AS Level Physics

Chapter 9 – Electrical Circuits

9.2.2 Internal Resistance

Worked Examples

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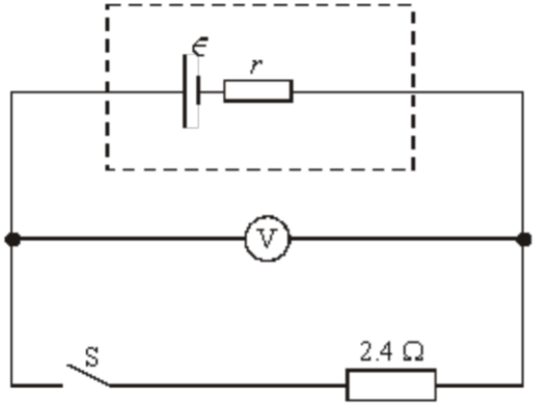
Internal Resistance

Exam Style Question 1

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 $r = 0.80\ \Omega$.

(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.

Internal Resistance

Exam Style Question 1

(a) (i) State what is meant by the emf of a battery.
Energy changed to electrical energy per unit charge passing through, or the p.d. when no current passes through.

(ii) Determine the current in the circuit when the switch is closed.
Use $V = IR$ and rearrang for I

$$I = \frac{V}{R} = \frac{6.0\ V}{2.4\ \Omega} = 2.5\ A$$

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

$$E = V + Ir$$
$$8.0\ V = 6.0\ V + (2.5\ A)r$$
$$8 - 6 = 2.5\ r$$
$$2 = 2.5\ r$$
$$r = \frac{2}{2.5} = 0.8\ \Omega$$

(b) Calculate:
(i) The power dissipated in the $2.4\ \Omega$ resistor,

Use $P = I^2R$

$$P = (2.5\ A)^2(2.4\ \Omega) = 15\ W$$

(ii) The total power dissipated in the circuit,

Use $P = I^2R$ and calculate the power dissipated by the battery because of its internal resistance:

$$P = (2.5\ A)^2(0.8\ \Omega) = 5\ W$$

Therefore the total power dissipated is:

$$P = 15\ W + 5\ W = 20\ W$$

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

Use $P = \frac{E}{t}$ and rearrange for E. Remember to convert time to seconds:

$$E = P \times t = (5\ W)(2\ minutes \times 60\ seconds) = 600\ J$$

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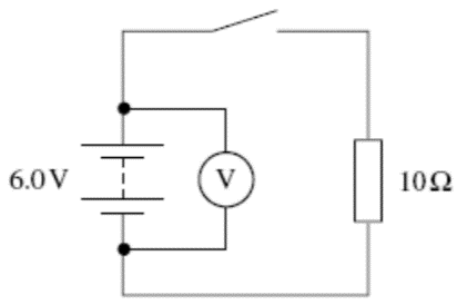
Internal Resistance

Exam Style Question 2

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



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

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

(b) Calculate the internal resistance of the battery.

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

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Internal Resistance

Exam Style Question 2

(a) (i) Define the emf of a battery.
Energy supplied per unit charge by the battery or p.d. across terminals when no current is passing through the cell.

(a) (ii) Explain why the readings are different.
When the switch is closed a current flows through the battery and hence lost volts are developed due to internal resistance.

(b) Calculate the internal resistance of the battery.

Step 1: Calculate current
We don't have I so use $V = IR$ and rearrange for I. Make sure to use $5.8\ V$ because a current only flows when the switch is closed:

$$I = \frac{V}{R} = \frac{5.8\ V}{10\ \Omega} = 0.58\ A$$

Step 2: Use $\varepsilon = V + Ir$

$$6.0\ V = 5.8\ V + (0.58\ A)r$$

$$(0.58)r = 6.0 - 5.8$$

$$r = \frac{0.2}{0.58} = 0.34\ \Omega$$

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

Low internal resistance means there can be a large current and this large current is needed to start the car. Internal resistance limits the current and increases lost volts.

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Internal Resistance

Exam Style Question 3

(a) In the circuit shown in Figure 1, the battery has an emf of $6.0\ V$. With the switch closed and the lamp lit, the reading on the voltmeter is $5.4\ V$.

