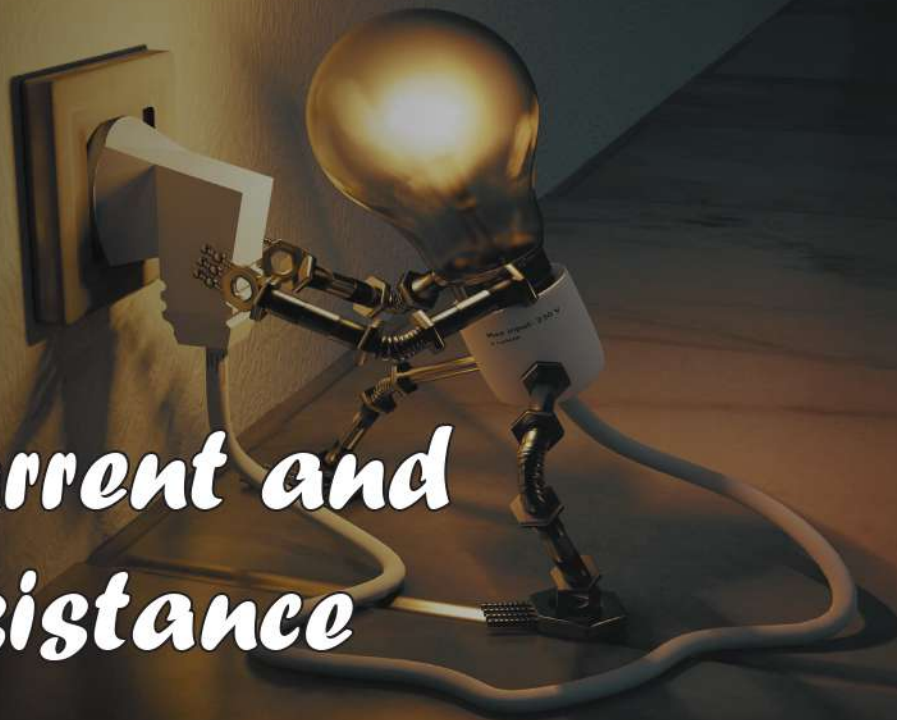




Unit

Current and resistance



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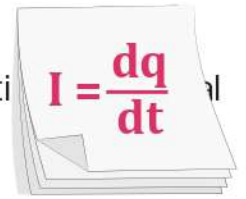
Energy and Power in Electric Circuits



Electric Current

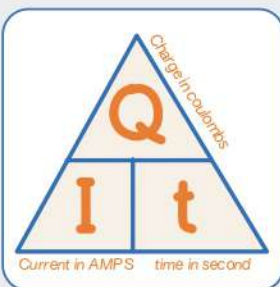
Electric current (I)

is the net flow of charge (dq) passes a point during time (dt). $I = \frac{dq}{dt}$



The ampere (A)

is the unit of current, equal to 1 coulomb per second ($1 \text{ A} = 1 \text{ C/s}$).



so electrical charge can be determined by:

$$q = \int dq = \int_0^t i dt'$$

- Electrical charge is an integral multiplication of electron charge: $Q = N \times e$ where $e = -1.602 \times 10^{-19} \text{ C}$

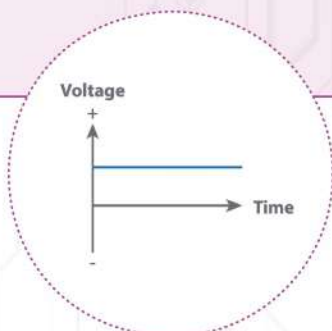
Charge Conservation

The total charge entering a conductor equals the total charge leaving it. Charge is never lost.

Types of Electric Current

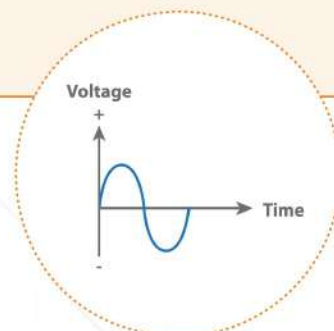
1 Direct Current (DC)

The current flows in one direction only. Sources include batteries.



2 Alternating Current (AC)

The current periodically changes direction. Sources include generators.





current direction: Conventional vs. Electron Current

Electron Current

The actual flow of electrons
(from negative to positive).

Conventional Current

The historical convention, where
we assume positive charge flows
(from positive to negative).



1

Which of the following is correct about the conventional direction of the current?

