ELECTRONICS DEVICES AND CITCUITS

TOPICS

PASSIVE COMPONENTS AND DC CIRCUITS

- Review of Passive Components (Resistor, Capacitor, and Inductors.
- Ohm’s Law.
- Series and Parallel Circuits.
- Voltage and Current Dividers.
- Kirchhoff’s Current and Voltage Law.
- Nodal Analysis
- Basic Soldering Techniques.

Intended Learning Outcome

- Identify and describe the functions of passive components including resistors, capacitors, and inductors.
- Apply Ohm's Law and analyze series and parallel circuits, including voltage and current dividers.
- Apply basic soldering techniques

Did You Know?

Lightning is a big spark caused by the buildup of electric charges in the clouds!

Review of Passive Components

Passive devices - are incapable of controlling current by means of another electrical signal.

- Resistor - is an electrical component that limits or regulates the flow of electrical current in an electronic circuit.
- Capacitor - a device used to store an electric charge, consisting of one or more pairs of conductors separated by an insulator.
- Inductor - is a passive electronic component that temporarily stores energy in a magnetic field when electric current flows through the inductor's coil.

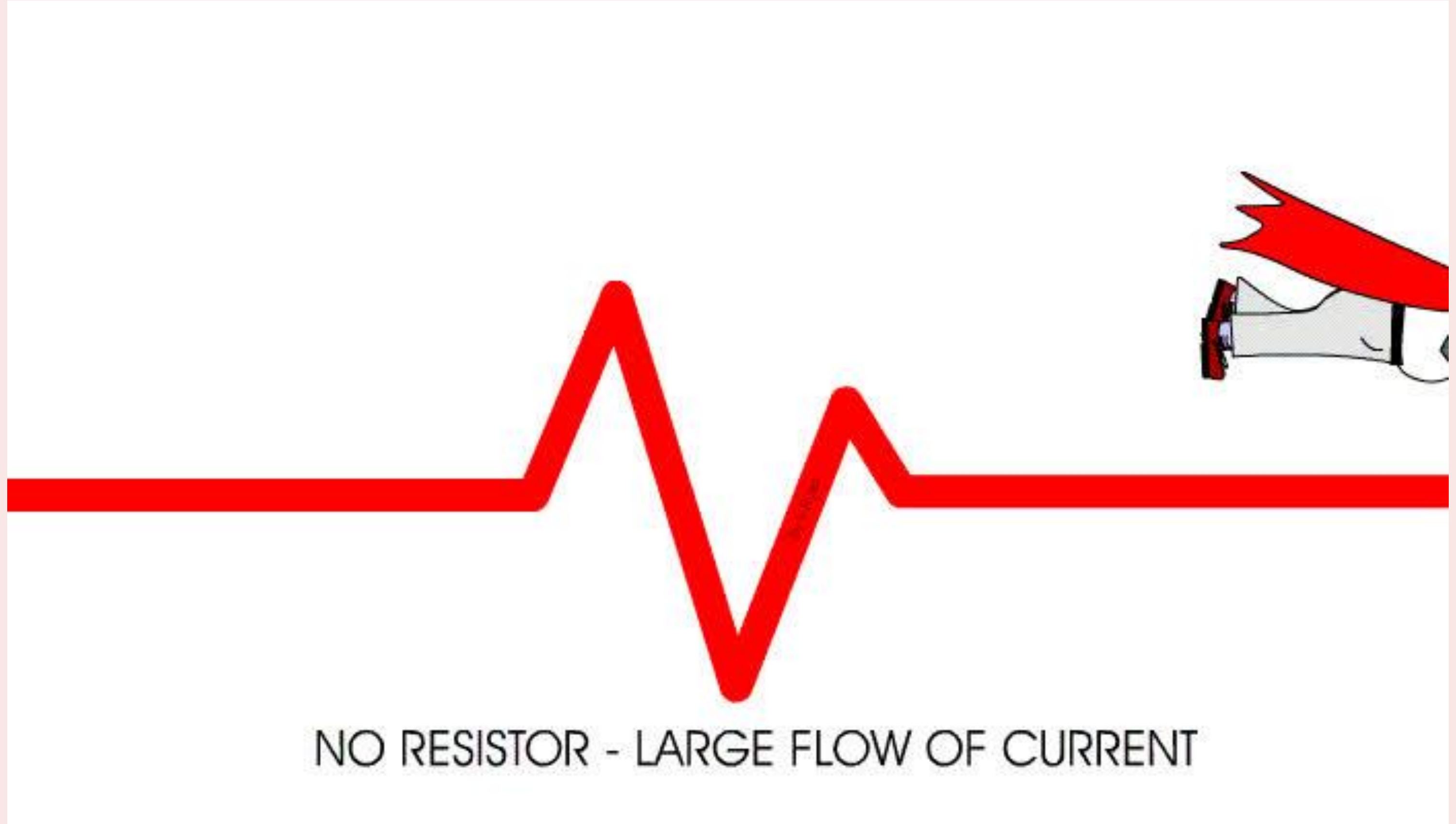
Review of Passive Components

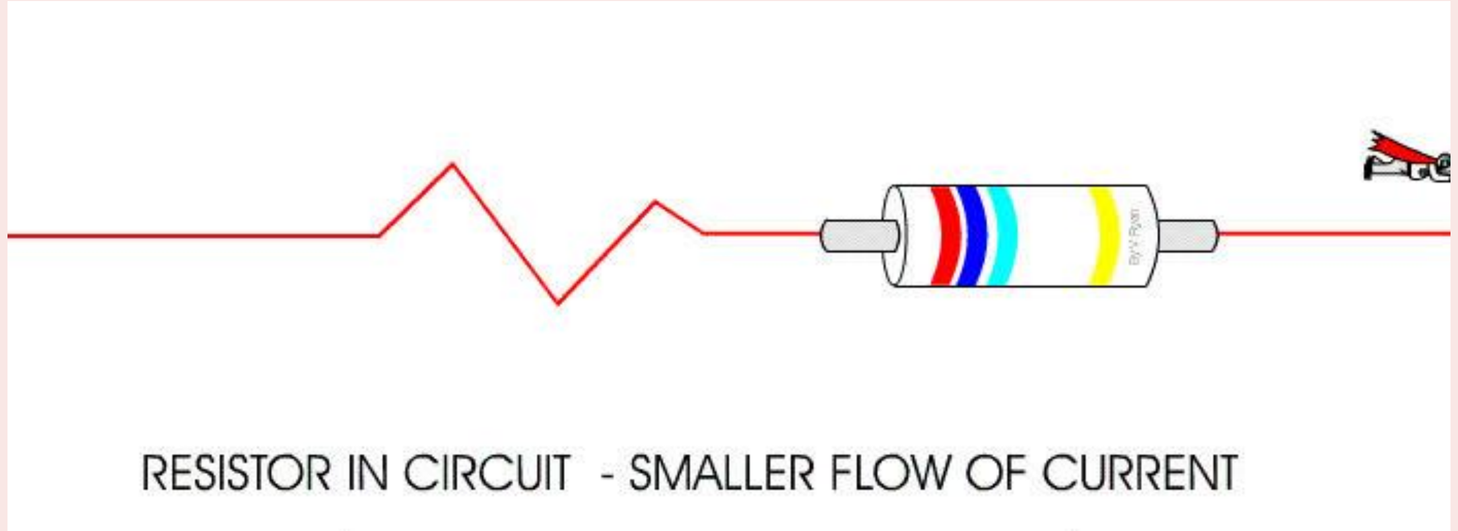
- Resistance - it is the measure of the opposition to the flow of current in an electrical circuit, measured in Ohms with a symbol “R”.

