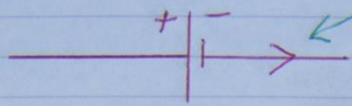
B McMULLEN ①

HIGHER EMF AND INTERNAL RESISTANCE

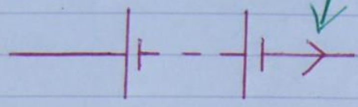
NATS RECAP

CURRENT FLOW
(ELECTRON FLOW)

CELL

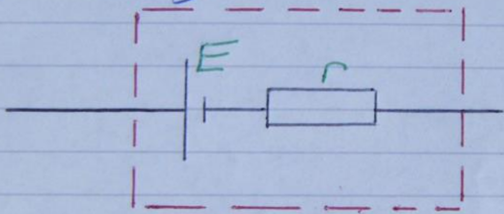


BATTERY



A battery is an accumulation of cells.

In reality



Everything inside the broken line box is within the battery.

E = Emf of a battery or cell.

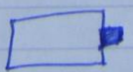
r = Internal resistance of the battery or cell.

↑ must be written as a small case letter.

Capital R stands for the external resistance or the load resistance.

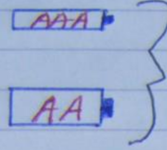
* The emf of a battery never changes ie it has a constant reading. *

eg/ Smoke alarm batteries



EMF = 9V.

eg2



} Emf = 1·5V

Internal resistance of a battery

- Brand new battery ⇒ r is low
- Old battery ⇒ r is high.

EQUATION

$$E = V + Ir$$

- E → Emf of the battery (Volts)
- V → Terminal P.d of the battery (Volts)
- Ir → Lost Volts (Volts)

* Lost Volts = Ir *

(I → Current, r → Internal resistance.)

- Emf is always constant
- New battery ⇒ r is low ⇒ lost volts is low.

If lost Volts is low then terminal potential difference is high.

$E = V + Ir$ (E ↔, V ↑, Ir ↓)

- Old battery ⇒ r is high ⇒ lost Volts is high

If lost Volts is high then terminal potential difference is low.

$$E = V + Ir$$

Definitions

* • Emf → Electromotive force (Volts)

→ The energy given to each coulomb of charge as it passes through the source.

* • V → Terminal potential difference (volts)

→ This is the energy given to each coulomb of charge.

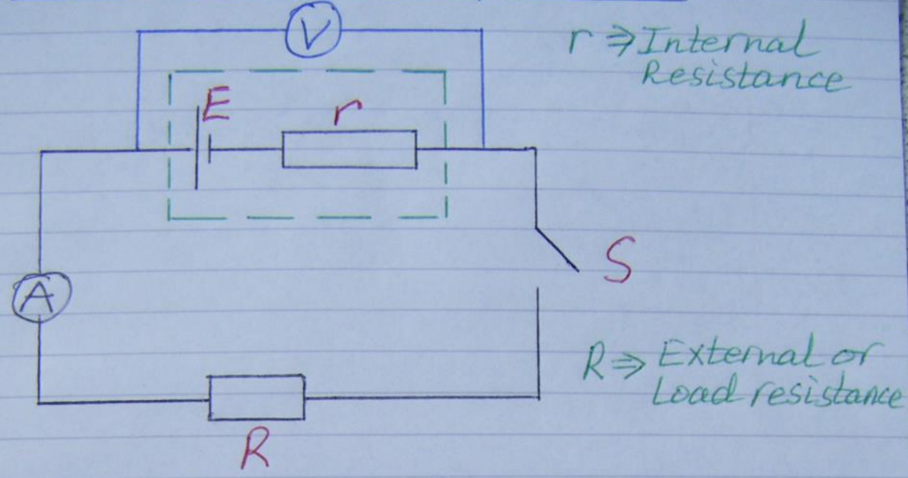
→ This is the effective output voltage of a battery.

* • Ir → lost Volts (Volts)

→ The voltage dropped across the internal resistance of a battery.

