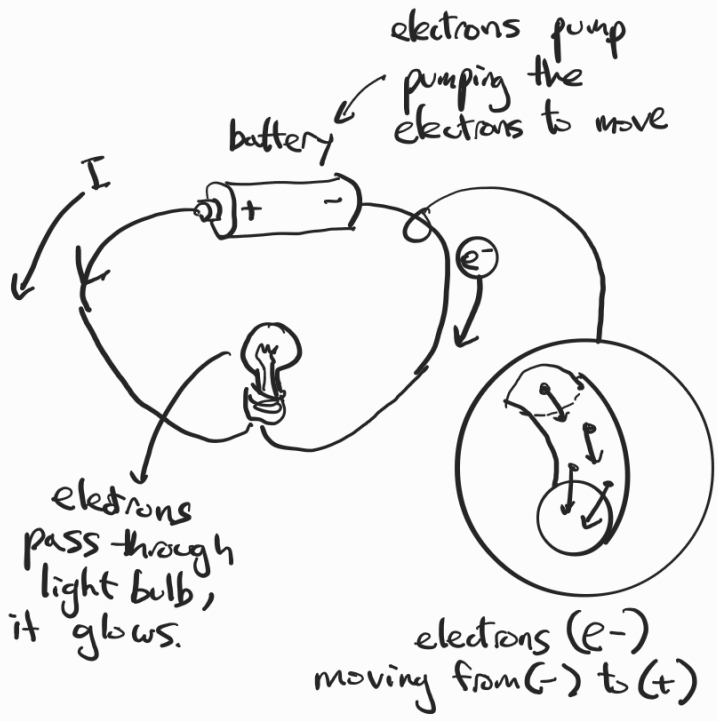
4.2 Circuit and Power

Charge and Current



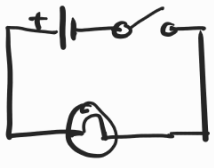
Set up of a simple circuit:

Note: movement of I current direction is opposite of electrons (-e) flow.

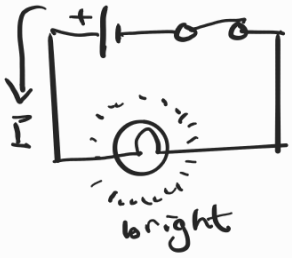
Circuit Symbols

- cell 電池
- battery
- resistor 電阻
- light bulb 燈
- variable resistor 可變電阻
- switch
- push switch
  } 開關 對手
- joint wires
- unjoint wires
- earth 接地
- V — 電壓表 voltmeter
- M — motor
- A — ammeter 電流表

OPEN CIRCUIT
no current



CLOSED CIRCUIT
I current flows



$$I = \frac{Q}{t}$$

↑ current 電流

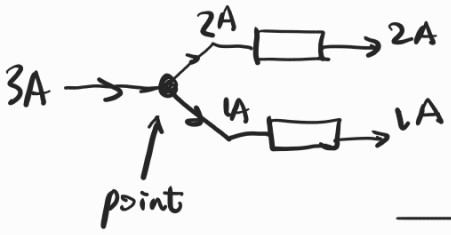
unit: $\frac{C}{s} \Rightarrow A$

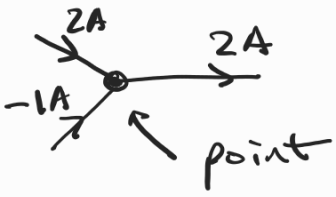
↑ ampere 安培

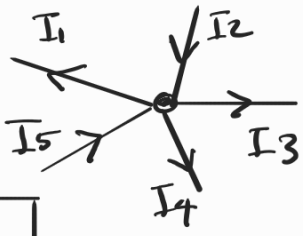
e.g. $I = 23\ A$
(current is 23 ampere)
flow rate 23C of electrons per second.