- Capacitance - it is the capacity of a material object or device to store electrical charge, measured in Farad with a symbol “C”.

- Inductance - it is the tendency of an electrical conductor to oppose a change in electric current flowing through it, measured in Henry with a symbol “L”.

Resistor


NO RESISTOR - LARGE FLOW OF CURRENT


RESISTOR IN CIRCUIT - SMALLER FLOW OF CURRENT

Resistor Functions

Resistors are fundamental components in electronic circuits. Their main function is to:

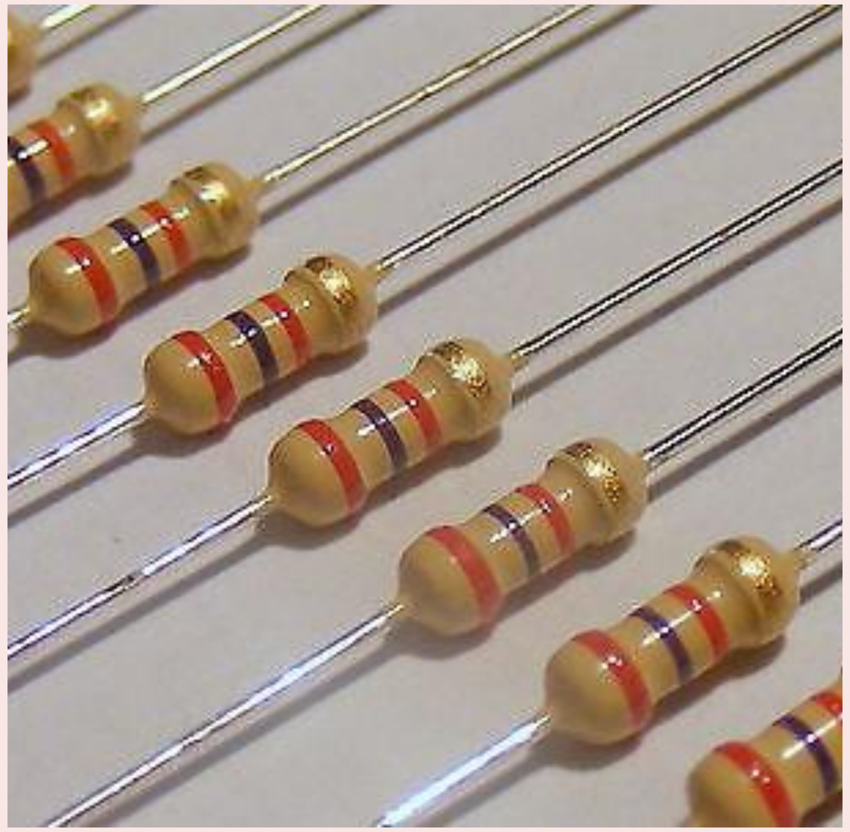
- Limit the flow of electric current: By introducing resistance in the path of the current, resistors help manage and control how much current flows through a circuit.
- Control voltage levels: In conjunction with Ohm’s Law (V=IR), resistors control voltage drops in a circuit, ensuring that devices receive appropriate voltage levels for proper operation.

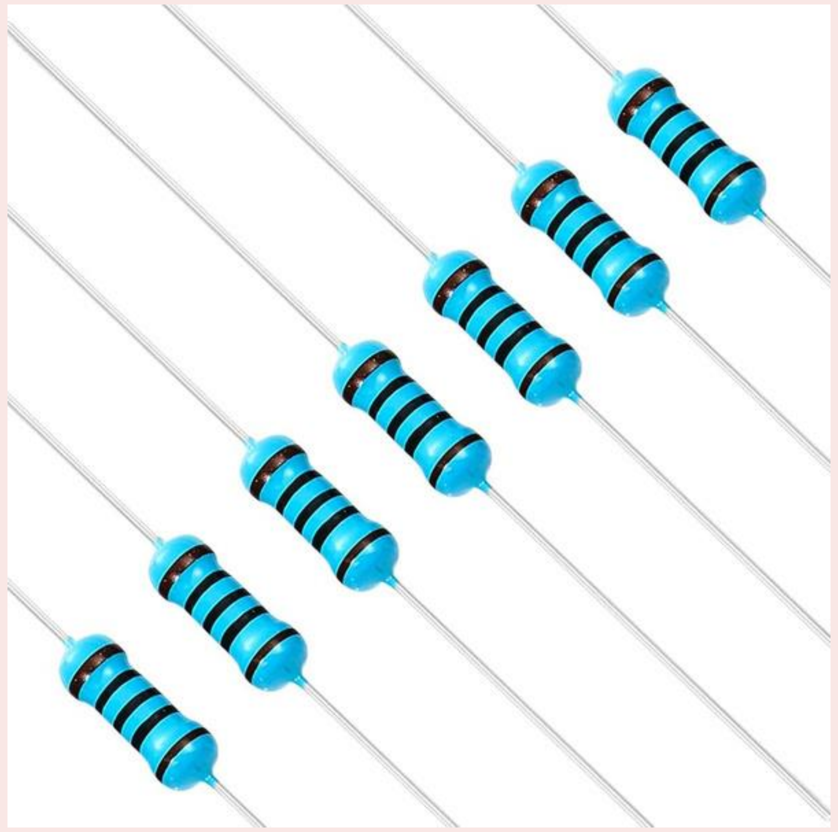
Without resistors, circuits could experience too much current, potentially damaging sensitive components or altering circuit behavior.

