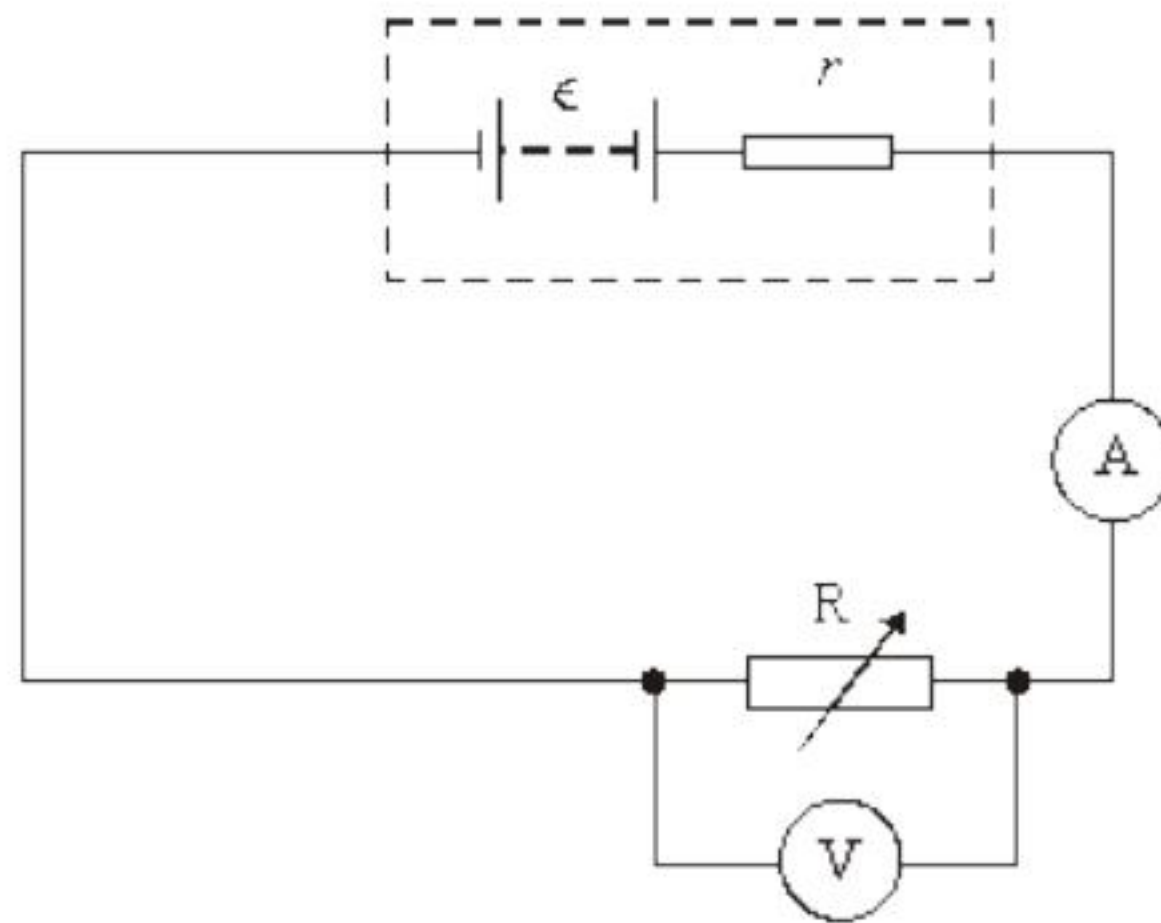
- (d) State and explain how you would expect the efficiency to vary as the value of R is increased.

(2)

(Total 9 marks)

5

A battery of emf ϵ and internal resistance r is connected in series to a variable resistor R and an ammeter of negligible resistance. A voltmeter is connected across R , as shown in the figure below.



- (a) (i) State what is meant by the emf of the battery.

- (ii) The reading on the voltmeter is less than the emf. Explain why this is so.

(2)

- (b) A student wishes to measure ϵ and r . Using the circuit shown in the figure above the value of R is decreased in steps and at each step the readings V and I on the voltmeter and ammeter respectively are recorded. These are shown in the table.

reading on voltmeter/V	reading on ammeter/A
8.3	0.07
6.8	0.17
4.6	0.33
2.9	0.44
0.3	0.63

- (i) Give an expression relating V , I , ϵ and r .

- (ii) Draw a graph of V (on the y -axis) against I (on the x -axis) on graph paper.

(Allow one sheet of graph paper)

- (iii) Determine the values of ϵ and r from the graph, explaining your method.

ϵ : _____

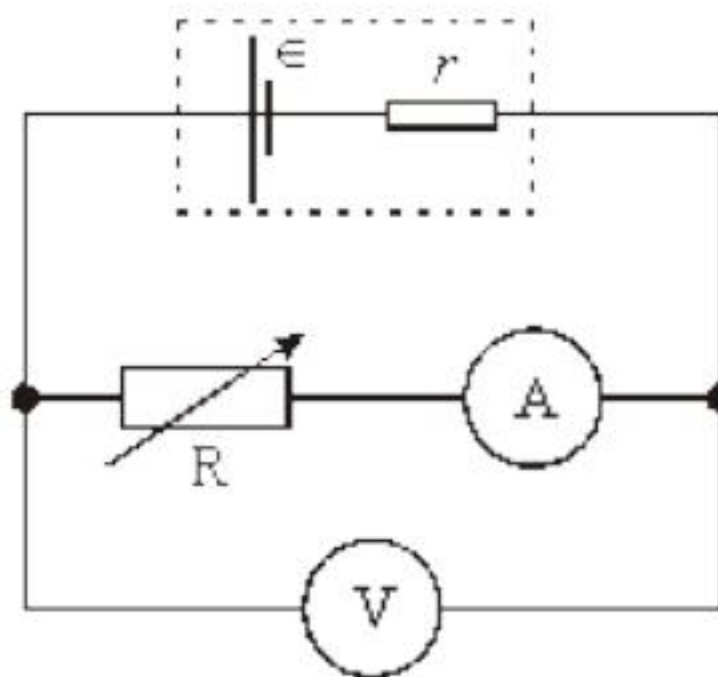
r : _____

(8)

(Total 10 marks)

6

In the circuit shown, a battery of emf ϵ and internal resistance r is connected to a variable resistor R . The current I and the voltage V are read by the ammeter and voltmeter respectively.