- A** In the same direction of the electron flow.
- B** In the opposite direction of the electric field that causes the charges to flow.
- C** Always from the negative to the positive terminals of the battery.
- D** Has the same direction as the current density.

2

3.8×10^{21} electrons pass a specific point of a uniform conductor during 240 s, what is the current represented by this charge?

- A** 0.54 A
- B** 1.58 A
- C** 2.53 A
- D** 3.16 A

3

Determine the current flowing through a conductor at $t=3$ s if the charge flow is given by $q(t)=(6t^2+3t-4)c$.

- A** 15 A
- B** 27 A
- C** 39 A
- D** 48 A

4 A current flowing through a conductor is given by $i(t) = (3t^2 + 4) \text{ A}$, how much charge passes through a point of this conductor during the interval $t = 0 \text{ s}$ to $t = 3 \text{ s}$?

- A 18.2 C B 24.8 C
C 38.0 C D 41.0 C

5 A nurse wants to administer $80 \mu\text{g}$ of dexamethasone using an iontophoresis device that applies a current of 0.14 mA . If the application rate is $650 \mu\text{g/C}$, how long does the administration take?

- A 0.89 s B 1.19 s
C 1.59 s D 2.09 s

6 How many protons are in a beam carrying 11 mA of current, traveling close to the speed of light around the 6.3 km circumference of the Tevatron ring?

.....

.....



Current Density

Current density (J)

is the amount of electric current (I) flowing per unit cross-sectional area (A) of a conductor.

$$J = \frac{I}{A}$$

- The direction of J is the same as the direction of the flow of positive charges .
- unit Amperes per square meter (A/m^2).
- the relation between current density and current intensity can also be written as an integration form

$$i = \int \vec{J} \cdot d\vec{A}$$

7

An aluminum wire with a diameter of 0.85 mm carries a constant current of 2.10 A. What is the current density?

- A $3.67 \times 10^6 \text{ A/m}^2$ B $1.08 \times 10^6 \text{ A/m}^2$
 C $2.10 \times 10^{-3} \text{ A/m}^2$ D $1.83 \times 10^7 \text{ A/m}^2$

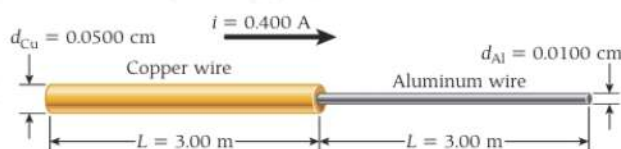
8

Which of the following is the best definition of current density?

- A The total amount of charge flowing through a conductor.
 B The rate at which charge flows through a conductor.
 C The amount of current flowing per unit cross-sectional area of a conductor.
 D The electric potential difference across a conductor.

9

5.30 A copper wire has a diameter $d_{\text{Cu}} = 0.0500 \text{ cm}$, is 3.00 m long, the copper wire is attached to an equal length of aluminium wire with a diameter $d = 0.0100 \text{ cm}$. A current of 0.400 A flows through the copper wire.



1) What is the ratio of the current densities in the two wires, $J_{\text{Cu}}/J_{\text{Al}}$?

.....

2) Same current flows through two conductors. The area of the first conductor is equal to one-third of the second one, What is the ratio of their current density J_1/J_2 ?

- A $J_1/J_2 = 3$ B $J_1/J_2 = 1/3$
 C $J_1/J_2 = 9$ D $J_1/J_2 = 1/9$

10

The total charge (q) passing through a conductor with a circular cross-section of radius 0.5 mm is given by the equation $q = 2t^3 + 5t$, where q is in coulombs and t is in seconds. What is the magnitude of the current density (J) in the conductor at $t = 2$ seconds?

.....

.....

11

Which of the following is **not true** for current density (j) and current (i)?

- A $i = \int \vec{j} \cdot d\vec{A}$
- B Unit of current density equal to Ampere per Meter
- C $j = i/A$
- D Unit of current density equal to Ampere per Meter square





Section 3 : Resistivity and Resistance

Resistance (R):

The opposition to the flow of electric current in a specific object or device. It depends on both the material and the object's geometry (length and cross-sectional area).

- **Units:** ohms (Ω).
- For a conductor with uniform resistivity, the resistance is:

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

Diagram illustrating the formula for Resistance (R):

- R is Resistance (Ω)
- ρ is Resistivity ($\Omega \cdot m$)
- L is the length (m)
- A is the cross-sectional area (m^2)

Conductance (G):

The reciprocal of resistance. It measures how easily current flows through a material or device.

