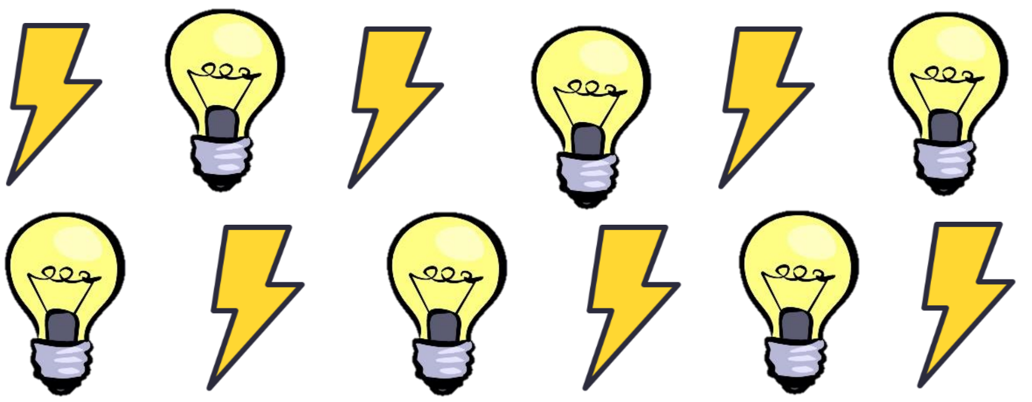
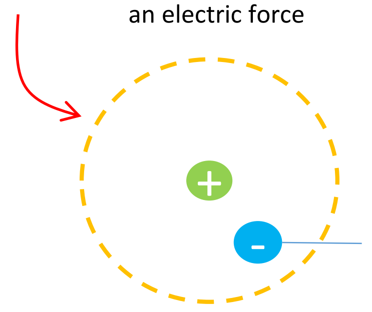
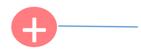


	Content standard	Learning standard
3.1	Current and Potential Difference	• Explain electric field • Define strength of electric field, E • Explain behaviour of charged particles in an electric field • Define electric current • Define potential difference, V
3.2	Resistance	• Compare and contrast ohmic and non-ohmic conductor • Solve problems involving combination of series and parallel circuits • Define resistivity of wire, ρ • Describe factors that affect resistance of a wire through experiments to conclude R=ρl/A • Communicate about applications of resistivity of wire in daily life • Solve problems involving the formula of wire resistance
3.3	Electromotive Force (e.m.f) and Internal Resistance	• Define electromotive force, Ɛ • Explain internal resistance, r • Conduct an experiment to determine e.m.f and internal resistance in a dry cell • Solve problems involving e.m.f and internal resistance in a dry cell
3.4	Electrical Energy and Power	• Formulate relationship between electrical energy (E), voltage (V), current (I) and time (t) • Formulate relationship between power (P), voltage (V), and current (I) • Solve problems involving electrical energy and power in daily life • Compare power and rate of energy consumptions in various electrical appliances • Suggest ways to save usage of electrical energy in household

3.1 Current and Potential Difference

Electric field : the region around a charged particle where any electric charge in the region will experience an electric force

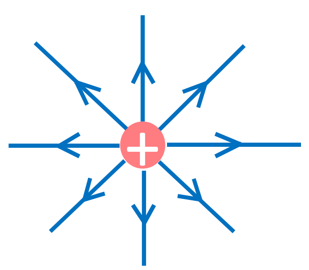


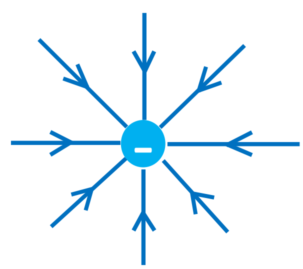


does not experience electric force (not repelled by +) because it is outside the electric field.

experience electric force (attracted to +) because it is inside the electric field

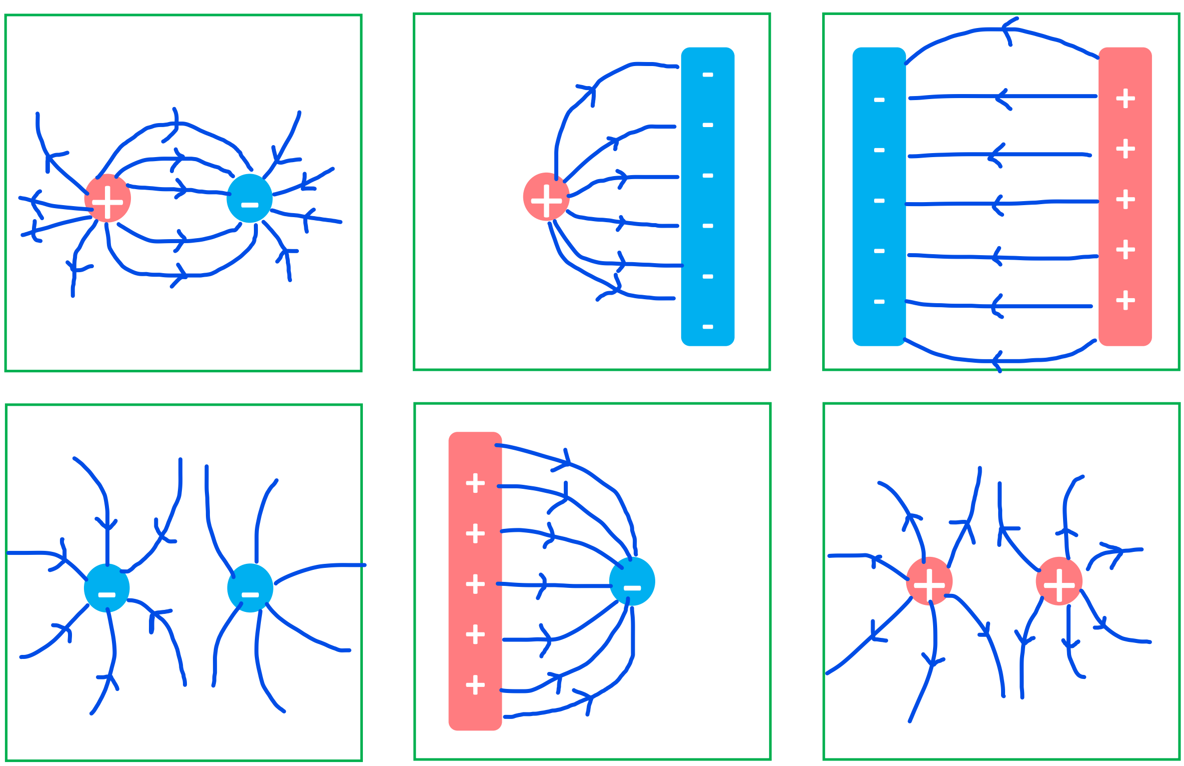
How to draw electric field?





