Current Electricity

Current
Electromotive force
Potential difference
Resistance

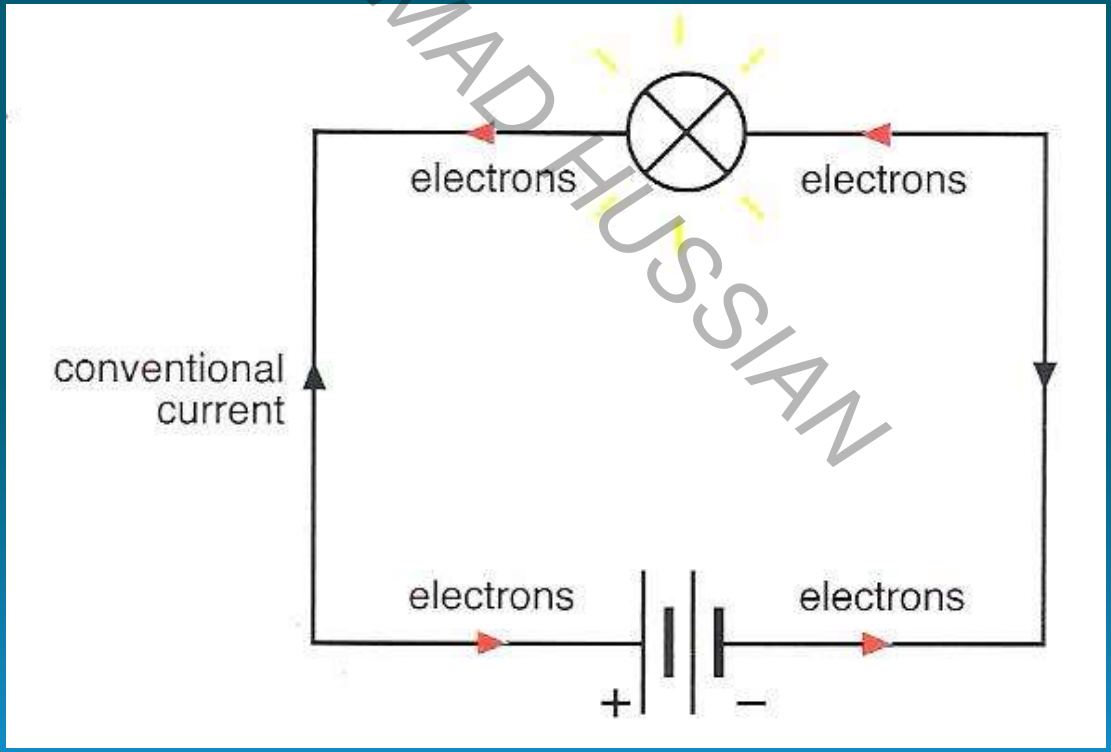
State that a current is a flow of charge and that current is measured in amperes.

Current

Electric Current

- **Current** is the rate of flow of charge, *Q*.
- When charges flow, they can be positive or negative.
- For historical reason, the **direction** of **conventional current** is taken as the **direction a positive charge will flow**.

- In conductor, the current is due to motion of negatively charged electrons. Therefore in a circuit, the **direction** of **conventional current** is **opposite** to the **direction of motion of electrons**.



Do calculations using the equation charge = current × time.

Current

Calculating Current

- Suppose that Q flows past a given point in a wire in a time t. The electric current I in the wire is

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

- The SI unit for current is **coulomb per second** (**Cs^{-1}**) or Ampere (**A**).

Problem Solving

1. A charge of 10 coulombs passes round a circuit in 4 s. Calculate the average current.
2. If 20 C of charge pass a point in a circuit in 1 s, what current is flowing?
3. A charge of 4 C passes a point in a circuit in 5 s. Calculate the current flowing through the circuit.
4. A current of 4 A flows around a circuit for 10 s. How much charge flows around the circuit in this time?

Problem Solving

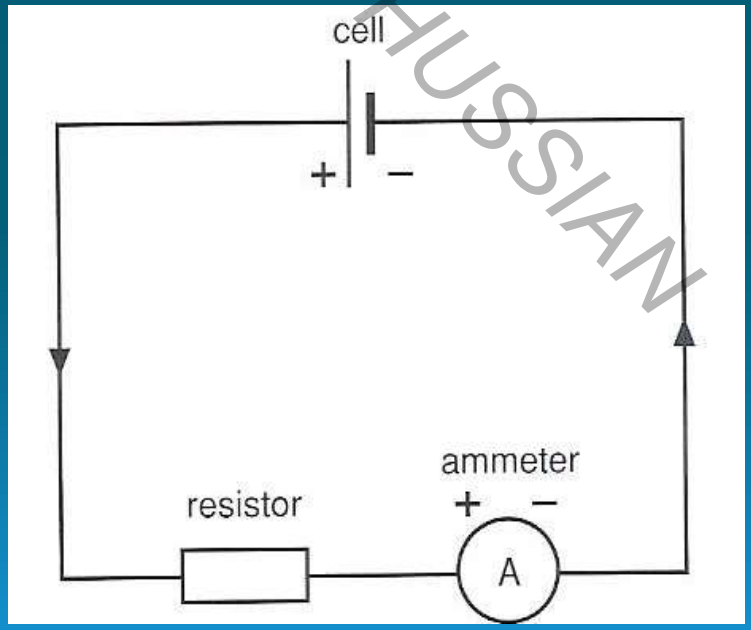
5. When a starter motor of a car is switched on for 0.5 s, 16 C of charge passes through the wires in the motor. How large is the electric current?
6. A 3 A current flows in a circuit for 2 minutes. What is the total charge flowing in the circuit.
7. A charge of 120 C flows for 4 minutes. What is the current?
8. A charge of 60 C produces a current of 0.5 A. How long does this take?

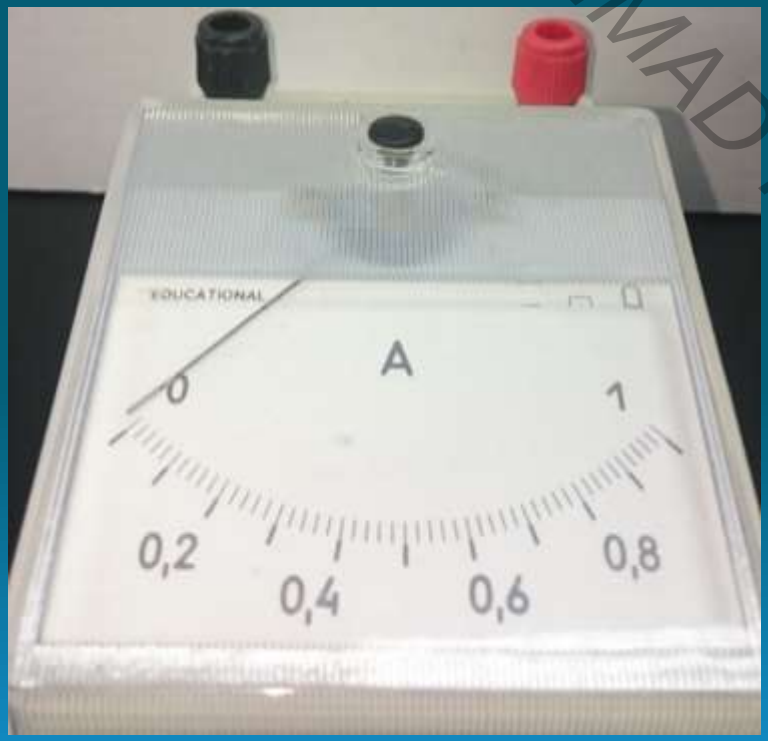
Describe the use of an ammeter with different ranges.

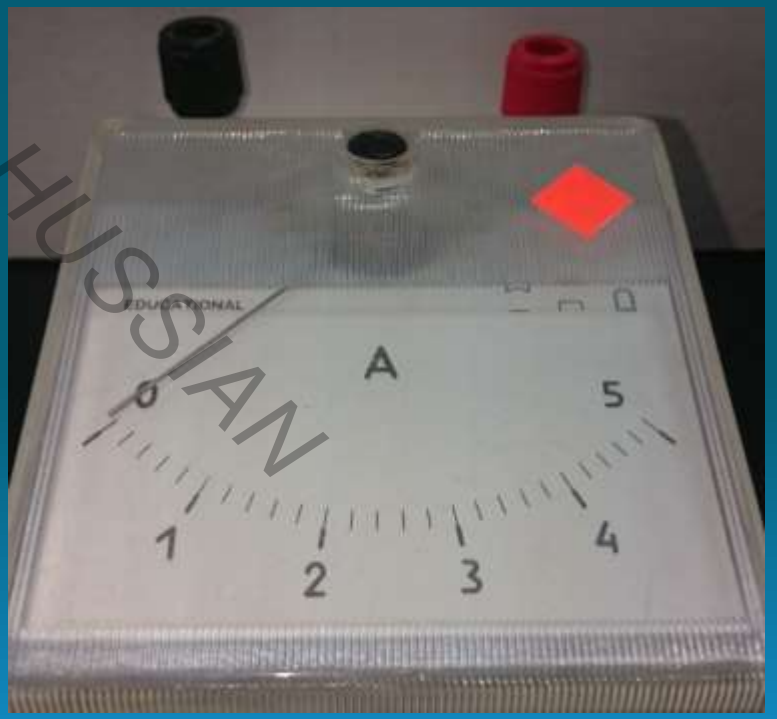
Current

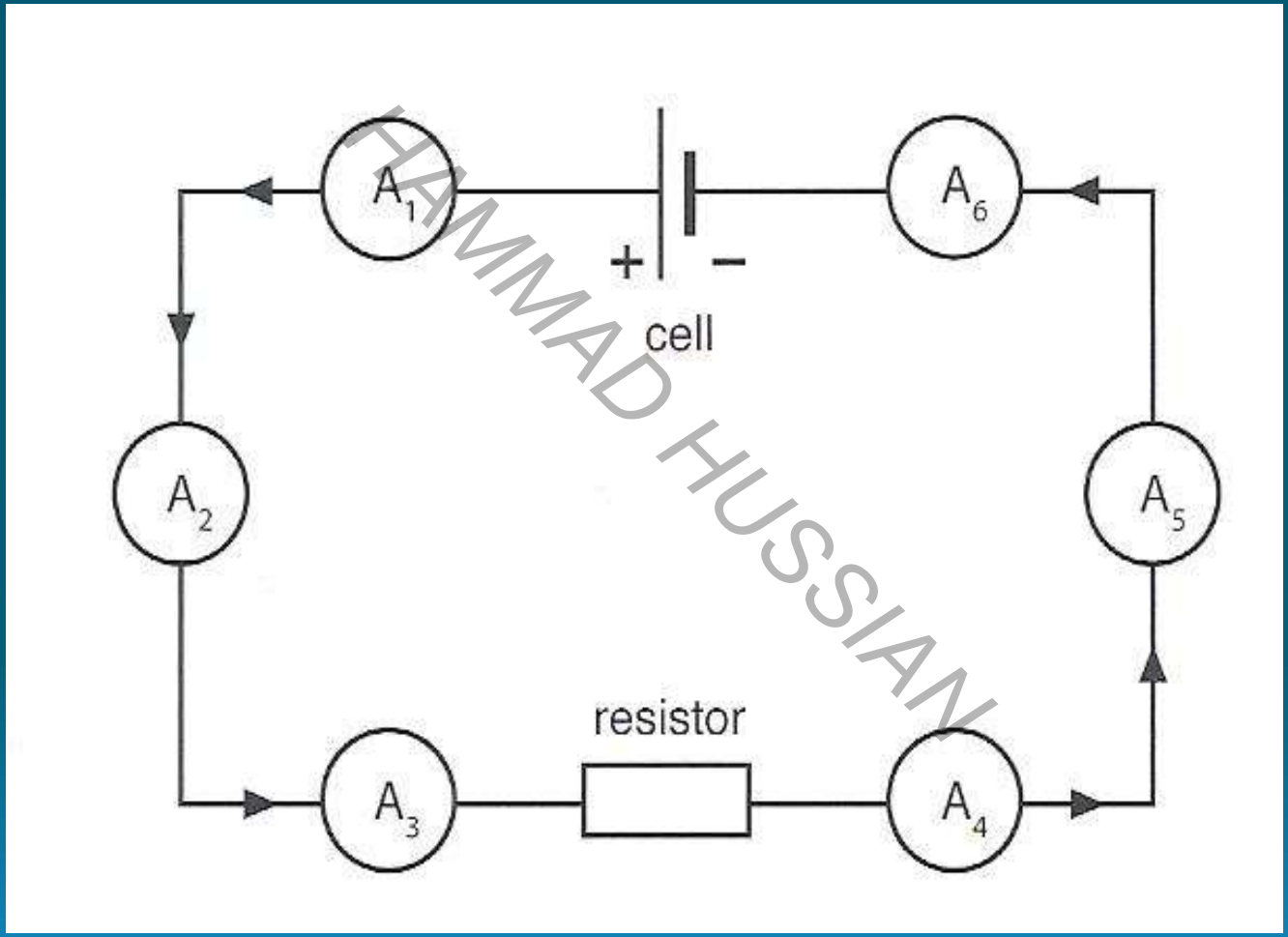
Measuring Current

- To measure the size of an electric current, an ammeter can be used.