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

- **Units:** siemens (S)

Resistivity (ρ):

A measure of how strongly a material opposes the flow of electric current. It depends on the material itself.

- **unit:** is ($\Omega \cdot m$)

Conductivity (σ):

The reciprocal of resistivity.

$$\sigma = \frac{1}{\rho}$$

- **Units:** siemens per meter (S/m) or $\Omega^{-1}m^{-1}$



Note

- Good conductors have low resistivity (and high conductivity).
- Insulators have high resistivity (and low conductivity).
- Both ρ , σ depend on the material type and temperature.
- Resistance increases with length and decreases with cross-sectional area.

1

What is the resistance of a 100.0 m copper wire with a diameter of 2.053 mm? (Resistivity of copper = $1.72 \times 10^{-8} \Omega\text{m}$)³

A 0.18 Ω B 0.28 Ω C 0.38 Ω D 0.48 Ω

2

A particular wire has a diameter of 1.7 mm and a length of 1.3 m. If its resistance is 15 m Ω , what is the resistivity of the metal from which it is made?

A $1.0 \times 10^{-7} \Omega\text{m}$ B $2.6 \times 10^{-8} \Omega\text{m}$ C $4.4 \times 10^{-6} \Omega\text{m}$ D $1.8 \times 10^{-5} \Omega\text{m}$

3

If the diameter of the wire in is doubled, its resistance will

A increase by a factor of 4.

B increase by a factor of 2.

C stay the same.

D decrease by a factor of 4.

4

If the area of a wire decrease to half, its resistance will:

A Increase by a factor of 4

B Increase by a factor of 2

C Stay the same

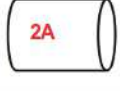
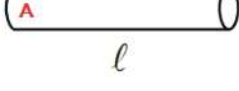
D Decrease by a factor of 4

5

Which of the following wires has the greatest resistance, assuming they are all made of the same material and are at the same temperature?

A B C D 

- 6 Rank the following wires from 1 to 4 based on their resistance, with 1 being the wire with the lowest resistance

$\frac{\ell}{2}$ 	$\frac{\ell}{2}$ 		
Cu	Cu	Fe	Cu

- 7 Two conductors are made of the same material and have the same length L . Conductor A is a hollow tube with inside diameter 2.00 mm and outside diameter 3.00 mm; conductor B is a solid wire with radius R_B . What value of R_B is required for the two conductors to have the same resistance measured between their ends?

.....

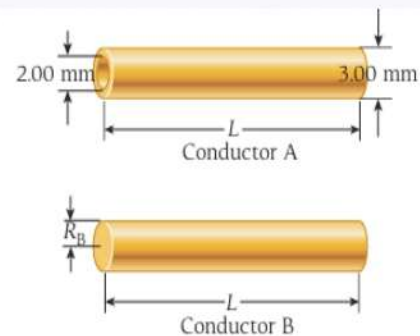
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- 8 A rectangular wafer of pure silicon, with resistivity $\rho = 2300 \Omega \cdot \text{m}$, measures 2.00 cm by 3.00 cm by 0.0100 cm. Find the maximum resistance of this rectangular wafer between any two faces.

.....

- 9 Two cylindrical wires have the same resistance. If the length of wire 2 is twice that of wire 1, what is the ratio of their cross-sectional areas (A_1/A_2)?

A 2

B 4

C 0.5

D 0.25

10 How will the resistance of a copper wire change if its length is tripled (without changing in its cross-sectional area)?

- A The resistance will decrease by $1/3$
- B The resistance will increase by 3 times
- C The resistance will decrease by $1/9$
- D The resistance will not change.

11 A 100.0 m long copper wire has a resistance of 0.28Ω . The resistivity of copper is $1.72 \times 10^{-8} \Omega m$. What is the radius of the wire?

.....

.....

12 What is the resistance of the 80.0 m standard copper wire with section area $A = 5.2612 \times 10^{-6} m^2$ $\rho = 1.72 \times 10^{-8} \Omega m$

- | | |
|-----------------|-----------------|
| A 0.26Ω | B 0.62Ω |
| C 0.88Ω | D 0.77Ω |

13 Which of the following wires has the greatest resistance, assuming they are all made of the same material and are at the same temperature?

- A Long and thin wire
- B Medium length and medium thickness wire
- C Short and thick wire
- D Long and thick wire



Section 4 : Electromotive Force (emf) and Ohm's Law

Emf (electromotive force)

is NOT a force, but a **potential difference** created by a device like a battery. Emf is measured in volts (V).