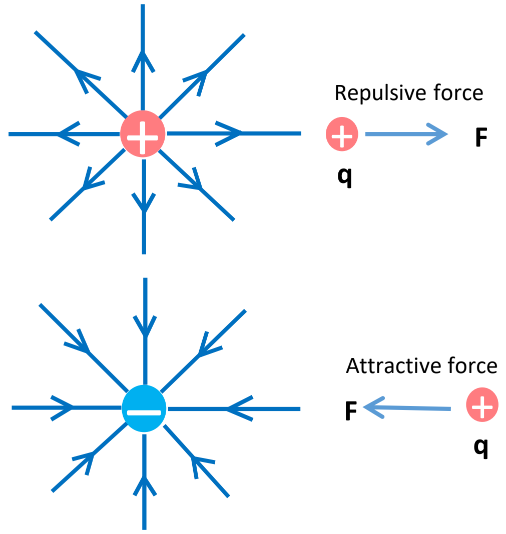
- Arrow goes out of positive charge
- Arrow goes into negative charge
- Lines cannot cross each other
- Like charges repel
- Opposite charges attract

Sketch the electric field for all the charges below. (Refer text book page 94)



Electric field strength, E

Electric force acting on a unit positive charge placed at the point



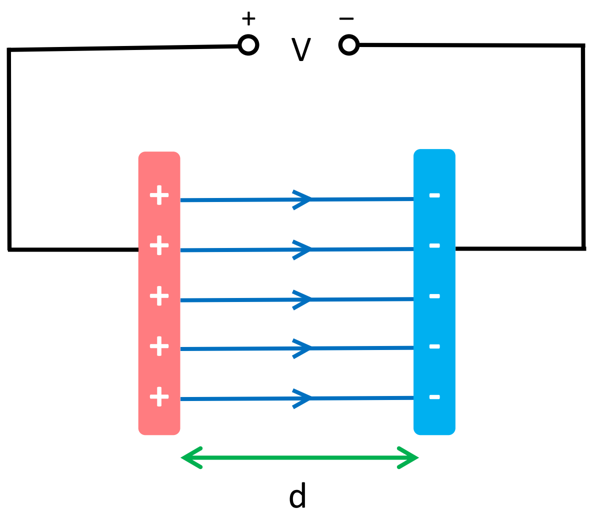
$$E = \frac{F}{q}$$

E = electric field strength, NC^{-1}

F = electric force, N

q = quantity of electric charge, C

Electric field strength produced by two parallel charged plates



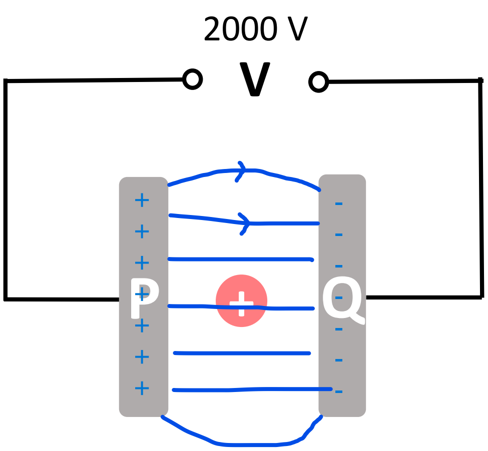
$$E = \frac{V}{d}$$

E = electric field strength, Vm^{-1}

V = potential difference, V

d = distance between plates, m

Exercise



A positively charge object moves to the right when placed between two parallel plates connected to power supply. The electric field strength is 50000 Vm^{-1}.

a. What are the charges of plates P and Q?

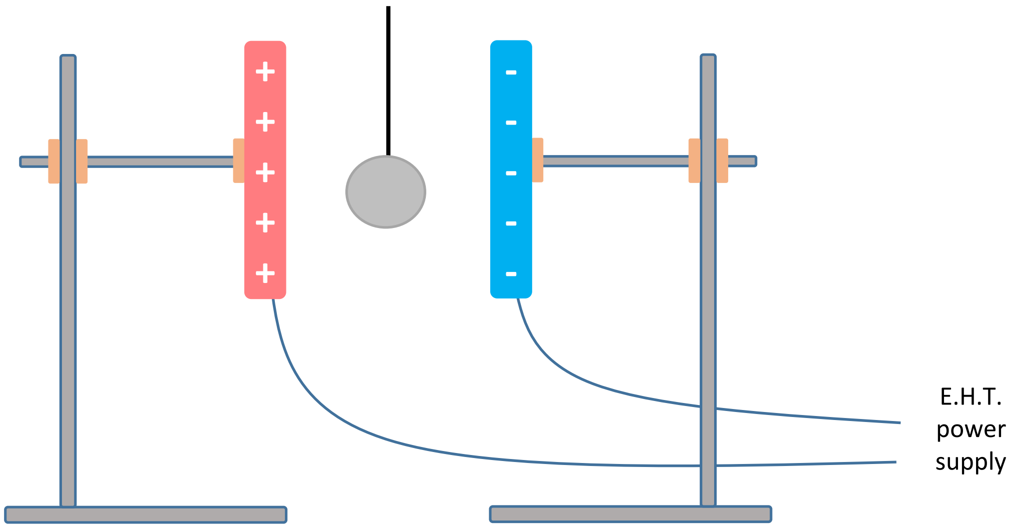
P = positive Q = negative

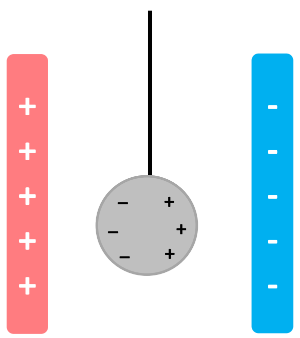
b. Calculate the distance between the two plates.

E = V/d
50000 = 2000/d
d = 2000/50000
=0.04m

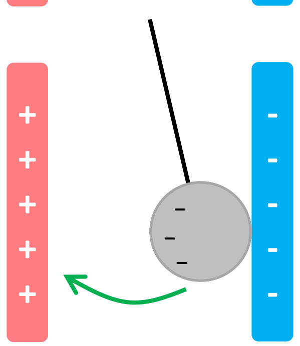
Behaviour of Charged Particles in an Electric Field

The effect of an electric field on a metal coated polystyrene ball
(Refer text book page 96-97)

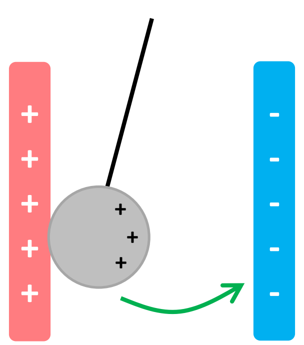




- ball does not move
- ball is neutral



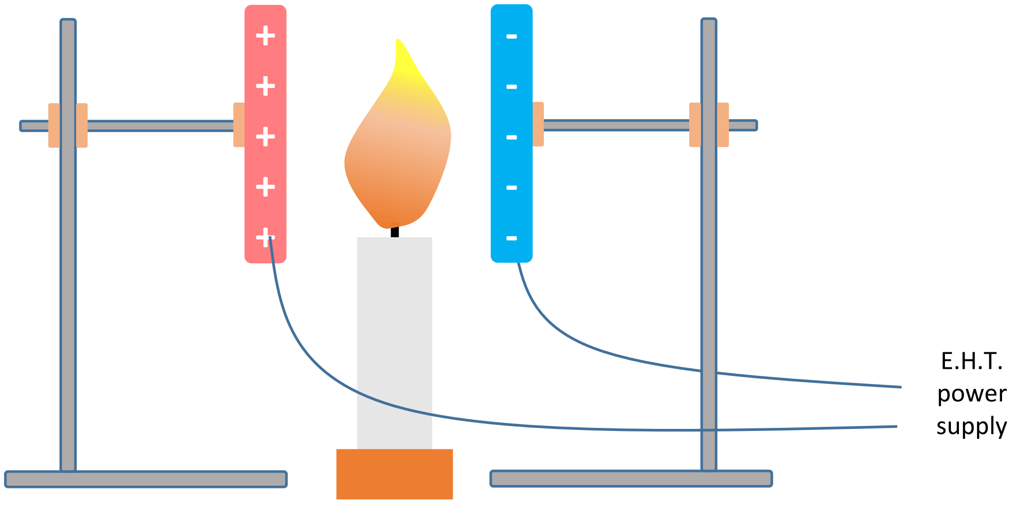
- ball is displaced to the negatively charged metal plate
- positive charges of the ball will be discharged
- ball is negatively charged
- like charges produce repulsive force
- ball is pushed away
- ball is attracted towards positive metal plate