* The difference in the definitions for Emf and V_{tpd} is the last SIX words in the Emf definition *

The standard Emf Circuit



- Switch is open ⇒ Ammeter reading = 0A
  Voltmeter reading = Emf

- Switch is closed ⇒ Ammeter reading > 0A
  Voltmeter reading = V

* Emf > V *

Why?

As a current flows we now have a voltage dropped across the internal resistance ie lost Volts

$$E = V + Ir$$

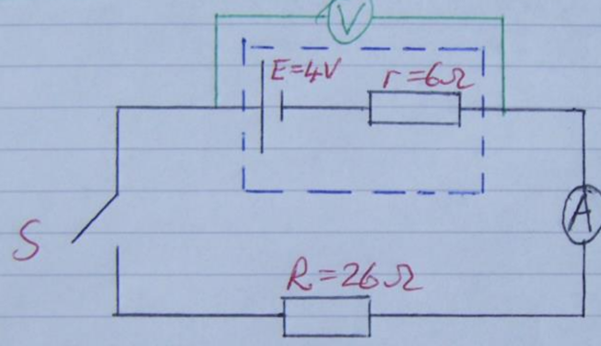
↔ ↓ ↑

As the terminal potential difference decreases the lost Volts increases.

Three variations of the equations

- $E = V + Ir$ ⇒ In DB!!
- $E = IR + Ir$ ⇒ From $V = IR$
- $E = I(R + r)$ ⇒ Taking I out as a common factor.

Ex 1



Q Calculate or find the following when the switch S is closed:

a) Emf

b) Reading on the (A)

c) Reading on the (V)

d) Explain why there is a difference between the readings in a) and c).

A a) Emf is the reading on the –(V)– when the switch is open ie 4V as no current will flow.

b) S closed ⇒ Current flowing

$E = 4V$ $\quad$ $E = V + Ir$

$V = ?$ $\quad$ $\Rightarrow E = IR + Ir$

$I = ?$

$r = 6\Omega$ $\quad$ $\Rightarrow E = I(R + r)$

$R = 26\Omega$ $\quad$ $\Rightarrow 4 = I(26 + 6)$

$\Rightarrow 32I = 4 \Rightarrow I = \frac{4}{32} = \underline{\underline{0.125A}}$

c) <u>OPTION 1</u> $\quad$ <u>OR</u> $\quad$ <u>OPTION 2</u>

OPTION 1:

$V = IR$

$\Rightarrow V = 0.125 \times 26$

$\Rightarrow \underline{\underline{V = 3.25V}}$

OPTION 2:

$E = V + Ir$

$\Rightarrow 4 = V + 0.125 \times 6$

$\Rightarrow 4 = V + 0.75$

$\Rightarrow \underline{\underline{V = 3.25V}}$

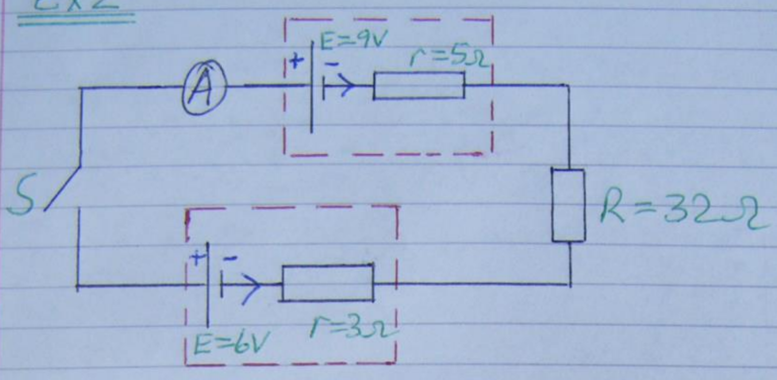
d) a) Emf = 4V

c) $V_{tpd} = 3.25V$

- Emf ⇒ switch open ⇒ no current flows
- V_{tpd} ⇒ switch closed ⇒ current flows

∴ We now have to take internal resistance r and lost volts Ir into consideration.

