Lecture 3

Kirchhoff's Laws

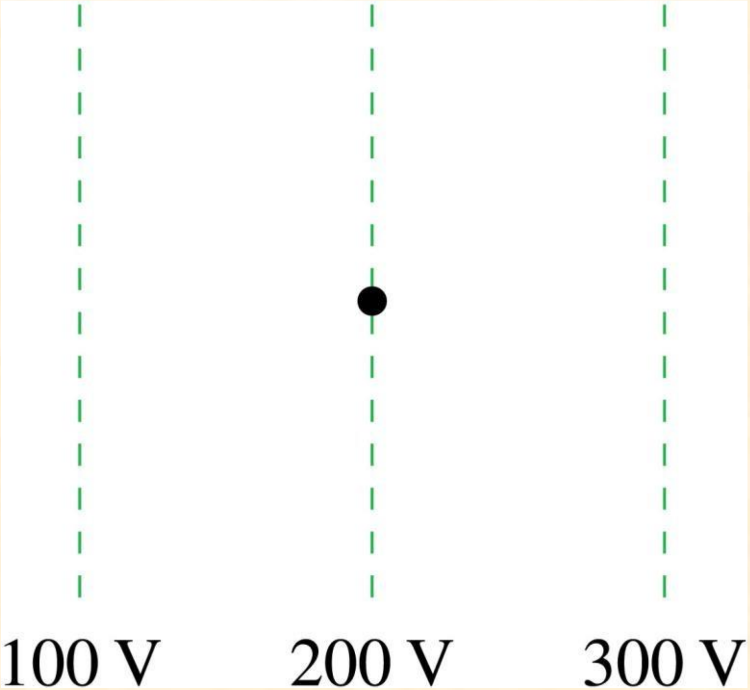
Stop to Think

An electron is released from rest at the dot. Afterward, the electron

A. Starts moving to the right.

B. $\boxed{\text{Starts moving to the left.}}$

C. Remains at rest.



Stop to Think

The charge carriers in metals are

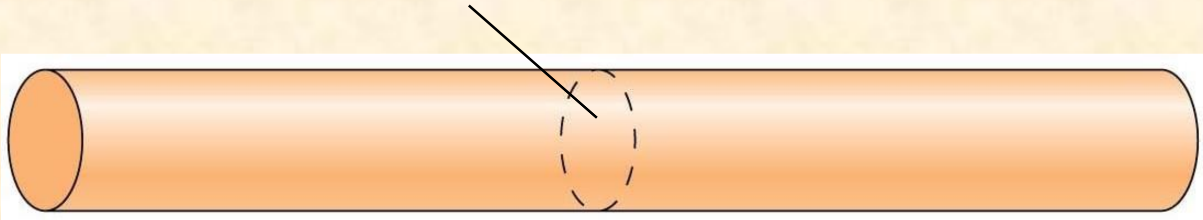
A. $\boxed{\text{Electrons.}}$
B. Positrons.
C. Protons.
D. A mix of protons and electrons.

The power dissipated in a resistor can be written as

A. $I\,V_R$
B. $(\Delta V_R)^2 / R$
C. $I^2\,R$
D. $\boxed{\text{All of the above.}}$
E. None of the above.

Stop to Think

Every minute, 120 C of charge flow through this cross section of the wire.



$$I(t) = \frac{dq}{dt}$$

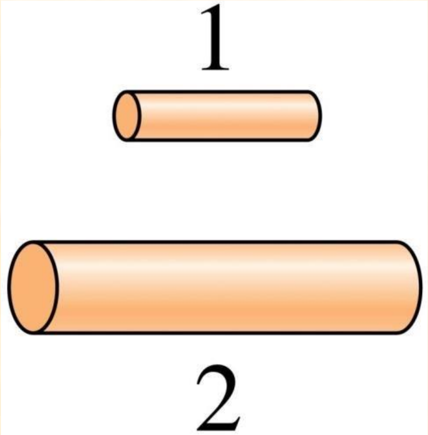
The wire's current is

A. 240A
B. 120A
C. 60A
D. 2A
E. Some other value

Stop to Think

Wire 2 is twice the length and twice the diameter of wire 1. What is the ratio R_2/R_1 of their resistances?

A. 1/4
B. $\boxed{1/2}$
C. 1
D. 2
E. 4



Stop to Think

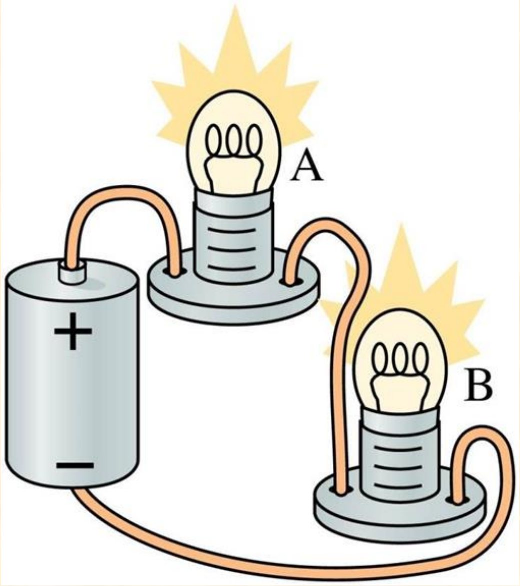
Which has a larger resistance, a 60 W lightbulb or a 100 W lightbulb?

A. The 60 W bulb
B. The 100 W bulb
C. Their resistances are the same.
D. There's not enough information to tell.

Stop to Think

A and B are identical lightbulbs connected to a battery as shown. Which is brighter?

A. Bulb A
B. Bulb B
C. $\boxed{\text{The bulbs are equally bright.}}$



Kirchhoff's Laws

Kirchhoff's Current Law (KCL)

Sum of all currents entering a node is zero

$$\sum_n I_n = 0$$

Sum of currents entering node is equal to sum of currents leaving node

$$\sum I_{in} = \sum I_{out}$$

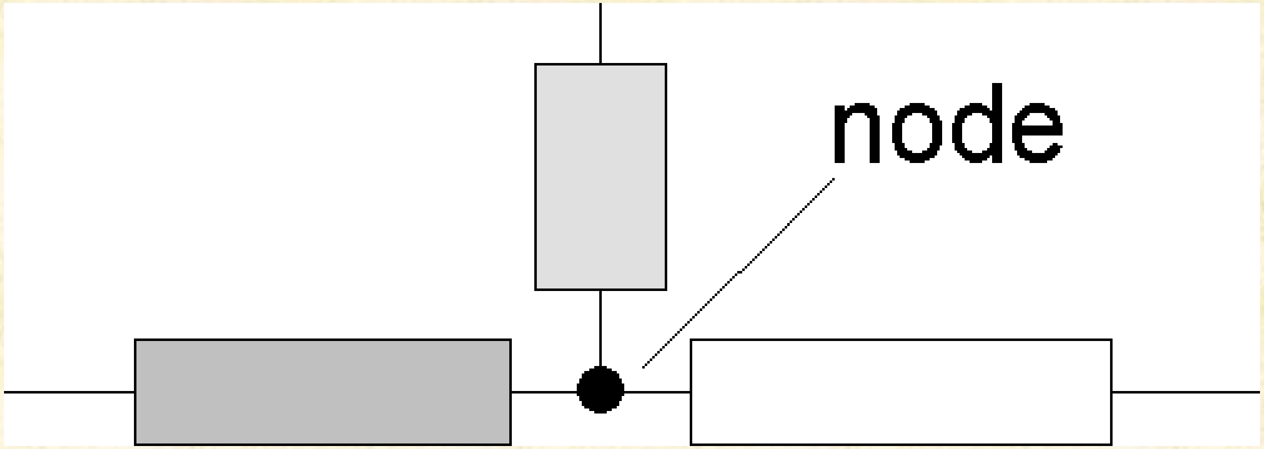
Kirchhoff's Voltage Law (KVL)

Sum of voltages around any loop in a circuit is zero

$$\sum_n V_n = 0$$

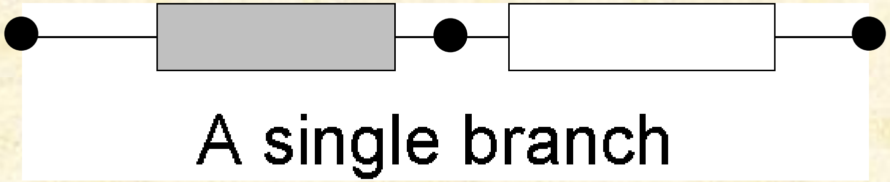
Circuit Topology

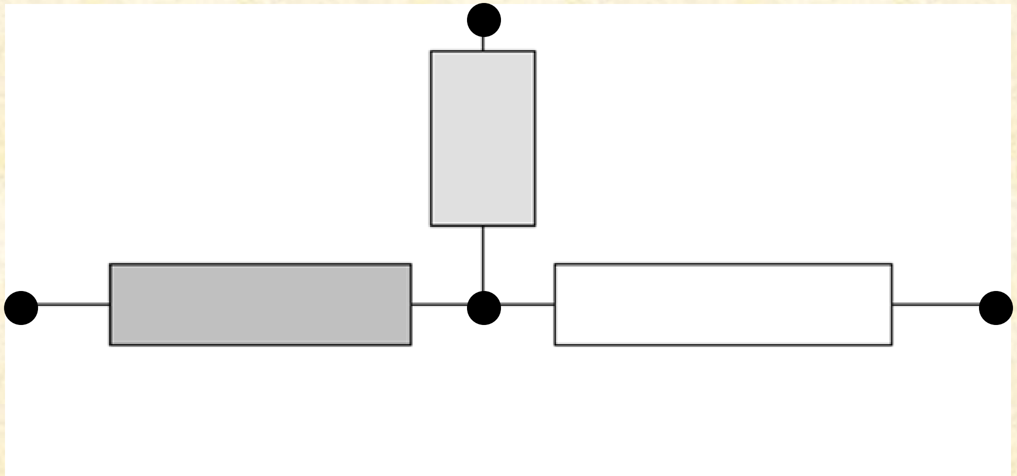
A **node** is the point of connection between two or more circuit elements



Circuit Topology

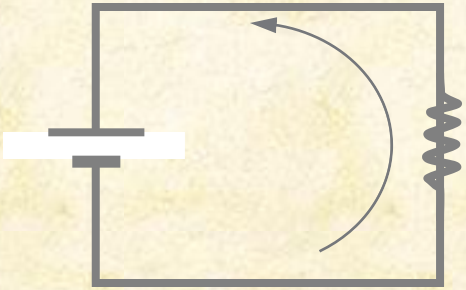
A **branch** represents a single circuit element; between any two nods.