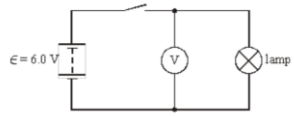


Figure 1

Explain without calculation, why the voltmeter reading is less than the emf of the battery.

(b) A torch is powered by two identical cells each having an emf of $1.5\ V$ and an internal resistance r. The cells are connected in series. The torch bulb is rated at $1.6\ W$ and the voltage across it is $2.5\ V$.

(i) Draw the circuit described.

(ii) Calculate the internal resistance of each cell.

(c) In the circuit in Figure 2 the cell has emf ε and internal resistance r. The voltage V across the cell is read on the voltmeter which has infinite resistance, and the current I through the variable resistor R is read on the ammeter.

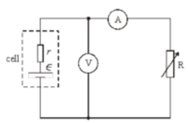


Figure 2

By altering the value of the variable resistor R, a set of values of V and I is obtained. These values, when plotted, give the graph shown in Figure 3.

Show how the values of ε and r may be obtained from this graph. Explain your method

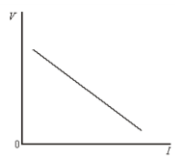


Figure 3

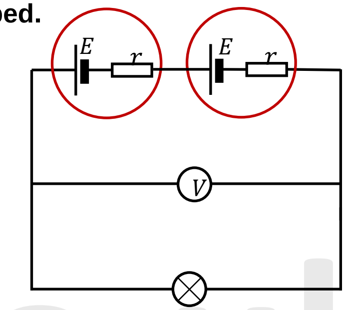
Internal Resistance

Exam Style Question 3

(a) Explain without calculation, why the voltmeter reading is less than the emf of the battery.

The battery has internal resistance when current passes through and lost volts are developed which reduces the value of the emf.

(b) (i) Draw the circuit described.



(b) (ii) Calculate the internal resistance of each cell.

Step 1: Calculate the current through the circuit using $P = IV$ and rearrange for I:

$$I = \frac{P}{V} = \frac{1.6\ W}{2.5\ V} = 0.64\ A$$

Step 2: Use $\varepsilon = V + Ir$ and rearrange for r:

$$r = \frac{\varepsilon - V}{I} = \frac{3.0\ V - 2.5\ V}{0.64\ A} = 0.78125\ \Omega$$

Step 3: Because there are two cells divide the answer by two:

$$r = \frac{0.78125\ \Omega}{2} = 0.390625\ \Omega = 0.39\ \Omega$$

(c) Show how the values of ε and r may be obtained from this graph. Explain your method.

Using $\varepsilon = V + Ir$ rearrange it to get $V = -Ir + \epsilon$ which is the equation of a straight line where:

ε = y-intercept

r = gradient

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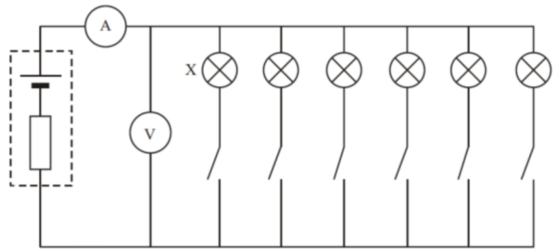
Internal Resistance

Exam Style Question 4

A student models a stage lighting system using a circuit-drawing computer package and a spreadsheet. He starts with a power supply of e.m.f. $120\ V$, and internal resistance $15\ \Omega$. He assumes that each lamp has fixed resistance $60\ \Omega$. He is interested in the effect of turning on the lamps one at a time, so that the number of lamps switched on increases from one to six. His circuit and part of his spreadsheet are shown below.



	A	B	C	D	E
1	Number of lamps switched on	Net resistance of lamps/Ω	Total current from supply/A	p.d. across lamps/V	Power to all lamps/W
2					
3	1	60	1.6	96	154
4	2	30	2.7	80	213
5	3	20	3.4	69	235
6	4	15	4.0	60	240
7	5	12	4.4	53	
8	6	10	4.8	48	230

a) The student has assumed that the voltmeter would have no effect on any of the values he has calculated. Explain why this is an appropriate assumption.

b) When 6 lamps are on (row 8), how much current flows through lamp X?

c) Calculate the value missing from cell E7.

d) The lamp marked X is the first to be switched on. Explain how lamp X would appear as successive lamps are switched on.

e) What would be a suitable formula for calculating cell C6?

f) Comment on how the internal resistance of the power supply affects the way in which the values in column E vary.