Ohm's Law

- For a simple circuit with an emf source and a resistor, Ohm's Law states

$$\text{the emf (potential difference)} \quad V_{\text{emf}} = i \times R \quad \text{is the resistance}$$

is the current flowing through the circuit



Note

- batteries also display a rating in mAh (milliampere-hour) → which provides information on the total charge the battery can deliver when fully charged.
- The mAh is another unit of charge:

$$1 \text{ mAh} = (10^{-3} \text{ A})(3600 \text{ s}) = 3.6 \text{ As} = 3.6 \text{ C}$$



Circuits

- An electric circuit needs at least one emf source to drive the current.
- The potential difference provided by the emf source creates a potential drop across the resistor.
- The total potential difference in any closed loop within a circuit must be zero (due to conservation of energy).

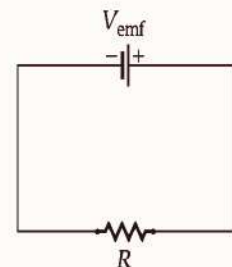


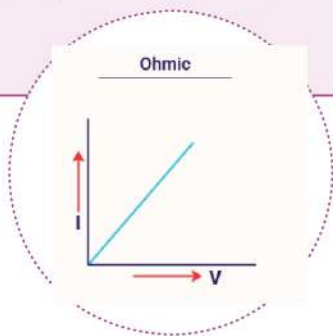
FIGURE 5.10 Simple circuit containing a source of emf and a resistor.



Ohmic vs. Non-ohmic Resistors

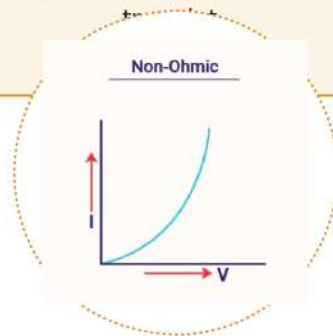
1 Ohmic resistors

Obey Ohm's Law (current is directly proportional to voltage)



2 Non-ohmic resistors

Do not obey Ohm's Law (current is not directly proportional to voltage e.g.,



1 A resistor with $R = 10.0 \, \Omega$ is connected across a source of emf with potential difference $V_{\text{emf}} = 1.50 \, \text{V}$. What is the current flowing through the circuit?

- A 0.15 A B 1.5 A C 6.67 A D 15 A

2 A rechargeable battery is rated at (3.0 mAh). What is the total charge in Coulombs (C) that the battery can deliver when fully charged? (mAh means milliamperere-hour)

- A 10.8 C B 3.6 C C 3.0 C D 1.6 C

3 Which of the following wires has the largest current flowing through it? ($\rho_{\text{copper}} = 1.72 \times 10^{-8} \, \Omega\text{m}$)

- A 1 m long copper wire of diameter 1 mm connected to a 10-V battery
 B 0.5-m long copper wire of diameter 0.5 mm connected to a 5-V battery
 C 2-m long copper wire of diameter 2 mm connected to a 20-V battery
 D 1 m long copper wire of diameter 0.5 mm connected to a 5-V battery

4

A 20 cm long and 1.0 mm diameter copper wire of resistivity $1.7 \times 10^{-8} \Omega\text{m}$ is connected across a 3.0 V battery. The current through the wire is _____?

A 0.70 A

B 1.25 A

C 6.93 A

D 7.89 A

5

A voltage difference of (12.0 V) was applied between the two ends of a wire whose length is (1000 m) and its cross-sectional area is 4.5mm^2 , a current of $(3.20 \times 10^{-3} \text{ A})$ flow through it, find the resistivity of the wire.

A $1.72 \times 10^{-8} \Omega\text{m}$ B $1.68 \times 10^{-5} \Omega\text{m}$ C $7.12 \times 10^{-8} \Omega\text{m}$ D $6.18 \times 10^{-8} \Omega\text{m}$

6

A potential difference of 12.0 V is applied across a wire of cross-sectional area 4.50 mm^2 and length 1000. km. The current passing through the wire is $3.20 \times 10^{-3} \text{ A}$

A What is the resistance of the wire?

.....

B What type of wire is this?

.....

7

A copper wire has radius $r = 0.0250 \text{ cm}$, is 3.00 m long, has resistivity $\rho = 1.72 \times 10^{-8} \Omega\text{m}$, and carries a current of 0.400 A.

A What is the resistance, R, of the wire?

.....

B What is the electric potential difference, ΔV , across the wire?

.....

8 A resistor with $R=10.0\Omega$ is connected across a source of emf with potential difference $V_{\text{emf}}=1.50\text{ V}$. What is the current flowing through the circuit?