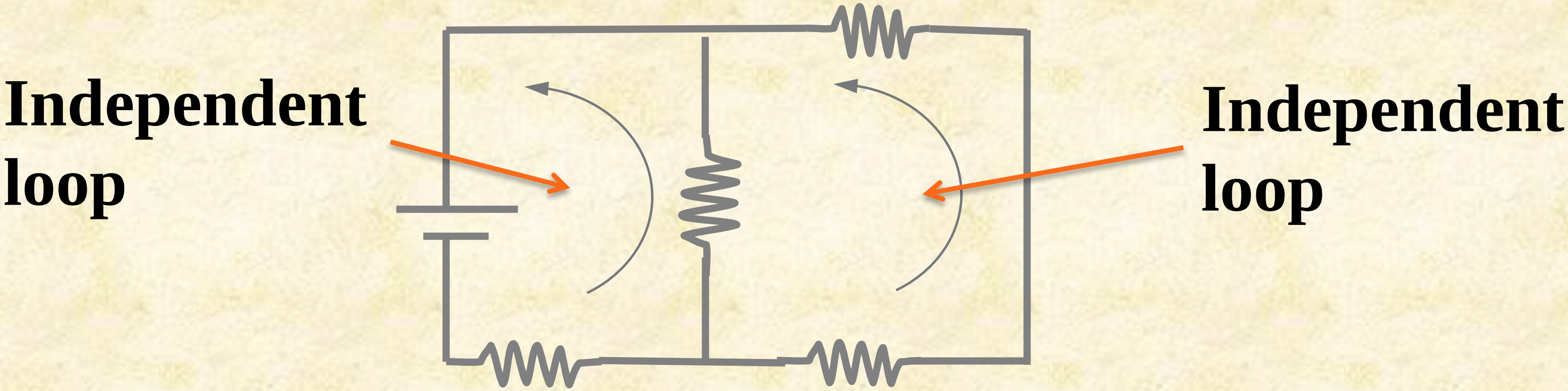


Circuit Topology

A **loop** is any closed path in a circuit (network).



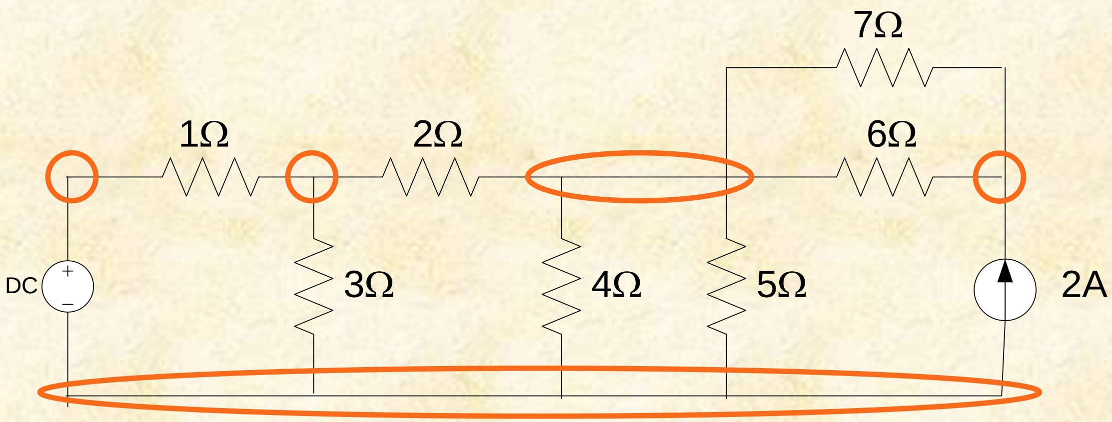
A **loop** is said to be **independent** if it contains at least one branch which is not a part of any other **independent loop**



For a network with ***b*** branches, ***n*** nodes and ***L*** loops:

$$b = l + n - 1$$

Example



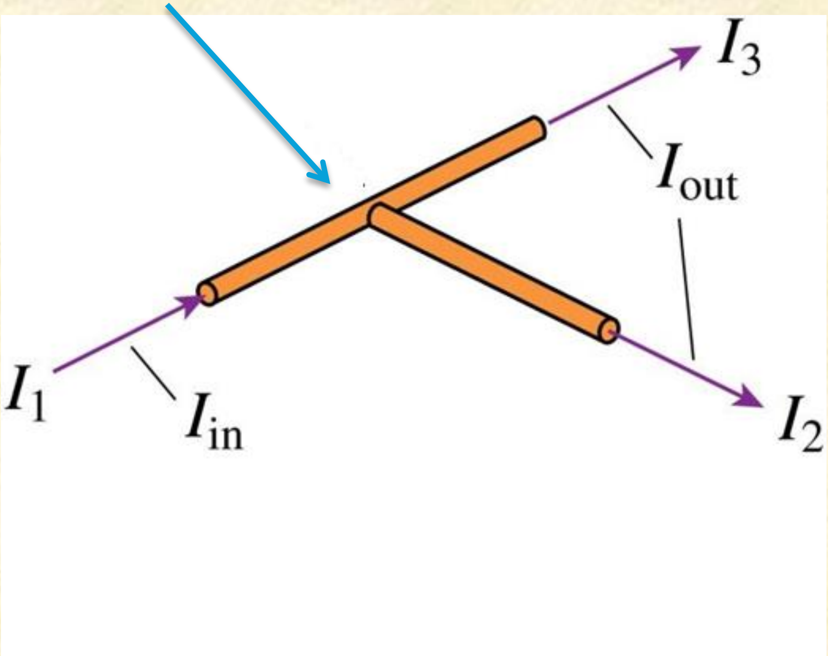
$n =$ **5**

$l =$ **5**

$b =$ **9**

Kirchhoff's Current Law (KCL)

Node



Sum of all currents entering a node is zero

$$I_1 + I_2 + I_3 = 0$$

Sum of currents entering node is equal to sum of currents leaving node

$$I_{in} = I_1$$

$$I_{out} = I_2 + I_3$$

$$I_1 = I_2 + I_3$$

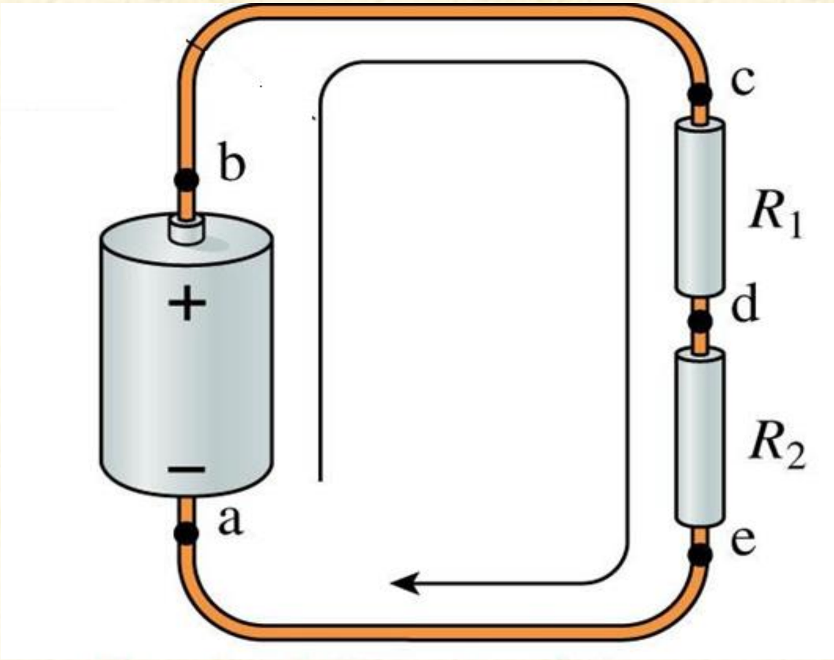
Kirchhoff's Voltage Law (KVL)

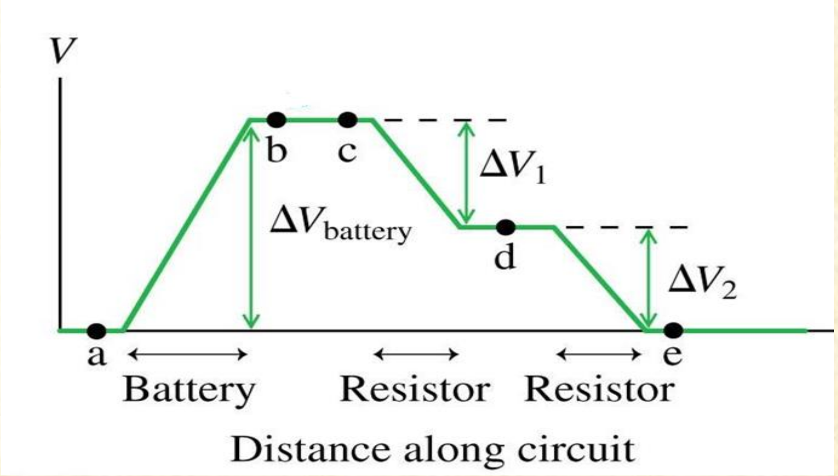
Sum of voltages around any loop in a circuit is zero

$$\Delta V_{bettary} = \Delta V_{R1} + \Delta V_{R2}$$

$$\Delta V_{bettary} + \Delta V_{R1} + \Delta V_{R2} = 0$$

$$\sum_n V_n = 0$$

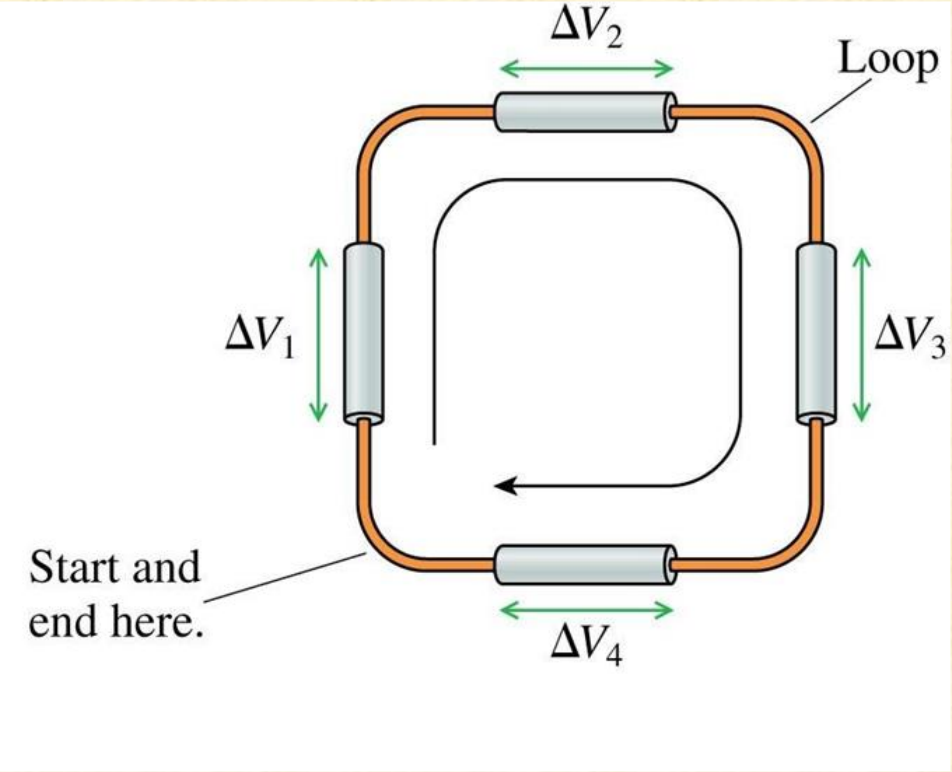




Kirchhoff's Voltage Law (KVL)

For any circuit, if we add all of the potential differences around the loop formed by the circuit, the sum must be zero.