- The ammeter is connected in series with the component.

Explain that electromotive force (e.m.f.) is measured by the energy dissipated by a source in driving a unit charge around a complete circuit.

Electromotive Force

State that e.m.f. is work done/charge.

Electromotive Force

State that the volt is given by J/C.

Electromotive Force

Electromotive force

- In a cell or battery, the chemical changes take place which provide the energy required to push the electric charge (electrons) round the circuit.
- The electromotive force (e.m.f.) of any electrical source is the work done by the source in driving a unit charge around a complete circuit.
- The SI unit for e.m.f. is joule per coulomb (J/C) or the volt (V).

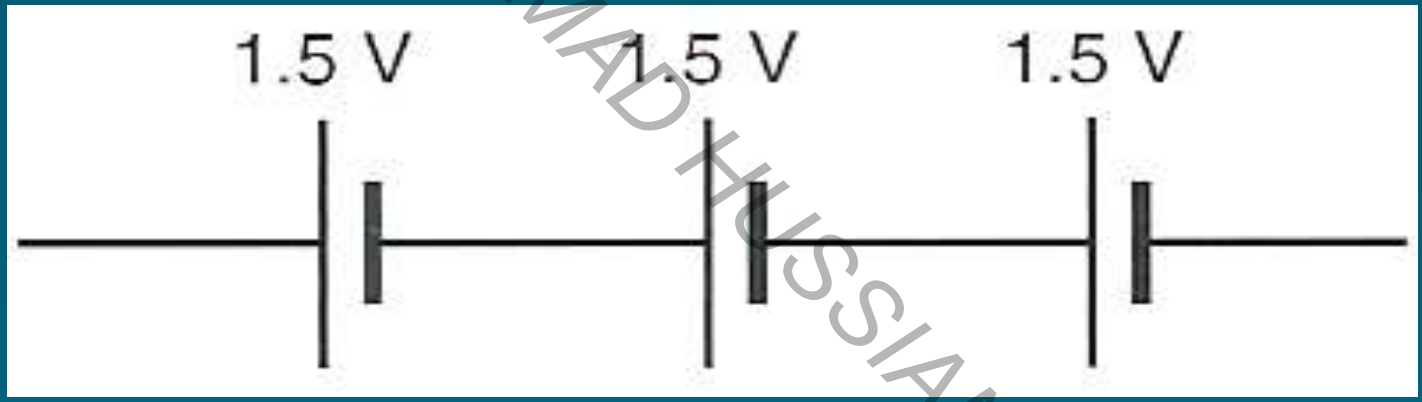
Calculate the total e.m.f. where several sources are arranged in series and discuss how this is used in the design of batteries.

Electromotive Force

Discuss the advantage of making a battery from several equal voltage sources of e.m.f. arranged in parallel.

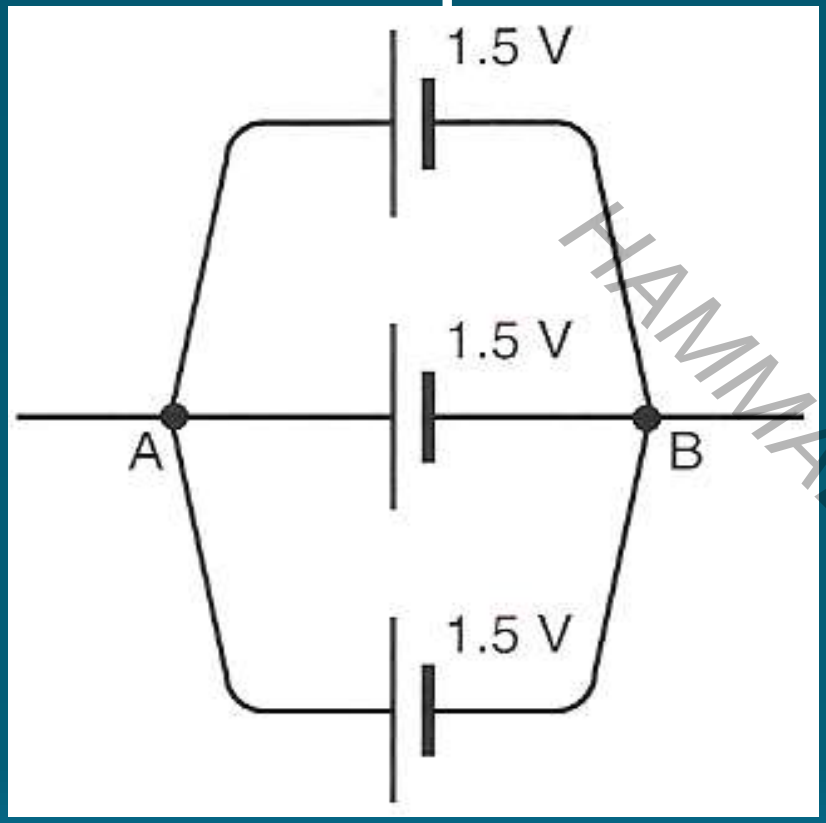
Electromotive Force

Cells in series



- The connection gives an increased e.m.f. because charges gain potential energy from all three cells when they pass through the cells.
- The combined e.m.f. is calculated by adding up the individual e.m.f.s.

Cells in parallel



- Charges flowing round the circuit will split into three equal portions when they reach A and each portion passes through one cell only.
- The gain in potential energy for any charge in each portion is only from one of the three cells.

The advantages of this arrangement are

a. The cells will last longer before going ‘flat’
b. The cells are able to supply a higher current

Example

1. What is the combined e.m.f. of each of the following combinations of cells?
   a. two 2.0 V cells in series
   b. two 2.0 V cells in parallel
   c. six 2.0 V cells in series

State that the potential difference (p.d.) across a circuit component is measured in volts.

Potential Difference

State that the p.d. across a component in a circuit is given by the work done in the component/charge passed through the component.

Potential Difference

Potential difference

- The **potential difference** across a component is defined as the work done to drive a unit charge through the component.

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge}} \qquad V = \frac{W}{Q}$$

- The SI unit for potential difference is **joule per coulomb (J/C)** or the **volt (V)**.

Example

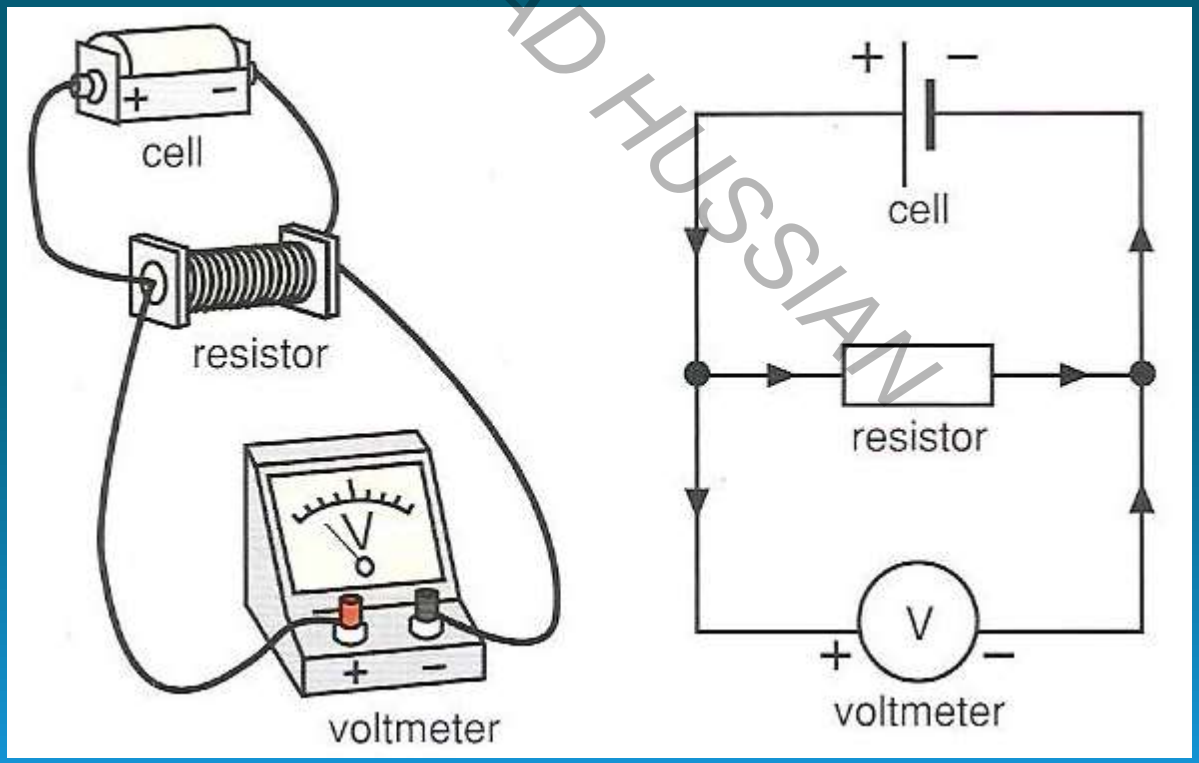
1. How much energy must a battery add to a charge of 35 C in a circuit to move it from a point at a potential of 60 V to another point where the potential is 83 V?
2. When 2 C of charge flows through a component in an electrical circuit, 20 J of work is done. What is the potential difference across the component
3. How much work is does it take to move a charge of 30 C through a potential difference of 6 V?
4. To toast a couple of slices bread, a toaster has to use 30 000 joules of energy, drawn from a 110 V wall outlet. How much charge flows through the toaster.

Describe the use of a voltmeter with different ranges.

Potential Difference

Measuring Potential Difference

- The potential difference across two points in a circuit can be measured by a **voltmeter**.

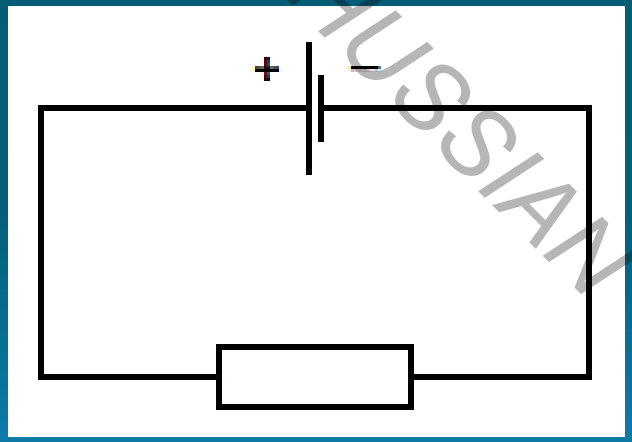


1. When there is an electric current in a metal wire, what flows through the wire?
   A. atoms
   B. electrons
   C. neutrons
   D. protons

2. The current in an electric heater is 10 A. It is switched on for five minutes.
3. How much charge flows through the heater?