- A 0.15 A B 0.23 A
C 6.67 A D 150 A

9 A potential difference of 2.0 V is applied across a wire. The current through the wire is 1mA. What is the resistance of the wire?

- A 2Ω B $2\times 10^2\Omega$
C $2\text{K}\Omega$ D $20\text{K}\Omega$

10 Which wire has the current when applying the same potential difference?

- A  B 
C  D 

11 Ohm's Law states that the potential difference across a device is equal to

- A the current flowing through the device times the resistance of the device.
B the current flowing through the device divided by the resistance of the device.
C the resistance of the device divided by the current flowing through the device.
D the current flowing through the device times the cross-sectional area of the device.



Section 5 : Series Connection



Current in Series Circuits:

- Electric charge in the circuit has **only one path** to take
- the same amount of charge entering the first lamp must exit that lamp and go to the other.
- The current has one value in each part of the electrical circuit.**



$$I_{\text{source}} = I_1 = I_2$$



Voltage Difference in Series Connection:

1

The potential difference across any source of energy (source ΔV) is equal to the sum of the potential differences across lamp 1 and lamp 2. This is represented by the following equation:

$$V_{\text{emf}} = \Delta V_1 + \Delta V_2$$

2

The potential difference across the resistor is the product of the current and the electrical resistance.

$$\text{First lamp } \Delta V_1 = IR_1$$

$$\text{second lamp } \Delta V_2 = IR_2$$

3

Where total voltage :

$$\Delta V_{\text{source}} = IR_1 + IR_2$$

4

The current passing through the circuit is represented by the following equation:

$$I = \frac{\Delta V}{(R_1 + R_2)} \quad \text{or} \quad I = \frac{\Delta V_{\text{emf}}}{R_{\text{eq}}}$$



Equivalent Resistance of a Series Circuit:

- The equivalent resistance of resistors connected in series is equal to the sum of the individual electrical resistance values

$$R_{\text{eq}} = R_1 + R_2 + \dots + R_n$$

$$R_{\text{eq}} = \sum_{i=1}^n R_i$$



Note

When connect resistors in series

- The equivalent resistance of resistors connected is always **greater** than the value of any individual resistance.
- If the battery voltage does not change, adding **more resistors** in **series** will **always reduce the current value**.
- If one of the resistors is damaged or disconnected from the circuit, the current in the circuit will become zero.
- For N equal resistors with a value of R, the equivalent resistance is: $R_{eq} = N.R$
- The current passing through a series circuit is equal to the potential difference of the power source divided by the equivalent resistance:

$$I = \Delta V_{emf} / R_{eq}$$



Internal Resistance of a Battery

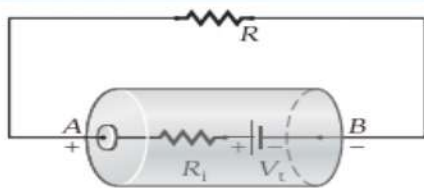


FIGURE 5.14 Battery (gray cylinder) with internal resistance R_i connected to an

Batteries have internal resistance, which can be modelled as a resistor in series with the circuit. This causes the battery's terminal voltage to drop when current flows:

$$V_t = iR_{eq} = i(R + R_i)$$

Batteries

- nonideal with internal resistance
- ideal zero internal resistance

1

A battery has a voltage of 48 V. When a 15Ω resistor is connected to the battery, the terminal voltage drops to 45.4 V. What is the internal resistance of the battery?

A 0.86Ω

B 1.0Ω

C 1.2Ω

D 1.3Ω

2

Consider a battery that has $V_t = 12.0 \text{ V}$ when it is not connected to a circuit. When a $10.0\text{-}\Omega$ resistor is connected with the battery, the potential difference across the battery's terminals drops to 10.9 V . What is the internal resistance of the battery?

A 0.11Ω B 0.91Ω C 1.1Ω D 9.1Ω

3

When a battery is connected to a $100. \Omega$ resistor, the current is 4.00 A . When the same battery is connected to a $400. \Omega$ resistor, the current is 1.01 A . Find the emf supplied by the battery and the internal resistance of the battery.

.....

.....

4

A light bulb is connected to a source of emf. There is a 6.20 V drop across the light bulb and a current of 4.10 A flowing through the light bulb.

A What is the resistance of the light bulb?

.....

.....

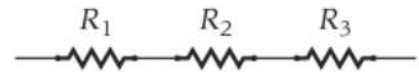
B A second light bulb, identical to the first, is connected in series with the first bulb. The potential drop across the bulbs is now 6.29 V , and the current through the bulbs is 2.90 A . Calculate the resistance of each light bulb.