- (a) The emf is related to V , I and r by the equation

$$\epsilon = V + Ir$$

Rearrange the equation to give V in terms of ϵ , I and r .

(1)

- (b) In an experiment, the value of R is altered so that a series of values of V and the corresponding values of I are obtained. Using the axes, sketch the graph you would expect to obtain as R is changed.



(2)

- (c) State how the values of ϵ and r may be obtained from the graph.

ϵ _____

r _____

(2)

(Total 5 marks)

7

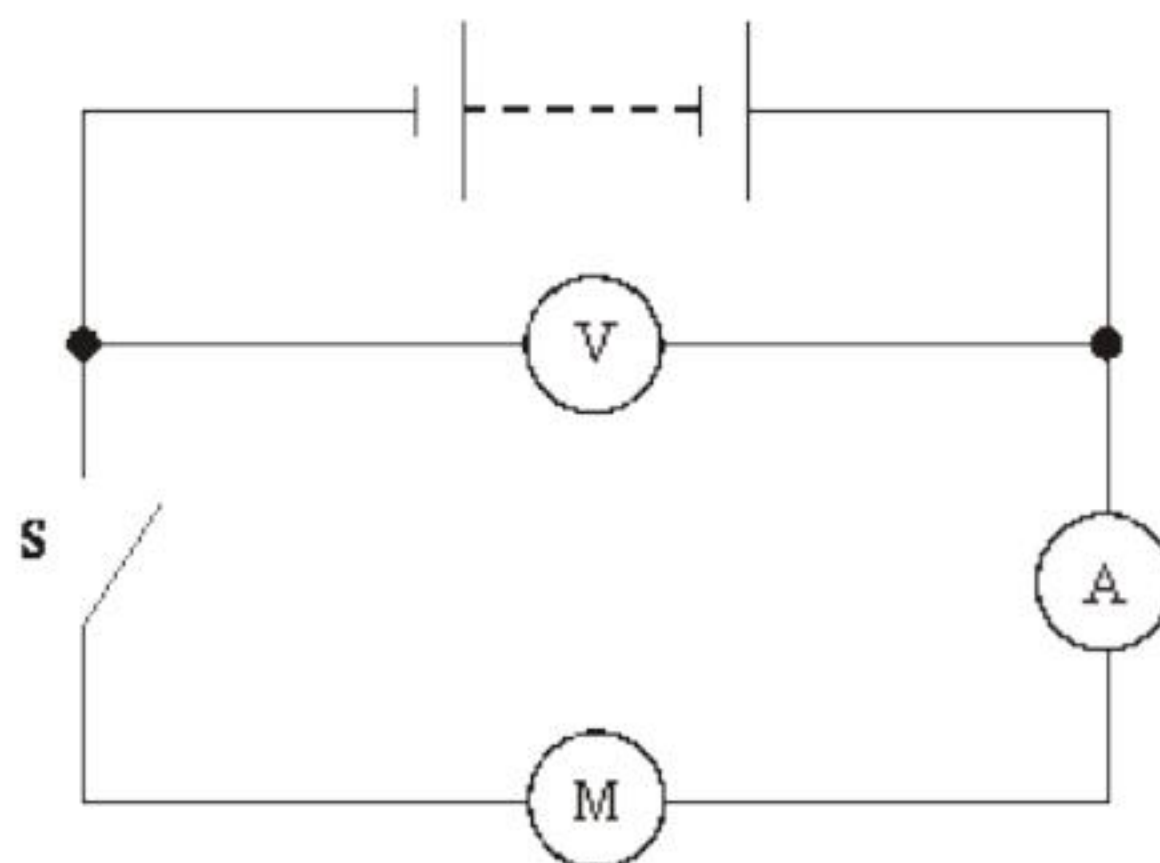
- (a) Define the *electromotive force (emf)* of an electrical power supply.

(2)

- (b) Explain why, when a battery is supplying a current to a circuit, the voltage measured between its terminals is less than its emf.

(2)

- (c) In the circuit shown in the figure below the voltmeter has a very high resistance and the resistance of the ammeter is negligible. The motor M is being tested using a battery with an emf of 9.00 V.



- (i) State the reading on the voltmeter when the switch S is open.

voltmeter reading _____

- (ii) When S is closed and the motor is allowed to run freely the voltmeter reading is 8.41 V and the ammeter reads 0.82 A. Calculate the internal resistance of the battery.

internal resistance _____

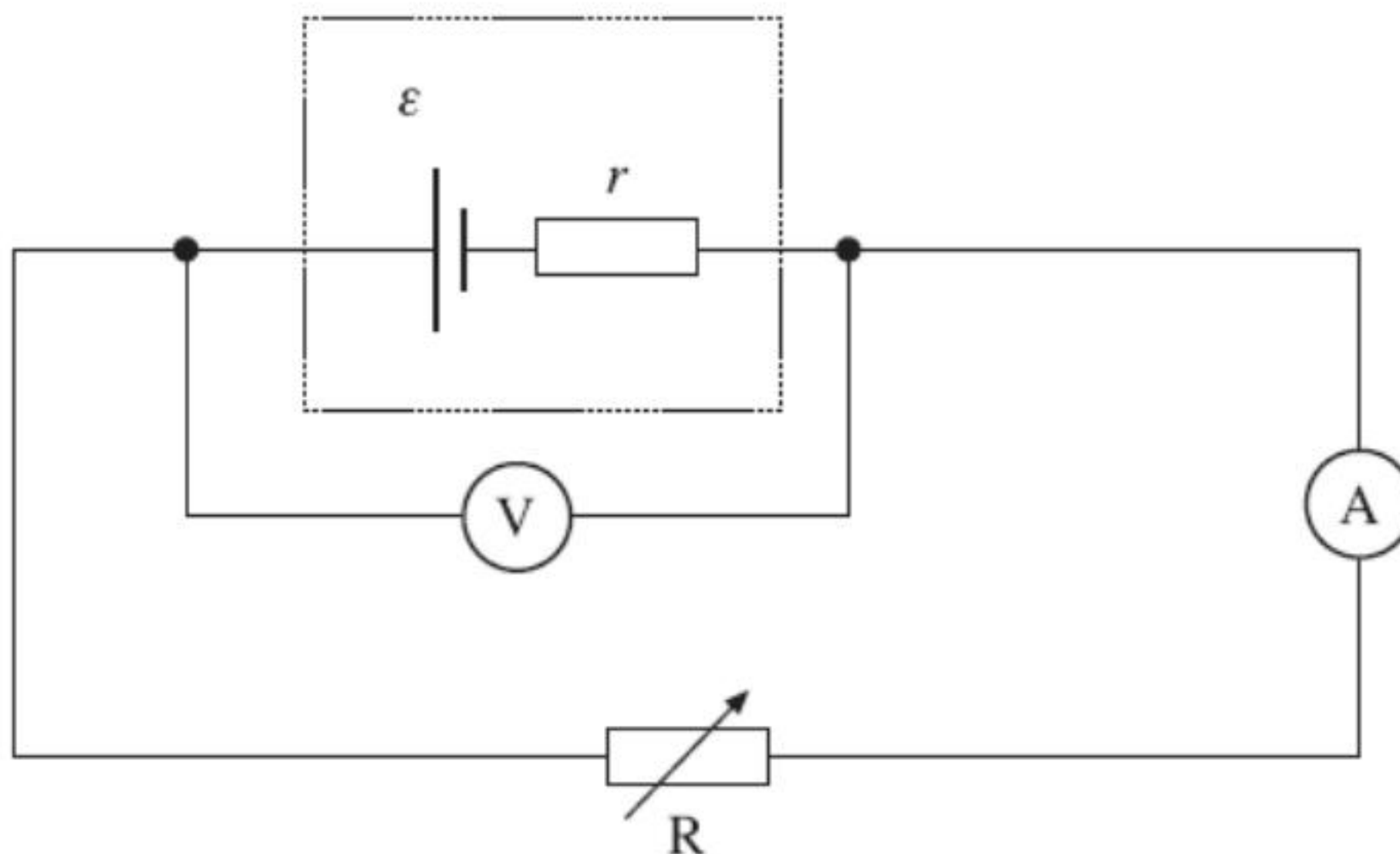
- (iii) Explain why the ammeter reading is greater than 0.82 A when the motor does work by lifting a load.