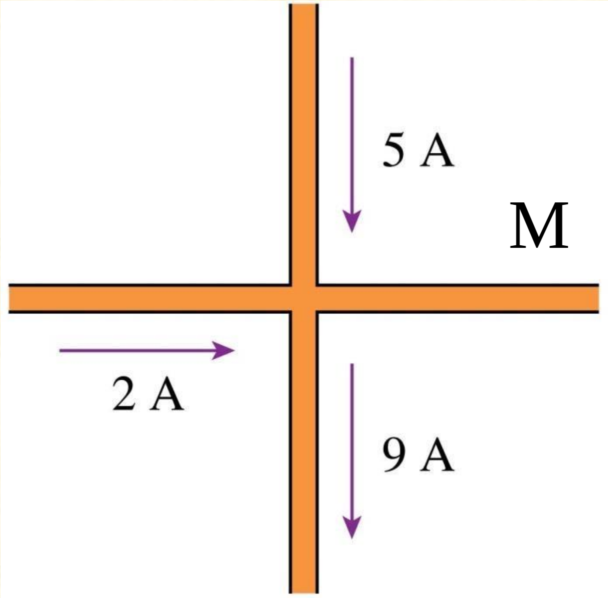
$\Delta V_1 + \Delta V_2 + \Delta V_3 + \Delta V_4 = 0$



Example

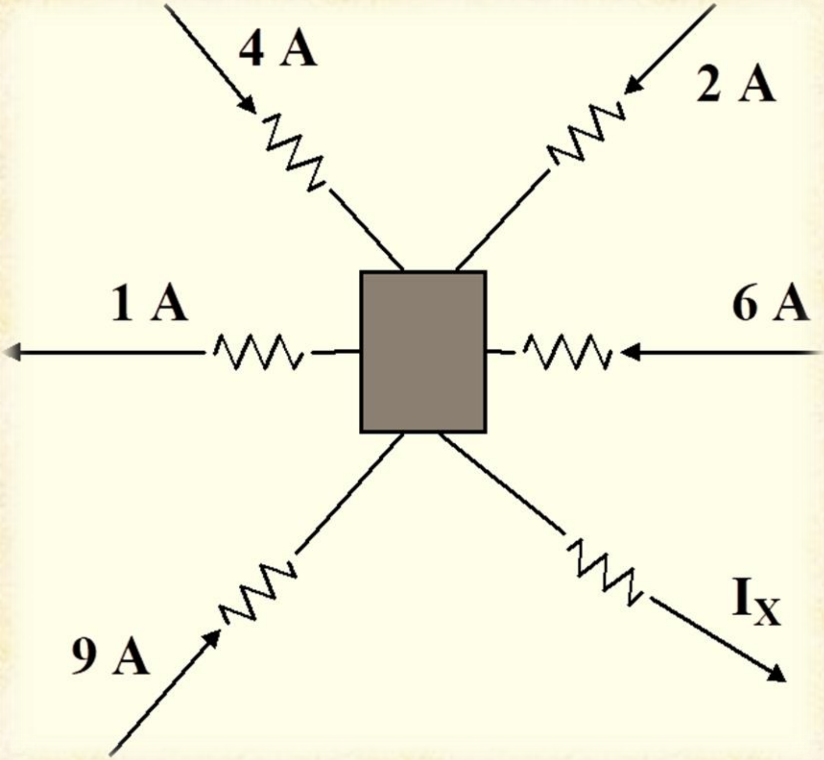
The current in the wire M is

A. 16 A to the right.
B. 4 A to the left.
C. 2 A to the right.
D. 2 A to the left.
E. Not enough information to tell



Example

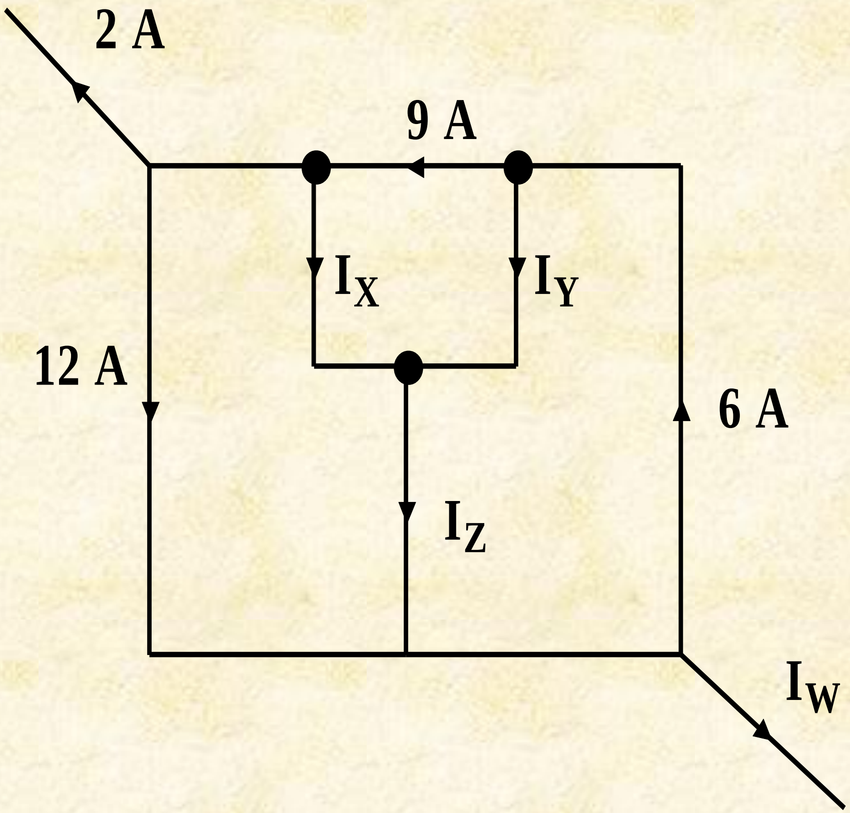
Find the current I $_x$.



I_X = **20 A**

Example

Find the currents I_W, I_X, I_Y, I_Z.



I_W = **-2 A**

I_X = **-5 A**

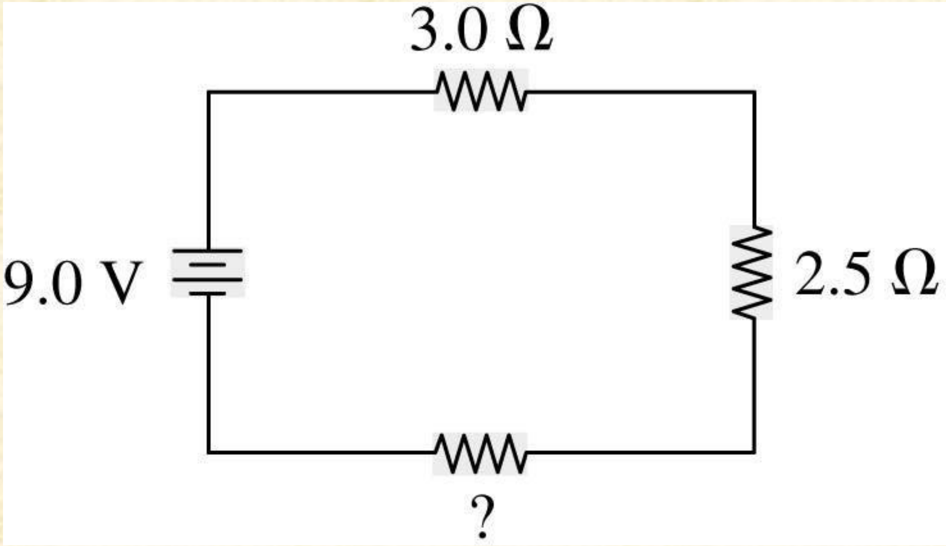
I_Y = **-3 A**

I_Z = **-8 A**

Example

There is a current of 1.0 A in the following circuit. What is the resistance of the unknown circuit element?

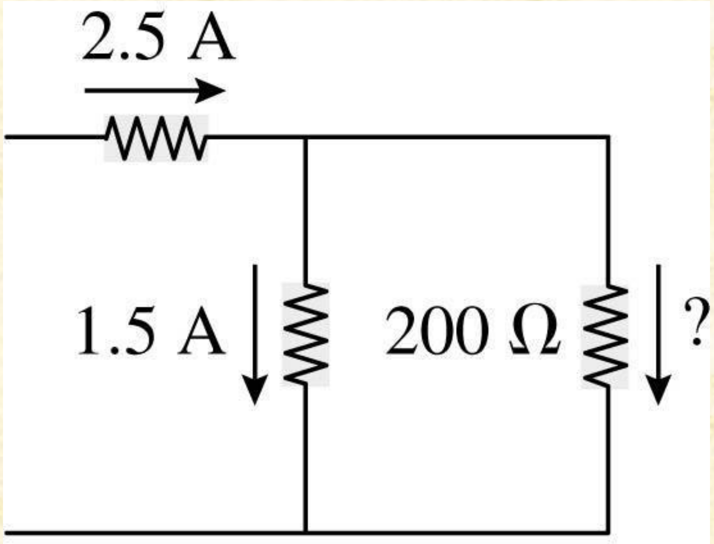
R = **3.5 Ω**



Example

The diagram below shows a segment of a circuit. What is the current in the 200 Ω resistor?