.....

.....

5 Three identical resistors R_1 , R_2 , and R_3 are wired together as shown in the figure. The current through R_2 :

- A Is the same as the current through R_1 and R_3
- B Is a third of the current through R_1 and R_3
- C Is twice the sum of the current through R_1 and R_3
- D Is three times the current through R_1 and R_3



6 You make a series combination using a resistor (A) having a very large resistance and a resistor (B) having a very small resistance. The equivalent resistance of this combination will be:

- A Slightly greater than the resistance of resistor A
- B Slightly less than the resistance of resistor A
- C Slightly greater than the resistance of resistor B
- D Slightly less than the resistance of resistor B

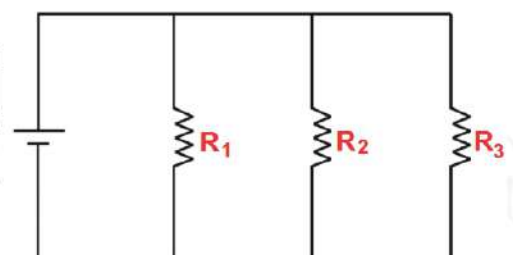
7 A resistor of unknown resistance and a $35.0\text{-}\Omega$ resistor are connected across a 120 V emf device in such a way that an 11.0 A current flows. What is the value of the unknown resistance?

.....

.....

Section 6 : Parallel Circuits

- Observe the illustrated electrical circuit, you'll find that the voltage difference remains constant while the current is distributed across the paths.



Voltage Difference in Parallel Connection

- The branches are connected in parallel with the battery, so the voltage difference across each branch is equal to the voltage difference of the source (battery).



Current in Parallel Circuits

- The total current in a parallel circuit is equal to the sum of the currents passing through each path, while the voltage difference is the same in each path.
- Each resistor has its own current because, in the case of constant voltage, the current is inversely proportional to the resistance. The current of each resistor can be obtained by:

$$I_{\text{source}} = I_1 + I_2 + I_3$$

$$I_1 = \frac{\Delta V}{R_1}$$

$$\frac{\Delta V}{R} = \frac{\Delta V}{R_1} + \frac{\Delta V}{R_2} + \frac{\Delta V}{R_3}$$

Equivalent Resistance of a Parallel Circuit

The equivalent resistance (R_{eq}) of resistors connected in parallel is the inverse of the sum of the inverses of the individual resistances.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

OR

$$R_{eq} = \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right]^{-1}$$

- In the case of two parallel resistors R_1 and R_2 , this relationship can be used:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

- For equal resistors with a value of R , the equivalent resistance is:

$$R_{eq} = \frac{R}{N}$$



Note

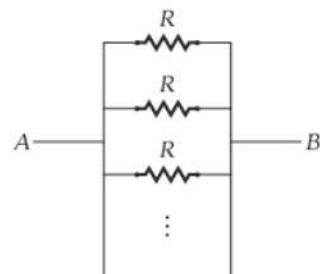
in parallel connection:

- The value of the equivalent resistance is less than the value of any individual resistor.
- Adding more resistors in parallel will always increase the value of the current coming from the battery because each new resistor provides an additional path for the current.
- The current passing through a parallel circuit is equal to the voltage difference of the power source divided by the equivalent resistance.
- If one of the resistors is damaged or disconnected from the circuit, the current in the remaining branches will not be affected, but it will reduce the total current through the power source.

8

You make a parallel connection between two resistors, resistor A having a very large resistance and resistor B having a very small resistance. The equivalent resistance for this combination will be

- A** slightly greater than the resistance of resistor A
- B** slightly less than the resistance of resistor A.
- C** slightly greater than the resistance of resistor B.
- D** slightly less than the resistance of resistor B



9

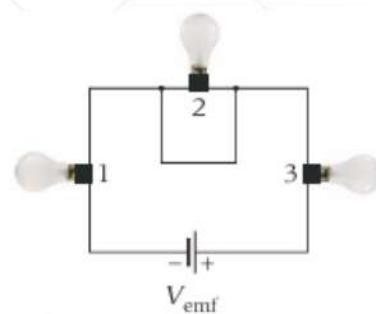
As more identical resistors, R , are added to the circuit shown in the figure, the resistance between points A and B will

- A** increase.
- B** stay the same.
- C** decrease.
- D** change in an unpredictable manner.