A. 0.5 C
B. 2 C
C. 50 C
D. 3000 C

3. The diagram shows a simple electric circuit.

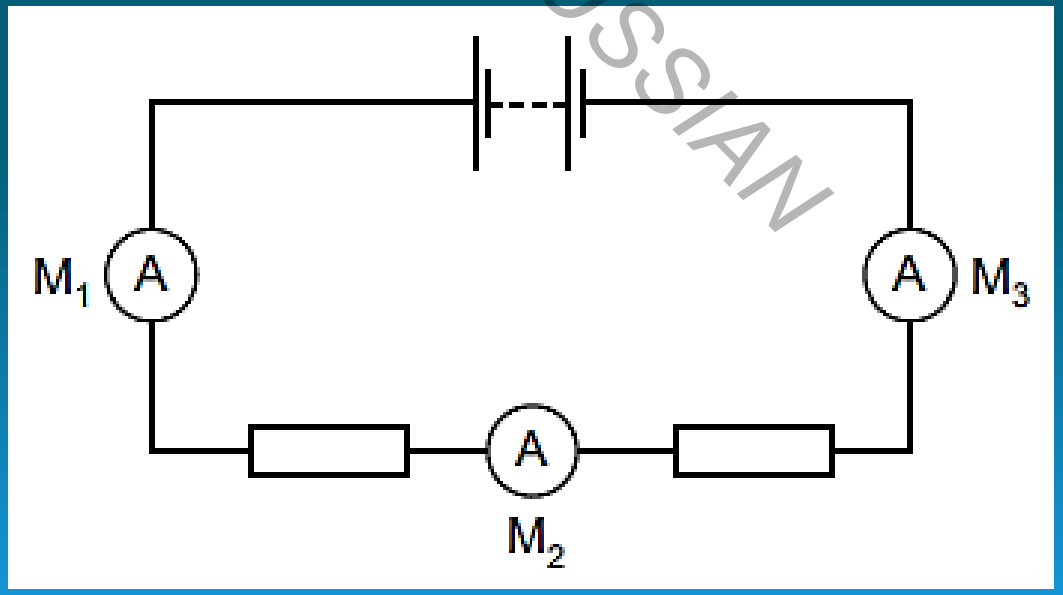


1. Which row describes the charge on an electron and the direction of electron flow through the resistor?

	charge on an electron	direction of electron flow
A	negative	– to +
B	negative	+ to –
C	positive	– to +
D	positive	+ to –

A

4. The diagram shows a battery connected to two identical resistors. Three ammeters M_1, M_2 and M_3 are connected in the circuit.

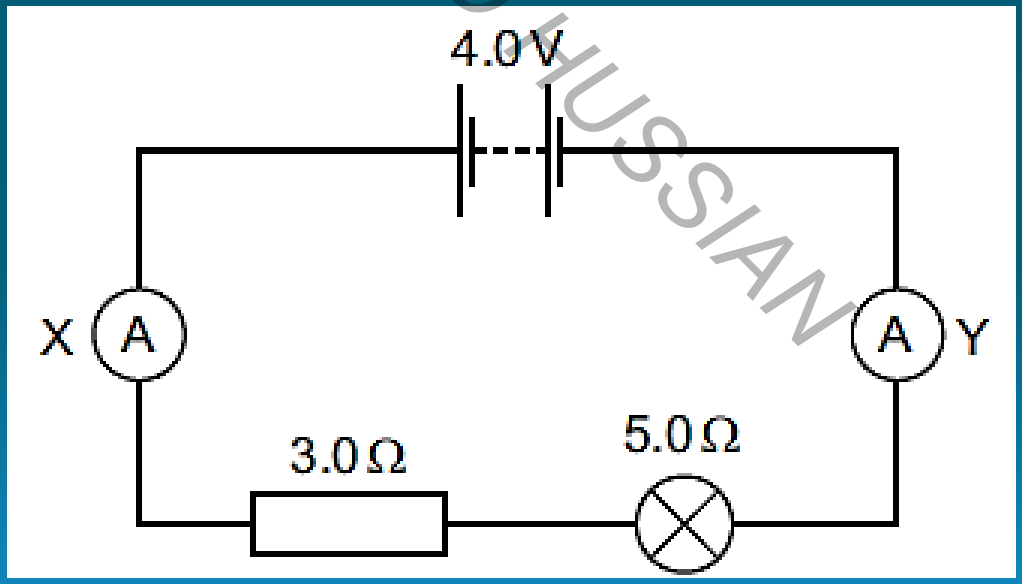


1. Meter M_1 reads 1.0 A.
2. What are the readings on M_2 and on M_3?

	reading on M_2 / A	reading on M_3 / A
A	0.5	0.0
B	0.5	0.5
C	0.5	1.0
D	1.0	1.0

D

5. In the circuit shown, ammeter X reads 0.5 A.

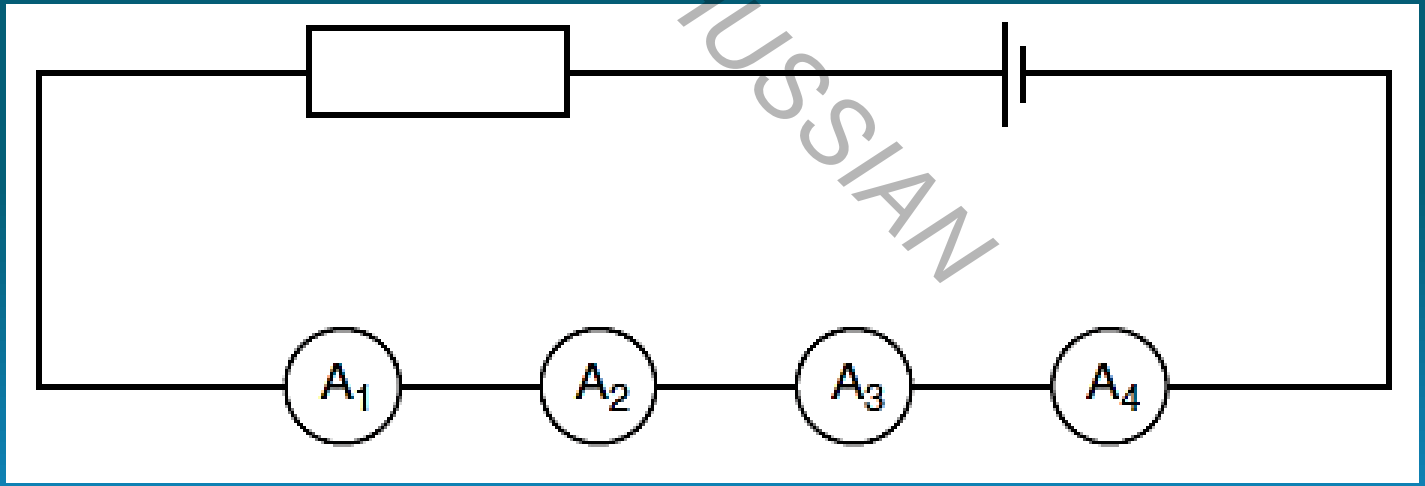


1. What does ammeter Y read?

A	0	**B**	0.5 A	**C**	3.5 A	**D**	4.0 A

B

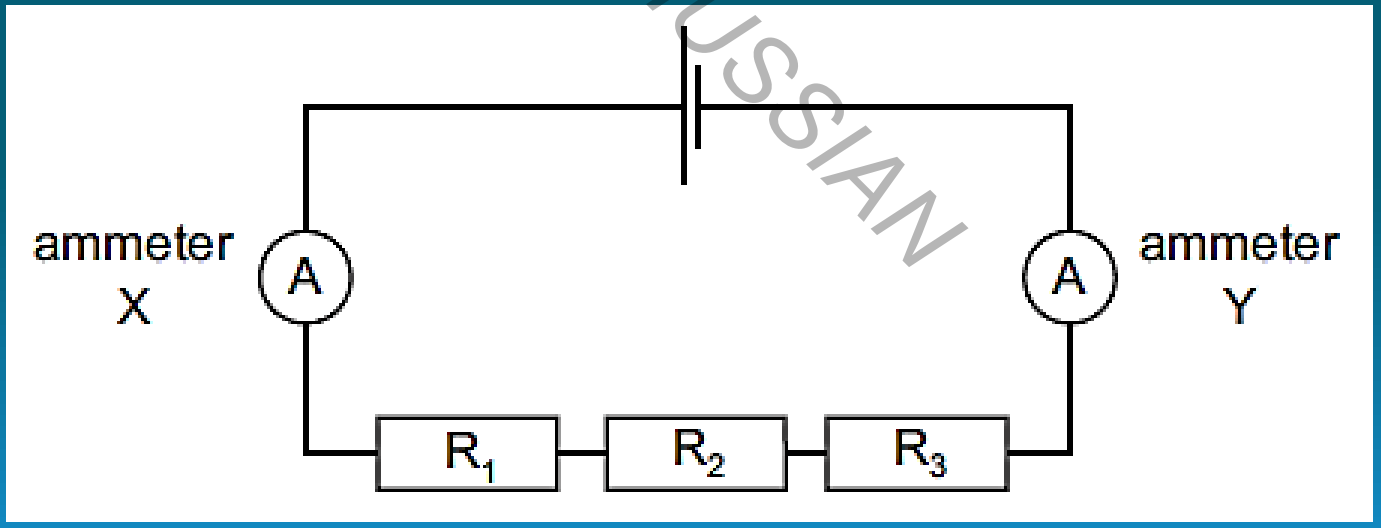
6. Two faulty ammeters and two perfect ammeters are connected in series in the circuit shown.



A. The readings on the ammeters are
   1. A_1 2.9 A
   2. A_2 3.1 A
   3. A_3 3.1 A
   4. A_4 3.3 A

B. Which two ammeters are faulty?
   A. A_1 and A_2
   B. A_1 and A_4
   C. A_2 and A_3
   D. A_3 and A_4

7. The diagram shows a circuit containing two ammeters and three resistors.



1. Which of the ammeters will show the current in resistor R_2?

A. ammeter X only
B. ammeter Y only
C. both ammeter X and ammeter Y
D. neither ammeter X nor ammeter Y

8. What is measured by the energy dissipated when a source drives a unit charge round a complete circuit?
   A. electromotive force
   B. potential difference
   C. Power
   D. resistance

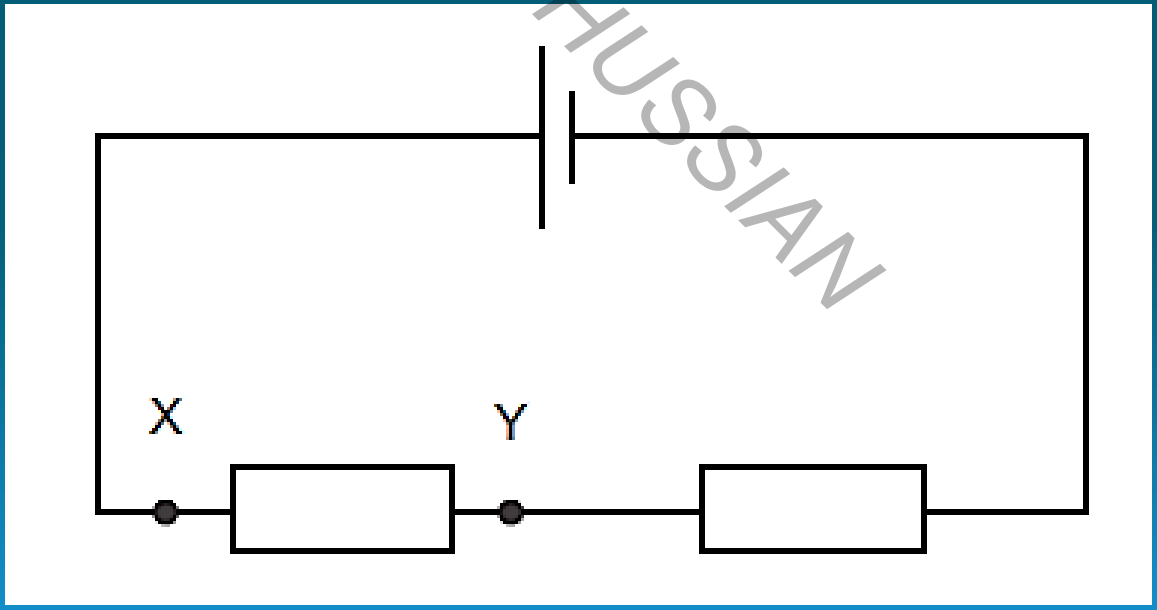
9. A cell is connected to a resistor.
10. What is the e.m.f. of the cell equal to?
    A. The potential difference across the resistor for each unit of current.
    B. The power produced in the circuit for each unit of charge that passes.
    C. The work done in the circuit for each unit of charge that passes.
    D. The work done in the circuit for each unit of current.