flow of current : (+) ⟶ (−)
flow of electrons(e⁻): (−) ⟶ (+)
} opposite

At any connection point **total current in = total current out**



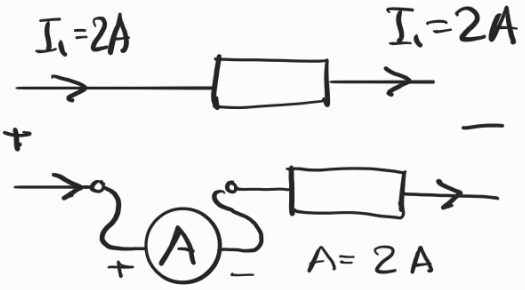


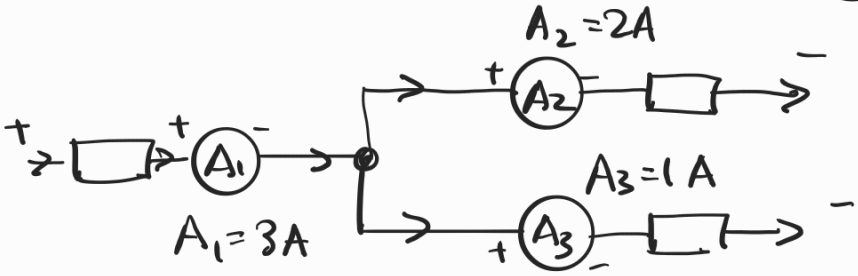


$I_5 + I_2 = I_1 + I_4 + I_3$

Measuring Current

cut wire, Ammeter in between 電流表



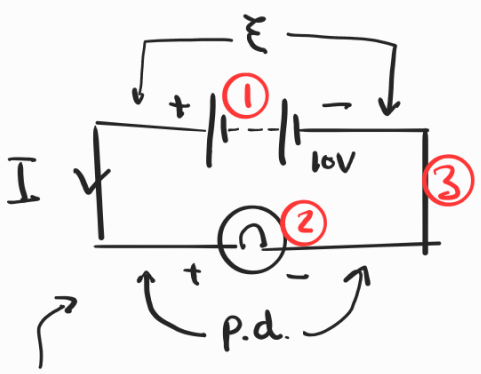


$A_1 = A_2 + A_3$

* Never overload the ammeter.

Voltage and Energy Transfer

A typical circuit has
1. Power Sources 電源
2. loads 負載
3. Connecting Wires 電線



ε (電動勢) emf : Electro Motive Force (by battery)

p.d. : Potential difference (across load) (電勢差)

In this circuit : ε = 10V, p.d. = 10V (both units V, 伏特 volt)

Supply side

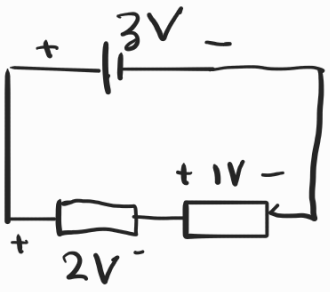
$\varepsilon = \frac{W}{Q}$ (emf) — energy supplied by battery / charge through the battery

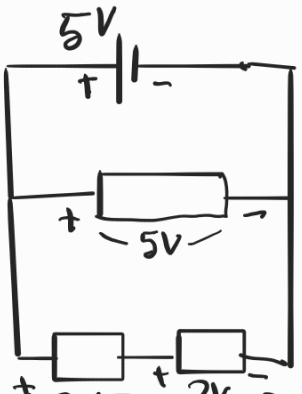
Load side

$V = \frac{W}{Q}$ (pd) — energy dissipated by load / charge through load

Voltage and Energy Conservation

For any closed loop, total emf = total p.d.



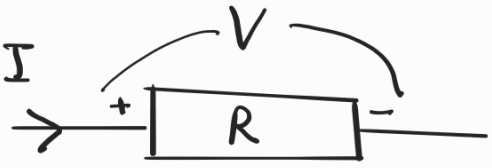


measure voltage, use a voltmeter across (+) and (−) terminals

V = 2V

[No need to cut wire!]