Ex2



Q Calculate or find the following when the switch in the circuit is closed:

a) The effective emf

b) The total internal resistance

c) The reading on the Ⓐ

d) The terminal potential difference, V_{tpd}

A a) Effective emf = 9V − 6V = 3V (Check polarity!!)

b) $r_T = 5 + 3 = 8\Omega$

c) $E = 3V$
$R = 32\Omega$
$r = 8\Omega$
$I = ?$

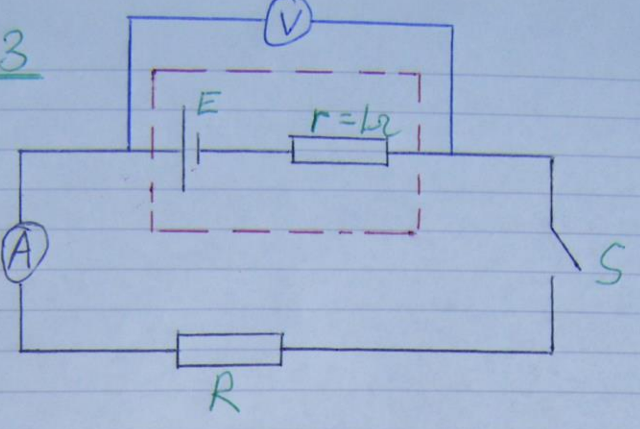
$E = V + Ir \Rightarrow E = I(R + r)$

$\Rightarrow 3 = I(32 + 8)$

$\Rightarrow I = \frac{3}{40} = 0.075A$

d) $V = IR = 0.075 \times 32 = 2.4V$
(Could also use $E = V + Ir$ for this part)

Ex3



Readings on V

- S is open ⇒ V = 12V
- S is closed ⇒ V = 10.5V

Q Calculate or find:

a) Emf of the cell. (E)

b) Terminal potential difference (V)

c) The reading on the ammeter when:
  i) S is open
  ii) S is closed.

d) External Load resistance (R).

A a) Emf, $E = 12V$

b) Vtpd, $V = 10.5V$

c) i) S open ⇒ $I = 0$.

c) ii) $E = 12V$ $\quad E = V + Ir$

$V = 10.5V$ $\quad \Rightarrow 12 = 10.5 + I \times 1$

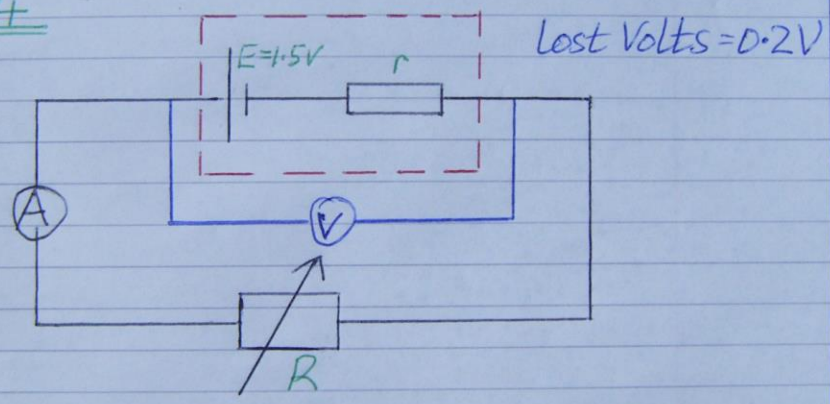
$r = 1\Omega$ $\quad \Rightarrow I = 12 - 10.5$

$I = ?$ $\quad \Rightarrow I = 1.5A$

d) $R = ?$ $\quad V = IR$

$$\Rightarrow R = \frac{V}{I} = \frac{10.5}{1.5} = 7\Omega$$

Ex4



Q a) Calculate the terminal potential difference across the cell.

b) Will the current increase or decrease as R is increased?

c) Explain what happens to the reading on the voltmeter when R is increased.