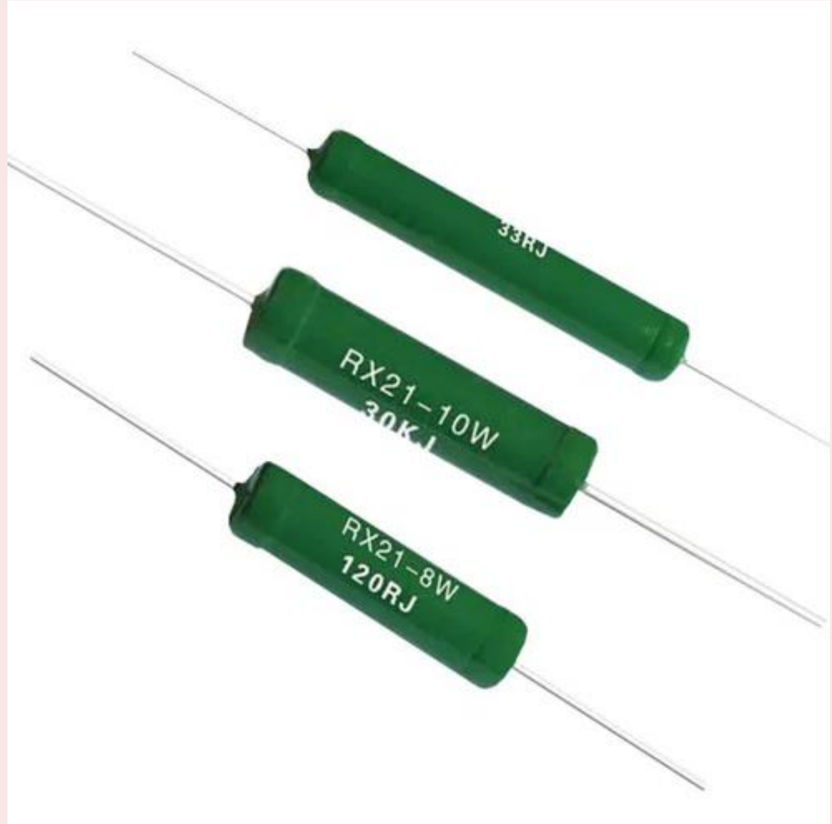
Types of Resistors

Fixed Resistors:

- Description: These resistors provide a constant, unchanging resistance value. They are widely used when a specific resistance is needed in a circuit.
- Common Materials: Carbon, metal film, or wire-wound.
- Applications: Used in circuits where precise and stable resistance is required, such as in timers, filters, and power supplies.







Types of Resistors

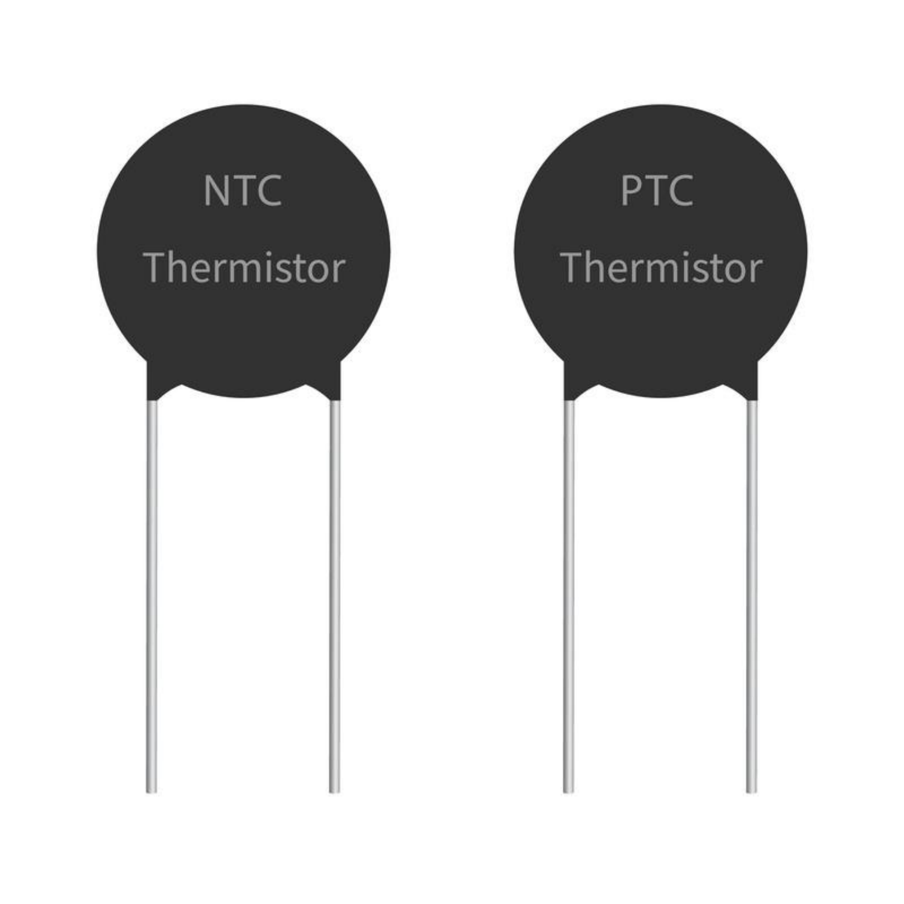
Variable Resistors (Potentiometers):

- Description: Variable resistors allow the user to adjust the resistance value within a given range. They consist of a resistive track and a movable wiper that adjusts the resistance.
- Applications: Used in applications where adjustable control is needed, such as in volume controls, light dimmers, and tuning circuits.

Types of Resistors

Thermistors:

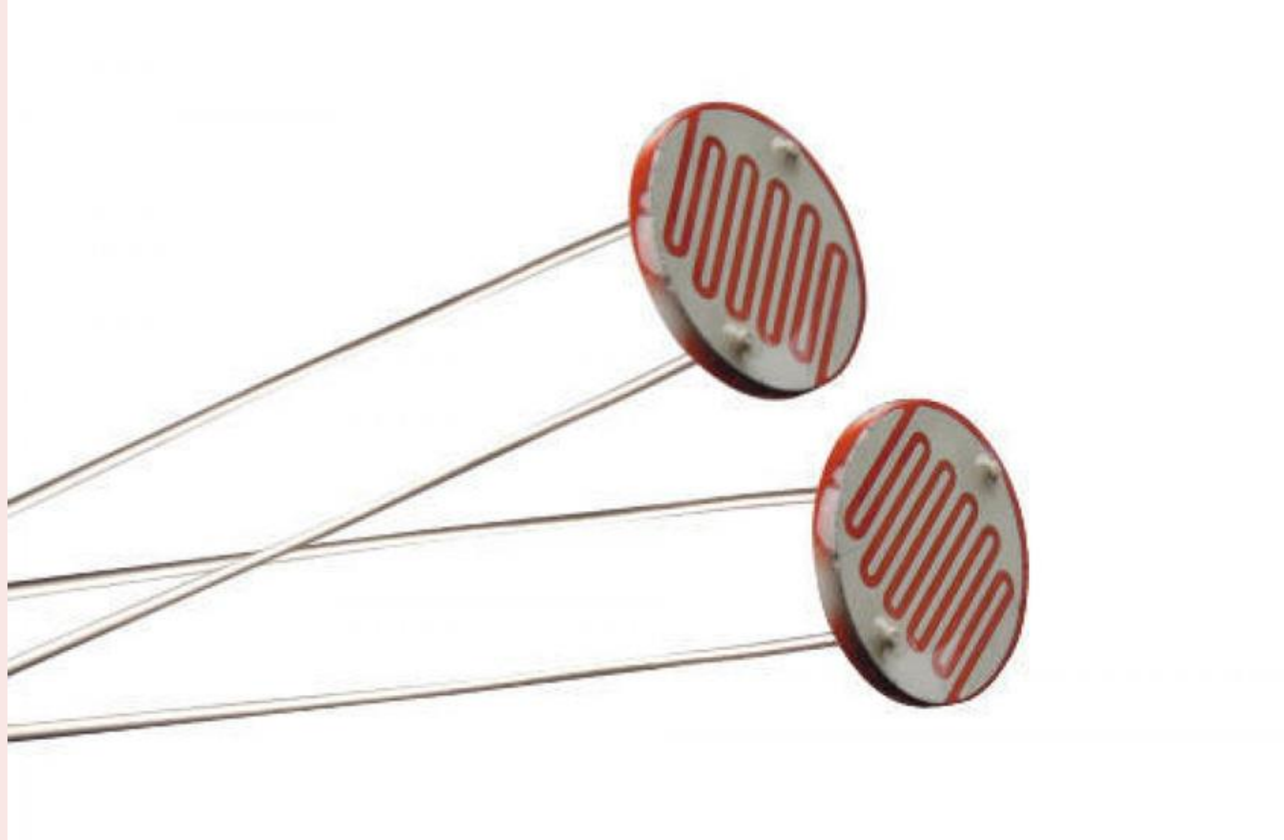
- Description: These are temperature-sensitive resistors whose resistance changes significantly with temperature.
- Types:
  - NTC (Negative Temperature Coefficient): Resistance decreases as temperature increases.
  - PTC (Positive Temperature Coefficient): Resistance increases as temperature increases.
- Applications: Used in temperature sensing and compensation circuits, such as thermometers and battery charging circuits.



Types of Resistors

Light-dependent Resistors (LDR):

- Function: Changes its resistance based on light exposure; it has higher resistance in the dark, lower resistance when exposed to light.
- Common Use: Automatic lighting systems, light meters, and streetlights.



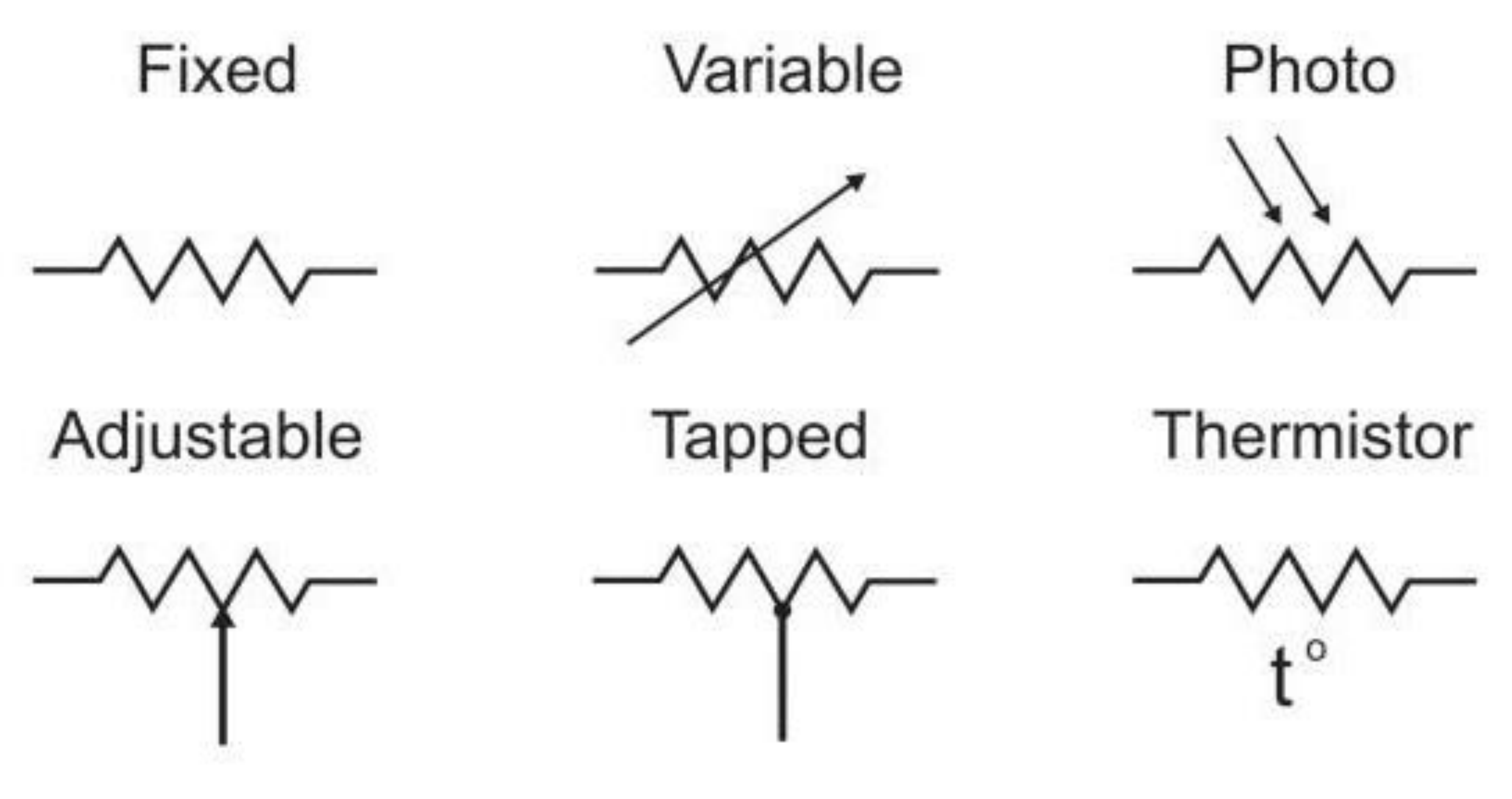
Applications of Resistor

- Voltage Dividers: Resistors are used to divide the input voltage into smaller, precise voltage levels. Common in sensor circuits and reference voltage applications.