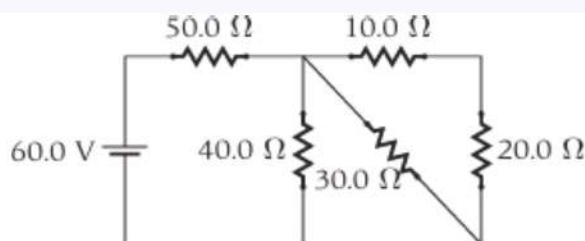
10

Three light bulbs are connected in series with a battery that delivers a constant potential difference, V_{emf} . When a wire is connected across light bulb 2 as shown in the figure, light bulbs 1 and 3

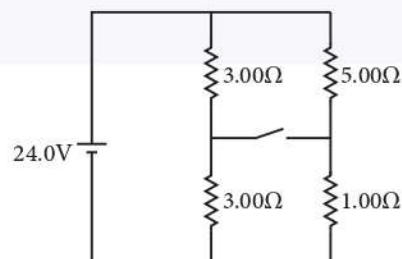
- A** burn just as brightly as they did before the wire was connected.
- B** burn more brightly than they did before the wire was connected.
- C** burn less brightly than they did before the wire was connected.
- D** go out



- 11 What is the equivalent resistance of the five resistors in the circuit in the figure?



- 12 What is the current in the circuit shown in the figure when the switch is (a) open and (b) closed?

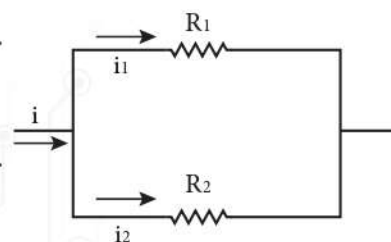


- 13 For the circuit shown in the figure, $R_1 = 6.00 \, \Omega$, $R_2 = 6.00 \, \Omega$, $R_3 = 2.00 \, \Omega$, $R_4 = 4.00 \, \Omega$, $R_5 = 3.00 \, \Omega$, and the potential difference is 12.0 V.

A What is the equivalent resistance for the circuit?

B What is the current through R_5 ?

C What is the potential drop across R_3 ?



- 14 For the connections shown in the figure, determine the current i_1 , in terms of the total current, i , and R_1 , and R_2 .

15

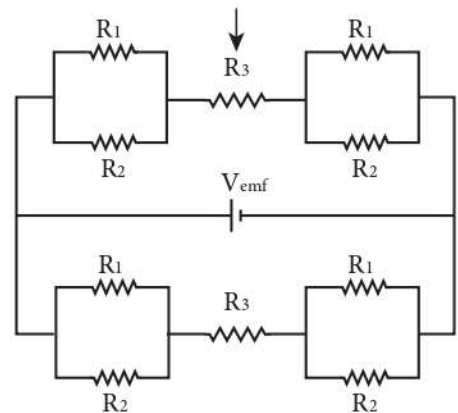
In the circuit shown in the figure, $R_1 = 3.00 \, \Omega$, $R_2 = 6.00 \, \Omega$, $R_3 = 20.0 \, \Omega$, and $V_{\text{emf}} = 12.0 \, \text{V}$

- A** Determine a value for the equivalent resistance.

.....

- B** Calculate the magnitude of the current flowing through R_3 on the top branch of the circuit (marked with a vertical arrow).

.....



16

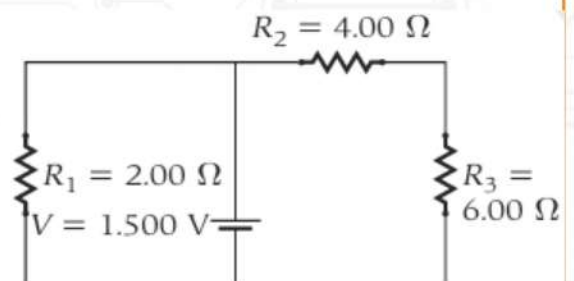
5.78 A battery with $V = 1.500 \, \text{V}$ is connected to three resistors as shown in the figure.

- A** Find the potential drop across each resistor.

.....

- B** Find the current in each resistor

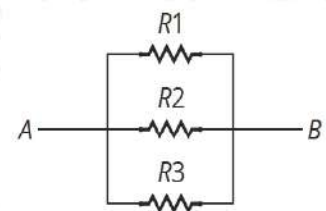
.....