10. An electrical quantity is defined as ‘the energy converted by a source in driving a unit charge round a complete circuit.’
11. What is this quantity called?
    A. current
    B. electromotive force
    C. potential difference
    D. power

11. How could the unit of potential difference, the volt, also be written?
    A. A / s
    B. C / A
    C. C / J
    D. J / C

12. One volt can also be written as
    A. one coulomb per ampere.
    B. one coulomb per joule.
    C. one joule per ampere.
    D. one joule per coulomb.

13. The diagram shows two resistors connected in series with a cell.



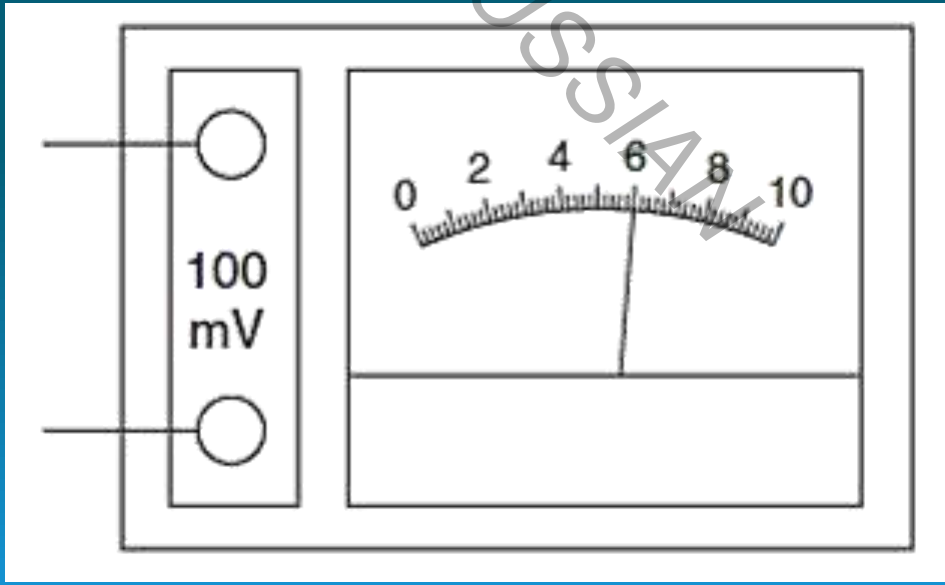
1. Which statement defines the potential difference across XY?

A. the power needed to drive a unit charge through the cell
B. the power needed to drive a unit charge between X and Y
C. the work done in driving a unit charge through the cell
D. the work done in driving a unit charge between X and Y

14. A student wishes to measure the electromotive force (e.m.f.) of a battery and the potential difference (p.d.) across a resistor.
15. She has the resistor, the battery and some connecting wires.
16. What else does she need?

A. a voltmeter only
B. an ammeter only
C. an ammeter and a voltmeter
D. a force meter (newton meter) and a voltmeter

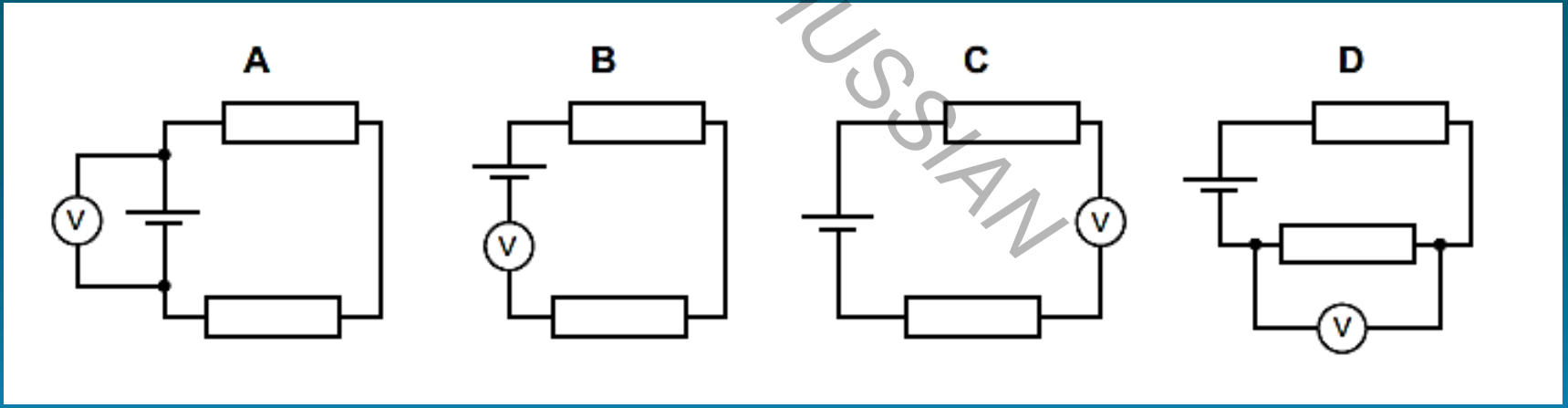
15. The diagram shows a voltmeter adapted to measure a range from 0–100 mV. The voltmeter is measuring the potential difference in a circuit.



1. What is the reading on the voltmeter?

A. 0.06 mV
B. 0.6 mV
C. 6 mV
D. 60 mV

16. Which circuit shows how a voltmeter is connected to measure the potential difference across the cell?



A

17. The potential difference between the ends of a conductor is 12 V.
18. How much electrical energy is converted to other forms of energy in the conductor when 100 C of charge flows through it?

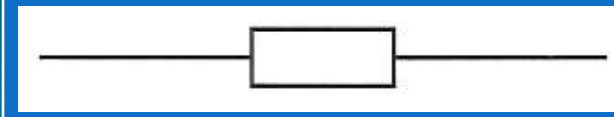
A. 0.12 J
B. 8.3 J
C. 88 J
D. 1200 J

State that resistance = p.d./current and use the equation resistance = voltage/current in calculations.

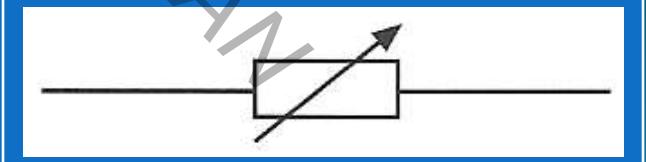
Resistance

Resistor

- A resistor is a component in an electrical circuit which provides a known value of resistance.
- Its purpose is to control the size of the current flowing in a circuit.



Electrical symbol for a fixed resistor



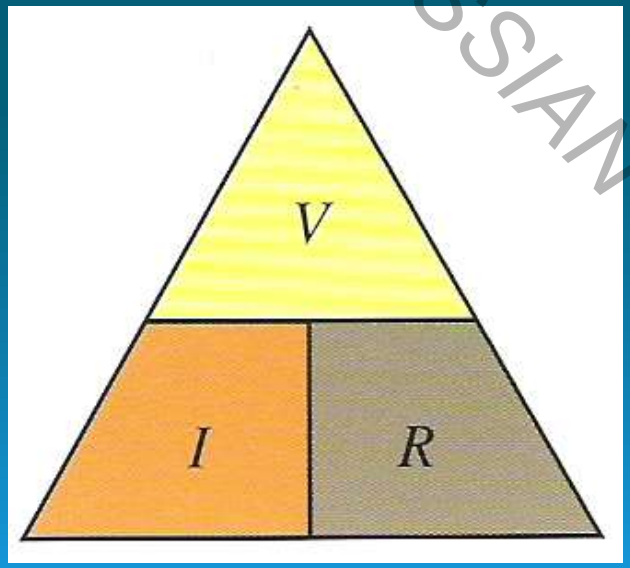
Electrical symbol for a variable resistor

Resistance

- Electrical resistance is a measure of the degree to which an electrical component opposes the passage of an electric current.
- Resistance is defined as the ratio of the potential difference across the component to the current flowing through it.

$$\text{Resistance} = \frac{\text{Potential difference}}{\text{Current}}$$

- The unit of resistance is the ohm (Ω).
- A resistor has a resistance of one ohm if a current of one ampere flows through it when the potential difference across it is one volt.



Problem Solving

1. When a current of 2 A flows through a resistor, the potential difference across the resistor is 10 V. What is the resistance of the resistor.
2. When a wire is connected to a 9 V battery, the current is 0.020 A. What is the resistance of the wire?
3. How much is the current in a light bulb whose resistance is 350 Ω when the bulb is connected to a 110 V outlet?
4. A moving-coil galvanometer has a resistance of 40 Ω and gives a full-scale deflection of 2 mA. What is the potential difference across its terminals when this current is flowing?

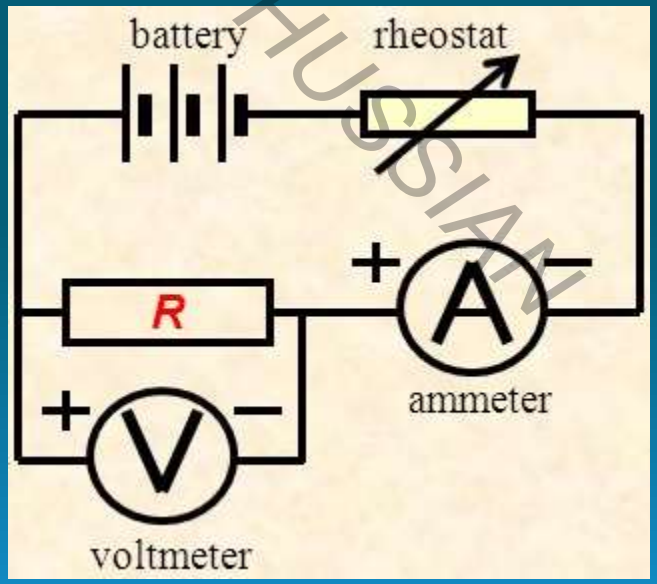
5. A resistor allows a current of 0.02 A to flow through it when there is a p.d of 10.0 V between its ends. What is its resistance?
6. A 12 Ω resistor has a p.d of 6 V across it. What is the current through the resistor?
7. What p.d. is needed to make a current of 1 A flow through a 20 Ω resistor?
8. What current flow when p.d. of 14.5 V is connected across a 1000 Ω resistor?

Describe an experiment to measure the resistance of a metallic conductor using a voltmeter and an ammeter and make the necessary calculations.

Resistance

- Aim: To measure electrical resistance of metallic conductor.
- Apparatus:
  - DC Supply
  - Rheostat (Variable Resistor)
  - Voltmeter
  - Ammeter

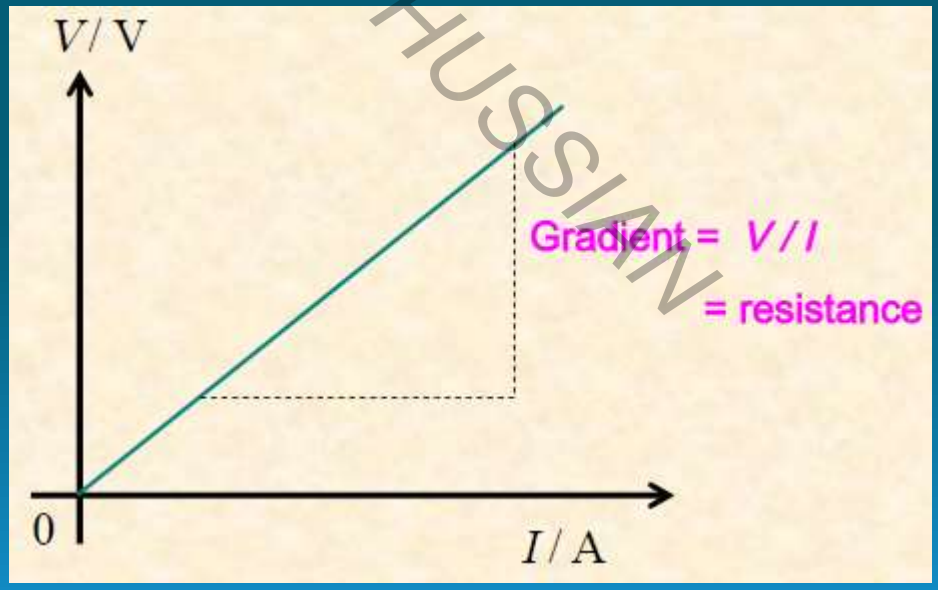
- Procedure:
  - Arrange the apparatus as shown below



- Procedure
  - Adjust the variable resistor the maximum resistance to get a small current flows in the circuit.
  - Record the ammeter reading (*I*) and voltmeter reading (*V*).
  - Adjust the variable resistor to allow a large current to flow in the circuit. Record the values of *I* and *V.*
  - Repeat for another 5 sets of *I* and *V*.