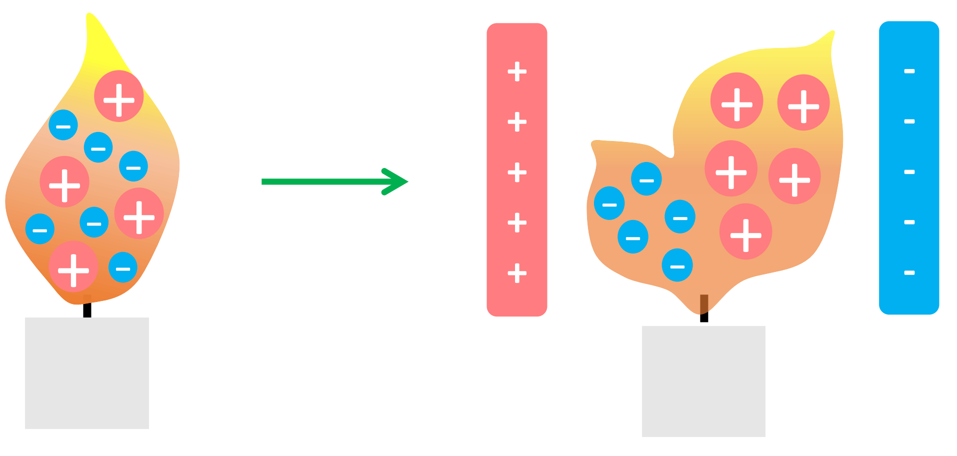


- electrons will be transferred to the metal plate
- ball becomes positively charged
- like charges produce a repulsive force
- ball is pushed away
- ball is attracted towards the negative metal plate.
- The process keeps repeating until the power supply is switched off.

Behaviour of Charged Particles in an Electric Field (cont.)

The effects of an electric field on a candle flame
(Refer text book page 98)

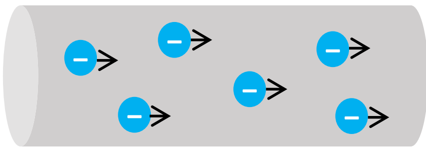




- heat from the candle flame ionize air to form positive ions and negative ions
- negative ions will be attracted to positively charged metal plate
- positive ions will be attracted to negatively charged metal plate
- positive ions have larger mass and size than negative ions
- spread of flames towards the negatively charged metal plate is greater than towards the positively charged metal plate

Electric current

Electric current: Rate of flow of charge in a conductor



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

I = current, A

Q = total charge, C

t = time, s

Exercise

1. 500 C charge flows in a conductor in 20s. Calculate the current.

I = Q/t
= 500/20
= 25

2. Charges flow in a conductor in 10s producing 5.5 A current. Calculate total charge.

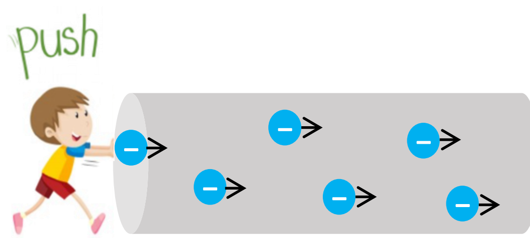
5.5 = Q/10
Q = 55C

Potential difference

Potential difference: Work done in moving one coulomb of charge from one point to another.

work done per unit charge

$$\boxed{V = \frac{W}{Q}} \qquad \boxed{V = \frac{E}{Q}}$$



V = potential difference, V

W = work done, J

E = energy transferred, J

Q = amount of charges flowing, C

Exercise

3. 500 J of energy was needed to move 40 C of charge in 10s. Calculate;
   a. the potential difference.
   b. the current.

V = E/Q
= 500/40
=12.5 V

I = Q/t
= 40/10
= 4A

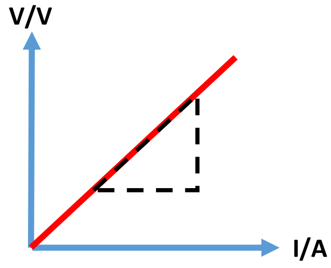
4. 30 V power supply was used to carry 50 C of charge. Calculate the amount of work done.

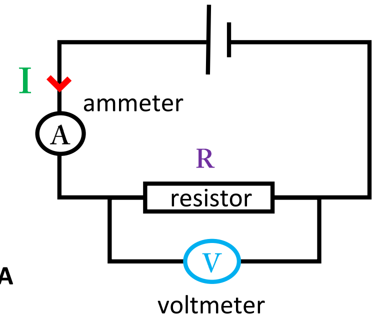
W = QV
= 50 * 30
= 1500C

RECAP: Ohm's Law

Potential difference flowing through a conductor is directly proportional to the electric current when the temperature and other physical properties are kept constant

$$\boxed{V = I \times R}$$

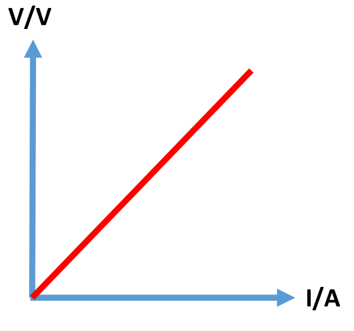
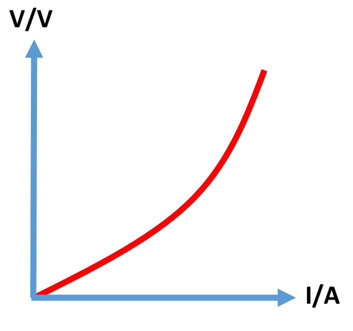




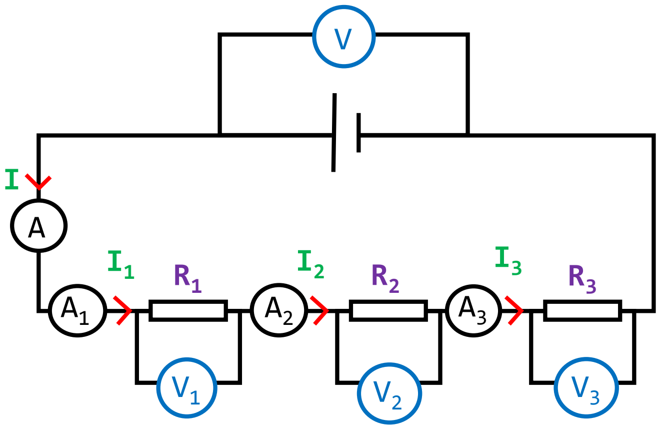
3.2 Resistance

↳ Constant → conductor which obeys Ohm's Law → Ohmic conductor
Example: Constantan wire

↳ Changes → conductor which does not obey Ohm's Law → Non-ohmic conductor
Example: Filament bulb

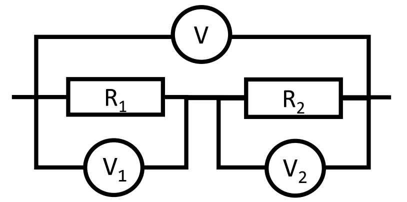
Type of conductor	Ohmic conductor	Non-ohmic conductor
Graph of V against I		
Relationship between V and I	V is directly proportional to I	V increases with I
Rate of increase of voltage	Constant	Increases
Resistance	Constant	Increases