(5)

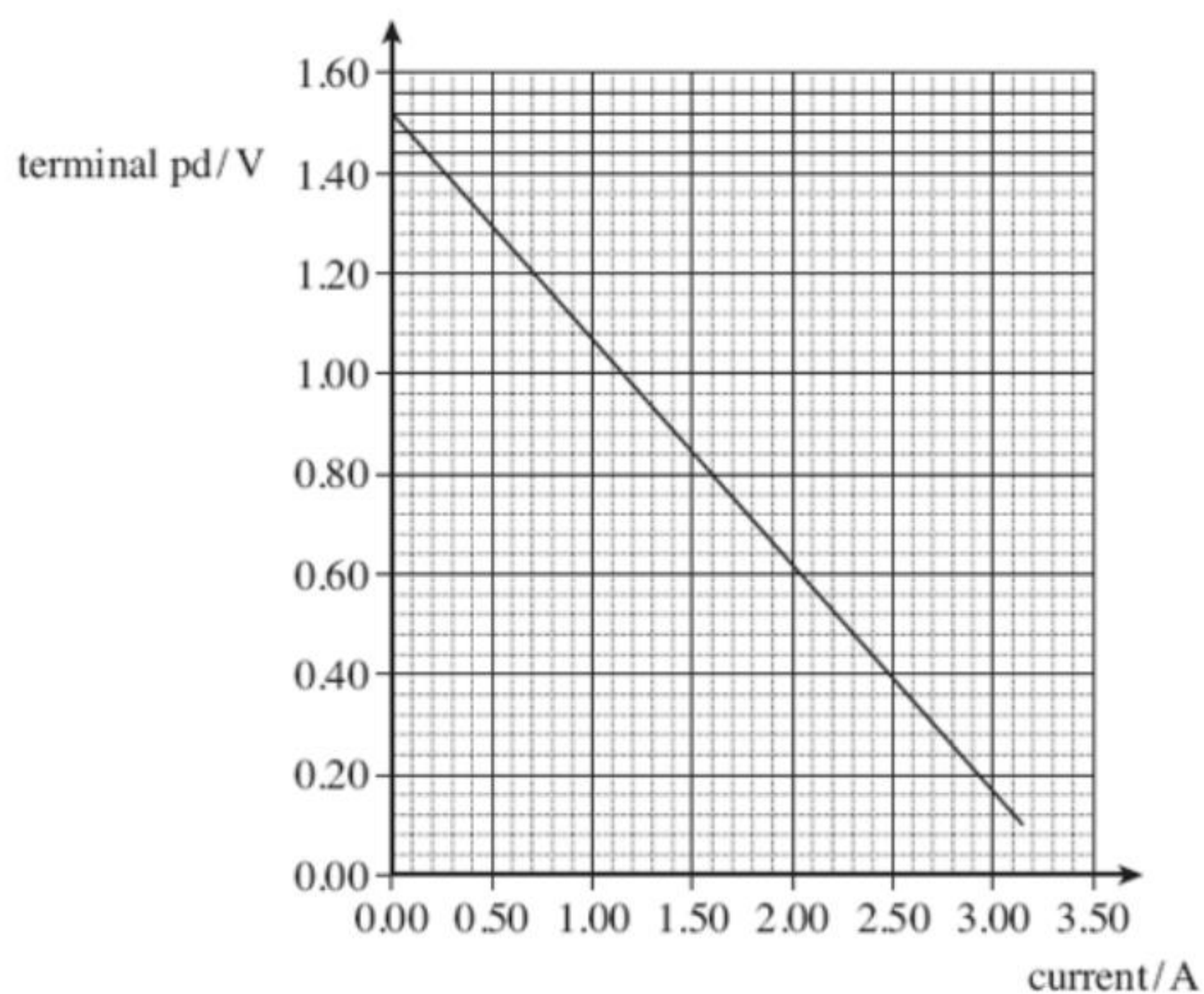
(Total 9 marks)

8

A cell of emf, $\mathcal{E}$, and internal resistance, r , is connected to a variable resistor R. The current through the cell and the terminal pd of the cell are measured as R is decreased. The circuit is shown in the figure below.



The graph below shows the results from the experiment.



- (a) Explain why the terminal pd decreases as the current increases.

(2)

- (b) (i) Use the graph to find the emf, $\mathcal{E}$, of the cell.

answer = _____ V

(1)

- (ii) Use the graph above to find the internal resistance, r , of the cell.

answer = _____ Ω

(3)

- (c) Draw a line on the graph above that shows the results obtained from a cell with
- (i) the same emf but double the internal resistance of the first cell labelling your graph **A**.