- Graph
  - Plot the graph of *V* (V) and *I* (A).
- Calculation
  - Determine the gradient of the graph

- Result
  - The gradient of the graph gives the resistance of the load R



Discuss the temperature limitation on Ohm's Law.

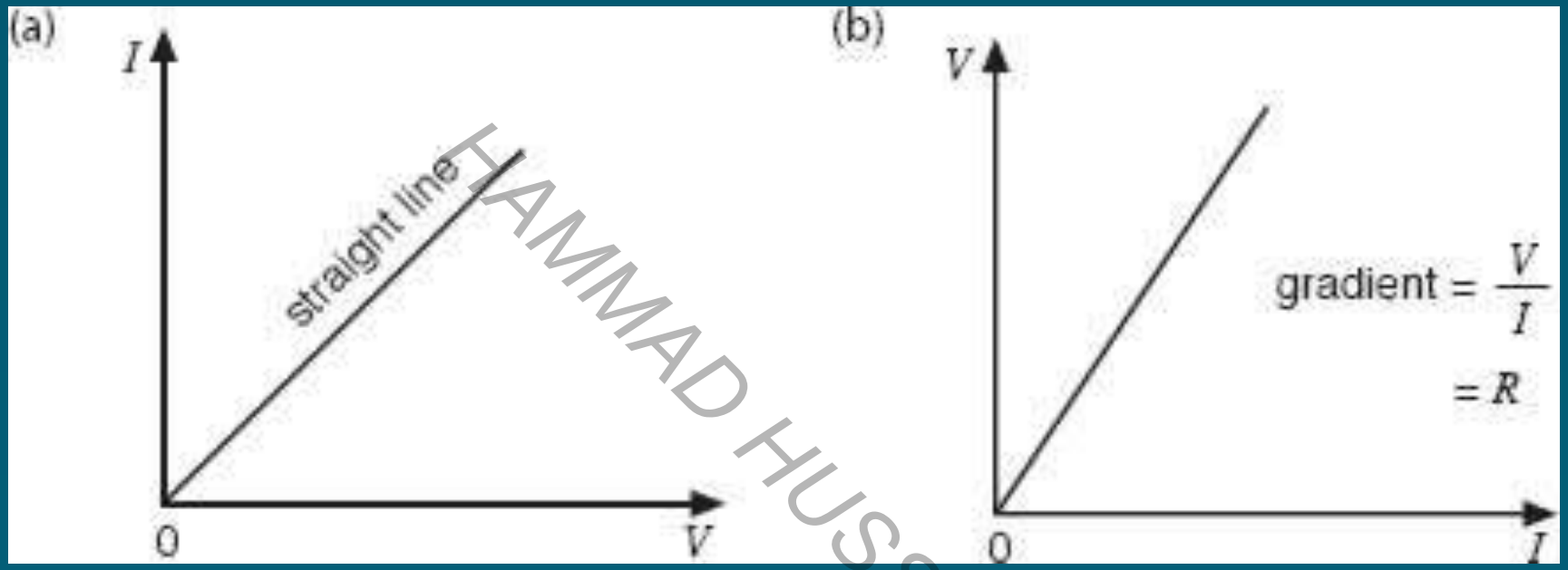
Resistance

Describe the effect of temperature increase on the resistance of a resistor and a filament lamp and draw the respective sketch graphs of current/voltage.

Resistance

Ohm's Law

- For some materials, the resistance is constant.
- A resistor that has constant resistance is said to obey Ohm's law.
- **Ohm's law** states that **current** through a **metal conductor** is **directly proportional** to the **potential difference** across the ends of the conductor provided that the physical condition and the temperature remain constant.

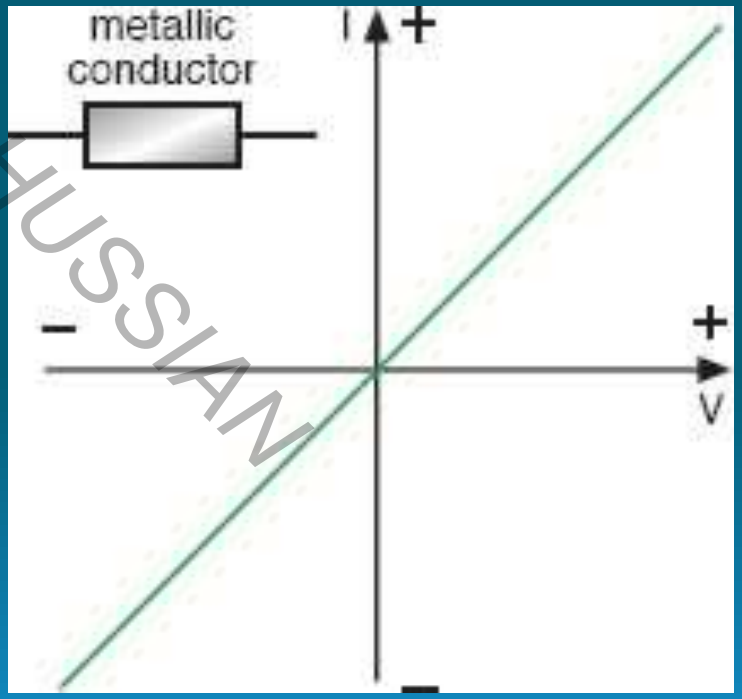


$$I \propto V$$

$$\frac{V}{I} = \text{constant}$$

Metallic Conductor

- When X is a metallic conductor, the graph is a straight line passing through the origin.
- The current I is directly proportional to potential difference V.
- The conductor obey Ohm's law and has a constant resistance.



Resistance Versus Temperature

- The value of a resistor changes with changing temperature as the resistivity of the material is changed caused mainly by the changing activity of the atoms of that make up the resistor.
- For conductors, their resistivity increase with an increase in temperature. However an insulators are able to decrease their resistivity with an increase in temperature.

- In a conductor where a large number of free electrons flowing through it, the vibration of the atoms causes many collisions between the free electrons and the captive electrons.
- Each collision uses up some energy from the free electron and is the basic cause of resistance.
- The more the atoms jostle around in the material the more collisions are caused and hence the greater the resistance to current flow.

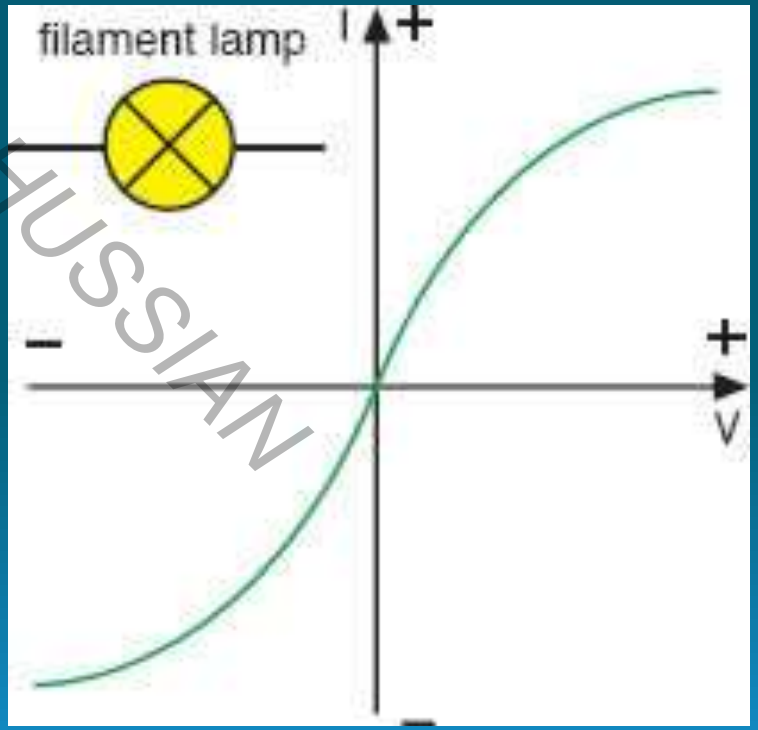
- In an insulator as there are so few free electrons that hardly any current can flow.
- Heating an insulating material vibrates the atoms, and if we heat it sufficiently the atoms vibrate violently enough to actually shake some of their captive electrons free, creating free electrons to become carriers of current.
- Thus at high temperatures the resistance of an insulator can fall, sometimes dramatically.

Filament Lamp

- As the current through the filament increases, the heating effect caused in the lamp also increases and so the temperature of the filament rises.
- This increase in the filament's temperature also increases the resistance of the filament.
- As a result the rate of increase of the current decreases and a greater change in the potential difference is required to cause a change in the current.

Filament Lamp

- When X is a filament lamp, the graph is a curve.
- Current *I* is not proportional to potential difference *V*.
- *V* increases more than *I*.
- It does not obey Ohm's law and its resistance increases as the current increases



Use quantitatively the proportionality between resistance and the length and the cross-sectional area of a wire.

Resistance

Factors affecting Resistance

- Length – Doubling the length of a wire doubles its resistance.
- Cross-sectional area – halving the ‘end on’ area of a wire doubles its resistance. So a thin wire has more resistance than a copper wire of the same size.
- Material – A nichrome wire has more resistance than a copper wire of the same size.
- Temperature – For metal conductors, resistance increases with temperature. For semiconductors, it decreases with temperature.