- Current Limiters: Prevent excessive current from damaging components, such as LEDs and transistors, by restricting current flow.

- Biasing of Active Devices: Used to set the operating point (current/voltage) for transistors and other active components, ensuring proper function in amplification and switching circuits.

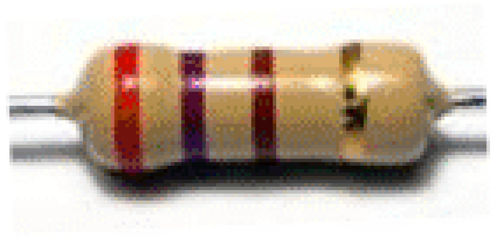
Resistor Symbols



Resistor Color Coding

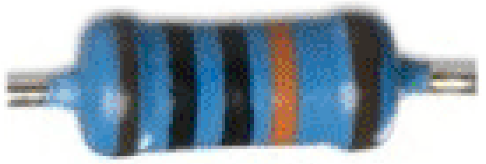
Color	Value	Multiplier	Tolerance
Black	0	$\times10^{0}$	± 20%
Brown	1	$\times10^{1}$	± 1%
Red	2	$\times10^{2}$	± 2%
Orange	3	$\times10^{3}$	± 3%
Yellow	4	$\times10^{4}$	- 0, + 100%
Green	5	$\times10^{5}$	± 0.5%
Blue	6	$\times10^{6}$	± 0.25%
Violet	7	$\times10^{7}$	± 0.10%
Gray	8	$\times10^{8}$	± 0.05%
White	9	$\times10^{9}$	± 10%
Gold	–	$\times10^{-1}$	± 5%
Silver	–	$\times10^{-2}$	± 10%

4-band resistor



270 ohms ± 5%

5-band resistor



100k ohms ± 1%

Examples:

Color	Value	Multiplier	Tolerance
Black	0	$\times 10^{0}$	± 20%
Brown	1	$\times 10^{1}$	± 1%
Red	2	$\times 10^{2}$	± 2%
Orange	3	$\times 10^{3}$	± 3%
Yellow	4	$\times 10^{4}$	- 0, + 100%
Green	5	$\times 10^{5}$	± 0.5%
Blue	6	$\times 10^{6}$	± 0.25%
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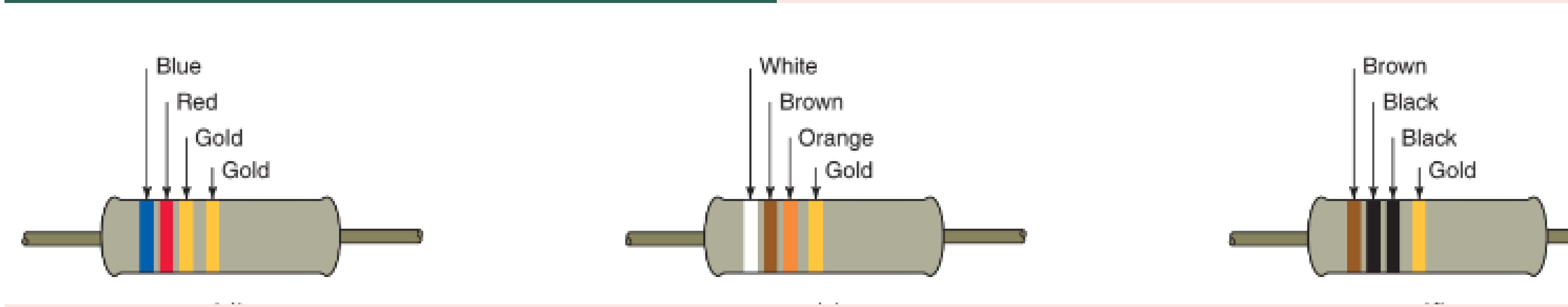
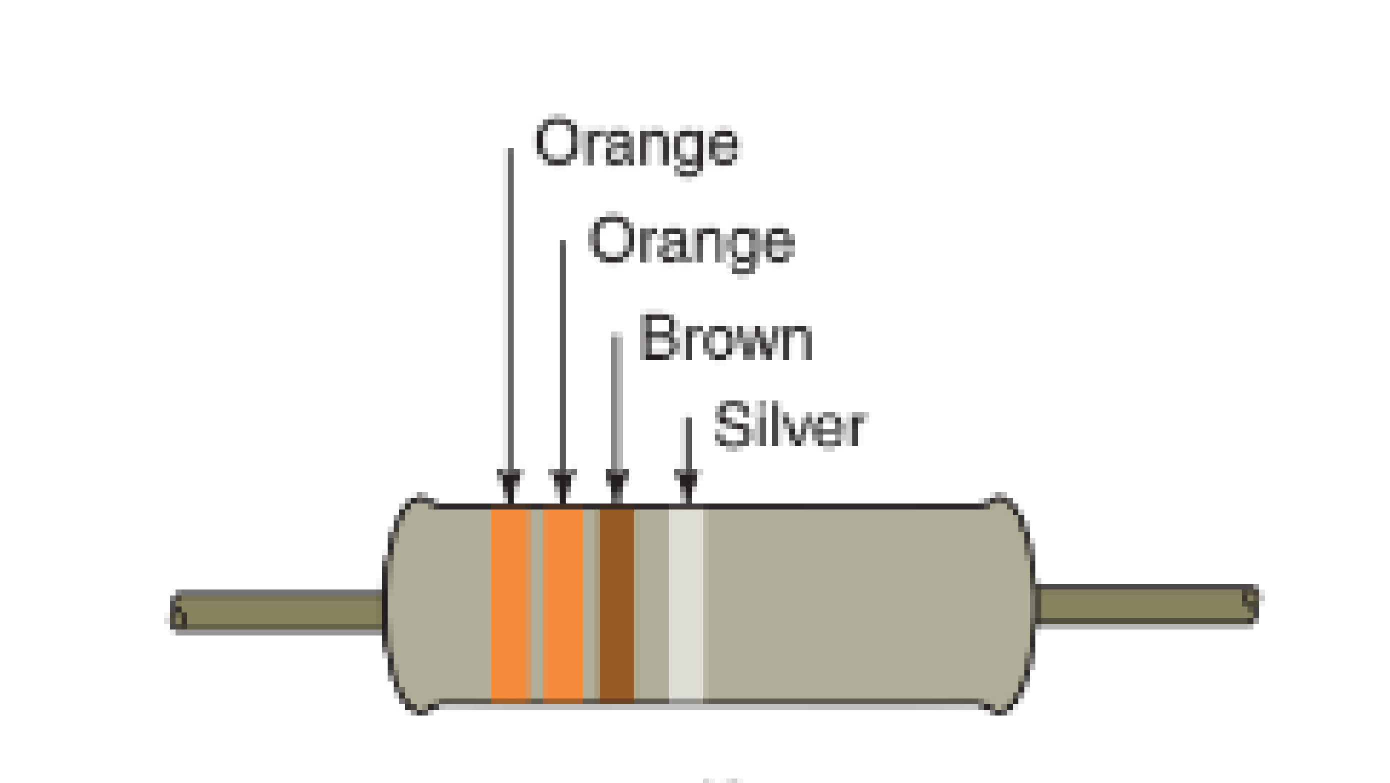
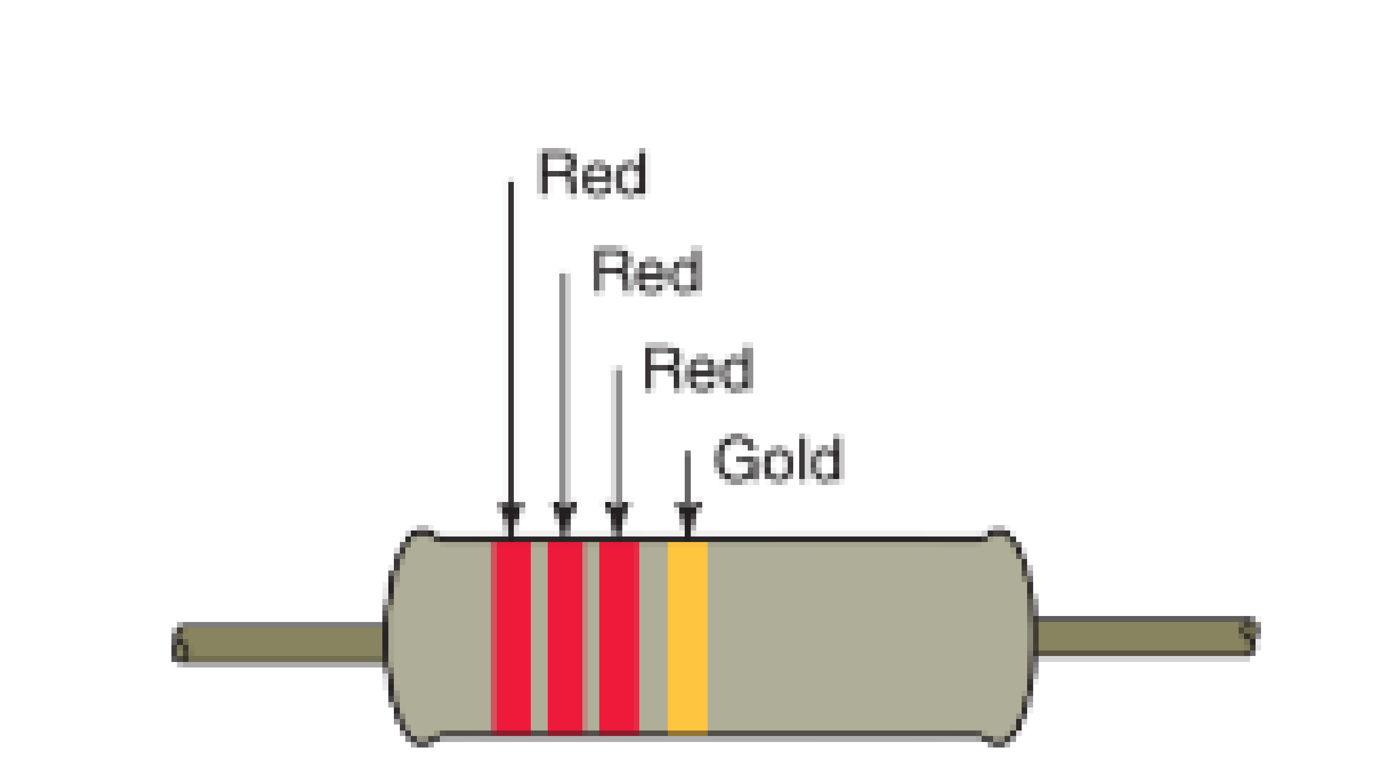
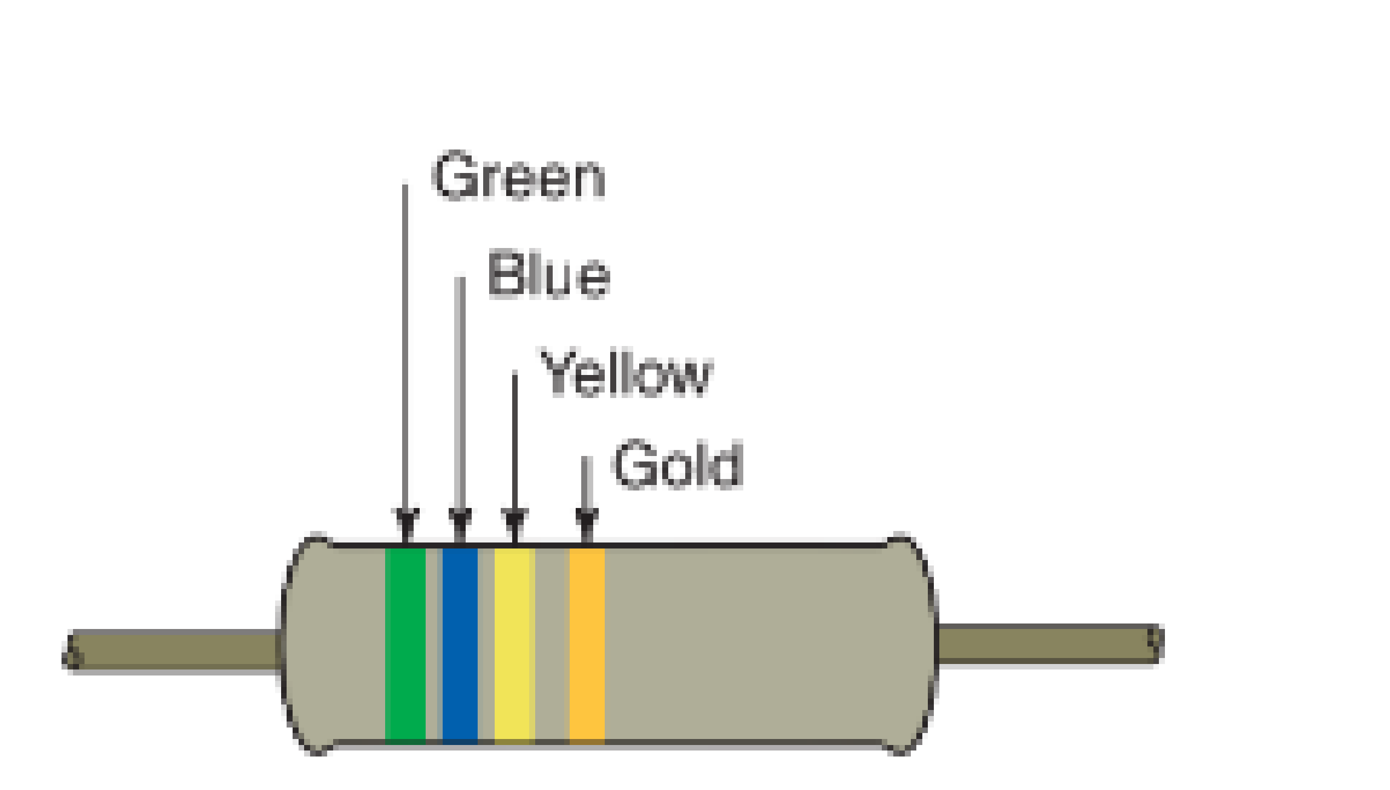
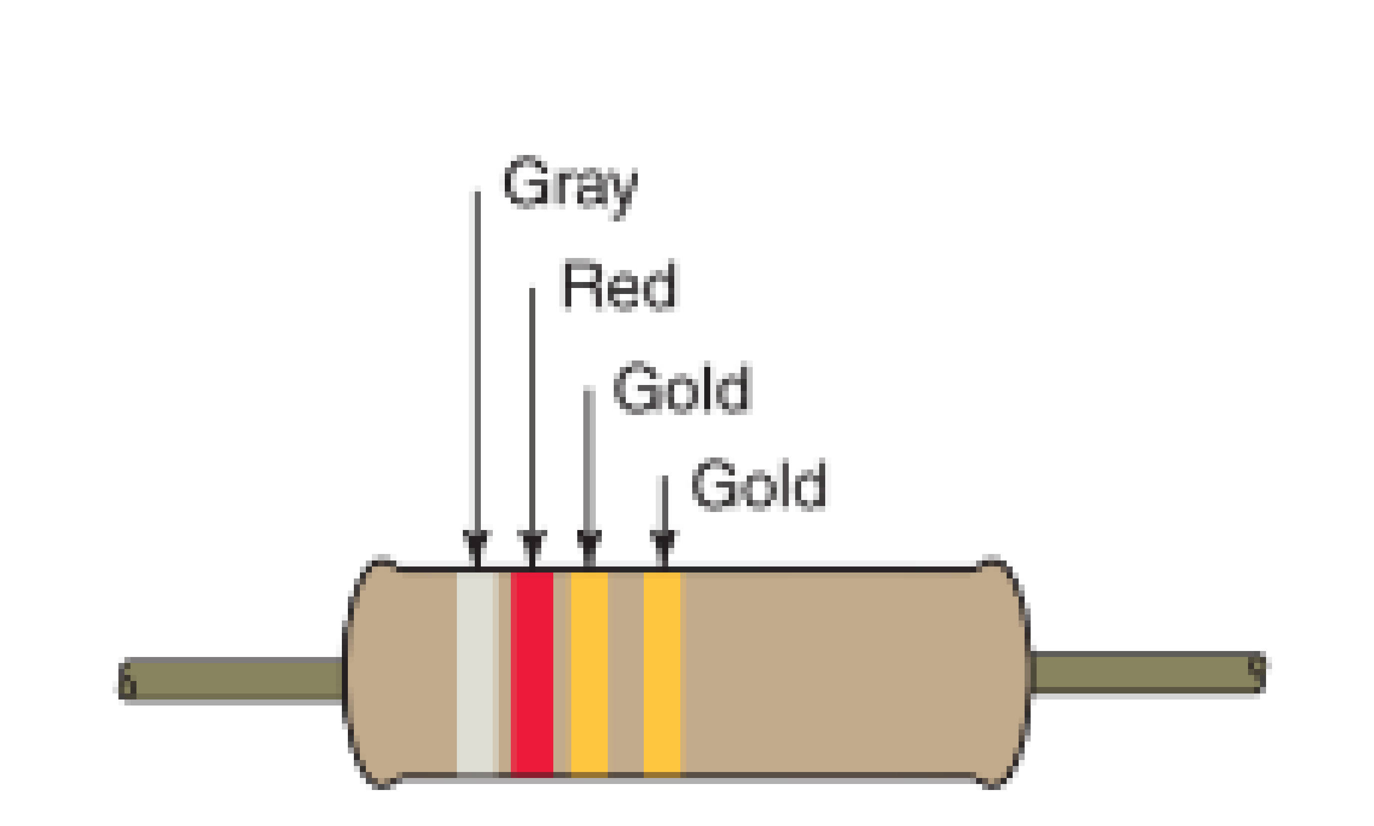