(2)

- (ii) the same emf but negligible internal resistance labelling your graph **B**.

(1)

- (d) In the original circuit shown in part (a), the variable resistor is set at a value such that the current through the cell is 0.89 A.

- (i) Calculate the charge flowing through the cell in 15 s, stating an appropriate unit.

answer = _____

(2)

- (ii) Calculate the energy dissipated in the internal resistance of the cell per second.

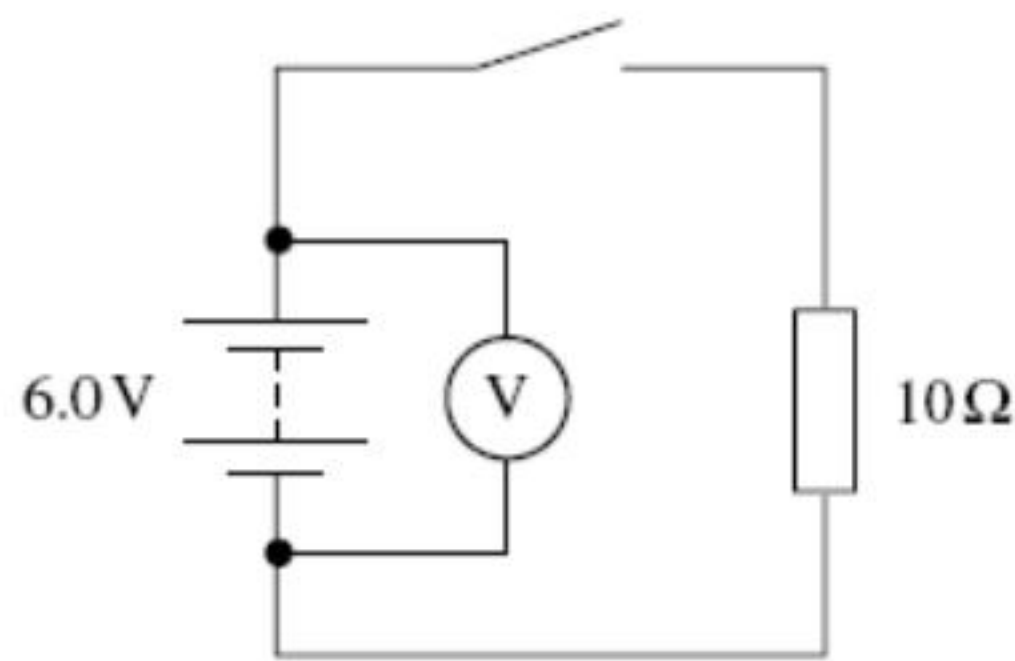
answer = _____ W

(2)

(Total 13 marks)

9

A battery is connected to a $10\ \Omega$ resistor as shown in the diagram below. The emf (electromotive force) of the battery is $6.0\ \text{V}$.



- (a) (i) Define the emf of a battery.

(1)

- (ii) When the switch is open the voltmeter reads $6.0\ \text{V}$ and when it is closed it reads $5.8\ \text{V}$.
Explain why the readings are different.

(2)

- (b) Calculate the internal resistance of the battery.

answer = _____ Ω

(3)

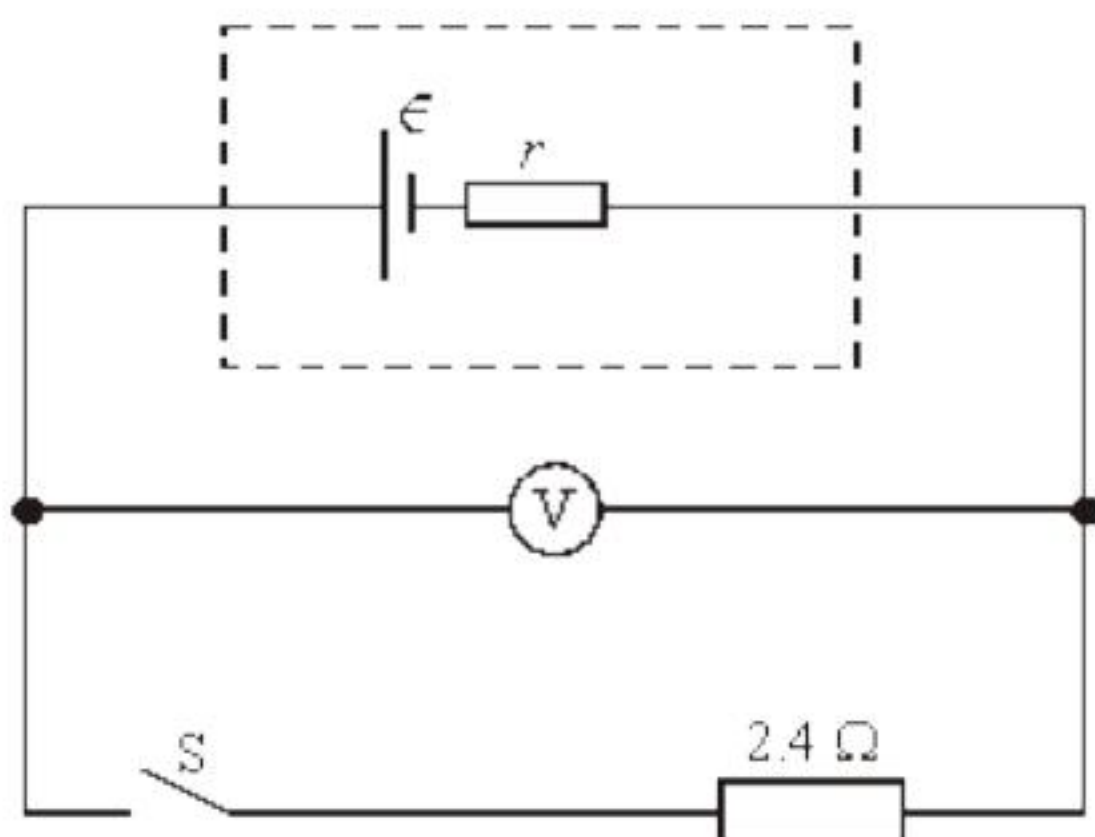
- (c) State and explain why it is important for car batteries to have a very low internal resistance.

(2)

(Total 8 marks)

10

In the circuit shown the battery has emf ϵ and internal resistance r .



- (a) (i) State what is meant by the emf of a battery.