Internal Resistance

Exam Style Question 4

a)Explain why this is an appropriate assumption.

Voltmeter has very high resistance and so takes in very small current.

(b) When 6 lamps are on (row 8), how much current flows through lamp X?

All the lamps have the same resistance therefore:

$$I = \frac{4.8\ A}{6} = 0.8\ A$$

(c) Calculate the value missing from cell E7.

Use $P = IV$

$$P = 4.4\ A \times 53\ V = 233\ W$$

(d) The lamp marked X is the first to be switched on. Explain how lamp X would appear as successive lamps are switched on.

Lamp X gets dimmer. As you can see from the table voltage is decreasing and the current in X is also decreasing. So power decreases.

(e) What would be a suitable formula for calculating cell C6?

Use $V = IR$ and rearrange for I, therefore:

$$I = \frac{\varepsilon}{R_{total}}$$

$$I = \frac{120}{(15\ \Omega + B6)}$$

(f) Comment on how the internal resistance of the power supply affects the way in which the values in column E vary.

Power has a maximum value and that's when external resistance = internal resistance. After that is achieved power starts to decrease.

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Internal Resistance

Exam Style Question 5

Fig. 1 shows a cell of $e.m.f.\ E$ and internal resistance r connected to a variable resistor.

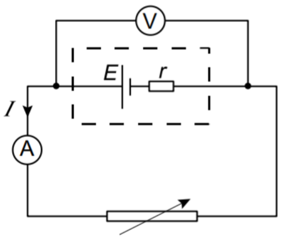

Fig. 1

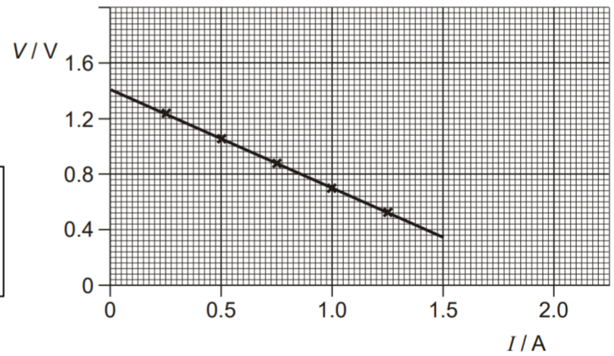

Fig. 2

Fig. 2 shows the variation of the p.d. V across the terminals of the cell with the current I drawn from the cell.

(a) Explain how Fig. 2 shows that the e.m.f. E is $1.4\ V$.

(b) (i) Use Fig. 2 to determine the maximum possible current that can be drawn from the cell.

(ii) Calculate the internal resistance r of the cell.

(iii) Suggest why it may not be advisable to maintain the current determined in (b)(i) for a long time.

Internal Resistance

Exam Style Question 5

(a)Explain how Fig. 2 shows that the e.m.f. E is $1.4\ V$.

$E = V + Ir$ and you can rearrange this to be $V = -Ir + E$ which is the equation of a straight line for Fig. 2. This means E is the y-intercept and the y-intercept is $1.4\ V$ therefore:

$$E = 1.4\ V$$

(b) (i) Use Fig. 2 to determine the maximum possible current that can be drawn from the cell.

Extend the line so it crosses the x-axis to give $2.0\ A$.