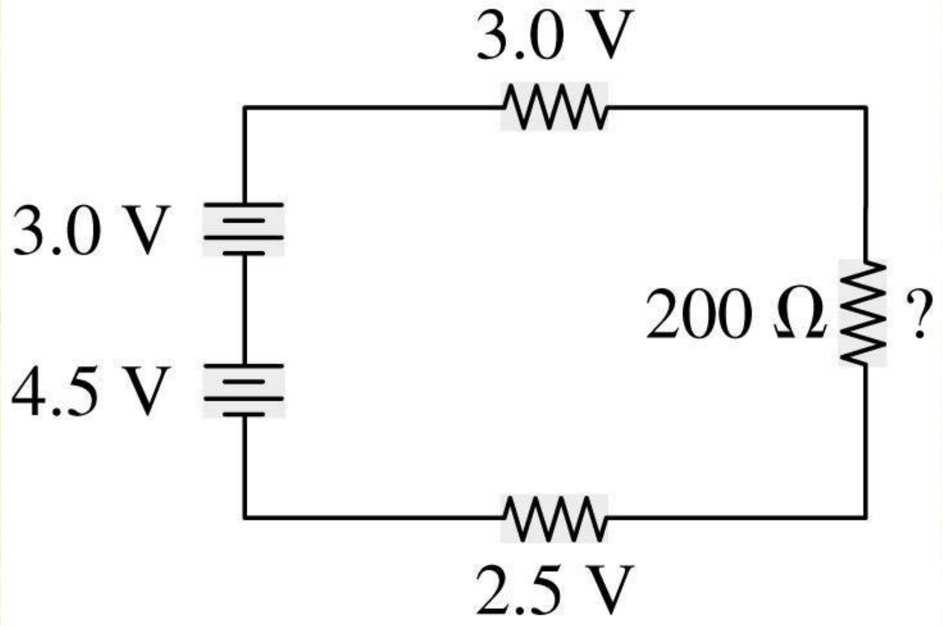
I = **1 A**



Example

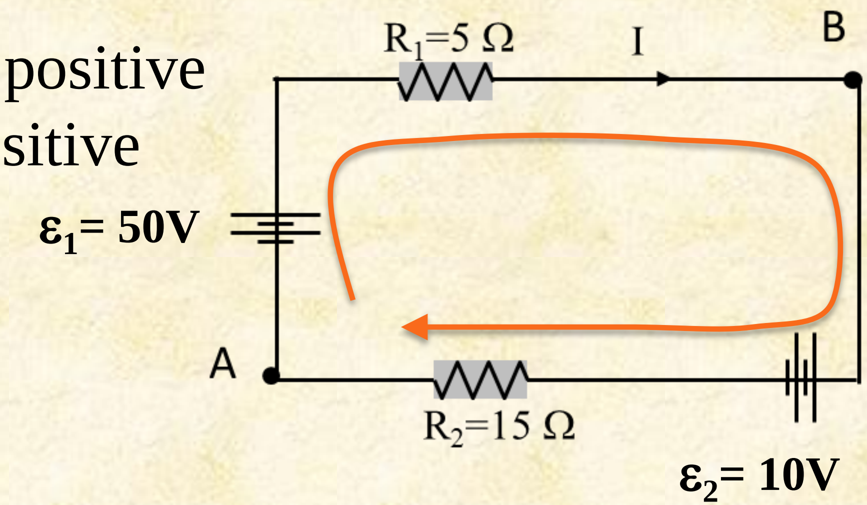
The diagram below shows a circuit with two batteries and three resistors. What is the potential difference across the 200 Ω resistor?

V = **2 V**

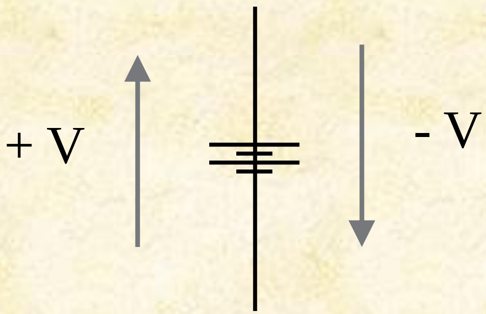


Example

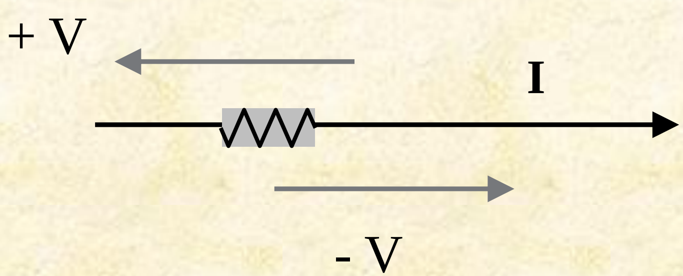
In the shown circuit . Find the current I .



For **batteries** – voltage change is positive when summing from negative to positive



For **resistors** – voltage change is negative when summing in the direction of the current

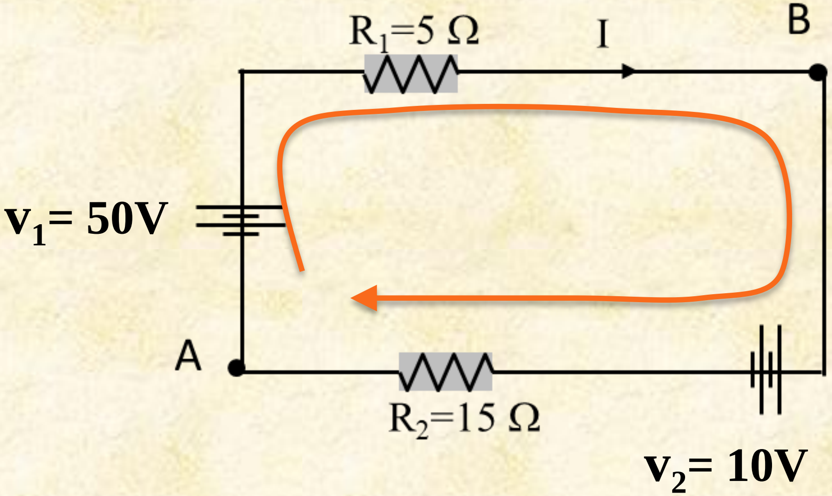


Electrical Basics

$$+V_1 - IR_1 - V_2 - IR_2 = 0$$

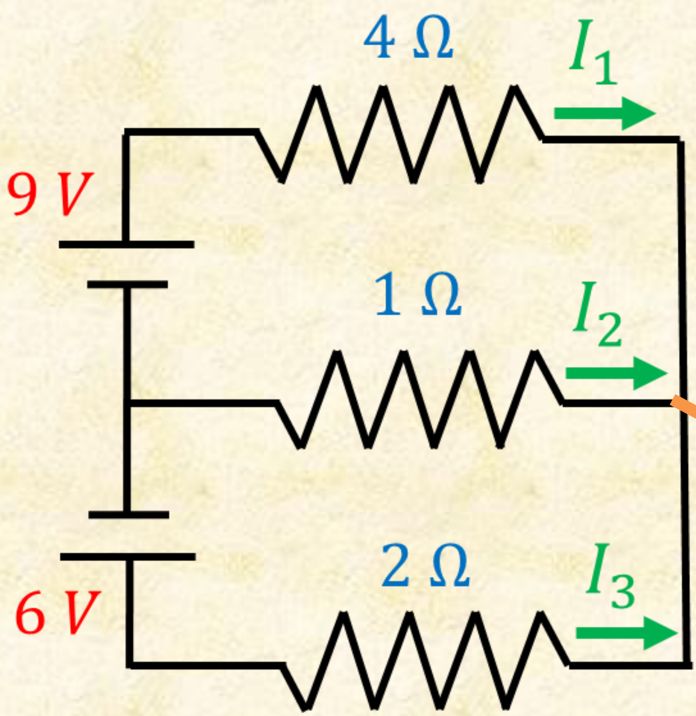
+50 - 5 I - 10 - 15 I = 0

I = +2 Amps

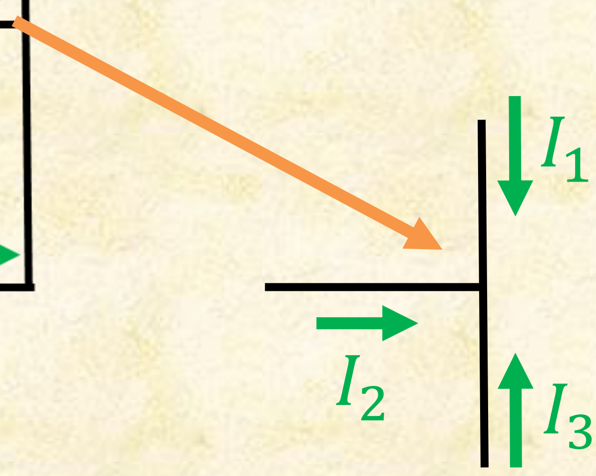


Example

What are the currents flowing in the 3 resistors?