- From the experiment on resistance of metallic conductor – the resistance R of a uniform wire is directly proportional to its length l, and inversely proportional to its cross-sectional area A.

$$R \alpha l$$

$$R \alpha \frac{1}{A}$$

- Combining both the results, we obtain

$$R \alpha \frac{l}{A} \qquad R = \rho \frac{l}{A}$$

- Where ρ is a constant known as the resistivity of the material of the wire. P is a property of the material and does not depend on size or shape of the wire. The SI unit for ρ is Ωm

Material	Resistivity ρ / Ω m
Silver	1.6×10^{-8}
Copper	1.7×10^{-8}
Aluminium	2.8×10^{-8}
Tungsten	5.5×10^{-8}
Iron	9.8×10^{-8}
Manganin	44×10^{-8}
Constantan	49×10^{-8}
Mercury	96×10^{-8}
Nichrome	100×10^{-8}
Graphite	200×10^{-8}

Resistivities of some materials

Problem Solving

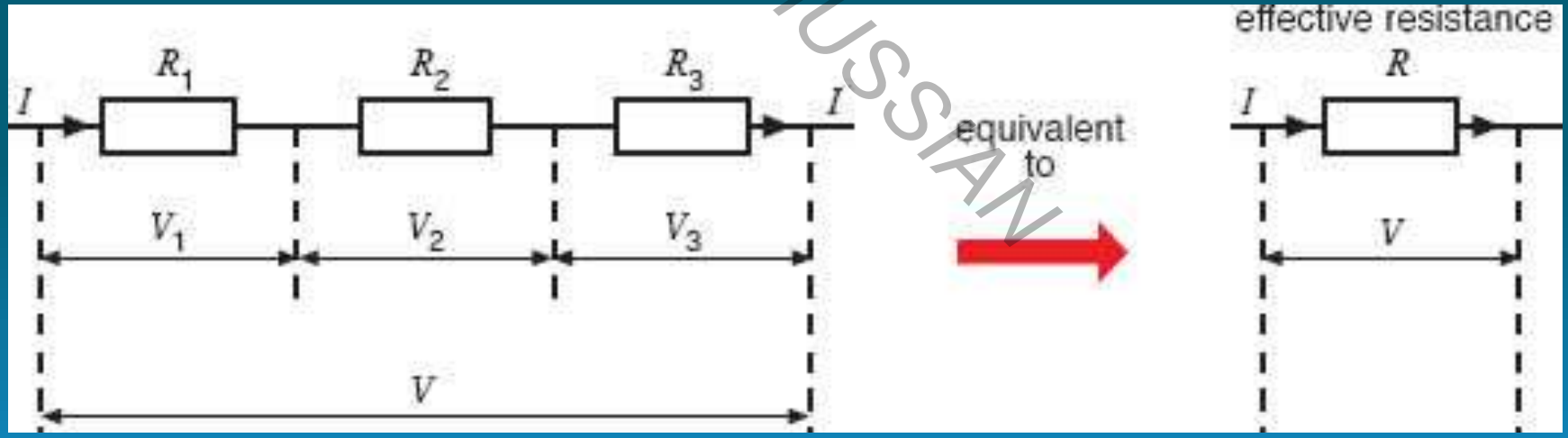
1. The resistivity of copper at room temperature is 1.72 x 10^{-6} Ωcm. What is the resistance of a copper wire 350 cm long and 0.025 cm^2 in cross section.
2. We would like to make a 600 Ω resistor out of Nichrome wire with a cross-sectional area of 3.0 x 10^{-3} cm^2. If the resistivity of Nichrome is 110 x 10^{-6} Ωcm, how long should the wire be?
3. A wire 0.40 m long and of diameter 0.60 m has a resistance of 1.5 Ω. What is the resistivity of the material which it is made?
4. What length of resistance wire of diameter 0.06 m and resistivity 1.1× 10^{-6} Ωm, would you cut from a reel in order to make a 44 Ω resistor?
5. A 1.0 m length of wire is found to have a resistance of 40 Ω. What would be the resistance of a piece of the same wire of length 2.0 m?

Calculate the net effect of a number of resistors in series and in parallel.

Resistance

Resistors in Series

- If two (or more) resistors are connected in series, the give higher resistance than any of the resistors by itself.

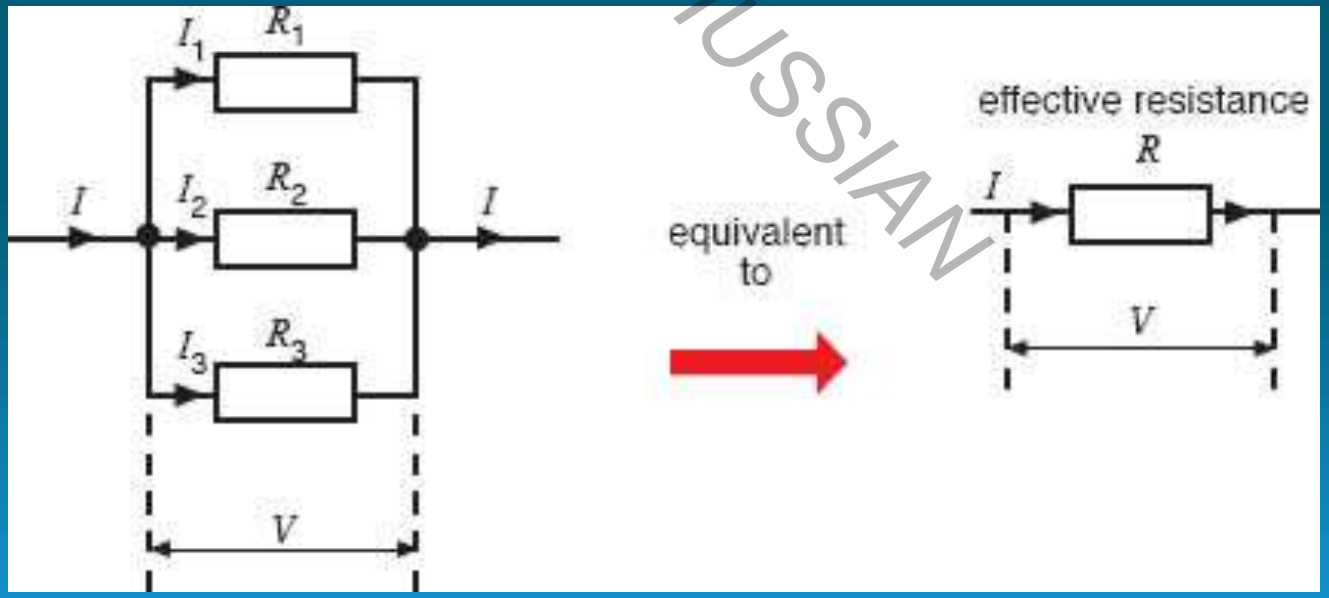


- For resistors in series, the effective resistance is the sum of the individual resistances

$$R = R_1 + R_2 + R_3$$

Resistors in Parallel

- If two (or more) resistors are connected in parallel, they give a lower resistance than any of the resistors by itself.



- For resistors in parallel, the reciprocal of the effective resistance is equal to the sum of the reciprocals of individual resistances.

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

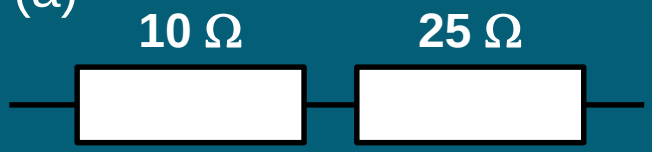
- For two resistors in parallel, the formula can be rearranged as

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

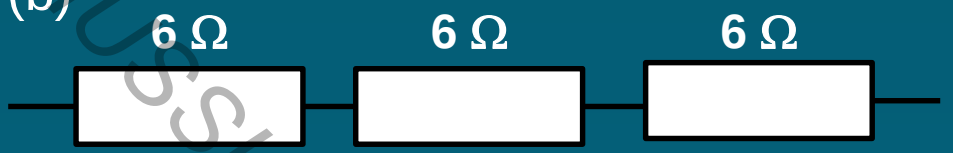
Problem Solving

1. Find the total resistance for each of the following resistor arrangement

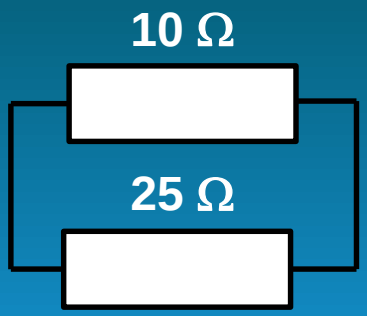
(a)



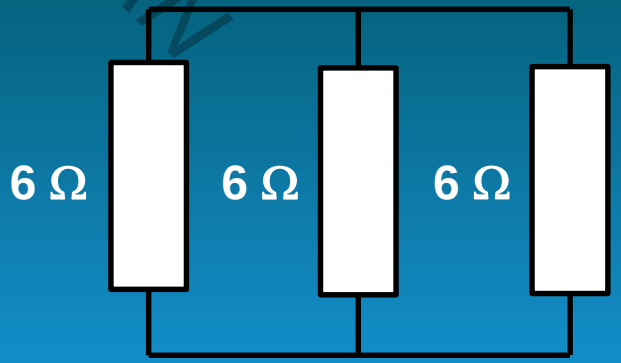
(b)



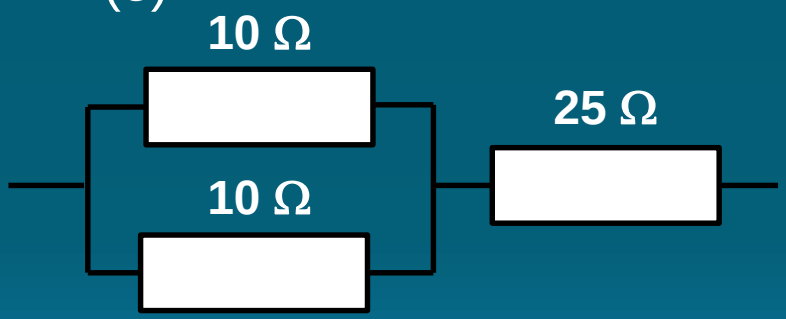
(c)



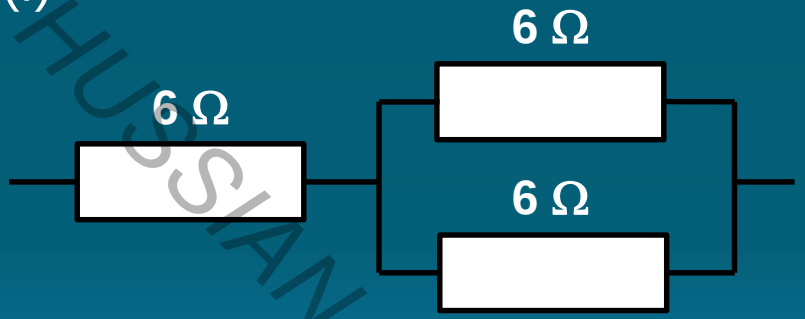
(d)



(e)

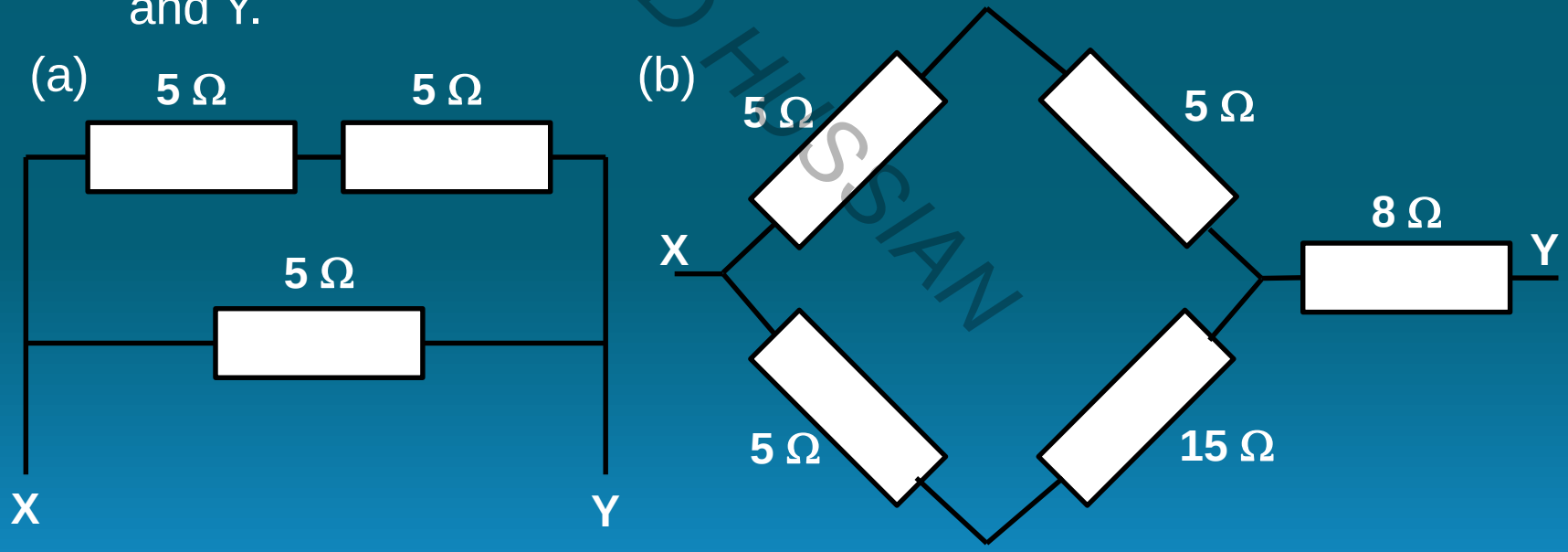


(f)



Problem Solving

2. Determine the total effective resistance between point X and Y.

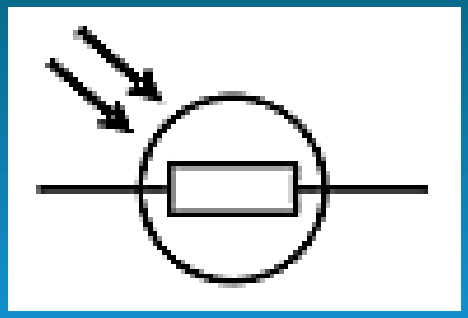


Describe the operation of a light-dependent resistor.