A a) $E = V + Ir \Rightarrow 1.5 = V + 0.2$

$\Rightarrow V = 1.5 - 0.2 = \underline{1.3V}$

b) As Resistance R↑ then the current I↓.

c) • As the resistance ↑ ∴ Current ↓

• As current ↓ ∴ Lost Volts = Ir ↓

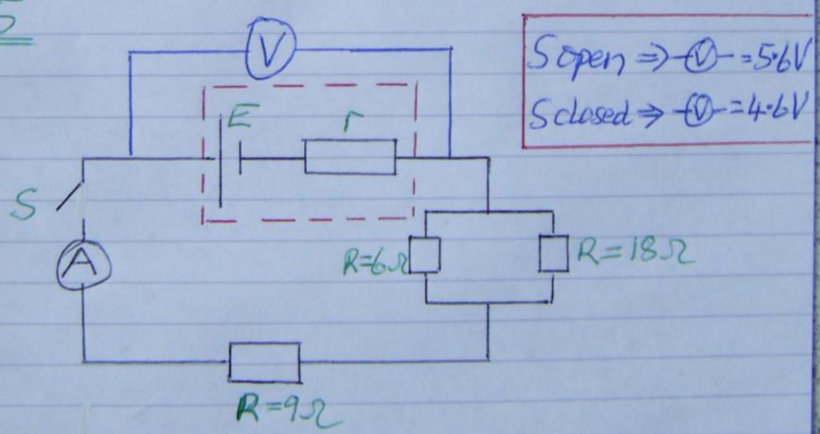
• As lost Volts = Ir ↓ ∴ Terminal P.d, V↑

IMPORTANT ⇒ • $E = V + Ir$

• The terminal P.d, V is the voltage

• dropped across the variable resistor R. ∴ (V) ↑

Ex5



Q Calculate or find:

a) Emf
b) Terminal potential difference
c) lost volts
d) Internal resistance.

A a) $Emf = 5 \cdot 6V$

b) $V_{tpd} = 4 \cdot 6V$

c) $\text{Lost Volts} = Emf - V_{tpd}$
$= 5 \cdot 6 - 4 \cdot 6$
$= \underline{1V}$

d) $r = ?$
$R = ?$

$R_T = R_P + R_S$

• R_P: $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{6} + \frac{1}{18} = 6^{-1} + 18^{-1}$

$\Rightarrow \frac{1}{R_P} = \frac{2}{9} \Rightarrow \frac{R_P}{1} = \frac{9}{2} \Rightarrow \underline{R_P = 4 \cdot 5\Omega}$

• R_T: $R_T = R_P + R_S = 4 \cdot 5\Omega + 9\Omega = \underline{13 \cdot 5\Omega}$

• $E = V + Ir$

• $V = IR \Rightarrow I = \frac{V}{R}$

$\Rightarrow I = \frac{4 \cdot 6}{13 \cdot 5} = \underline{0 \cdot 34A}$

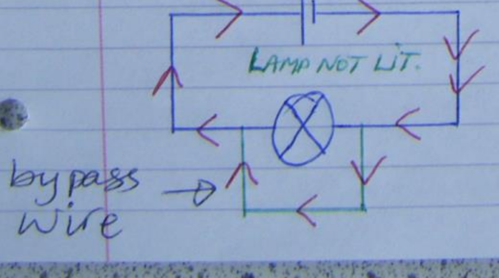
$\Rightarrow 5 \cdot 6 = 4 \cdot 6 + 0 \cdot 34r$