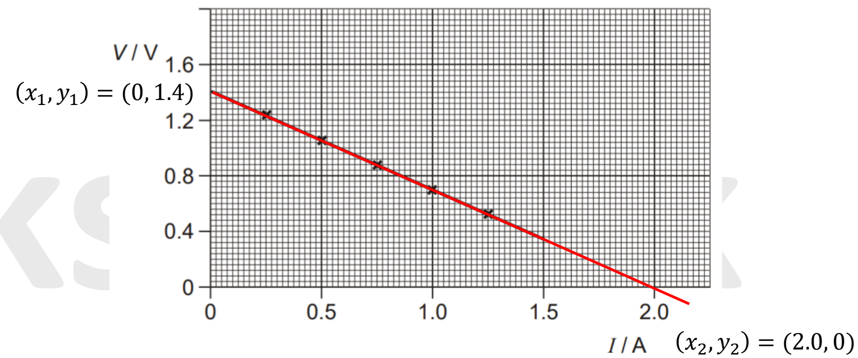

Fig. 2

(b) (ii) Calculate the internal resistance r of the cell.

Internal resistance r is the gradient of the graph which is:

$$r = \frac{y_2 - y_1}{x_2 - x_1} = \frac{0 - 1.4}{2.0 - 0} = \frac{-1.4}{2.0} = -0.7$$

The negative sign just indicates a negative gradient therefore the internal resistance r is $0.7\ \Omega$.

(b) (iii) Suggest why it may not be advisable to maintain the current determined in (b)(i) for a long time.

Operating the cell at maximum current means excessive heating of the cell and this might lead to the cell exploding in extreme cases.

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Internal Resistance

Exam Style Question 6

A cell is a source of e.m.f. When the cell is connected into a circuit the potential difference measured between its terminals, called the terminal $p.d.$, is less than its e.m.f.

(a) (i) Define the term e.m.f.

(ii) Explain why the terminal p.d. is less than the e.m.f.

(b) In the circuit of Fig. 3.1 the cell of e.m.f. $1.6\ V$ and internal resistance r is delivering a current of $0.20\ A$ to a resistor of resistance R. The voltmeter reads the terminal p.d. It is $1.2\ V$.

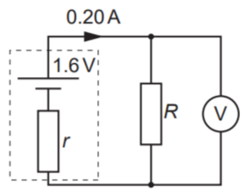

Fig. 3.1

Calculate the values of

(i) The resistance R

(ii) The internal resistance r.

(c) (i) The current in the resistor of Fig. 3.1 remains constant at $0\ 20\ A$ for several hours. Calculate

1) The charge which passes through the resistor in $1.5\ hours$.

2) The energy dissipated by the resistor in $1.5\ hours$.

(ii) The cell is left connected to the resistor for $12\ hours$. The graph of Fig. 3.2 shows the variation of current I with time t.

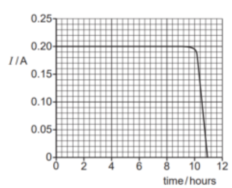

Fig. 3.2

Describe how the current varies with time. Suggest reasons why it varies in this way.

Internal Resistance

Exam Style Question 6

(a) (i) Define the term e.m.f.
Energy supplied per unit charge by the battery or p.d. across terminals when no current is passing through the cell.

(a) (ii) Explain why the terminal p.d. is less than the e.m.f.
All sources (i.e. battery or cell) have an internal resistance which cause 'lost' volts across the cell when a current is drawn and some energy is lost as heat.

(b) Calculate the values of
(i) The resistance R
Use $V = IR$ and rearrange for R

$$R = \frac{V}{I} = \frac{1.2\ V}{0.2\ A} = 6.0\ \Omega$$

(ii) The internal resistance r.
Use $E = V + Ir$ and rearrange for r

$$r = \frac{E - V}{I} = \frac{1.6\ V - 1.2\ V}{0.2\ A} = 2\ \Omega$$

(c) (i) 1) Calculate the charge which passes through the resistor in $1.5\ hours$.
Use $Q = It$ but remember to convert 1.5 hours into seconds:

$$Q = (0.2\ A)(3600\ seconds \times 1.5\ hours)$$
$$Q = 1080\ C$$

(c) (i) 2) The energy dissipated by the resistor in $1.5\ hours$.
Use $E = QV$

$$E = (1080\ C)(1.2\ V) = 1296\ J$$

(c) (ii) Describe how the current varies with time. Suggest reasons why it varies in this way.
I is constant for about 9 to 10 hours because internal resistance remains constant and cell operates at constant emf. I falls rapidly towards zero over the last hour because the cell's chemical energy is used up so E falls.

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