- (ii) When the switch S is open, the voltmeter, which has infinite resistance, reads 8.0 V. When the switch is closed, the voltmeter reads 6.0 V. Determine the current in the circuit when the switch is closed.

- (iii) Show that $r = 0.80 \, \Omega$.

(4)

- (b) The switch S remains closed. Calculate

- (i) the power dissipated in the $2.4 \, \Omega$ resistor,

- (ii) the total power dissipated in the circuit,

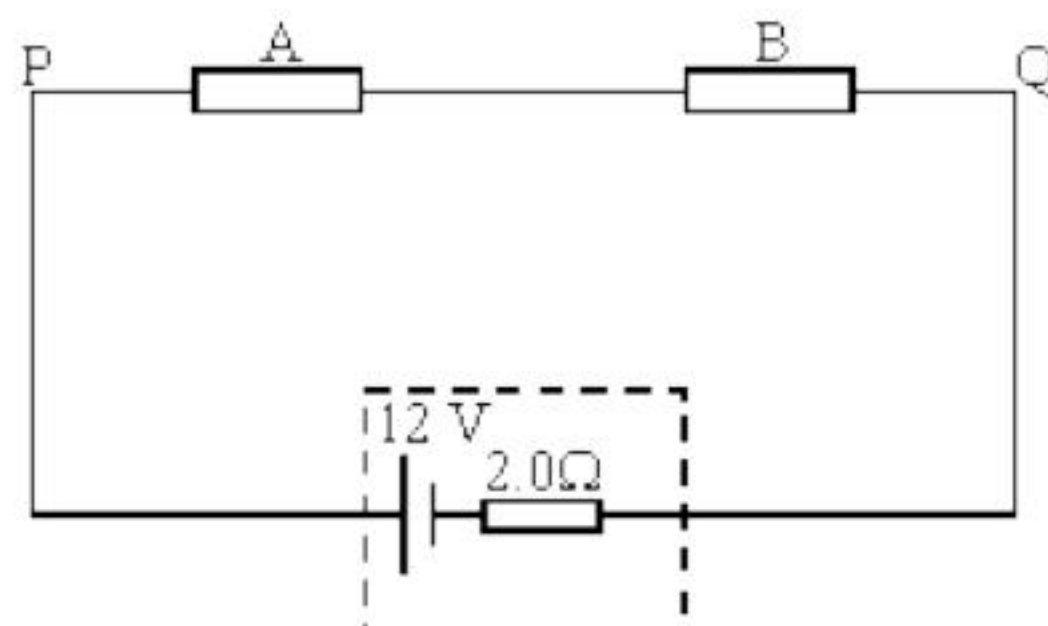
- (iii) the energy wasted in the battery in 2 minutes.

(4)

(Total 8 marks)

11

In the circuit shown, the battery has an emf of 12 V and an internal resistance of $2.0 \, \Omega$. The resistors A and B each have resistance of $30 \, \Omega$.



Calculate

- (i) the total current in the circuit,

- (ii) the voltage between the points P and Q,

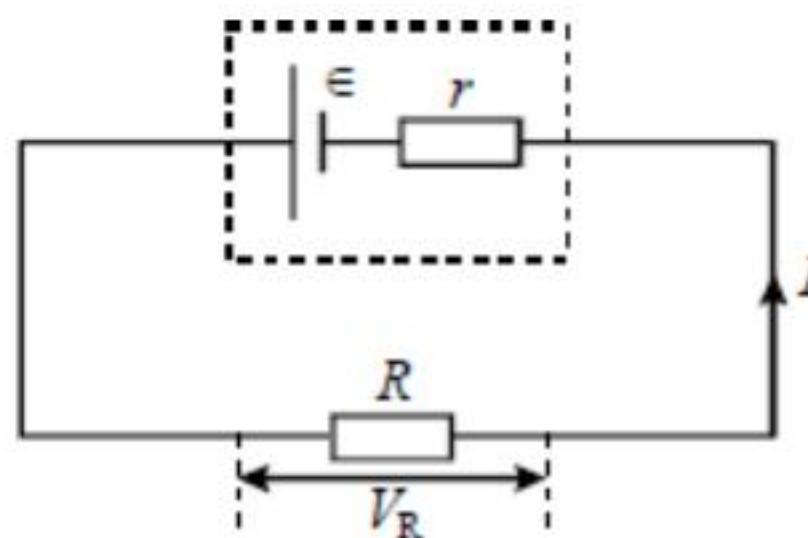
- (iii) the power dissipated in resistor A,

- (iv) the energy dissipated by resistor A in 20 s.

(Total 8 marks)

12

- (a) A cell of emf ϵ and internal resistance r is connected in series to a resistor of resistance R as shown. A current I flows in the circuit.



- (i) State an expression which gives ϵ in terms of I , r and R .

- (ii) Hence show how V_R , the potential difference across the resistor, is related to ϵ , I and r .

(2)

- (b) A lamp, rated at 30 W, is connected to a 120 V supply.

- (i) Calculate the current in the lamp.

- (ii) If the resistor in part (a) is replaced by the lamp described in (b), determine how many cells, each of emf 1.5 V and internal resistance $1.2\ \Omega$, would have to be connected in series so that the lamp would operate at its proper power.

(5)

(Total 7 marks)

13

A battery of e.m.f. $\mathcal{E}$ and internal resistance r is connected in series with a variable resistor R as shown in **Figure 1**. A voltmeter is connected as shown.

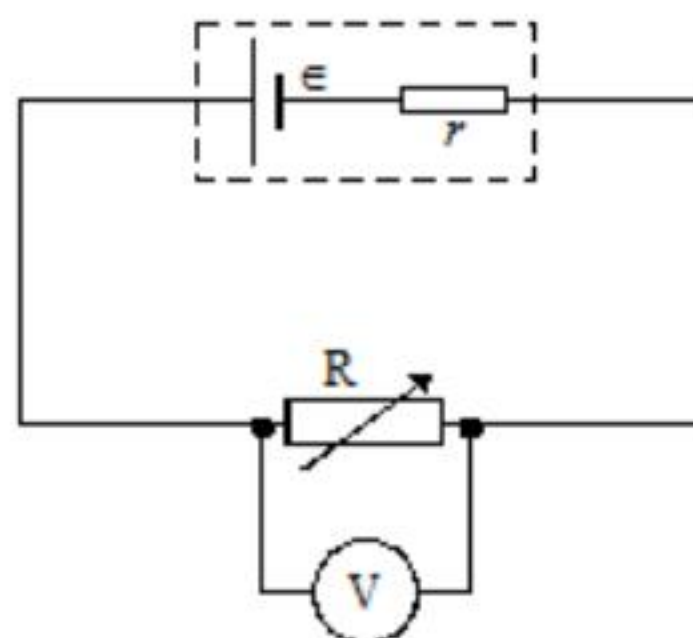


Figure 1

- (a) (i) State what is meant by the e.m.f of a battery.

