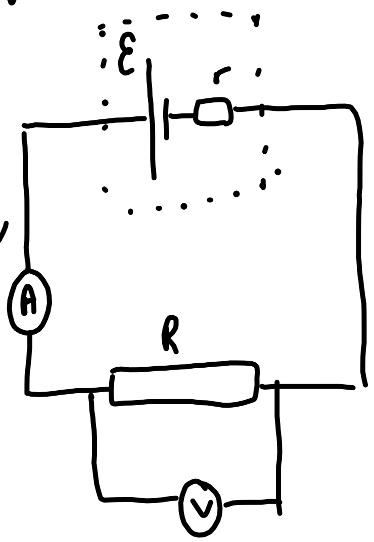
Internal Resistance

Recall the circuit equation:

$$\varepsilon = V + Ir$$

$$I = \frac{\varepsilon}{(R+r)}$$



$$V = \varepsilon - Ir$$

$$\varepsilon = V + Ir$$

$V = IR$

$$\varepsilon = IR + Ir$$

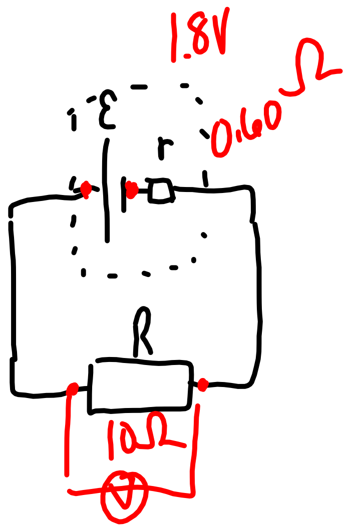
$$\varepsilon = I(R+r)$$

Data Booklet

Example

In the circuit shown, the cell has an emf of 1.8V and an internal resistance of 0.60Ω. Find the potential difference across the cell terminals and the current drawn if the value of R is 10Ω

$I = \frac{V}{R}$



$$\mathcal{E} = I(R+r)$$

$$I = \frac{\mathcal{E}}{(R+r)}$$

$$I = \frac{1.8V}{(10\Omega + 0.60\Omega)}$$

$$I \doteq 0.17A$$

$$V = \mathcal{E} - Ir$$

$$V = 1.8V - (0.17A)(0.60\Omega)$$

$$V \doteq 1.7V$$

Example

A photoelectric cell can draw a current of 0.10A when driving a small load of resistance 2.0Ω. If the emf of the cell is shown 0.8V, determine its internal resistance under these conditions.

$I = 0.10A$
$R = 2.0\Omega$
$\mathcal{E} = 0.8V$
$r = ?$

$$\mathcal{E} = I(R + r)$$

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

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

$$r = \frac{0.8V}{0.10A} - 2.0\Omega$$

$$r = 8.0\Omega - 2.0\Omega$$

$$r = 6.0\Omega$$

Example

A cell has an internal resistance of 0.45Ω. The potential difference across its terminals is 1.35V when a current of 0.18A is being drawn from it.

What is the EMF of the cell?

$r = 0.45\Omega$
$V = 1.35V$
$I = 0.18A$
$\mathcal{E} = ?$

$$\mathcal{E} = V + Ir$$

$$\mathcal{E} = 1.35V + (0.18A)(0.45\Omega)$$

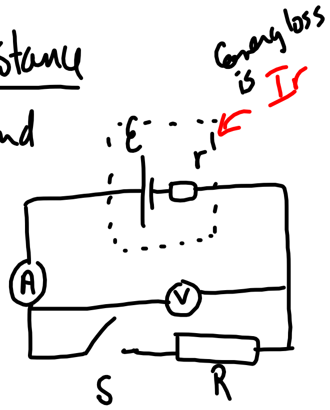
$$\mathcal{E} = 1.4V$$

When a battery goes dead .....