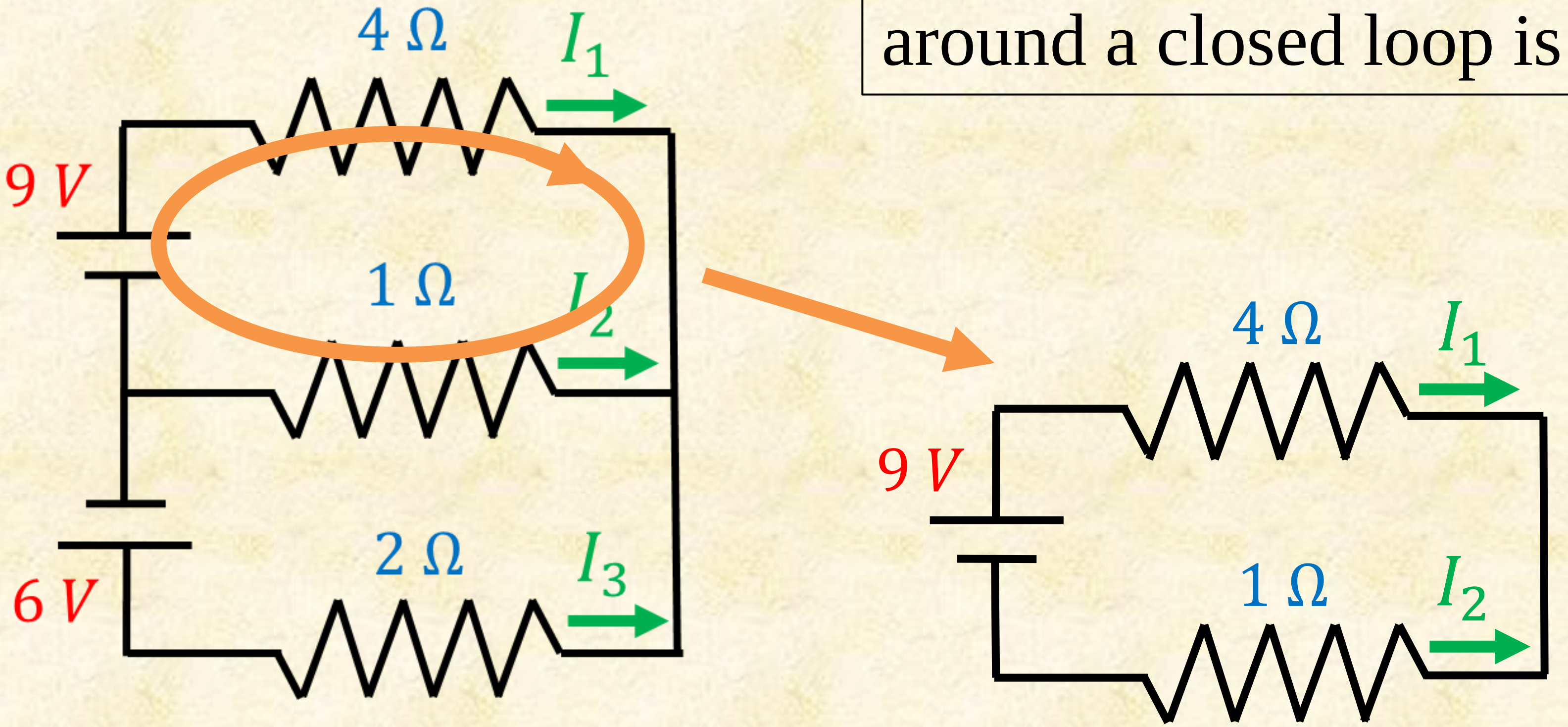


Kirchoff's junction rule :
the sum of currents at any junction is zero



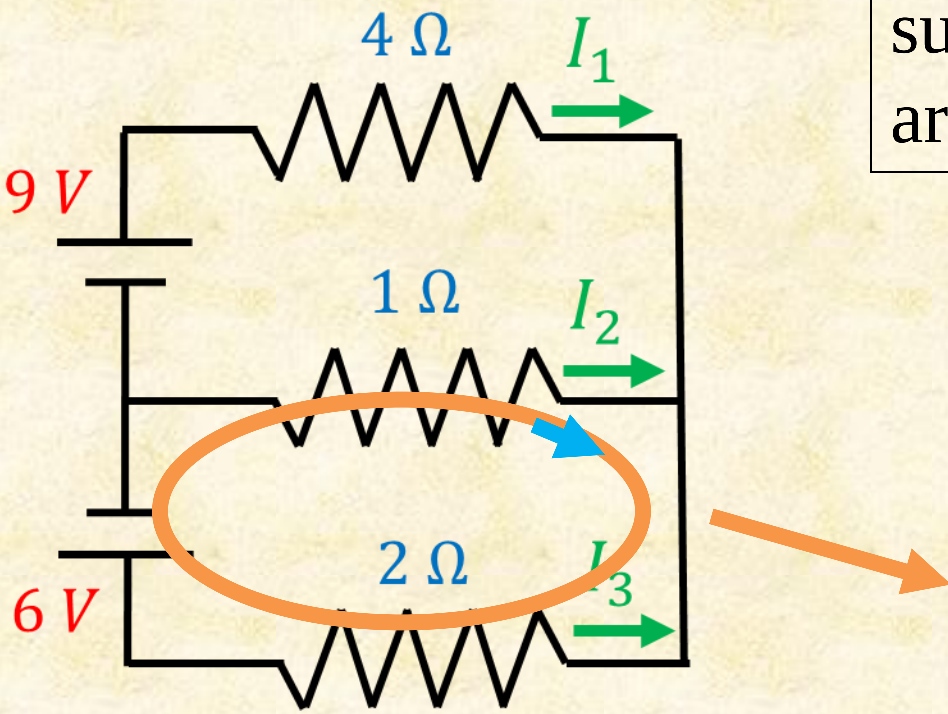
$$I_1 + I_2 + I_3 = 0$$

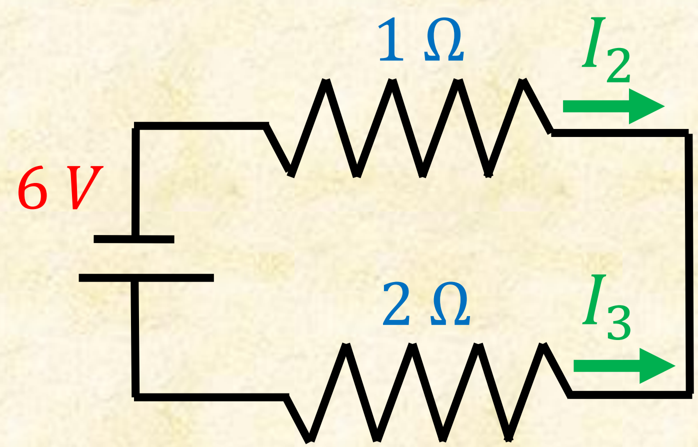
Kirchoff's loop rule : the sum of voltage changes around a closed loop is zero



$$9 - 4\,I_1 + 1\,I_2 = 0$$

Kirchoff's loop rule : the sum of voltage changes around a closed loop is zero





$$-6 - 1\,I_2 + 2\,I_3 = 0$$

We now have 3 equations:

$$I_1 + I_2 + I_3 = 0 \quad (1)$$
$$9 - 4I_1 + I_2 = 0 \quad (2)$$
$$-6 - I_2 + 2I_3 = 0 \quad (3)$$

To solve for I_1 we can use algebra to eliminate I_2 and I_3 :

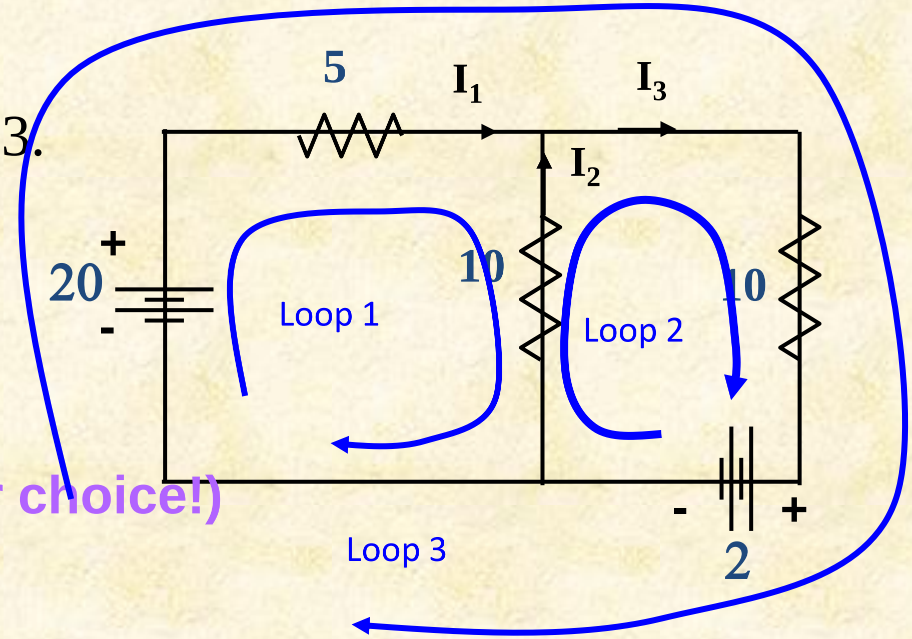
$$(1) \rightarrow \quad I_3 = -I_1 - I_2$$

$$Sub.in\ (3) \rightarrow I_2 = -2 - \tfrac{2}{3} I_1$$

$$Sub.in\ (2) \rightarrow I_1 = 1.5\ A$$
$$\rightarrow I_2 = -3\ A$$
$$\rightarrow I_3 = -1.5\ \ A$$

Example

In the shown circuit . Find I1, I2 and I3.



1. **Label all currents**
2. **Write down node equation**

   Node: $I_1 + I_2 = I_3$

3. **Choose loop and direction (Your choice!)**
4. **Write down voltage changes**

Loop 1: $+V_1 - I_1R_1 + I_2R_2 = 0$

$$20 - 5I_1 + 10I_2 = 0$$

Loop 2: $- I_2R_2 - I_3R_3 - V_2 = 0$

$$-2 - 10I_2 - 10I_3 = 0$$

Loop 3: $+V_1 - I_1R_1 - I_3R_3 - V_2 = 0$

$$20 - 5I_1 - 10I_3 - 2 = 0$$

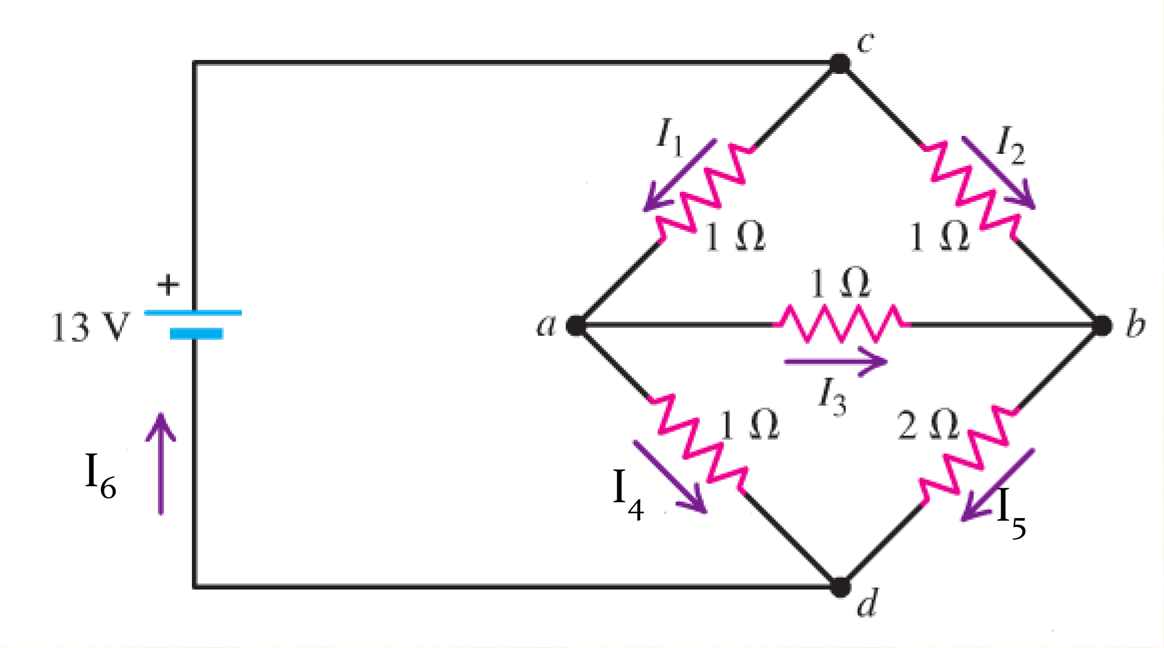
$I_1 = 1.90$ A

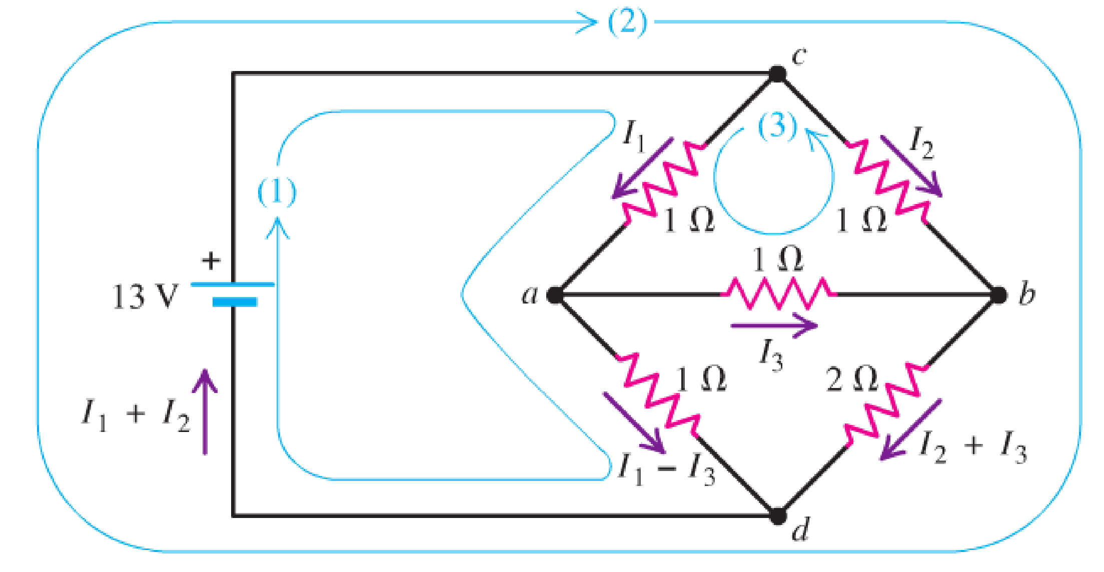
$I_2 = -1.05$ A

$I_3 = 0.85$ A

Example

Find the equivalent resistance for the following circuit





loop1: $$13V - I_1 \times 1\Omega - \left(I_1 - I_3\right) \times 1\Omega = 0$$

loop2: $$13V - I_2 \times 1\Omega - \left(I_2 + I_3\right) \times 2\Omega = 0$$

loop3: $$-I_1 \times 1\Omega - I_3 \times 1\Omega + I_2 \times 1\Omega = 0$$

From 3: $I_1 = I_2 - I_3$ **into 1:**

$$13V - I_2 \times 1\Omega + I_3 \times 1\Omega - \left(I_2 - 2I_3\right) \times 1\Omega = 0$$