- (ii) The reading V on the voltmeter is the voltage across R .
Why is V less than $\mathcal{E}$?

(3)

- (b) In order to measure ε and r , an ammeter is used in the circuit, as shown in **Figure 2**.

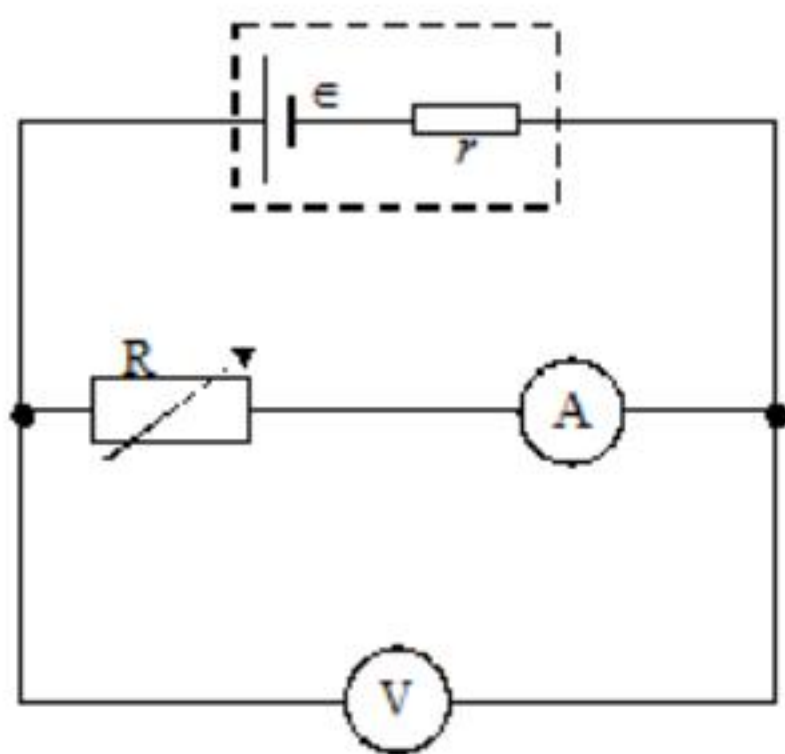
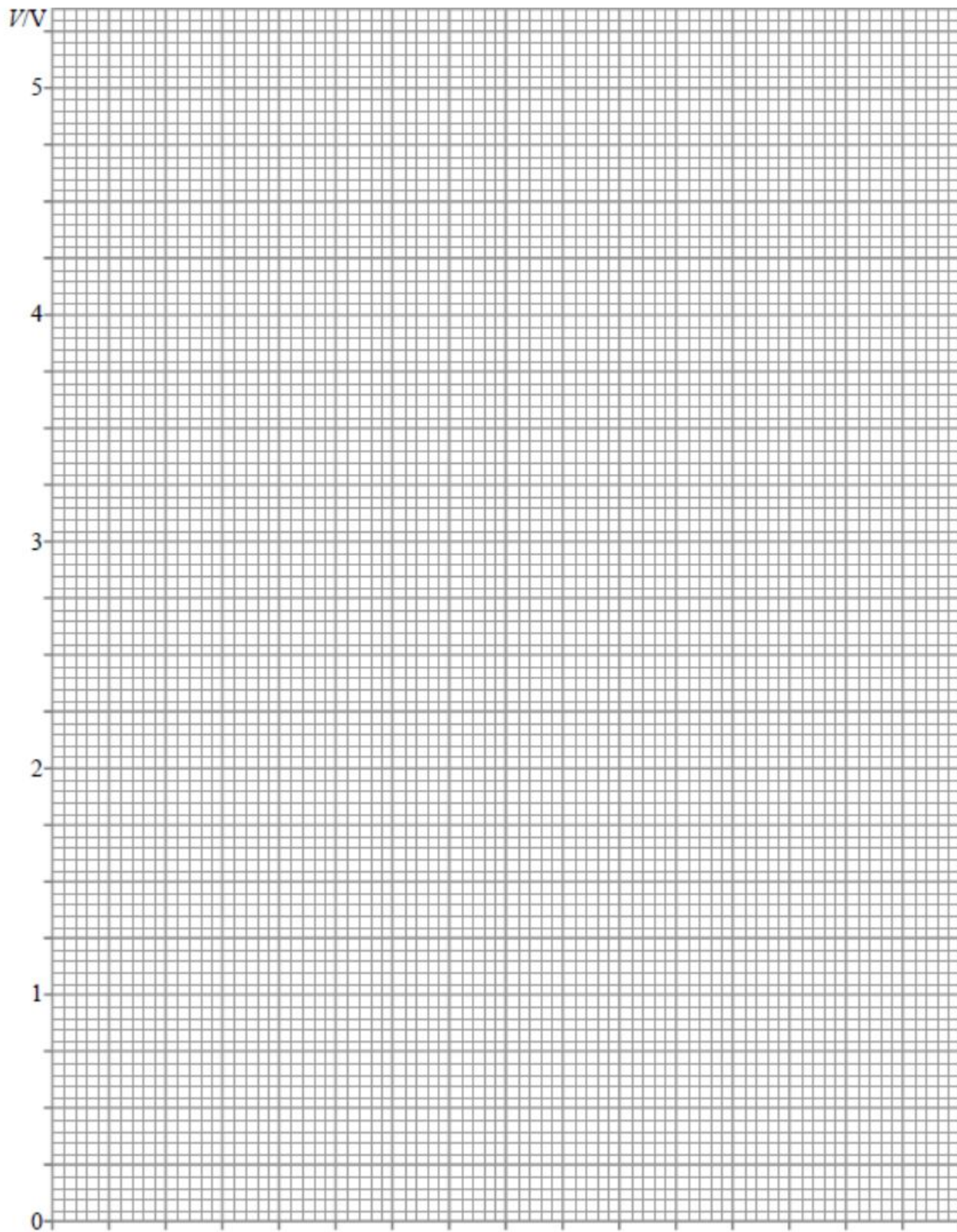


Figure 2

The value of R is decreased in steps and at each step the readings V and I on the voltmeter and ammeter, respectively, are recorded. These are shown in the table.

reading on voltmeter/ V	reading on ammeter/ A
4.0	0.07
3.0	0.14
2.0	0.21
1.0	0.28

- (i) Plot a graph of V (on y axis) against I (on x axis) and draw the best straight line through the points.