Circuits arrangement (Series circuit)



$$V = V_1 + V_2 + V_3$$
$$I = I_1 = I_2 = I_3$$
$$R = R_1 + R_2 + R_3$$

Potential difference in series circuit



$$V_1 = V\left(\frac{R_1}{R_1 + R_2}\right) \quad V_2 = V\left(\frac{R_2}{R_1 + R_2}\right)$$

EXAMPLE 1

Observe the circuit diagram above. Given that the values for ammeter reading A is 1.5A, reading of voltmeter V is 9V, and all the resistors have the same resistance of 2Ω. What are the values for;

a. A_1 = *1.5 A ($I=I_1$)*

b. A_2 = *1.5 A ($I=I_2$)*

c. A_3 = *1.5 A ($I=I_3$)*

d. V_1 = *3.0 V ($V_1+V_2+V_3=9V$)*

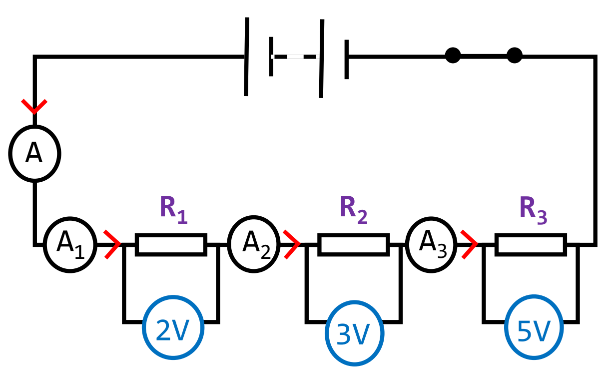
e. V_2 = *3.0 V ($V_1+V_2+V_3=9V$)*

f. V_3 = *3.0 V ($V_1+V_2+V_3=9V$)*

g. Effective resistance, R = *6.0 Ω (R= 2+2+2)*

EXAMPLE 2

Observe the circuit diagram below. Given that the values for ammeter reading A is 2A. What are the values for;



a. A_1 = *2 A (current in series is the same)*

b. Total potential difference across the resistors.
V = 2+3+5
V = 10 V

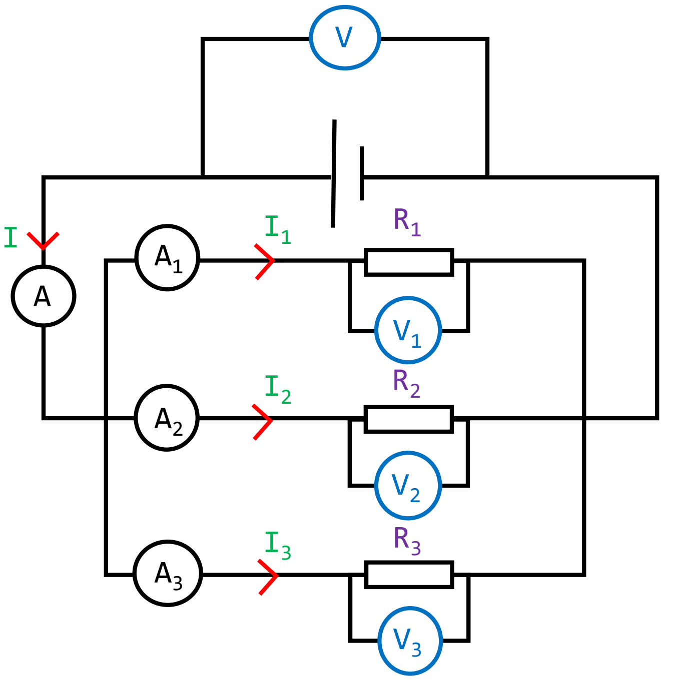
c. Resistance of R_1
V = I R
2 = 2 (R)
R = 1 Ω

d. Resistance of R_2
V = I R
3 = 2 (R)
R = 1.5 Ω

e. Resistance of R_3
V = I R
5 = 2 (R)
R = 2.5 Ω

f. Effective resistance
$R = R_1 + R_2 + R_3$
R = 5 Ω

Circuits arrangement (Parallel circuit)

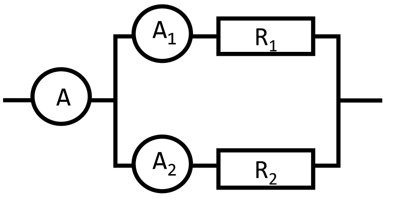


$$V = V_1 = V_2 = V_3$$

$$I = I_1 + I_2 + I_3$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Current split in a parallel circuit



$$I_1 = I\left(\frac{R_2}{R_1 + R_2}\right) \qquad I_2 = I\left(\frac{R_1}{R_1 + R_2}\right)$$

E X A M P L E 1

Observe the circuit diagram above. Given that the values for ammeter reading A is 1.5A, reading of voltmeter V is 1.0 V, and all the resistors have the same resistance of 2Ω. What are the values for;

a. A_1 = *0.5 A* ($I=I_1+I_2+I_3$)

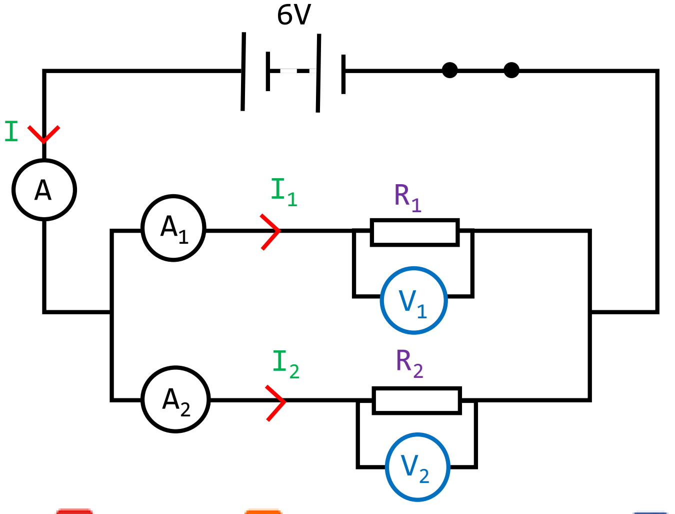
b. V_1 = *1.0 V* ($V = V_1=V_2=V_3$)

c. Effective resistance, R = *0.67 Ω*

1/R =1/2+1/2+1/2
1/R =3/2
R/1 =2/3
R = 0.67 Ω

E X A M P L E 2

Observe the circuit diagram above. Given that the values for ammeter reading A_i and A_2 are 2A and 4A respectively. What are the values for;



a. A = *6 A* ($I = I_1 + I_2$)

b. Voltmeter reading, V_1 = *6V* ($V = V_1 = V_2$)