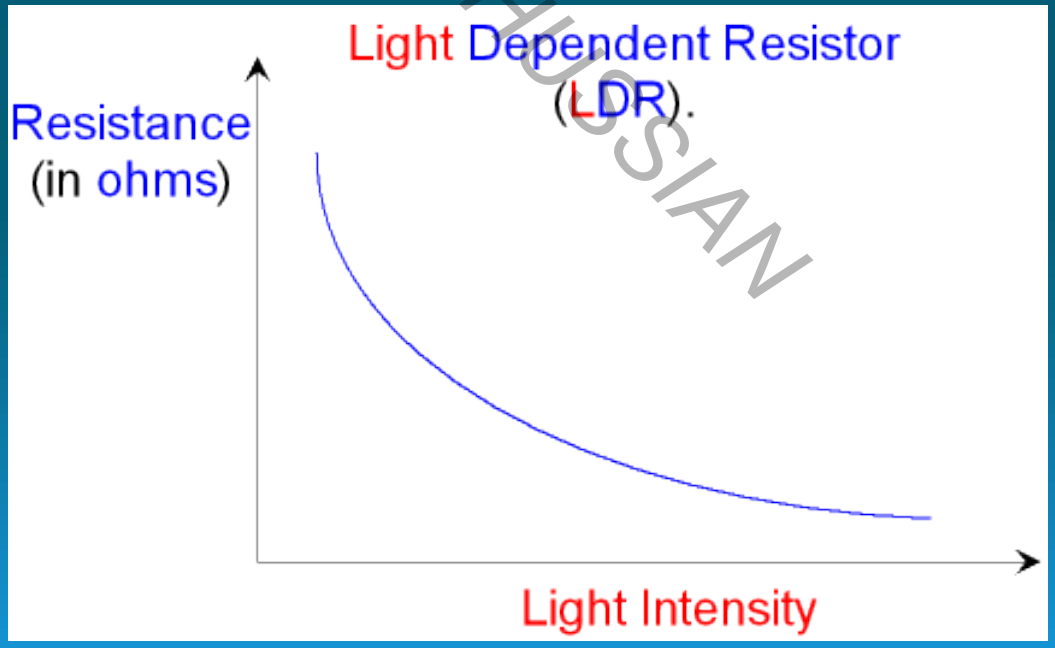
Resistance

LDR

- LDRs (light-dependent resistors) are used to detect light levels, for example, in automatic security lights. Their resistance decreases as the light intensity increases:
  - In the dark and at low light levels, the resistance of an LDR is high, and little current can flow through it.
  - In bright light, the resistance of an LDR is low, and more current can flow through it.



- LDRs are also useful for controlling how long the shutter should remain open on a digital camera.



1. A pupil measures the potential difference across a device and the current in it.
2. Which calculation gives the resistance of the device?

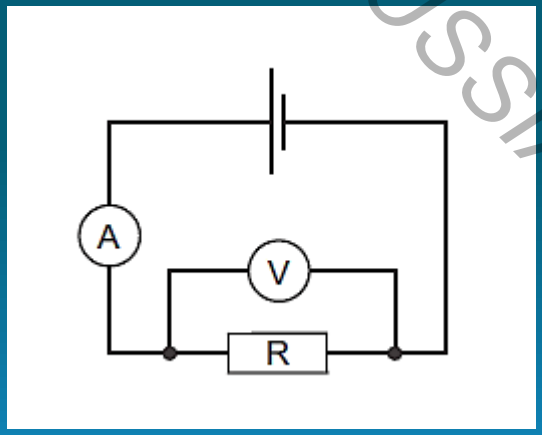
A. current + potential difference
B. current ÷ potential difference
C. potential difference ÷ current
D. potential difference × current

2. What are the symbols used for the units of current and resistance?

	unit of current	unit of resistance
A	A	W
B	A	Ω
C	V	W
D	V	Ω

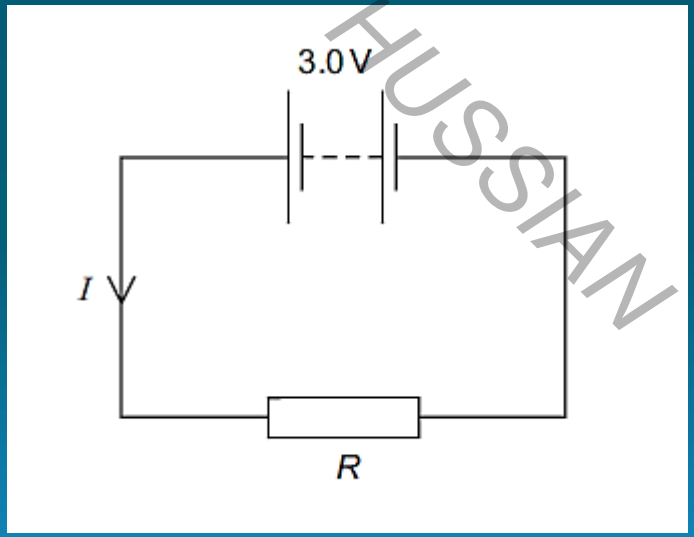
B

3. A circuit is set up to measure the resistance of a resistor R. The meter readings are 2.0 A and 3.0 V.



1. What is the resistance of the resistor R?
   A. 0.67 Ω
   B. 1.5 Ω
   C. 5.0 Ω
   D. 6.0 Ω

4. The circuit shows a current I in a resistor of resistance R.



1. Which line gives possible values of I and of R?

	I/A	R/Ω
A	1.5	1.5
B	1.5	2.0
C	6.0	2.0
D	4.0	12.0

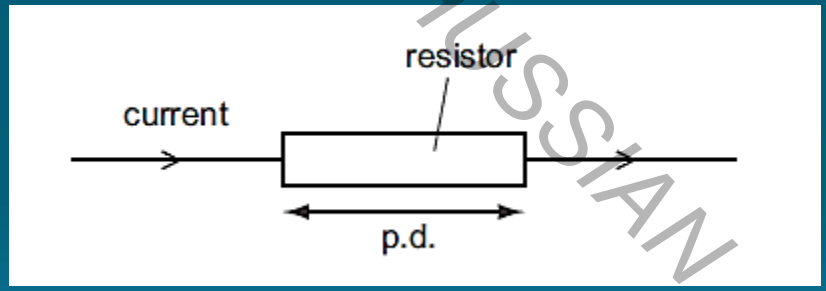
B

5. The table shows the voltage and current ratings for four electric heaters.
6. Which heater has the least resistance?

	voltage / V	current / A
A	110	5.0
B	110	10.0
C	230	5.0
D	230	10.0

B

6. A potential difference (p.d.) across a resistor causes a current in it.



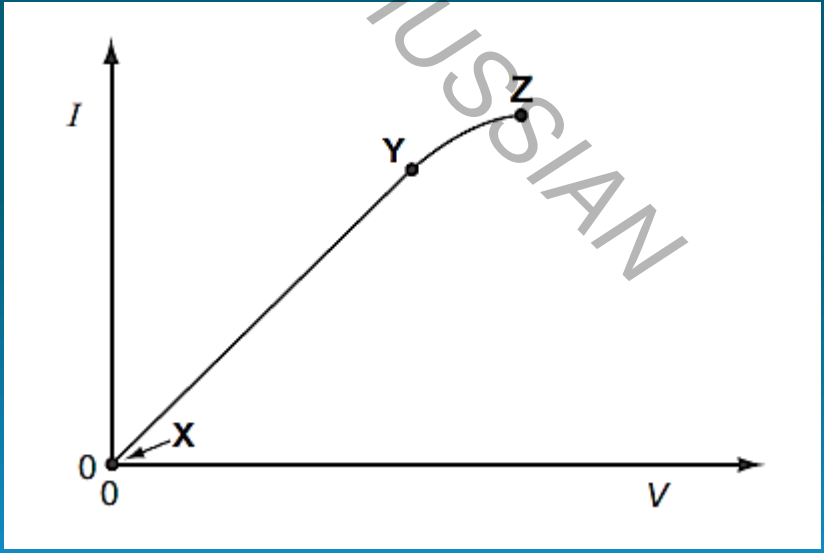
1. The p.d. and the resistance of the resistor can both be changed.
2. Which row shows two changes that will both increase the current in the resistor?

	change	change
A	decrease p.d.	decrease resistance
B	decrease p.d.	increase resistance
C	increase p.d.	decrease resistance
D	increase p.d.	increase resistance

C

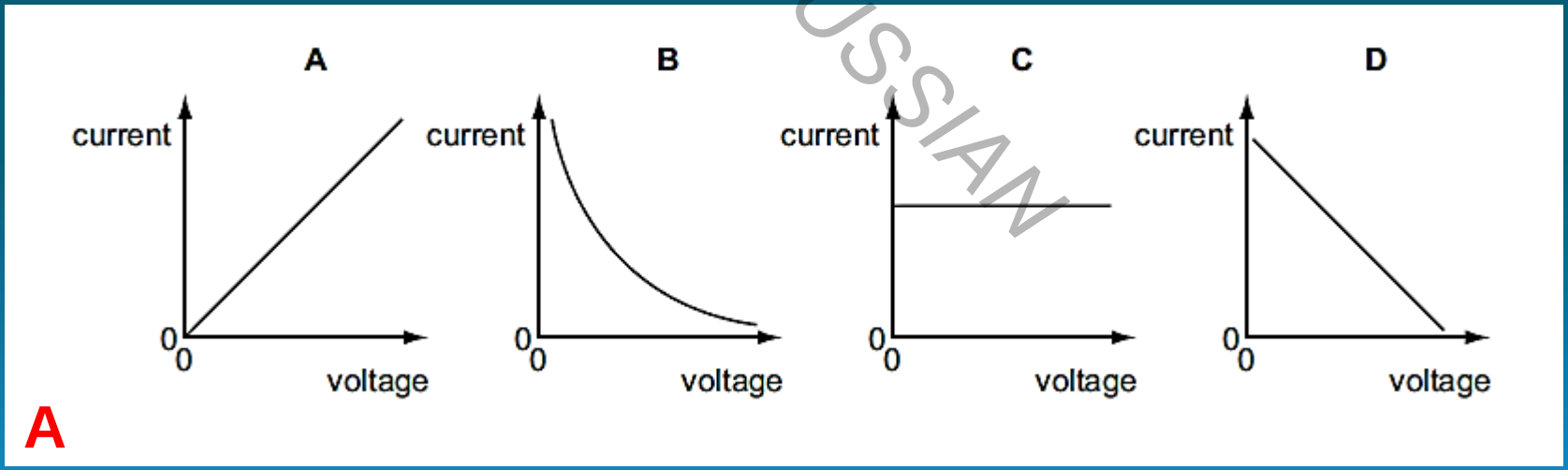
7. Ohm’s law states that the current in a conductor is proportional to the potential difference across it, provided that a certain quantity remains constant.
8. What is this quantity?
   A. length
   B. pressure
   C. temperature
   D. thickness