Resistance 電阻

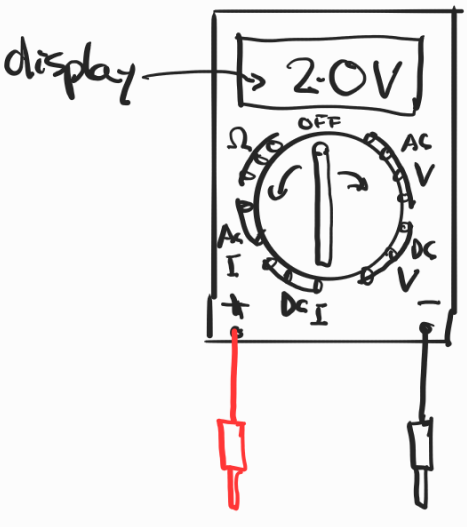


歐姆定律 ohm's law

$V = IR$

- V ↑ 電壓 unit: V volt
- I ↑ 電流 unit: A ampere
- R ↖ 電阻 unit: Ω ohm

What is a Multimeter? 萬用電表



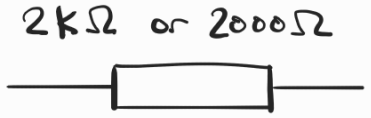
Can measure

resistance : Ω

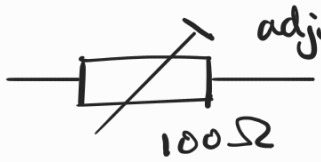
current : AC and DC

voltage : AC and DC

Resistor

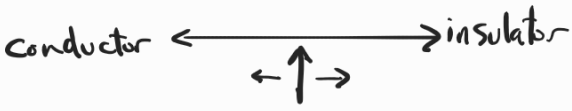


fixed value resistor

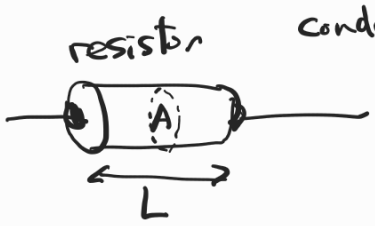


(i.e. 0~100Ω)
variable resistor

internally, resistor is made up of ohmic material
歐姆物料



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



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

(unit of ρ: Ωm)

ρ: resistivity 電阻率

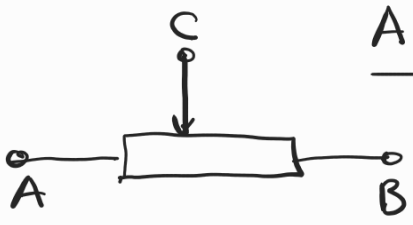
$\frac{1}{\rho}$: conductivity 導電率

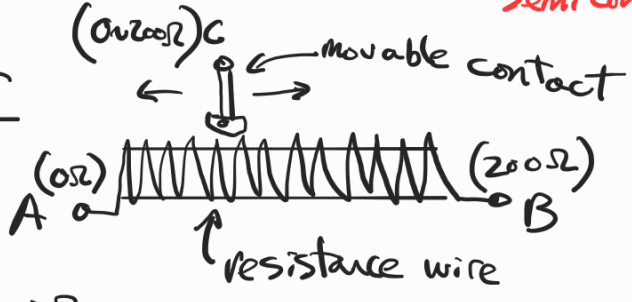
examples of ρ: gold 2.3×10^{-8} Ωm, graphite 3.5×10^{-5} Ωm (conductors)

rubber 10^{13} Ωm, glass 10^{14} Ωm, silicon 10^{3} Ωm (insulators)