$\Rightarrow 0 \cdot 34r = 5 \cdot 6 - 4 \cdot 6$

$\Rightarrow 0 \cdot 34r = 1$

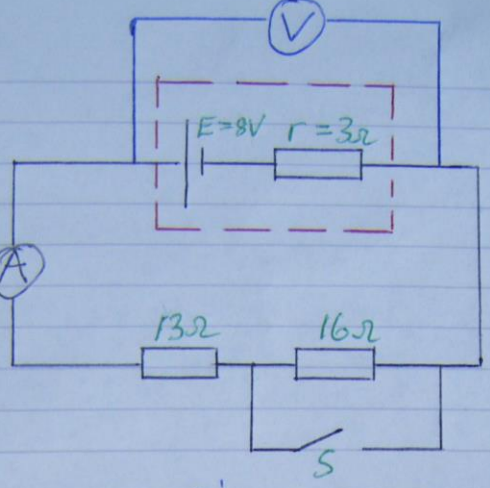
$\Rightarrow r = \frac{1}{0 \cdot 34} = \underline{3\Omega}$

Short Circuits



A lamp is a resistor that gives off light. A bypass wire placed around the lamp will take the current with none going through the lamp ie current follows the path of least resistance.

Ex6



When S is closed the 16Ω resistor is short circuited from the circuit

Q Calculate or find:

a) Reading on (A) when
i) S is open
ii) S is closed

b) Reading on (V) when
i) S is open
ii) S is closed.

A a) i) S open $\Rightarrow R = 13 + 16 = 29\Omega$

$r = 3\Omega$

$E = 8V$

$E = I(R + r)$

$\Rightarrow 8 = I(29 + 3)$

$\Rightarrow 32I = 8$

$\Rightarrow I = \frac{8}{32} = 0.25A$

ii) S closed $E = I(R + r)$

$\Rightarrow 8 = I(13 + 3) \Rightarrow 16I = 8$

$\Rightarrow I = \frac{8}{16} = 0.5A$

b) i) S open $\Rightarrow V = IR = 0.25 \times 29 = 7.25V$

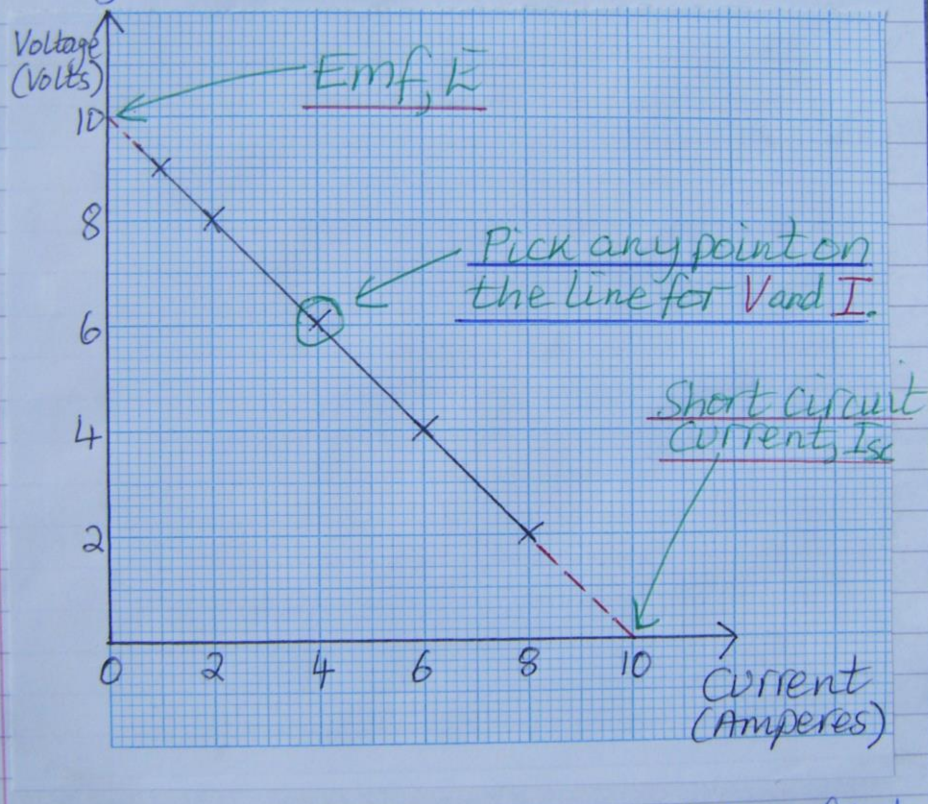
ii) S closed $\Rightarrow V = IR = 0.5 \times 13 = 6.5V$

Ex 7

Q.