c. Resistance of R_1

V = I R
6 = 2 (R)
$R_1 = 3\ \Omega$

d. Resistance of R_2

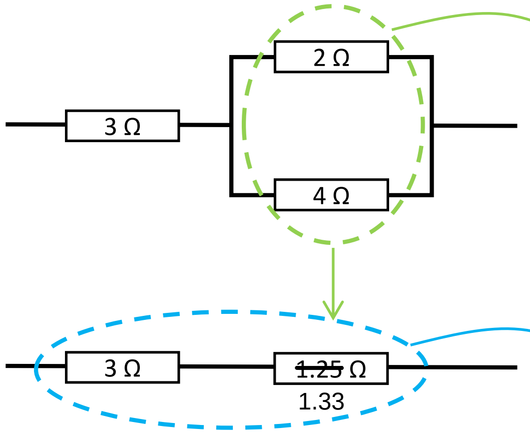
V = I R
6 = 4 (R)
$R_2 = 1.5\ \Omega$

e. Effective resistance

$1/R = 1/R_1 + 1/R_2$
1/R = 1/3 + 1/1.5
1/R = 1
R = 1.0 Ω

Calculation for effective resistance in a combined circuit

EXAMPLE 1



Parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{4}$$

$$\frac{1}{R} = \frac{3}{4}$$

$$\frac{R}{1} = \frac{4}{3} \rightarrow R = 1.33\ \Omega$$

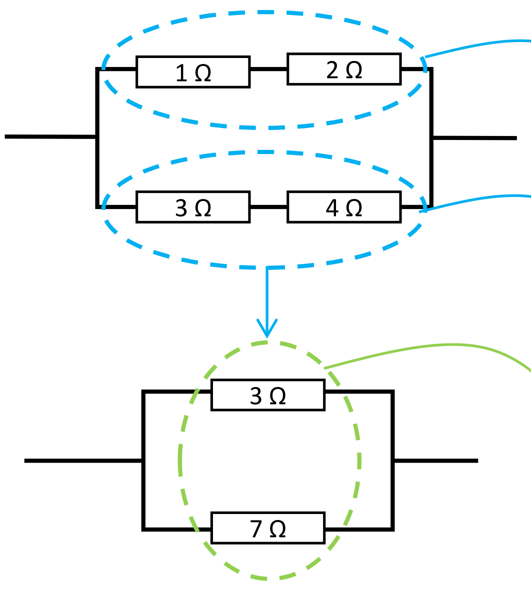
Series

$$R = R_1 + R_2$$

$$R = 3 + 1.25$$

$$R = 4.25\ \Omega$$

EXAMPLE 2



Series

$$R = R_1 + R_2$$

$$R = 1 + 2$$

$$R = 3\ \Omega$$

Series

$$R = R_1 + R_2$$

$$R = 3 + 4$$

$$R = 7\ \Omega$$

Parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R} = \frac{1}{3} + \frac{1}{7}$$

$$\frac{1}{R} = \frac{10}{21}$$

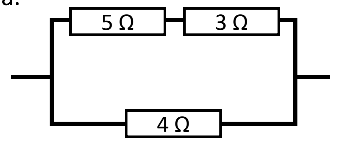
$$\frac{R}{1} = \frac{21}{10}$$

$$R = 2.1\ \Omega$$

Exercise

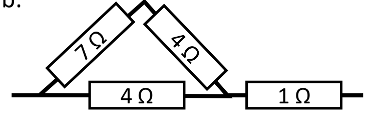
Calculate effective resistance in the combinations below.

a. R1 = 8



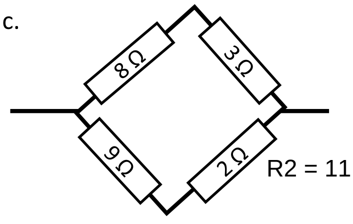
1/R = 1/8 + 1/4
1/R = 3/8
R = 2.67

b. R1 = 11



1/R(series) = 1/11 + 1/4
R(series) = 2.93
R = 2.93 + 1
= 3.93

c. R1 = 8+3 = 11

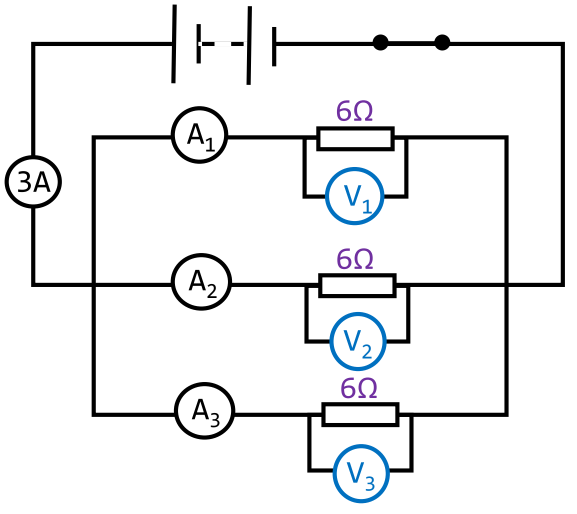


R2 = 11

1/R = 1/11 + 1/11 = 2/11
R = 5.5

Exercise (cont.)

1.



Based on the circuit diagram on the left, calculate the following values.

a. Effective resistance of the circuit.
b. A_1.
c. V_3.

1/R = 1/6 + 1/6 + 1/6 = 3/6
R = 2

V= IR = 3*2 = 6
I1 = V1/R1 = 6/6 = 1

I1 = 3/3 = 1A

V3 = I3*R3 = 1*6 = 6V

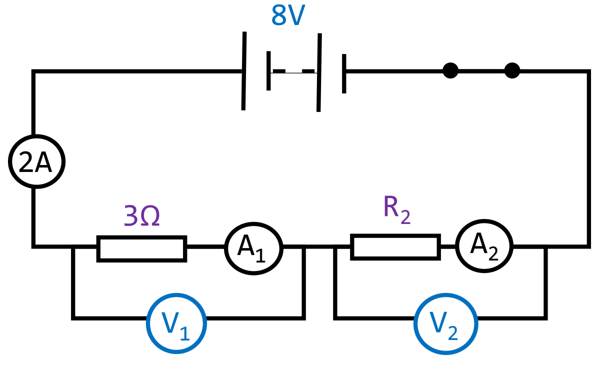
2. Based on the circuit on the right, calculate the following values.

a. Effective resistance of the circuit.
b. R_2.
c. A_1.
d. V_1.
e. V_2.

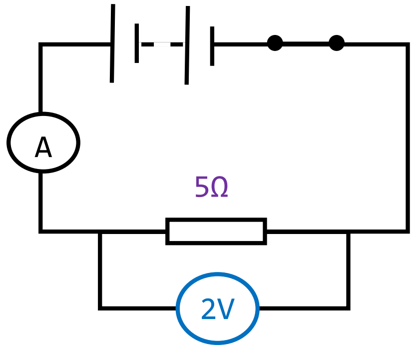
R = V/I = 8/2 = 4
R2 = R - R1 = 1

I1 = I = 2

V1 = 3 * 2 = 6V
V2 = 8 - 6 = 2V



3.

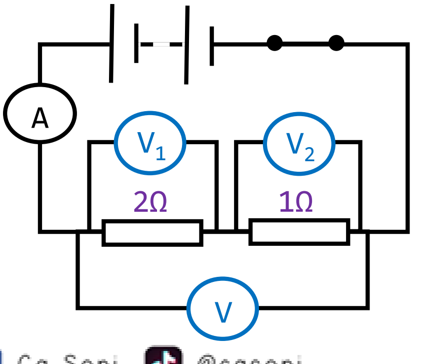


When the switch is closed, the voltmeter reading is 2V across a 5Ω resistor. Calculate the current flowing through the circuit.

V = IR
I = V/R
= 2/5
= 0.4A

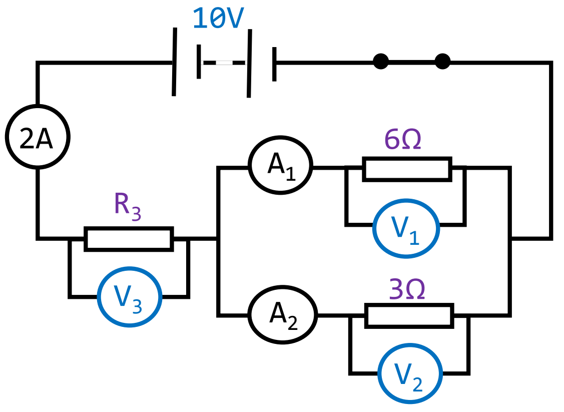
4. When the switch is closed, the ammeter reading is 2A. Calculate the reading of the voltmeter;

a. V. V = IR = 2(3) = 6V
b. V_1. V1 = IR1 = 2(2) = 4V
c. V_2. V2 = 1(2) = 2V



Exercise (cont.)