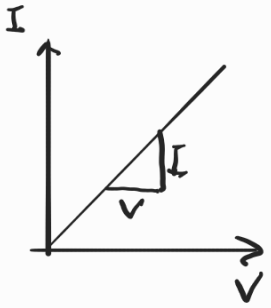
semiconductor

A variable resistor





200Ω VR



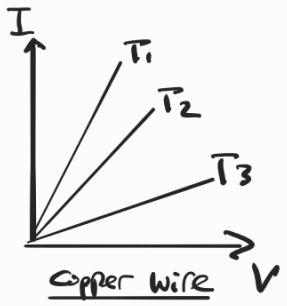
$V = IR$

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

$= \frac{1}{\text{slope}}$

= Conductivity

slope $= \frac{1}{R}$

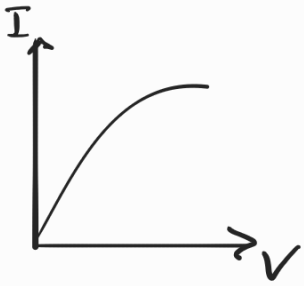


copper wire

may change with temperature

T_1, T_2, T_3

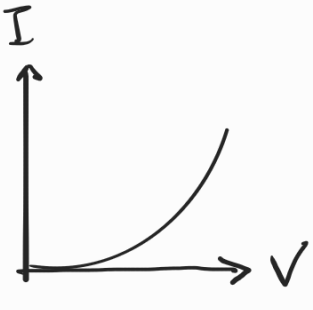
ρ changes



Light Bulb

$\frac{1}{\rho}\downarrow$ or $\rho\uparrow$

as V increase



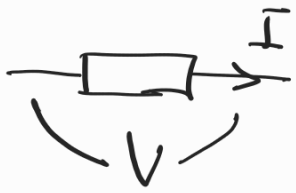
Thermistors

$\rho\downarrow$

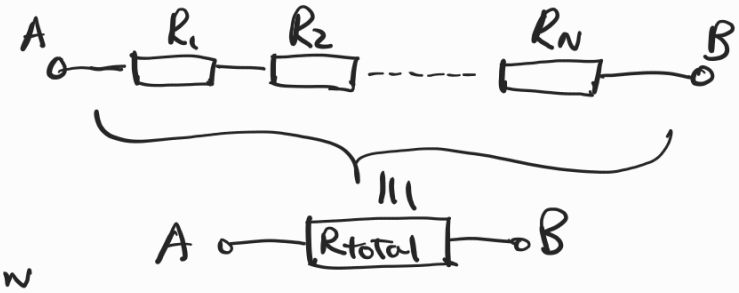
as V increase

Resistor Networks

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

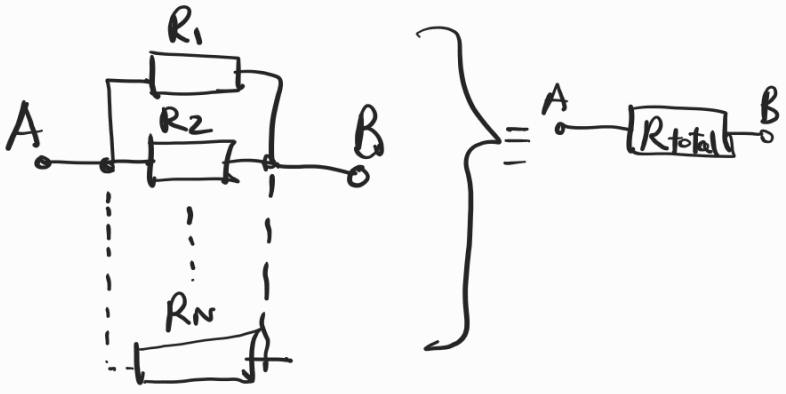


Series 串 connection



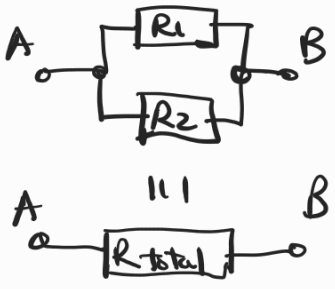
$$R_{total} = R_1 + R_2 + \cdots R_N$$

Parallel 並 connection



$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_N}$$

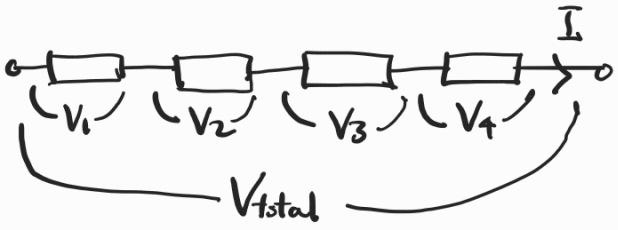
For 2 resistors parallel connection



$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2}$$

$$\therefore R_{total} = \frac{R_1 \times R_2}{R_1 + R_2} \quad //$$

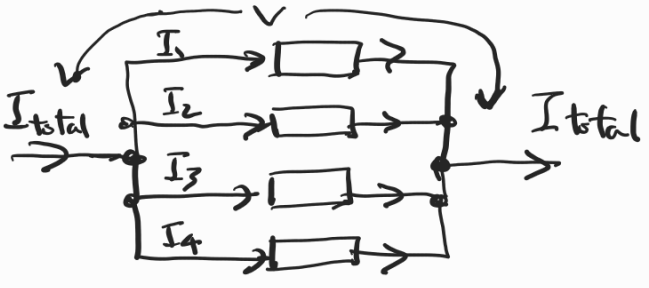
For Series Connection Voltages are shared out to resistors



I : no change

V : $V_{total} = V_1 + V_2 + V_3 + V_4$

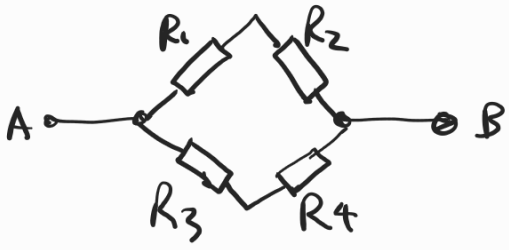
For Parallel Connection Currents are shared out to resistors