Voltage (V)	9	8	6	4	2
Current (A)	1	2	4	6	8

a) Draw a line graph of Voltage (V) against current (A).



b) From the graph, calculate or find:

I) Emf, E

II) Internal Resistance, r

III) Short circuit current, I_{sc}

A b) i) Emf, E when $I = 0$ ie when the line cuts the y-axis.

$Emf = 10V$

ii) Take one point (any) from the line and substitute this into $E = V + Ir$ to find r.

This is easier than the gradient method!!

eg $V = 6V$ and $I = 4A$

$\Rightarrow E = V + Ir \Rightarrow 10 = 6 + 4r$

$\Rightarrow 4r = 10 - 6 \Rightarrow 4r = 4 \Rightarrow r = 1\Omega$

iii) I_{sc} can be found when the external or load resistor R is short circuited ie $R = 0$.

Two methods can be used to find I_{sc}.

METHOD 1 FROM GRAPH.

$I_{sc} \Rightarrow R = 0 \therefore V = 0$

This occurs when the line cuts the x-axis

$\therefore I_{sc} = 10A$

XXX Use METHOD 1 IF IT IS POSSIBLE XXX

METHOD 2 FROM EQ^N

$E = V + Ir$

$\Rightarrow E = IR + Ir$

as $R = 0 \Rightarrow I = I_{sc}$

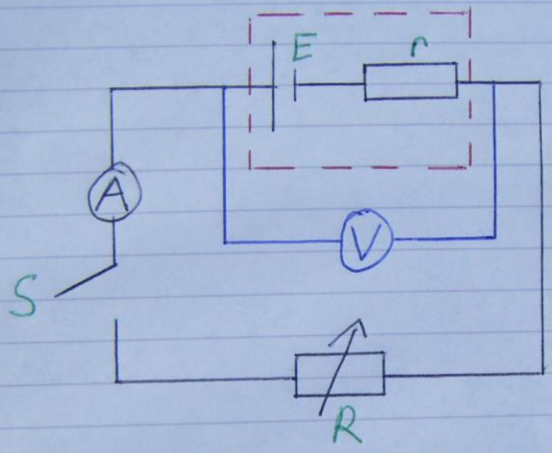
$\Rightarrow E = I_{sc} r$

$\Rightarrow I_{sc} = \frac{E}{r} = \frac{10}{1}$

$\Rightarrow I_{sc} = 10A$

Ex8 – The Beast ('A' standard).

To investigate the characteristics of a power supply unit, a student uses an ammeter and a variable resistor in the following circuit:



S open
-(V)- = Emf, E
-(A)- = 0A

S closed
-(V)- = V_{tpd}, V
-(A)- > 0A

Q a) From $E = V + Ir$ show that $R = \frac{E}{I} - r$

A a) $E = V + Ir \Rightarrow E = IR + Ir$

$\Rightarrow E - Ir = IR$

then divide each side by I

$\Rightarrow \frac{E - Ir}{I} = \frac{IR}{I}$

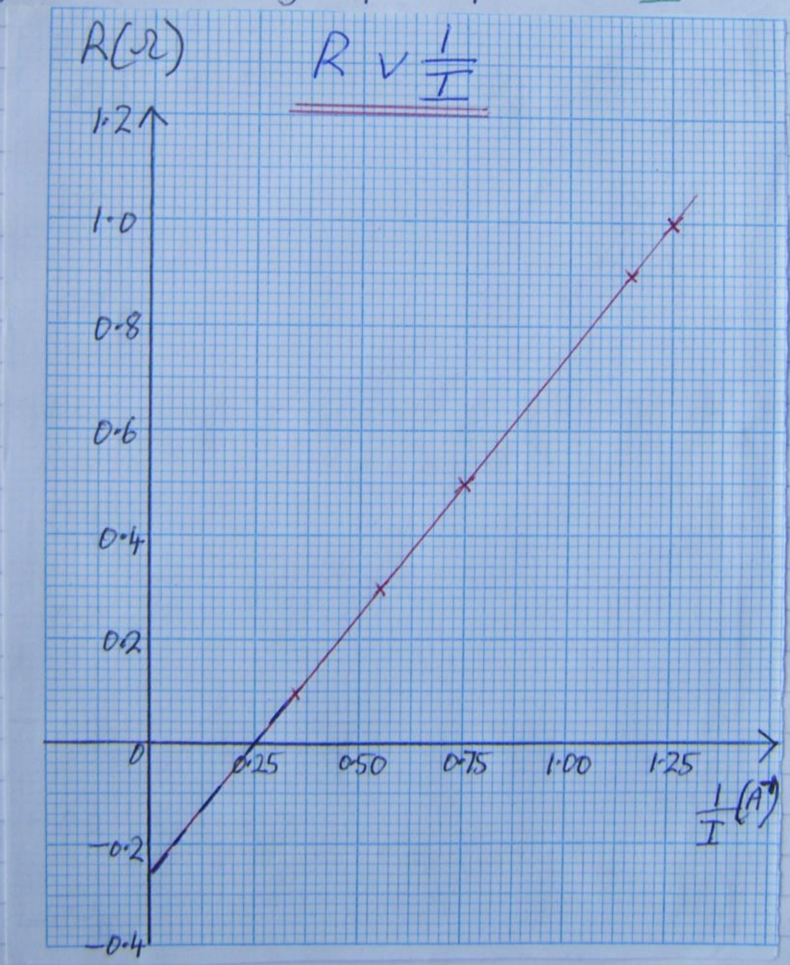
$\Rightarrow \frac{E}{I} - \frac{Ir}{I} = \frac{IR}{I} \Rightarrow \frac{E}{I} - r = R$

$\Rightarrow \boxed{R = \frac{E}{I} - r}$ ∴ QED.

Q b) A graph of R v $\frac{1}{I}$ is plotted using the readings below from the table.

$R (\Omega)$	0·1	0·3	0·5	0·7	0·9	1·0
$\frac{1}{I} (A^{-1})$	0·35	0·55	0·75	0·95	1·15	1·25

1) Plot the graph of R v $\frac{1}{I}$



Q ii) Why is a graph of R v $\frac{1}{I}$ drawn?

A From $E = V + Ir \Rightarrow R = \frac{E}{I} - r$

This equation with R as the subject of the formula can be compared with $y = mx + c$.

ie $R = \frac{E}{I} - r$ with $y = mx + c$

$\Rightarrow y = R$

$x = \frac{1}{I}$

$m = E$ ← gradient

$c = -r$ ← y-intercept

Q iii) Find the gradient of the line which is the emf of the power supply unit.

A iii) E = gradient m

2 points from the line $(0.55, 0.3)$ and $(0.95, 0.7)$

$$E = m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{0.7 - 0.3}{0.95 - 0.55} = \frac{0.4}{0.4}$$

$\therefore E = m = \underline{\underline{1V}}$

Q iv) Find r, the internal resistance of the power supply unit.

A iv) $c = -r \Rightarrow c = -0.25$ from the graph.

$\Rightarrow -0.25 = -r \Rightarrow \underline{\underline{r = 0.25\Omega}}$

Q v) Find I_{sc}, the short circuit current.

A v) In a short circuit, $R=0$ and $V=0$ (From $V=IR$).