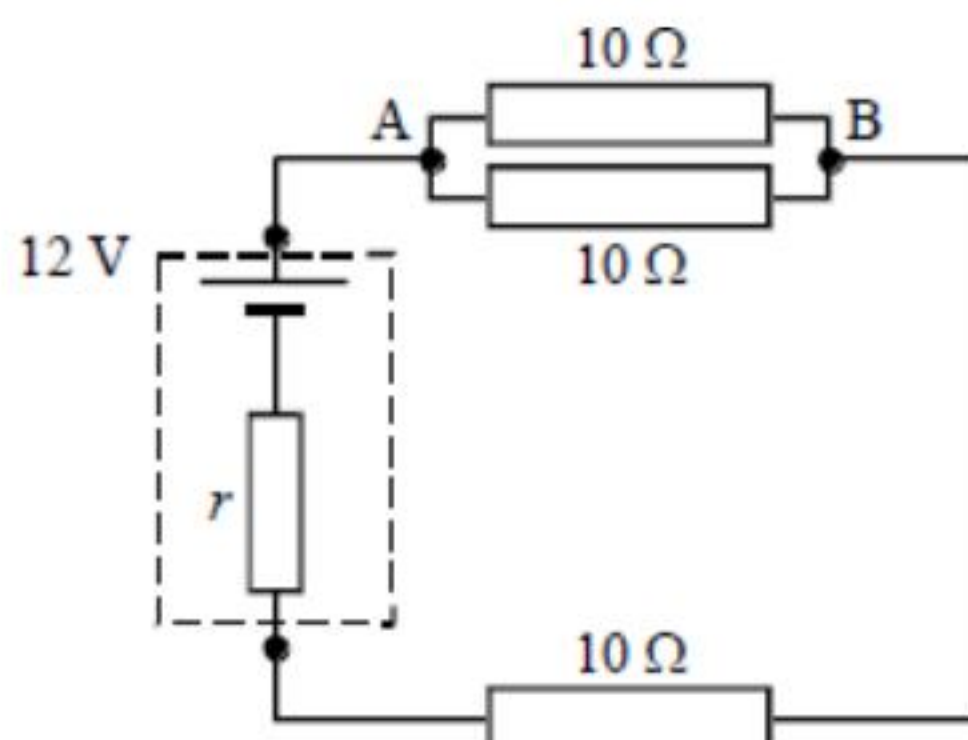
- (ii) Determine the values of ε and r from the graph, explaining your method.

(8)

(Total 11 marks)

14

A battery of e.m.f. 12 V and internal resistance r is connected in a circuit with three resistors each having a resistance of $10\ \Omega$ as shown. A current of 0.50 A flows through the battery.



Calculate

- (a) the potential difference between the points A and B in the circuit,

- (b) the internal resistance of the battery,

(c) the total energy supplied by the battery in 2.0 s,

(d) the fraction of the energy supplied by the battery that is dissipated within the battery.

(Total 7 marks)

Mark schemes

1	D				[1]
2	D				[1]
3	(a)	work done per unit charge <i>Allow $V=W/Q$ if W and Q defined</i>	1		
	(b)	Voltmeter reading / terminal pd drops Battery has internal resistance pd occurs within battery / 'lost volts' within battery / emf is shared between internal and external resistances	3		[4]
4	(a)	(i) Voltmeter across terminals with nothing else connected to battery / no additional load. ✓	1		
		(ii) This will give zero / virtually no current ✓	1		
	(b)	(i) $\frac{VI}{\mathcal{E}I}$ Answer must clearly show power: $\mathcal{E}I$ and VI , with I cancelling out to give formula stated in the question ✓	1		
		(ii) Voltmeter connected across cell terminals ✓ Switch open, voltmeter records $\mathcal{E}$ Switch closed, voltmeter records V Both statements required for mark ✓ <i>Candidates who put the voltmeter in the wrong place can still achieve the second mark providing they give a detailed description which makes it clear that:</i> <i>To measure emf, the voltmeter should be placed across the cell with the external resistor disconnected</i> <u>And</u> <i>To measure V, the voltmeter should be connected across the external resistor when a current is being supplied by the cell</i>	2		

- (c) Vary external resistor and measure new value of V , for at least 7 different values of external resistor ✓

Precautions - switch off between readings / take repeat readings (to check that emf or internal resistance not changed significantly) ✓

2

- (d) Efficiency increases as external resistance increases ✓

Explanation

Efficiency = Power in R / total power generated

$$I^2 R / I^2 (R + r) = R / (R + r)$$

So as R increases the ratio becomes larger or ratio of power in load to power in internal resistance increases ✓

Explanation in terms of V and ε is acceptable

2

[9]

5

- (a) (i) electrical energy produced (in the battery) per unit charge (1)
[or potential/voltage across terminals when there is no current]
- (ii) there is a current (through the battery) (1)
voltage 'lost' across the internal resistance (1)

Max 2

- (b) (i) $\varepsilon = V + Ir$ (1)
- (ii) labelled scales (1)
correct plotting (1)
best straight line (1)
 ε : intercept on y axis (1) = 9.2 (± 0.1) V (1)

$$r: (-) \text{ gradient} = \frac{9.2}{0.65} = 14.2 \, \Omega \text{ (1) (range 14.0 to 14.3)}$$

8

[10]

6

- (a) $V = -Ir + \varepsilon$ (1)
- (b) straight line (within 1st quadrant) (1)
negative gradient (1)
- (c) ε : intercept on voltage axis (1)
 r : gradient (1)

1

2

2

[5]

7

- (a) the (total) energy transferred/work done when one unit/coulomb of charge

B1

is moved around a circuit/provided by the supply

B1

2

- (b) work is done inside the battery/there is resistance inside the battery

B1

so less energy is available for the external circuit/some voltage is lost between the terminal/mention of lost volts

B1

2

- (c) (i) 9.00 V

c.a.o.