5.



R = (R1)(R2) / R1 + R2
* must be parallel and has 2 resistors

Based on the circuit on the left, calculate the following values.

a. Effective resistance of the circuit.
b. R_3.
c. A_1.
d. A_2.
e. V_3.

R = I/V = 2/10 = 5

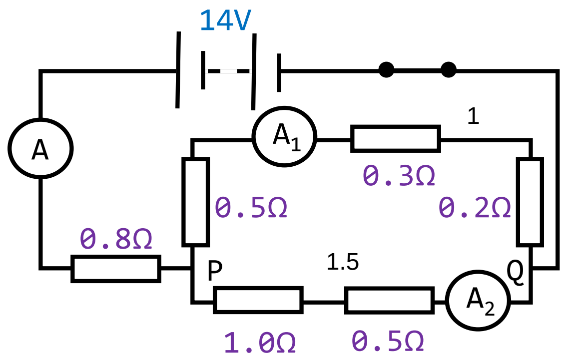
1/R = 1/6 + 1/3 = 1/2
R(series) = 2
R3 = 5 - 2 = 3

I1 = (3/9)2 = 0.6667
I2 = (6/9)2 = 1.3333

V3 = IR3 = 2(3) = 6V

6. Based on circuit diagram on the right, calculate the following quantities.

a. effective resistance
b. current flowing through ammeter A
c. current flowing through ammeter A_1
d. current flowing through ammeter A_2
e. potential difference across points P and Q

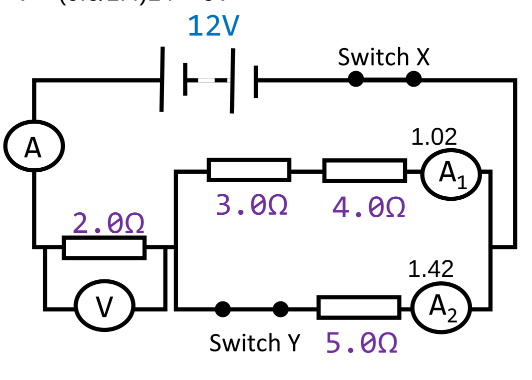


1/R(s) = 1/1 + 1/1.5 = 5/3
R(s) = 0.6
R = 0.8 + 0.6 = 1.4

I = V/R = 14/1.4 = 10A
A1 = (1.5/2.5)10 = 6A
A2 = 4A

V = (0.6/1.4)14 = 6V

7.



Calculate the following quantities when switch X and Y is closed. Given that ammeter readings for A_1 and A_2 are 1.02 A and 1.42A respectively.

a. Current flowing through ammeter A.
b. Potential difference across 2.0Ω resistor.
c. Effective resistance of the circuit.

a) I = 1.02 + 1.42 = 2.44

b) V = IR = 2(2.44) = 4.88V

c) 1/R(s) = 1/7 + 1/5 = 12/35
R(s) = 2.917
R = 2 + 2.917 = 4.917

Calculate the following quantities when switch X is closed but switch Y is open.

a. Effective resistance of the circuit.
b. Current flowing through ammeter A.
c. Potential difference across 2.0Ω resistor.

R = 2+3+4 = 9

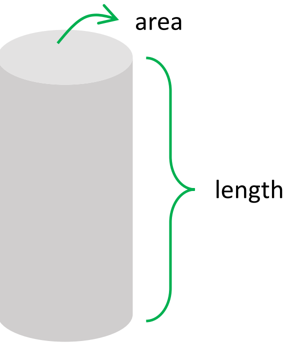
I = V/R = 12/9 = 1.333A

V = IR = 1.333(2) = 2.666V

Factors that affect the resistance of a wire

- l = length of the wire, m → $R \propto l$
  (l increase, R increase)
- A = cross-sectional area of the wire, m^2 → $R \propto \frac{1}{A}$
  (A increase, R decrease)
- ρ = resistivity of the wire, Ωm → $R \propto \rho$
  (ρ increase, R increase)

$$\boxed{R = \frac{\rho\, l}{A}}$$



Resistivity of a conductor, ρ

- a measure of a conductor's ability to oppose the flow of electric current
- unit is ohm-meter (Ω m)
- depends on the temperature and the nature of the conductor material.

Applications of Resistivity of Conductors in Daily Life

heating element
- heating plate is a heating element
- high resistivity, melting point and is durable

connecting wire
- connecting wire uses copper (low resistivity)
- avoid heating up too quickly when current flows

Comparing non-conductors, semiconductors, conductors and superconductors

Non-conductor	Semiconductor	Conductor	Superconductor
• does not conduct electricity • good insulator	• conducts electricity better than an insulator but not as good as a conductor	• conducts electricity	• conducts electricity without any resistance
• highest resistivity	• resistivity between a non-conductor and a conductor	• low resistivity	• zero resistivity at critical temperature
• Example: plastic and wood	• Examples: silicone and germanium	• Examples: iron and carbon	• Example: caesium at a temperature of 1.5 K or lower

Critical temperature, T_c is the temperature when the resistivity of a superconductor becomes zero.

Exercise

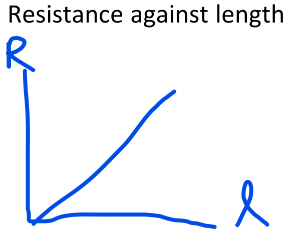
1. What are the factors affecting resistance of a wire? State the relationship between each factors with resistance of a wire.

2. Which of the following combination has;
   a. the highest resistance?
   b. the lowest resistance?

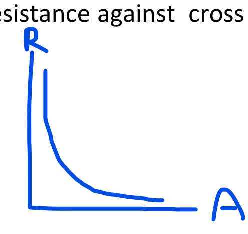
1	2	3	4
Long wire high	Long wire high	Short wire low	Long wire high
Thick wire low	Thin wire high	Thick wire low	Thin wire high
High resistivity high	High resistivity high	Low resistivity low	Low resistivity low

3. Sketch graphs;

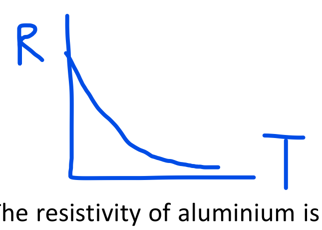
a. Resistance against length of wire



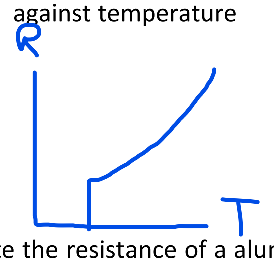
b. Resistance against cross sectional area



c. Resistance of semiconductor against temperature



d. Resistance of superconductor against temperature



4. The resistivity of aluminium is 2.8 x 10^{-8} Ωm. Calculate the resistance of a aluminium wire with a length of 30.0 cm and a diameter of 1.0 mm.

R = pl / A
= 2.8 x 10 ^-8 (30) / 7.854
= 1.07 x 10^-7

A = (0.5 x 10-3) ^2 x 3.142
= 7.854

5. Calculate the total resistance of a coil of nichrome wire with a length of 25.0 m and a cross-sectional area of 5.0 mm^2. Given that the resistivity of copper at a temperature of 20°C is 1.1 x 10^{-6} Ωm.