17

Three identical resistors, R_1 , R_2 , and R_3 , are wired together as shown in the figure. An electric current is flowing from point A to point B. The current flowing through R_2

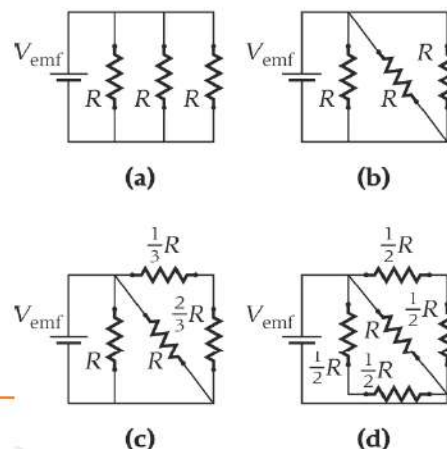
- A** is the same as the current through R_1 and R_3 .
- B** is a third of the current through R_1 and R_3 .
- C** is twice the sum of the current through R_1 and R_3 .
- D** is three times the current through R_1 and R_3 .



18

Which combination of resistors has the highest equivalent resistance?

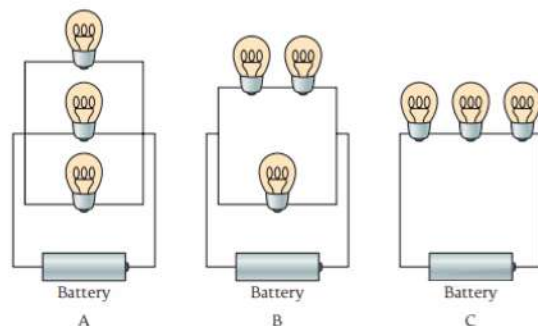
- A** combination (a)
- B** combination (b)
- C** combination (c)
- D** combination (d)
- E** The equivalent resistance is the same for all four.



19

Which of the arrangements of three identical light bulbs shown in the figure has the highest resistance?

- A** A
- B** B
- C** C
- D** All three have equal resistance.
- E** A and C are tied for having the highest resistance.



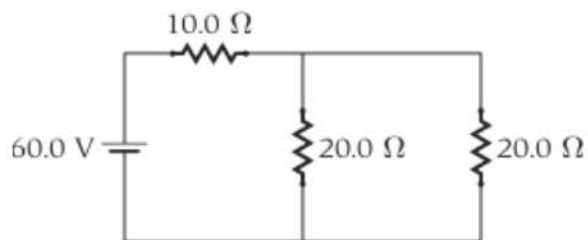
20

Which of the following is an incorrect statement?

- A** The currents through electronic devices connected in series are equal.
- B** The potential drops across electronic devices connected in parallel are equal.
- C** More current flows across the smaller resistance when two resistors are connected in parallel.
- D** More current flows across the smaller resistance when two resistors are connected in series.

21

What is the current in the $10.0\ \Omega$ resistor in the circuit in the figure?



22

The circuit shown in Figure a has four resistors and a battery with $V_{\text{emf}} = 149\text{ V}$. The values of the four resistors are $R_1 = 17.0\ \Omega$, $R_2 = 51.0\ \Omega$, $R_3 = 114.0\ \Omega$, and $R_4 = 55.0\ \Omega$. What is the magnitude of the potential drop across R_2 ?

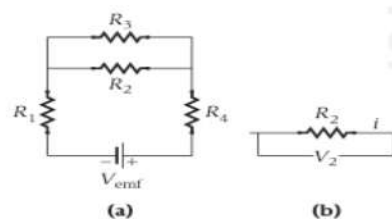
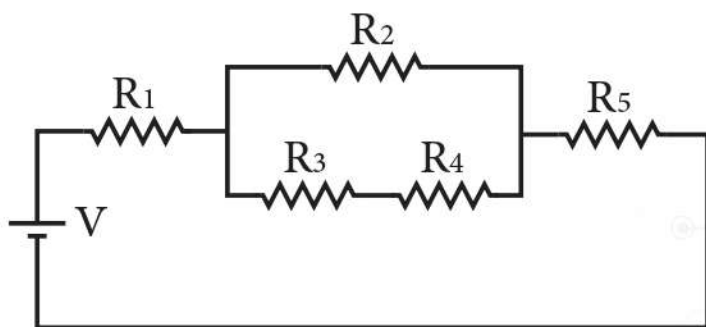


FIGURE 5.20 (a) A circuit with four resistors and a battery. (b) Potential drop across resistor R_2 .

23

When a 40.0 V emf device is placed across two resistors in series, a current of 10.0 A flows through each of the resistors. When the same emf device is placed across the same two resistors in parallel, the current through the emf device is 50.0 A . What is the magnitude of the larger of the two resistances?