B1

- (ii) lost voltage = $E - V$ or $E = I(R + r)$

C1

$$0.82r = 0.59$$

C1

5

$$\text{internal resistance} = 0.720 \, \Omega$$

A1

- (iii) because the battery has to provide more energy/power

B1

[9]

8

- (a) mention of pd across internal resistance **or** energy loss in internal resistance **or** $\text{emf} > V$ ✓

pd across internal resistance/lost volts increases with current **or** correct use of equation to demonstrate ✓

2

- (b) (i) y – intercept $1.52 \text{ V } (\pm 0.01 \text{ V})$ ✓ 1
- (ii) identifies gradient as r **or** use of equation ✓
 substitution to find gradient **or** substitution in equation ✓
 $r = 0.45 \pm 0.02 \Omega$ ✓ 3
- (c) (i) same intercept ✓
 double gradient (must go through $1.25, 0.40 \pm 1.5$ squares) ✓ 2
- (ii) same intercept horizontal line ✓ 1
- (d) (i) (use of $Q = It$)
 $Q = 0.89 \times 15 = 13$ ✓ C ✓ 2
- (ii) use of $P = I^2 r$ ✓
 $P = 0.89^2 \times 0.45$
 $P = 0.36 \text{ W}$ ✓ 2

[13]

9

- (a) (i) work (done)/energy (supplied) per unit charge (by battery) (1)
 (or pd across terminals when no current passing through
 cell or open circuit) 1
- (ii) when switch is closed a **current flows** (through the battery) (1)
 hence a pd/lost volts develops across the internal resistance (1) 2
- (b) (use of $\epsilon = V + Ir$)
 $I = 5.8/10 = 0.58 \text{ (A)}$ (1)
 $6.0 = 5.8 + 0.58r$ (1)
 $r = 0.2/0.58 = 0.34 \text{ (}\Omega\text{)}$ (1) 3

- (c) need large current/power to start the car **(1)** (or current too low)

internal resistance limits the current/wastes power(or energy)/reduces terminal pd/increases lost volts **(1)**

2

[8]

10

- (a) (i) energy changed to electrical energy per unit charge/coulomb passing through
[or electrical energy produced per coulomb or unit charge]
[or pd when no current passes through/or open circuit] **(1)**

(ii) $I = \frac{6}{2.4} = 2.5 \text{ A}$ **(1)**

(iii) (use of $\epsilon = I(R + r)$ gives) $\epsilon = V + Ir$ and $8 = 6 + Ir$ **(1)**

substitution gives $8 - 6 = 2.5r$ **(1)** (and $r = 0.8 \Omega$)

4

(b) (i) (use of $P = I^2 R$ gives) $P_R = 2.5^2 \times 2.4 = 15 \text{ W}$

[or $P = VI$ gives $P = 6 \times 2.5 = 15 \text{ W}$] **(1)**

(allow C.E. for value of I from (a))

(ii) $P_T = 15 + (2.5^2 \times 0.8)$ **(1)**
 $= 20 \text{ (W)}$ **(1)**

(allow C.E. for values of P_R and I)

(iii) $E = 5 \times 2 \times 60 = 600 \text{ J}$ **(1)**

(allow C.E. for value of P from (i) and P_T from (ii))

4

[8]

11

(i) ($V = IR$ gives) $12 = (30 + 30 + 2)I$ **(1)**

$I = \left(\frac{12}{62}\right) = 0.19 \text{ A}$ **(1)** (0.194 A)

(ii) $V_{PQ} = 12 - (0.19 \times 2)$ **(1)**
 $= 11.6 \text{ V}$ **(1)**

(allow C.E. for incorrect I in (i))

[or $V_{PQ} = 0.19 \times 60 = 11.6 \text{ V}$] ($I = 0.194 \text{ A}$ gives 11.6 V)

[or $V_{PQ} = 12 \times \frac{60}{62} = 11.6 \text{ V}$]

(iii) ($P_A = I^2 R$ gives) $P_A = (0.19)^2 \times 30 = 1.08$ (1) W (1)

[or $P_A = \frac{V^2}{R}$]

(allow C.E. for incorrect I in (i) or incorrect V in (ii))

(iv) ($E = P_A t$ gives) $E = 1.08 \times 20$ (1)

$= 21.6$ J (1)

(allow C.E. for incorrect P_A in (iii))

[8]

12

(a) (i) $\epsilon = I(R + r)$ (1)

(ii) $V_R = IR$ gives $V_R = \epsilon - I_r$ (1)

2

(b) (i) $P = VI$ gives $30 = 120 I$ (1)
 $I = 0.25$ A (1)

(ii) I through lamp = 0.25 (A) and p.d. across it = 240 V (1)
 p.d. due to 1 cell = $1.5 - (0.25 \times 1.2) = 1.2$ (V) (1)

number of cells = $\frac{120}{1.2} = 100$ (1)

[or R_L given by $30 = 0.25^2 R_L$ and $R_L = 480$ (Ω) (1)

$1.5n = 0.25(480 + 1.2n)$ (1)

$1.2n = 120$ and $n = 100$ (1)]

[or $\epsilon = V + Ir$ gives $1.5n = 120 + 0.25 \times 1.2n$ (2)

$n = 100$ (1)]

5

[7]

13

(a) (i) energy provided by the battery (1)
 per unit charge (1)
 [or potential difference across battery (1) when no current flows (1)]

(ii) when current flows, work is done inside the battery
 to overcome the resistance (hence $V < \epsilon$) (1)
 (or any correct alternative)

(3)

(b) (i) suitable scale for I (1)
 four correct points (1) (1)
 best straight line (1)

- (ii) ($\epsilon = Ir + V$ gives) $V = -rI + \epsilon$ (1)
 intercept = $\epsilon = 5 \text{ V}$ (1)
 gradient = $(-r)$ (1)

$$= \frac{5}{0.35} = 14.2857 \approx 14.3 \Omega \text{ (1)}$$

(8)

[11]

14

- (a) $R_{AB} = 5.0 \Omega$ (1)
 $V (= 5.0 \times 0.50) = 2.5 \text{ V}$ (1)

- (b) $V_r = 12 - 2.5 + 5.0$ (1) $= 4.5 \text{ (V)}$ (1)

$$r = \left(\frac{V_r}{I} = \frac{4.5}{0.5} \right) = 9.0 \Omega \text{ (1)}$$

- (c) $W (= EIt) = 12 \text{ J}$ (1)

- (d) $W_r (= V_r It) = 4.5 \text{ (J)}$ (1)

$$\frac{W_r}{W} \left(= \frac{4.5}{12} \right) = 0.375 \text{ (1)}$$

[Max 7]