- its emf doesn't change but its internal resistance increases.
- if we measure the internal resistance of a cell or a battery, we can see if it is dead or not

Measurement of internal resistance

- We need to measure current and potential difference:



- When the switch S is open no current flows so there is no energy lost in the internal resistance ($Ir = 0$) and the voltmeter reads the emf of the cell.

$$V = \varepsilon - Ir \quad \leftarrow 0$$

$$V = \varepsilon$$ ← only if no current (switch is open)

- If the switch is closed, the current I flows and now the potential difference will be less than the Emf.

$$V = \varepsilon - Ir$$

$$Ir = \varepsilon - V$$

$$r = \frac{\varepsilon - V}{I}$$

If r is large, then $V << \varepsilon$

If r is zero, then $V = \varepsilon$

Example

A voltmeter connected across the terminals of a battery reads 7.5V (ε). When the battery is connected to a load, the voltage reading across the terminal is 6.2V (V) and the current flowing is 0.65A (I). Calculate the internal resistance (r) of the battery under these conditions.

$\varepsilon = 7.5\,V$

$V = 6.2\,V$

$I = 0.65\,A$

$r = ?$

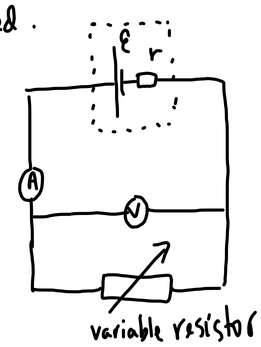
$$r = \frac{\varepsilon - V}{I}$$

$$r = \frac{7.5V - 6.2V}{0.65A}$$

$$r = 2.0\,\Omega$$

Measurement of internal resistance - graphical method

- measure the potential difference across the terminals of a battery as the current is changed.
- the current is varied by changing the resistance. (independent variable)
- the potential difference is the dependent variable.



$$V = \varepsilon - Ir$$

$$(y = b + mx)$$

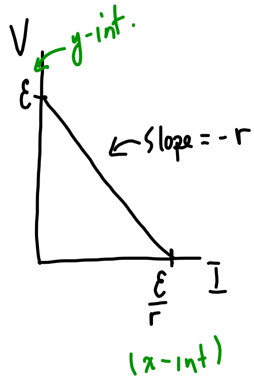
$$V = -rI + \varepsilon$$

$$(y = mx + b)$$

V vs I is linear

Slope is $-r$

y-int is ε

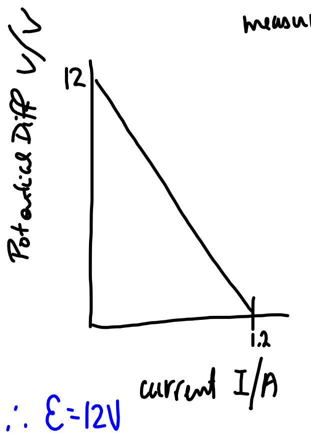


Recall from Ohm's Law: I vs V was linear (here we changed V and measured I)

Now for internal resistance: V vs I (we are changing the current and measuring V)

Example

Determine the emf and the internal resistance of the battery



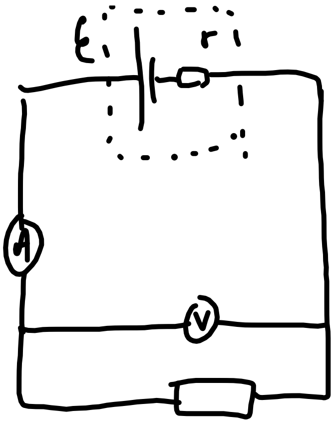
Emf is the y-intercept $\therefore \varepsilon = 12V$

slope $= -r$

$$\text{slope} = \frac{-12V}{1.2A} = -10\Omega$$

$$\therefore -r = -10\Omega$$

$$r = 10\Omega$$



Power

- Power delivered by the battery:

$$P = \varepsilon I$$

- Power generated in the resistor is

$$P = VI$$

- Power lost as heat generated in the battery

$$P = I^2 r$$

Power battery = Power in R + Power in r

$$\varepsilon \cancel{I} = V\cancel{I} + \cancel{I}^2 r$$

$$\varepsilon = V + Ir$$

The circuit equation.