$$13V - 2I_2 \times 1\Omega + 3I_3 \times 1\Omega = 0$$

Together with eq. 2 we get

$$\left.\begin{aligned} 13V - 2I_2 \times 1\Omega + 3I_3 \times 1\Omega = 0 \\ 13V - 3I_2 \times 1\Omega - 2I_3 \times 1\Omega = 0 \end{aligned}\right\} \quad \left.\begin{aligned} 39V - 6I_2 \times 1\Omega + 9I_3 \times 1\Omega = 0 \\ -26V + 6I_2 \times 1\Omega + 4I_3 \times 1\Omega = 0 \end{aligned}\right\} \Rightarrow$$

$$13V + 13I_3 \times 1\Omega = 0$$

$\Rightarrow$ $I_3 = -1A$

$\Rightarrow$ $I_2 = 5A$

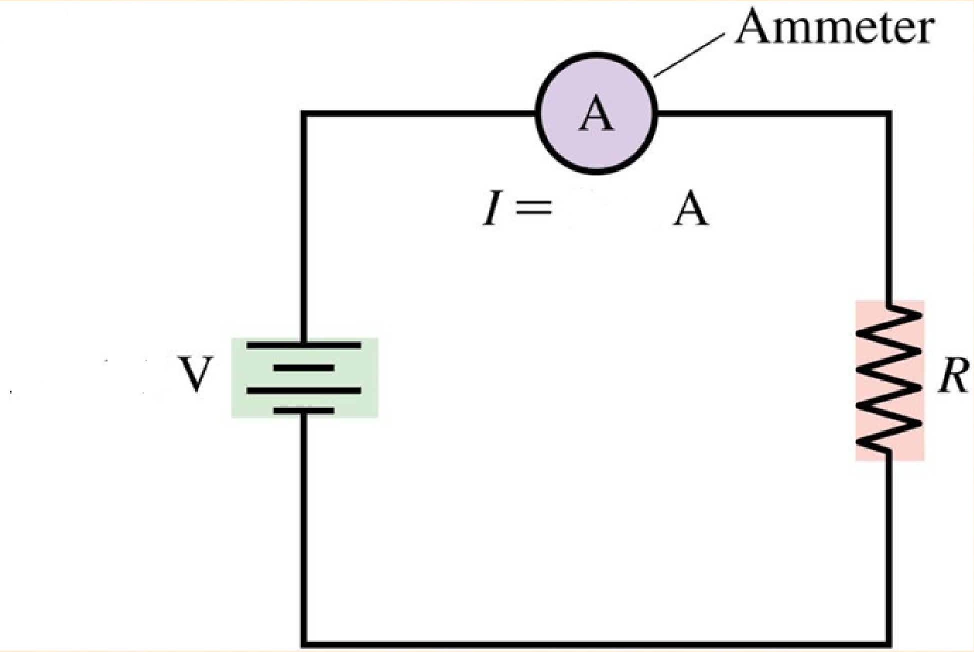
$\Rightarrow$ $I_1 = 6A$

$\Rightarrow$ **Total current through the network** $I_6 = I_1 + I_2 = 11A$

$\Rightarrow$ **Equivalent resistance** $R_{eq} = \dfrac{13V}{11A} = 1.18\Omega$

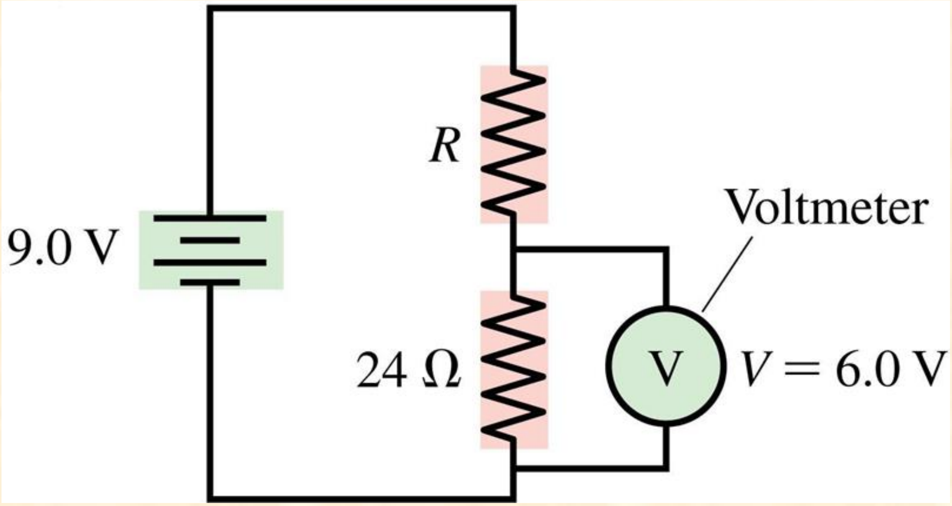
Measuring Voltage and Current

- An **ammeter** is a device that measures the current in a circuit element.
- Because charge flows *through* circuit elements, an ammeter must be placed *in series* with the circuit element whose current is to be measured.



Measuring Voltage and Current

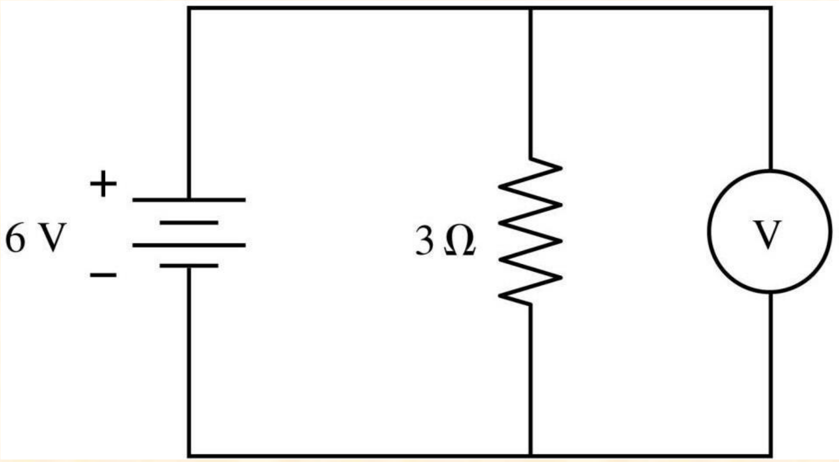
- A **voltmeter** is used to measure the potential differences in a circuit.
- Because the potential difference is measured *across* a circuit element, a voltmeter is placed in *parallel* with the circuit element whose potential difference is to be measured.



Measuring Voltage and Current

What does the voltmeter read?

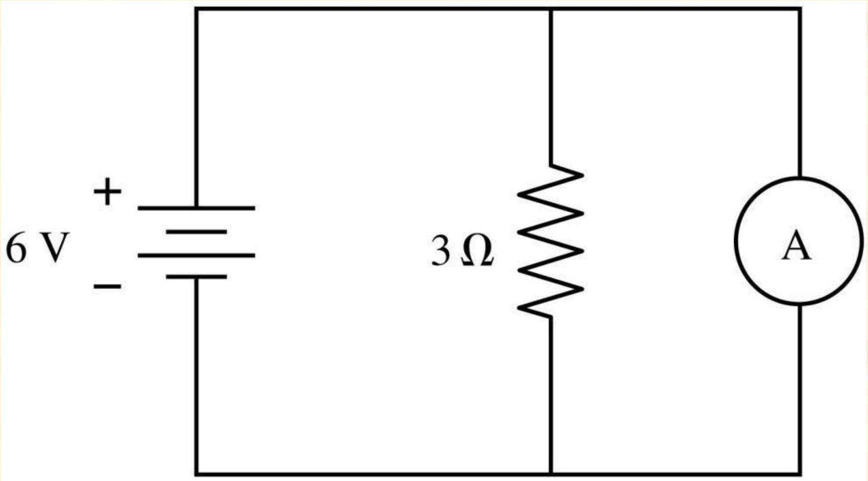
A. $\boxed{6V}$
B. 3V
C. 2V
D. Some other value
E. Nothing because this will fry the meter.



Measuring Voltage and Current

What does the ammeter read?