R = 1.1 x 10^-6 (25) / 5 x 10-3
= 5.5

3.3 Electromotive Force (e.m.f.) and Internal Resistance

Energy transferred or work done by an electrical source to move one coulomb of charge in a complete circuit.

$$\boxed{\varepsilon = \frac{E}{Q}}$$

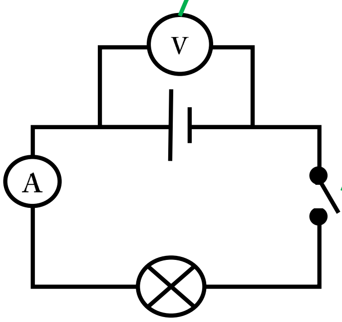
ε = electromotive force, V

E = energy transferred / work done, J

Q = the amount of charge flowing, C

ε Voltmeter reading in an open circuit

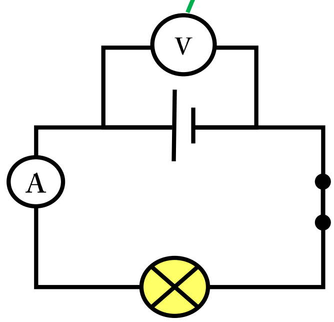
I = 0A



Open circuit

V Voltmeter reading in a closed circuit

I ≠ 0A



Closed circuit

Internal resistance, r

resistance caused by electrolyte in the dry cell

↓

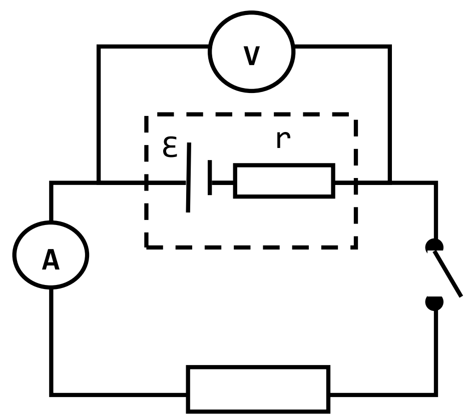
causes loss of energy (heat) in dry cells as work has to be done to move one coulomb charge against the resistance within the dry cell

↓

$\varepsilon > V$

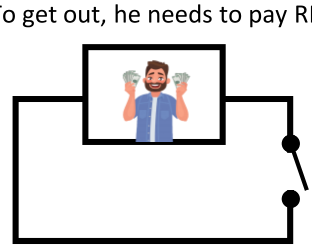
Voltage drop

$$\boxed{Ir = \varepsilon - V}$$

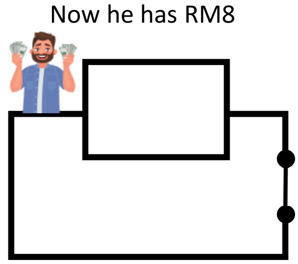


A N A L O G Y

Initially, he has RM10
To get out, he needs to pay RM2



Now he has RM8



E.M.F = “RM 10”

Voltage drop = “RM 2”

Internal resistance = “door of the box”

Potential difference = “RM 8”

Formula relating E, V, I, R and r

$$Ir = \mathcal{E} - V \quad \longrightarrow \quad \mathcal{E} = V + Ir$$

$$\downarrow$$

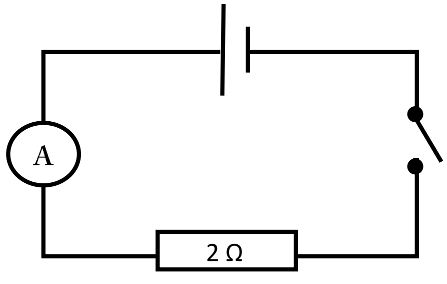
$$\mathcal{E} = IR + Ir$$

$$\downarrow$$

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

Exercise

1.

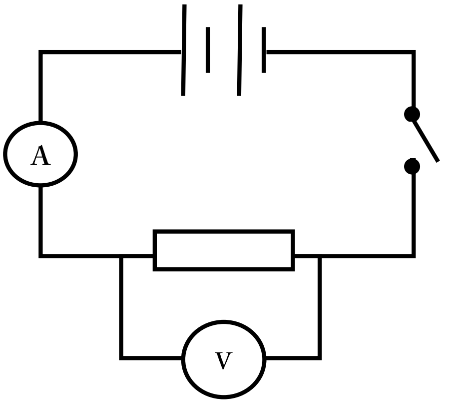


Given that the e.m.f., $\mathcal{E}$ of dry cell is 1.5 V and the internal resistance, *r* is 0.5 Ω. Calculate current flow.

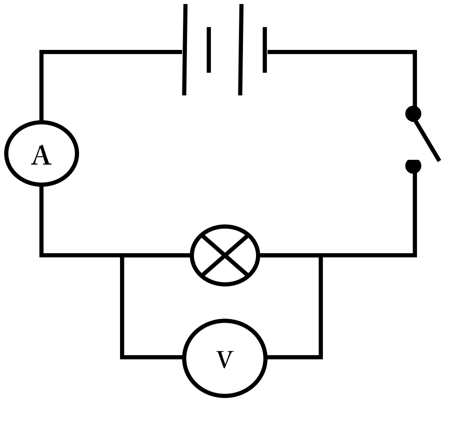
emf = I(R + r)
1.5 = I (2+0.5)
I = 1.5/2.5
= 0.6

2. Given that the total e.m.f., $\mathcal{E}$ of dry cell is 3.0 V and the total internal resistance, *r* is 0.5 Ω. What is the reading of the voltmeter if current flow is 0.2 A?

V = emf - Ir
= 3 - 0.2(0.5)
= 2.9



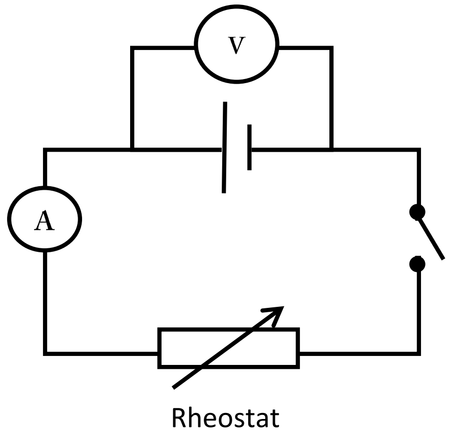
3.

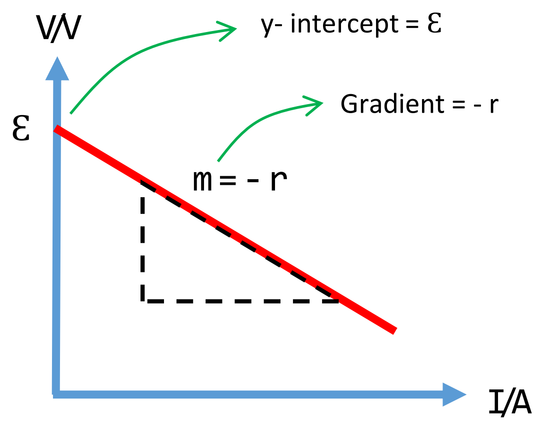


Given that the total e.m.f., $\mathcal{E}$ of dry cell is 3.0 V and the total internal resistance, *r* is 0.5 Ω. What is the resistance the bulb if current flow is 0.2 A?

emf = I(R+r)
3 = 0.2(R + 0.5)
15 = R + 0.5
R = 14.5

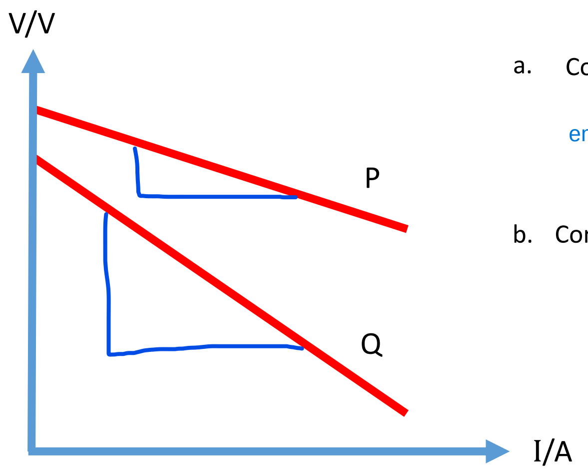
Determining the e.m.f. and Internal Resistance of a Dry Cell





Exercise

1.