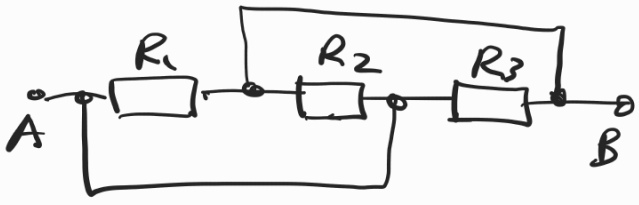


I : $I_{total} = I_1 + I_2 + I_3 + I_4$

V : no change

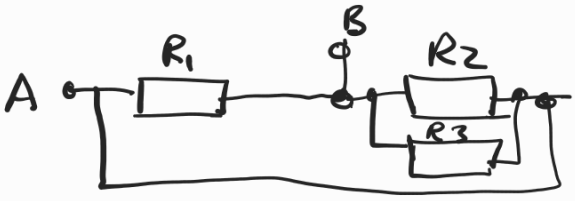
Find the equivalent resistance

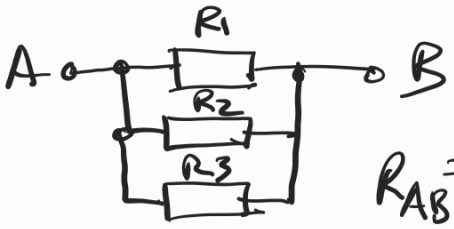




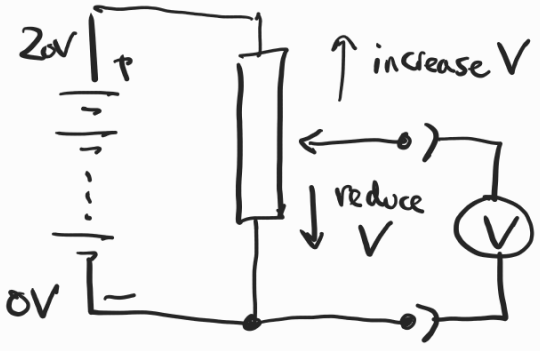
$$R_{AB} = R_1 + R_2 \,//\, R_3 + R_4$$

in parallel with





$R_{AB} = R_1 // R_2 // R_3$



potential divider circuit

Electrical Power

$$\text{Power} = \frac{\text{energy transformed}}{\text{time taken}} \Rightarrow P = \frac{E}{t} \quad \left(\text{unit } \frac{J}{s}\right)$$

(unit: W) watt

$1\ W = 1\ J\ s^{-1}$

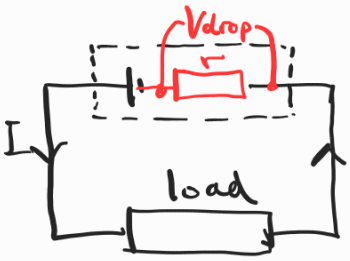
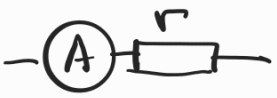
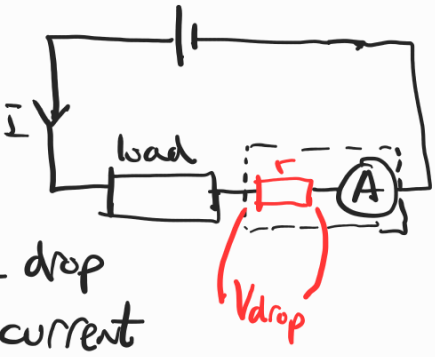
$P = V \times I$

$P = I^2 R \quad (V = IR$ ohm's law$)$

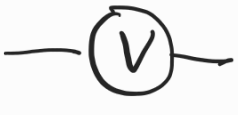
$P = V^2/R \quad (I = V/R$ ohm's law$)$

By conservation of energy: $P_{out} = P_{in}$

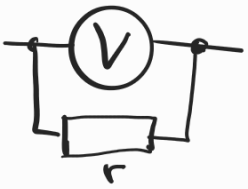
Practical Cells and Meters

	Ideal	Practical	Observation
Battery	 $r = 0\,\Omega$	 $r \approx 0.1\,\Omega$	 Voltage drop under heavy load
Ammeter	 $r = 0\,\Omega$	 $r = 0.1\,\Omega$	 Voltage drop under high current

Voltmeter



$r = \infty$



$r = 10{,}000\,\Omega$