A. 6A
B. 3A
C. 2A
D. Some other value
E. Nothing because this will free the meter.



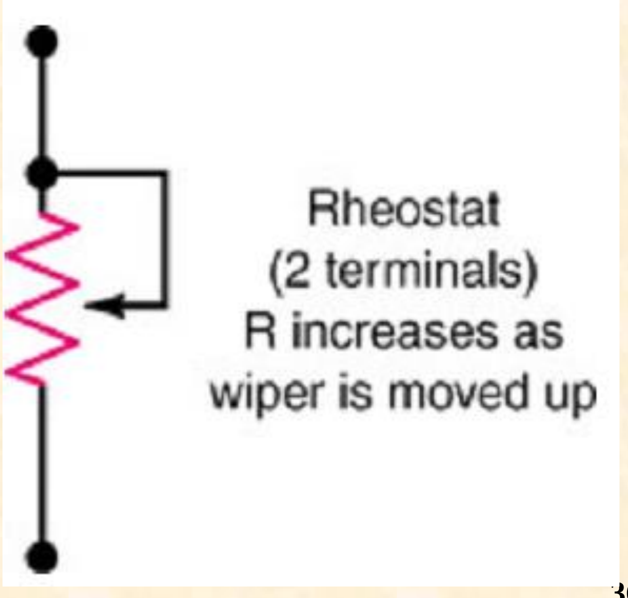
Variable Resistor

The variable resistor is variable resistance used to vary the amount of **current** or **voltage** in a circuit

Type of variable Resistor

1- Rheostats

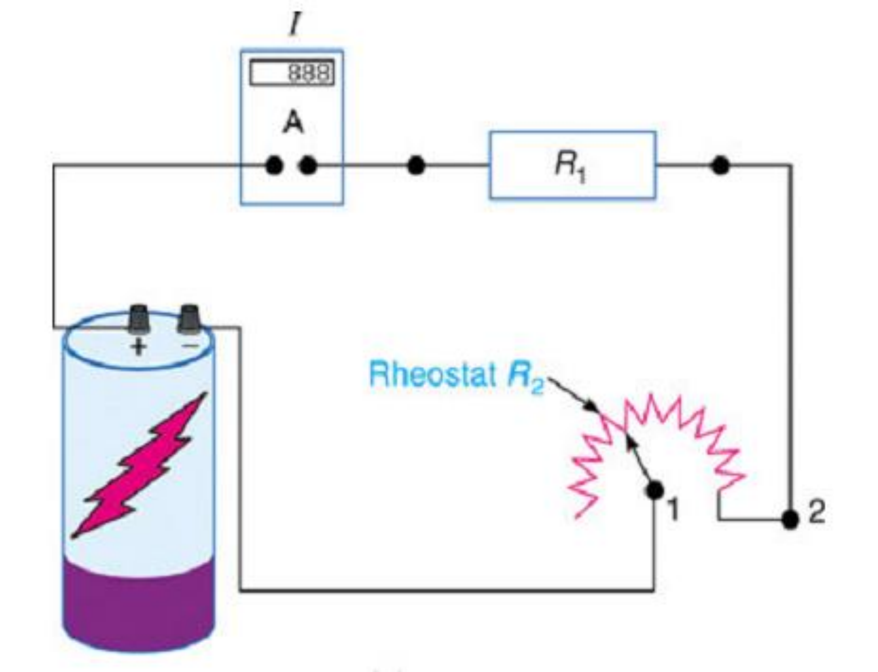
Rheostat is a variable resistor, which is used to control the flow of electric current by manually increasing or decreasing the resistance.

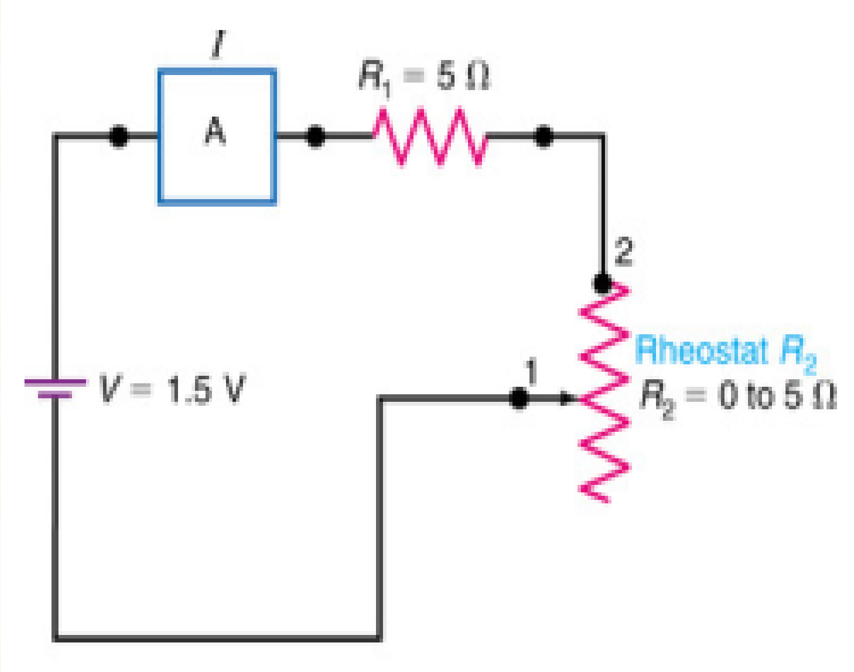


1- Varies the current. 2- Two terminals.

3- Connected in series with the load and the voltage source.

Variable Resistor Construction

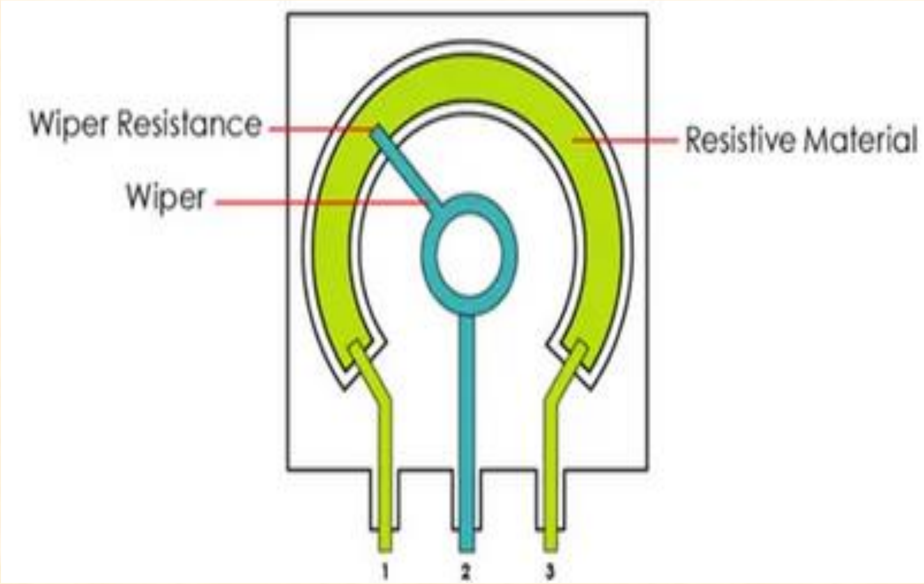




Types of Rheostats

1- Rotary Rheostats

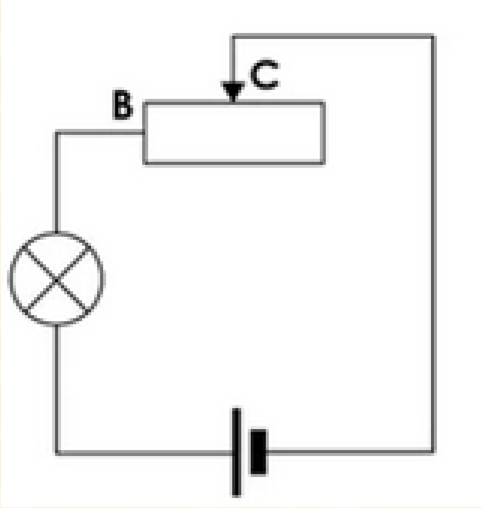
when the dial is turned fully to the left, there is minimal resistance between the left and center pins (usually 0 W) and maximum resistance between the center and right pins. The resistance between the left and right pins will always be the total resistance.

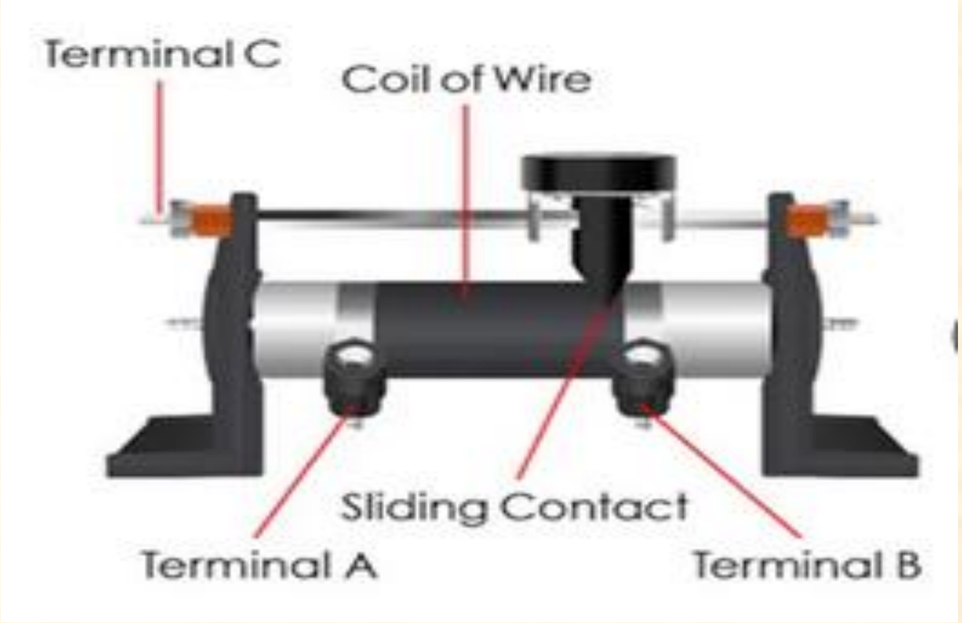


Types of Rheostats

2- Linear Rheostats

A linear rheostat is a two-terminal variable resistor in which the sliding contact, or wiper, is attached to a wire coil running in a straight line along an insulating cylinder. The mechanical operation of a linear rheostat thus takes the form of a two-way slider. They are often called linear rheostats (or sliding rheostats) for this reason.





Variable Resistor application

1- Rheostat is generally used in the applications where high voltage or current is required.

2- Rheostats are used in dim lights to change the intensity of light. If we increase the resistance of the rheostat, the flow of electric current through the light bulb decreases. As a result, the light brightness decreases.

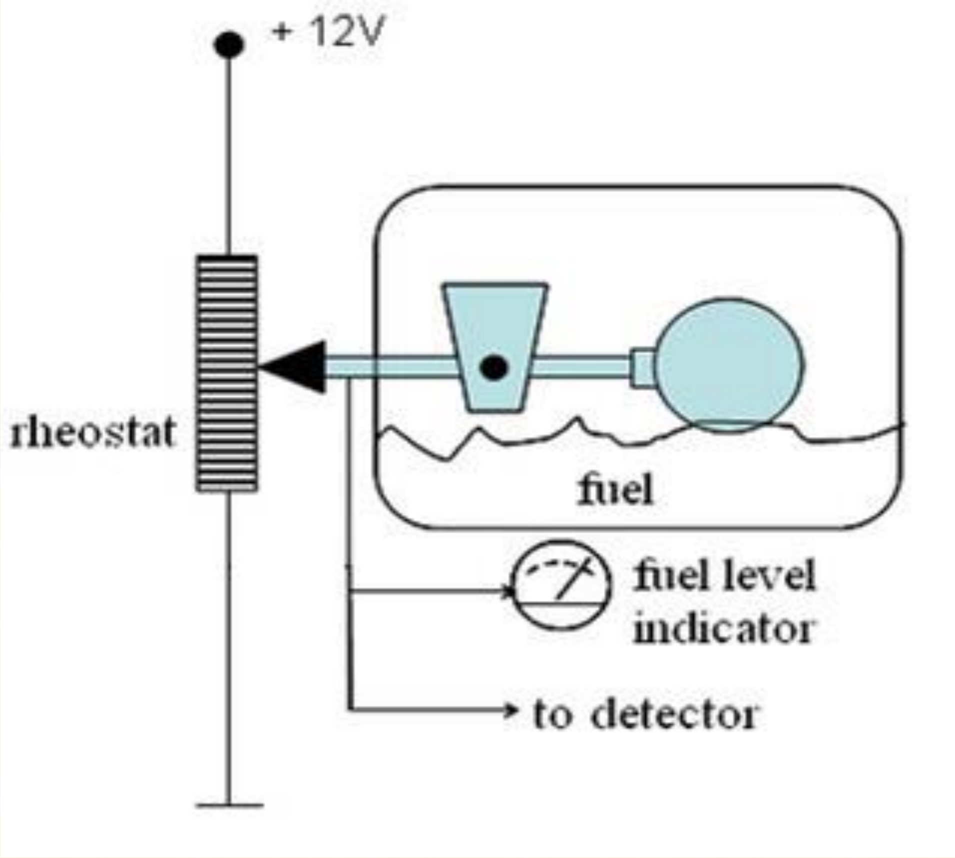
In the similar way, if we decrease the resistance of the rheostat, the flow of electric current through the light bulb increases. As a result, the light brightness increases.