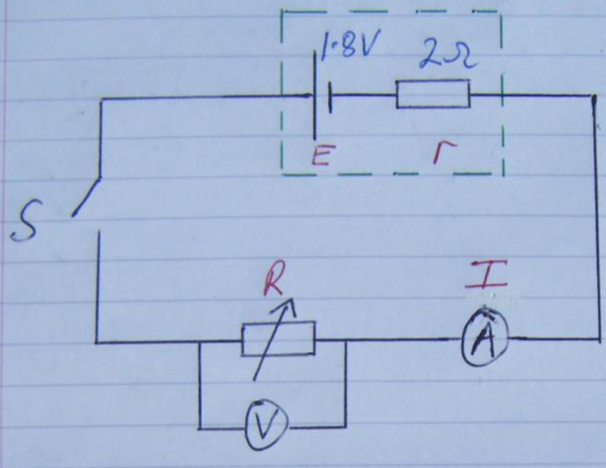
From the graph $R=0$ when the line cuts the x-axis.

$\frac{1}{I_{sc}} = 0.25 \Rightarrow I_{sc} = \frac{1}{0.25}$

$\Rightarrow \underline{\underline{I_{sc} = 4A}}$

Ex9

The circuit below is used to investigate electrical power transfer in a circuit.



By varying the external resistor R and measuring the corresponding current and potential difference values, it is possible to determine the power delivered to the external circuit.

A set of results were taken from the experiment above and put into the table below.

R(Ω)	7·0	4·0	2·5	1·6	1·0	0·6
I (A)	0·2	0·3	0·4	0·5	0·6	0·7
V_R(V)						
P(W)						

Q a) Complete the last two rows of the table.

b) Draw a graph of P(W) vs R(Ω).

c) i) From the graph identify the external resistance R when the maximum power P is transferred.

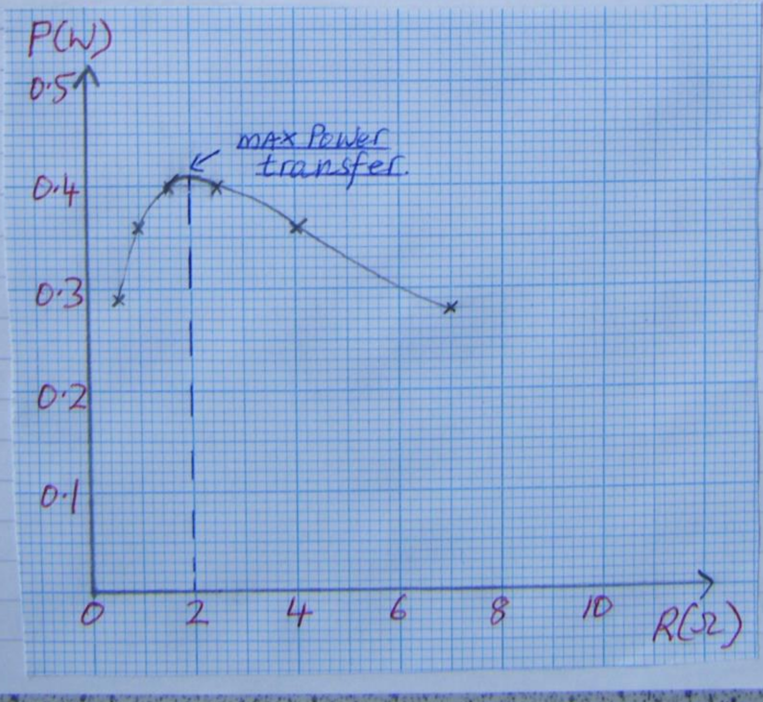
ii) How does this external resistance R compare with the internal resistance r in the circuit?

iii) What conclusion can be made from this experiment?

A a)

R (Ω)	7.0	4.0	2.5	1.6	1.0	0.6
I (A)	0.2	0.3	0.4	0.5	0.6	0.7
V_R (V)	1.40	1.20	1.00	0.80	0.60	0.42
P (W)	0.28	0.36	0.40	0.40	0.36	0.29

b)



c) i) From the graph produced the external resistance $R = 2\Omega$ when the maximum power P is transferred.

ii) At maximum power transfer $r = R$ ie 2Ω, the same.

iii) The maximum power transferred in a circuit occurs when the internal resistance = external resistance.

* Remember that the term load resistance is often used instead of external resistance. *