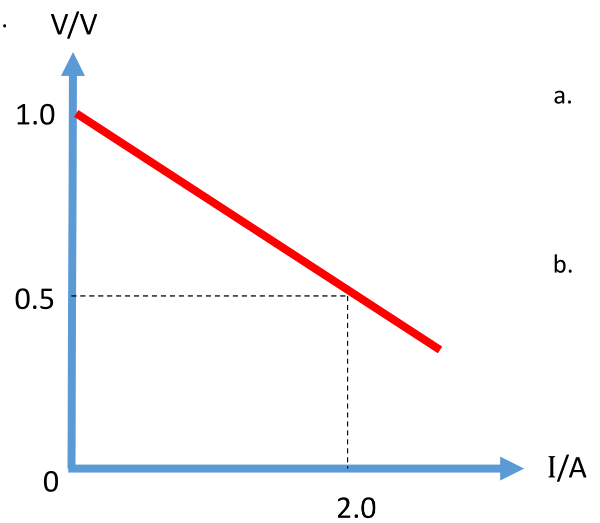
a. Compare the e.m.f of dry cell P and Q.

emf of dry cell P is higher than Q

b. Compare the internal resistance of dry cell P and Q.

Q > P

2.



a. What is the e.m.f of the dry cell?

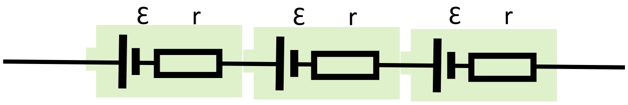
1.0V

b. Calculate the internal resistance of the dry cell.

m = -0.5 / 2
-r = -0.25
r = 0.25

Effects of Dry Cell Connected in Series and Parallel Arrangements

Dry Cell in Series



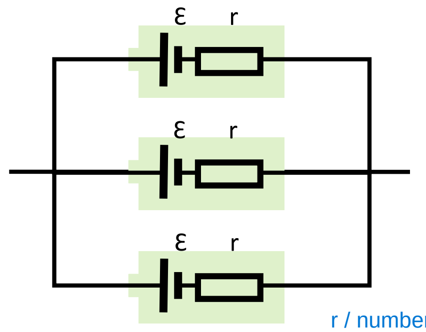
Total r = r + r + r

= 3 r

Total ε = ε + ε + ε

= 3 ε

Dry Cell in Parallel



r / number of dry cell

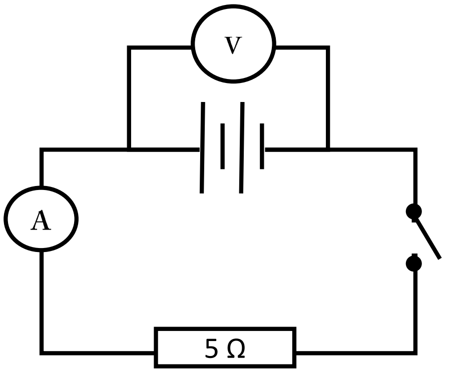
$$\frac{1}{r} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r}$$

Total r = $\frac{r}{3}$

Total ε = ε

Exercise

1.



emf

When the switch is open, the reading of the voltmeter is 6V. When the switch is closed, the voltmeter reading is 5.6V. Calculate;

a. the e.m.f of each dry cell 6V
b. total voltage drop 6 - 5.6 = 0.4V
c. current flow when switch is closed
d. internal resistance of each dry cell

I = V/R
= 5.6 / 5
= 1.12 A

emf = V + Ir
6 = 5.6 + 1.12 r
1.12 r = 0.4
r = 0.3571

Types of Vehicles Using Electric Power

Electric vehicle (E.V)	Hybrid car
• 100% power from rechargeable batteries • Li-Ion or Ni-MH batteries	• 25 – 40% from rechargeable batteries • remainder by fossil fuels
• Battery voltage range: 300 – 800 V	• Battery voltage range: 100-200 V

3.4 Electrical Energy and Power

Power rating label - displays the voltage and electrical power required to operate the electrical appliance.

The food steamer will use 900 J of electrical energy in one second when a voltage of 120 V is supplied

Relationship between E,V, I and t

$$Q = It$$

$$V = \frac{E}{Q} \rightarrow E = VQ \rightarrow \boxed{E = VIt}$$

E = electrical energy, J

V = potential difference, V

I = electric current, A

t = time, s

Relationship between P, V and I

$$E = VIt$$

$$P = \frac{E}{t} \rightarrow P = \frac{VI\cancel{t}}{\cancel{t}} \rightarrow \boxed{P = VI}$$

P = power, W

V = potential difference, V

I = electric current, A

Relationship between P, V, I and R

$$V = IR$$

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

$$P = VI$$

$$\boxed{P = I^2 R}$$

$$\boxed{P = \frac{V^2}{R}}$$

Exercise

1. 

A bulb has a power rating label 60W, 240V. Calculate;

a. current flow when the bulb lights up at normal condition.
b. resistance of the bulb.
c. energy used up by the lamp in 5 minutes.

$P = VI$
$60 = 240\, I$
$I = 0.25A$

$R = V/I$
$R = 240/0.25$
$R = 960$

$E = Pt$
$= 60(5*60)$
$= 18kJ$

2. A hair dryer used 500kJ of energy in 3 minutes when connected to 240V power supply. Calculate;

a. current flow.
b. resistance.
c. power of the hair dryer.

$E = VIt$
$500000 = 240(3*60)\, I$
$I = 500000 / 43200$
$= 11.574A$

$R = V/I$
$= 240 / 11.57$
$= 20.74$

$P = E/t$
$= 500000/ (3*60)$
$= 2777.78$

3. 

The television used 130 J of energy per second when connected to 240 V power supply. Calculate;

a. energy used if it is used for an hour.
b. resistance.
c. current flow.

$E = Pt$
$= 130* (1*60*60)$
$=468kJ$

$P = V^2 / R$
$130 = 240^2 / R$
$R = 443.077$

$P = I^2 R$
$130 = I^2 (443.077)$
$I^2 = 130/443.077$
$= 0.293$
$I = 0.5417A$

The Power and Energy Consumption Rate for Various Electrical Devices

Calculating energy consumption

$$\boxed{E = P t}$$

E = energy consumed, kWh

P = power, kW

t = time, hour

Calculating cost of consumption

$$\boxed{Total\ Cost = E \times Cost\ per\ kWh}$$

Exercise

1. 100 W appliance used for 3 hours per day for 30 days. If the cost per unit is RM0.218, calculate the total cost.

   E = Pt
   = 100 * 30 * 3 * 60 * 60
   = 32400kW

   32400 * 0.218 = RM 7063.20

2. Compare the total cost used by CFL and LED below if both are used for 15 hours per day for 30 days. Given that the cost per unit is RM0.218

CFL

P = 40 W

LED

P = 12 W

<u>Conclusion</u>
Lower energy consumption:
Higher efficiency:
Saves more energy:

3. List out some FIVE steps that can be done to reduce household's electrical energy usage. (Refer textbook page 128)