8. The diagram shows the current *I* / voltage V graph for a length of resistance wire.



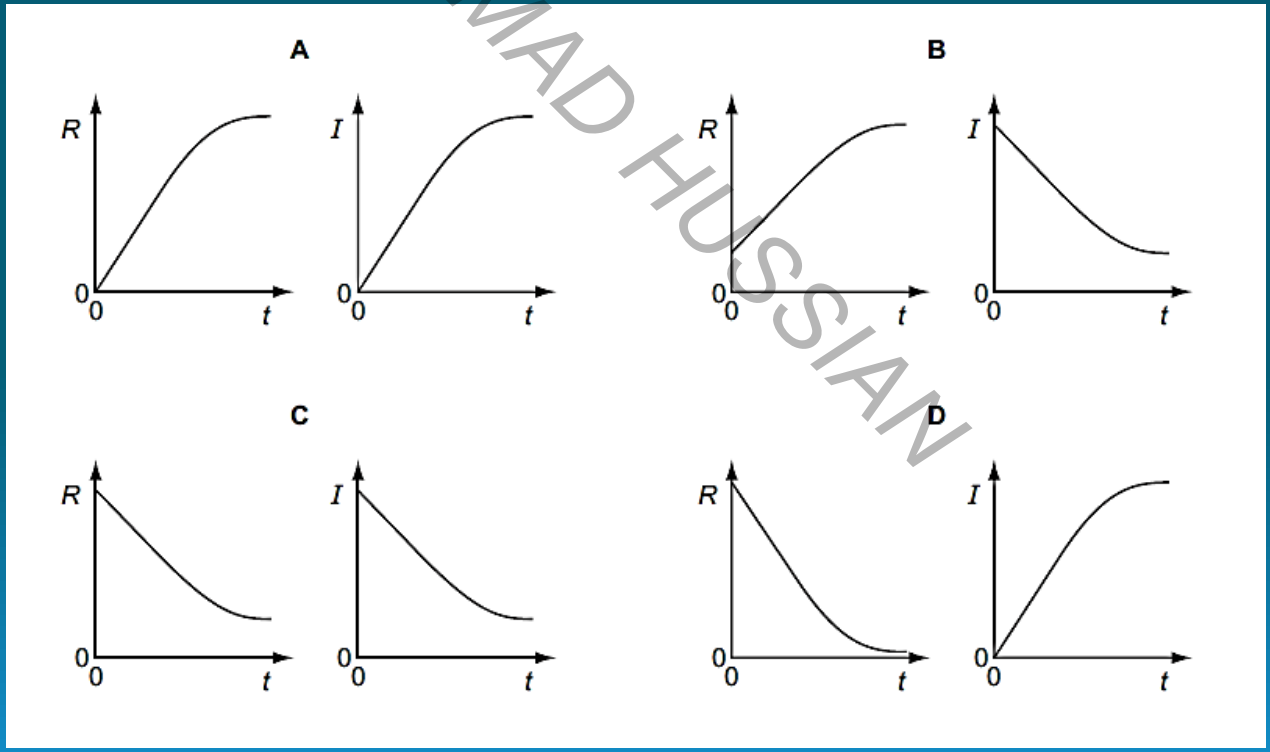
1. Where can Ohm's law be applied to the wire?
   A. at Y only
   B. at Z only
   C. from X to Y
   D. from X to Z

9. Which graph shows how the current changes when the voltage across a fixed resistance is varied?



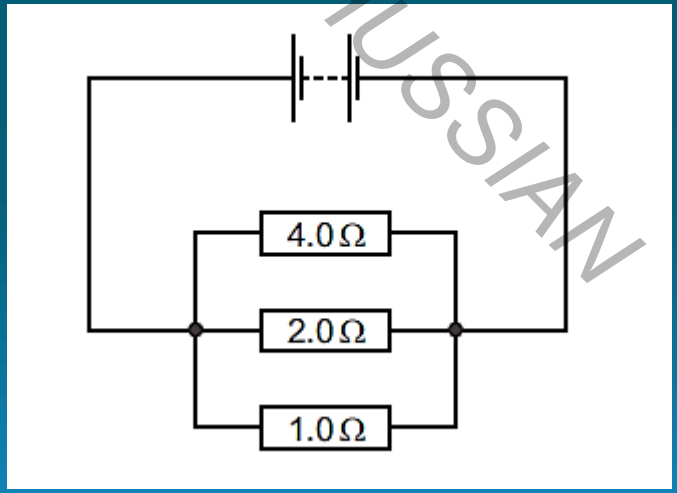
A

10. When a filament lamp is switched on, there is a current in the lamp. As the temperature of the filament rises, its resistance changes.
11. Which pair of graphs shows how the resistance R of the filament and the current *I* vary with time after the lamp is switched on?



B

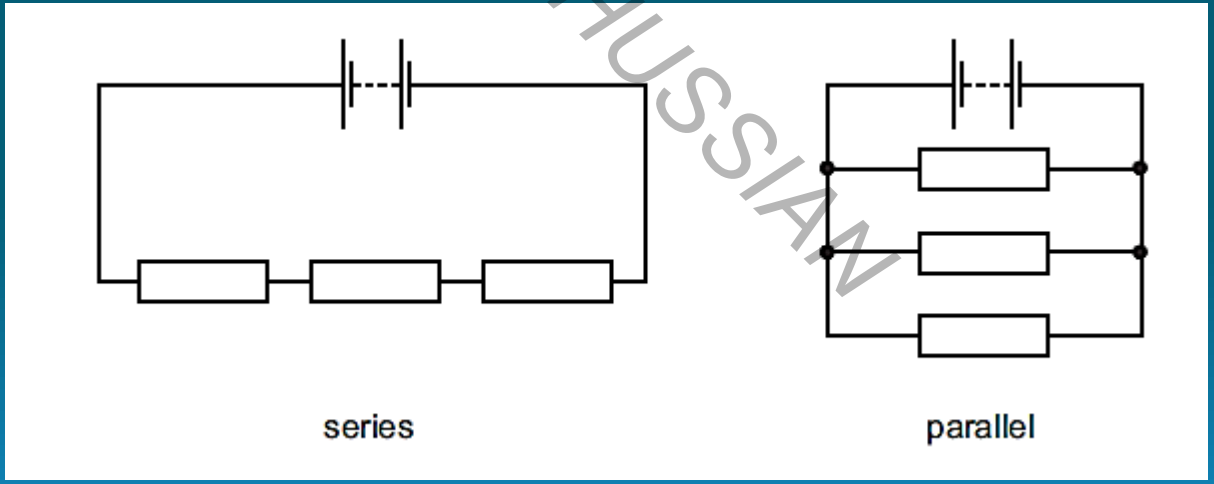
11. The circuit diagram shows three resistors in parallel with a battery.



1. What is the effective resistance of these three resistors?

A. 0.57 Ω
B. 0.86 Ω
C. 1.75 Ω
D. 7.00 Ω

12. When three identical resistors are connected in series, their combined resistance is 6 Ω.

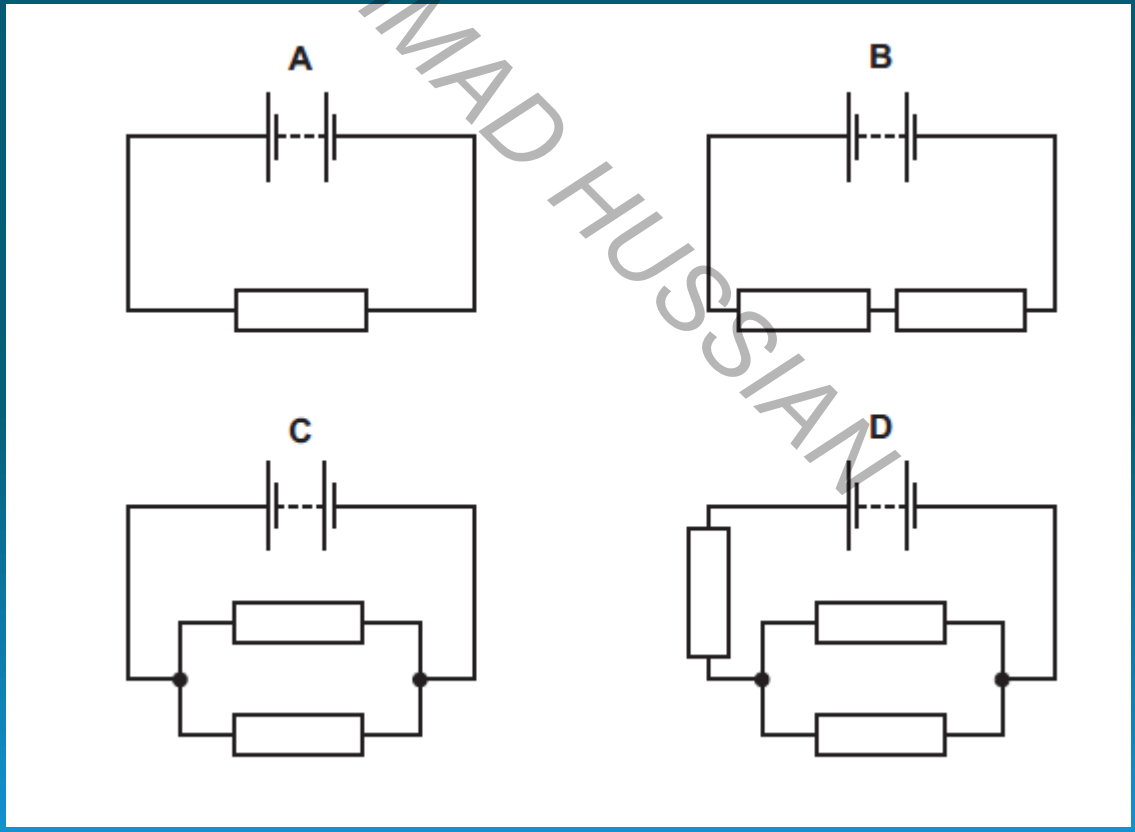


1. What is their combined resistance when they are connected in parallel?

A	$\frac{1}{6}\,\Omega$	**B**	$\frac{2}{3}\,\Omega$	**C**	$\frac{3}{2}\,\Omega$	**D**	$6\,\Omega$

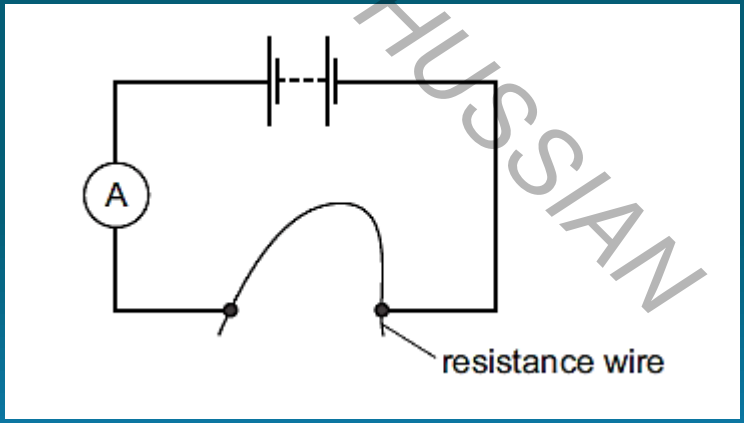
B

13. In the circuits shown, all the resistors are identical.
14. Which circuit has the least resistance?



C

14. A length of resistance wire is used as a resistor in a simple circuit.



1. Four separate changes are made to the wire.
2. Which change will not reduce the value of the resistance of the wire?

A. It is covered in an insulating sleeve.
B. Its cross-sectional area is increased.
C. Its length is decreased.
D. Its temperature is decreased.

15. Which factors will both increase the resistance of a wire in a circuit?

	size of wire	temperature of wire
A	longer	lower
B	shorter	lower
C	thicker	higher
D	thinner	higher

D

16. The table shows the lengths and diameters of four copper wires.
17. Which wire has the least resistance?

	length / m	diameter / mm
A	0.50	1.0
B	0.50	2.5
C	0.75	1.0
D	0.75	2.5

B

17. Four wires are made from the same material.

1. Which wire has the greatest resistance?

	length of wire / cm	diameter of wire / mm
A	50	0.1
B	50	0.2
C	100	0.1
D	100	0.2

C

18. A wire has a resistance of 8 Ω. A second wire, made of the same material, has half the length and twice the cross-sectional area.

1. What is the resistance of the second wire?

A. 1 Ω
B. 2 Ω
C. 8 Ω
D. 16 Ω

19. A student uses a length of wire as a resistor. He discovers that the resistance of the wire is too small.
20. To be certain of making a resistor of higher value, he should use a piece of wire that is
    A. longer and thicker.
    B. longer and thinner.
    C. shorter and thicker.
    D. shorter and thinner.