3- Rheostats are used to increase or decrease the volume of a radio and to increase or decrease the speed of an electric motor.

Variable Resistor application

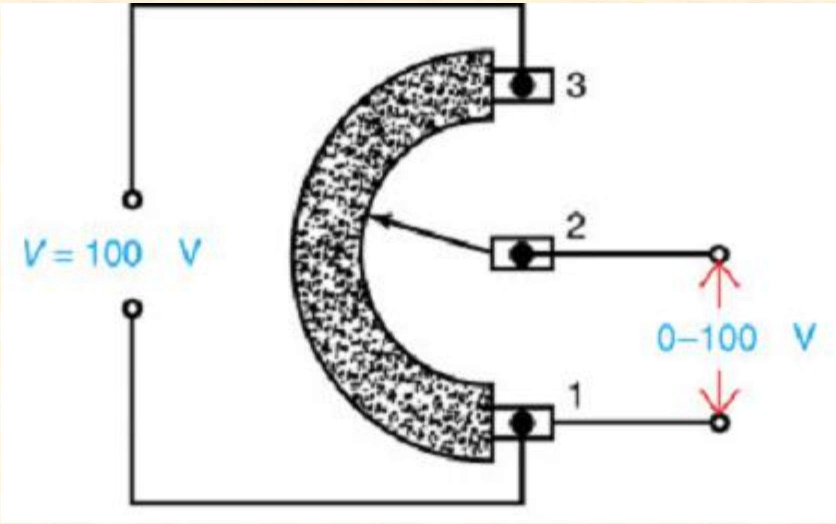
Fuel level indicator

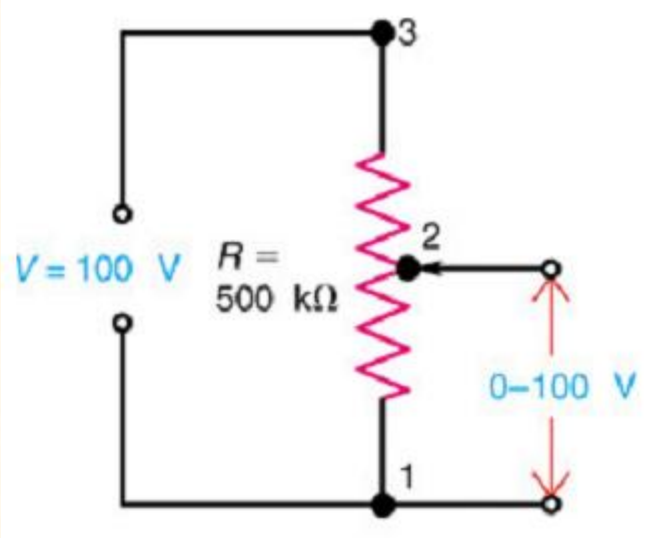
This is a normal resistor with an additional arm contact that can move along the resistive material and tap off the desired resistance.



2- Potentiometers:

A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable **voltage divider**





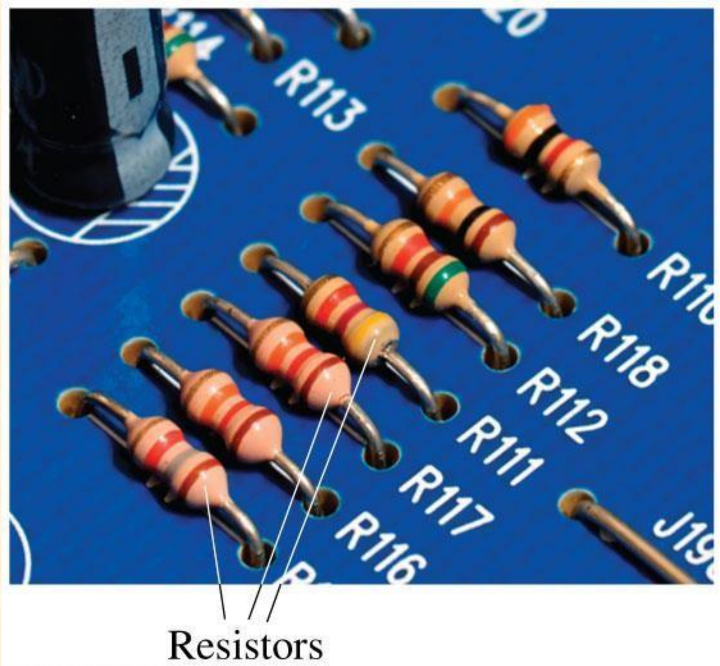
Potentiometers are three terminal devices

The applied V is input to the two end terminals of the potentiometer.

The variable V is output between the variable arm and an end terminal

Resistor applications

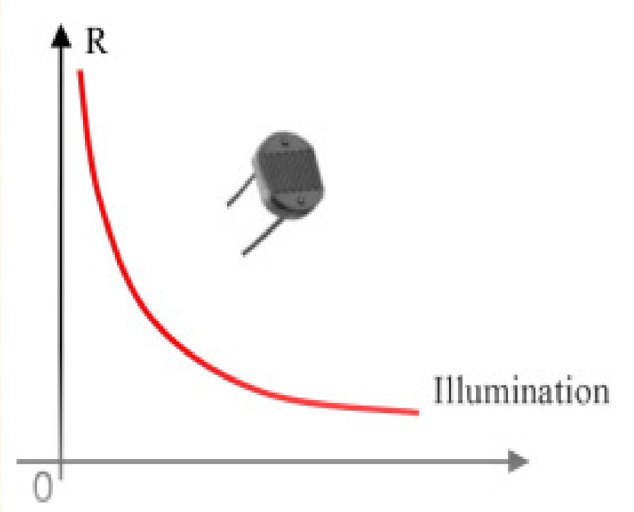
Circuit Elements

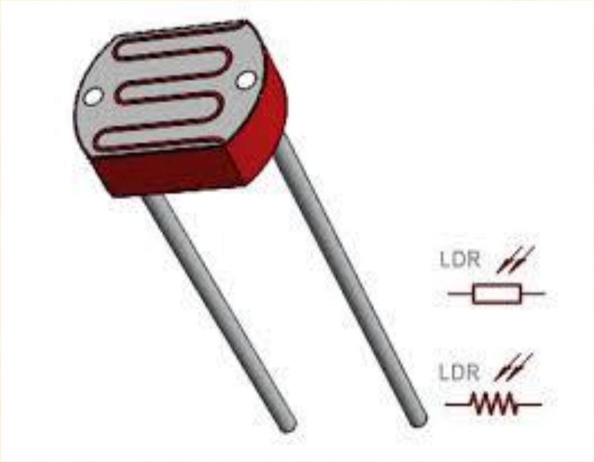


Inside many electronic devices is a circuit board with many small cylinders. These cylinders are resistors that help control currents and voltages in the circuit. The colored bands on the resistors indicate their resistance values.

Resistor applications

Photoresistor (Sensor Elements)



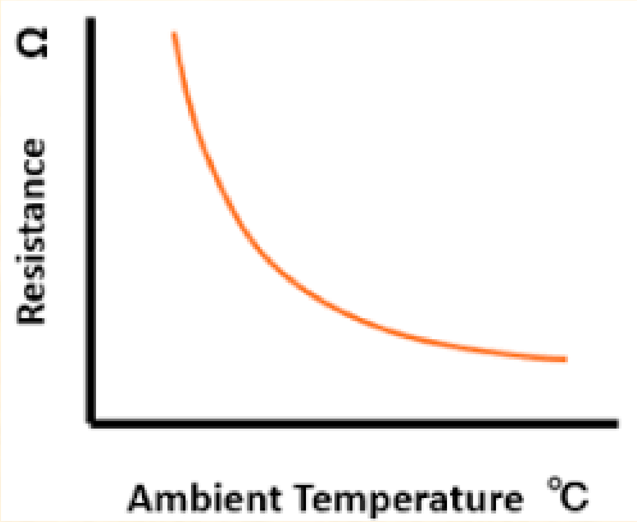


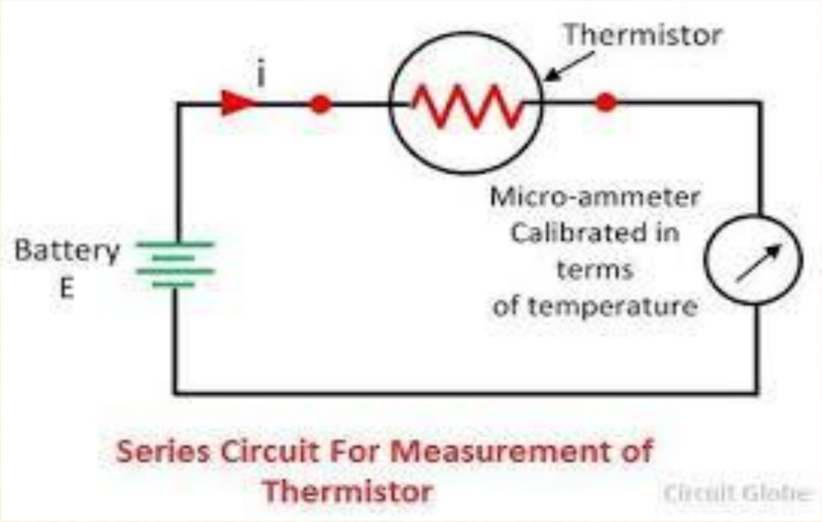
Photoresistors, also known as LDR (light-dependent resistors), are components made of semiconductors.

A photoresistor is sensitive to light. Its resistance decreases when lighting increases. Photoresistors have multiple uses, for example, automatic door opening.

Resistor applications

Thermistor (Heating Elements)





A thermistor is a resistance thermometer, or a resistor whose resistance is dependent on temperature.

Digital thermometers (thermostats)

Automotive applications (to measure oil and coolant temperatures in cars & trucks)