Try it Yourself!









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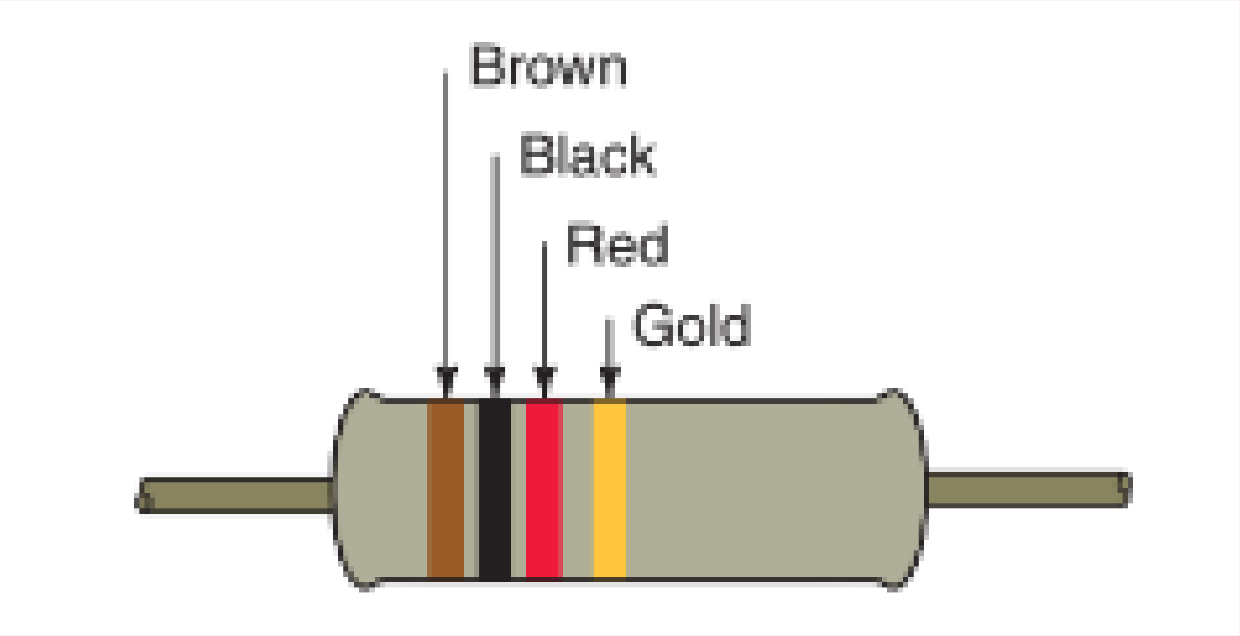

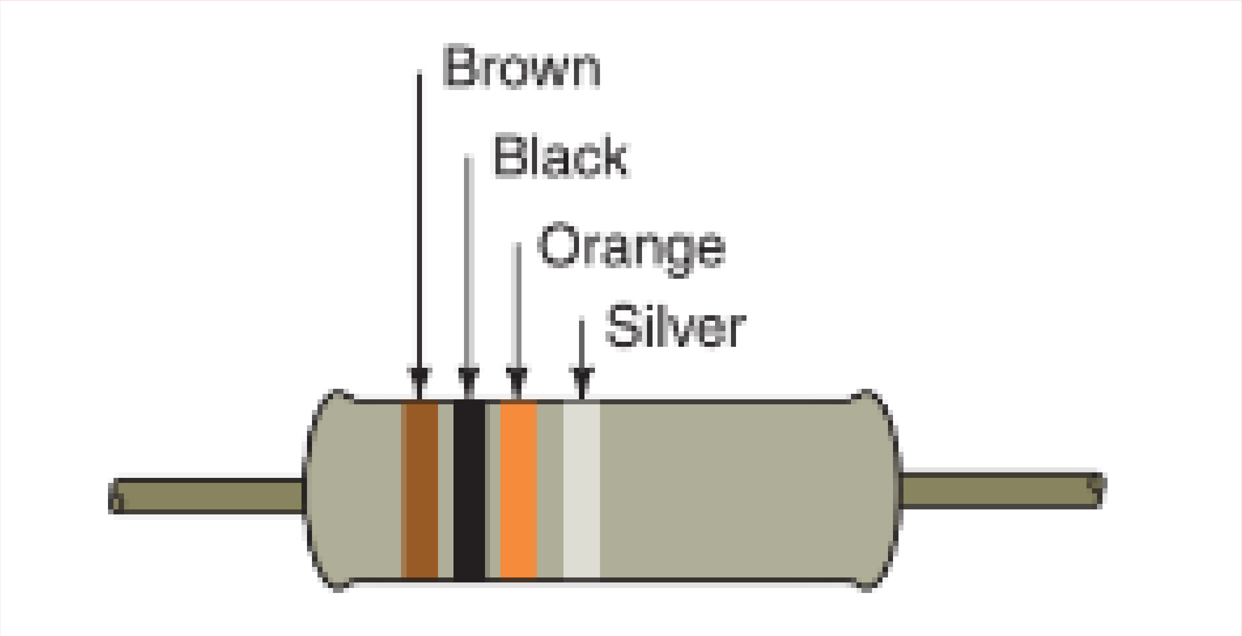

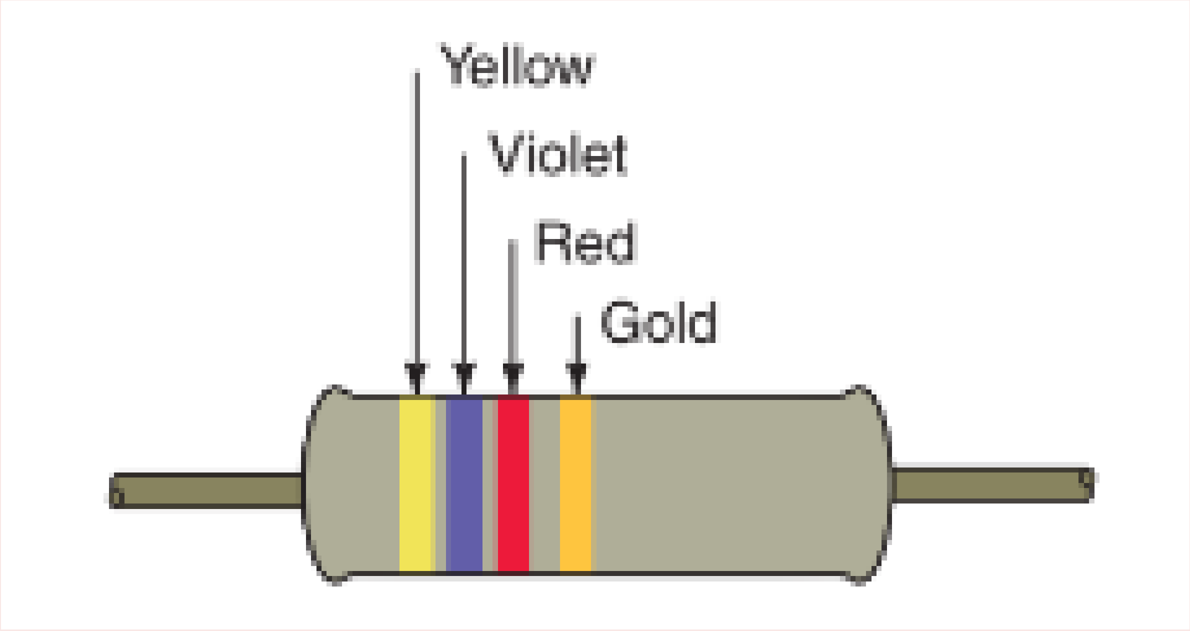

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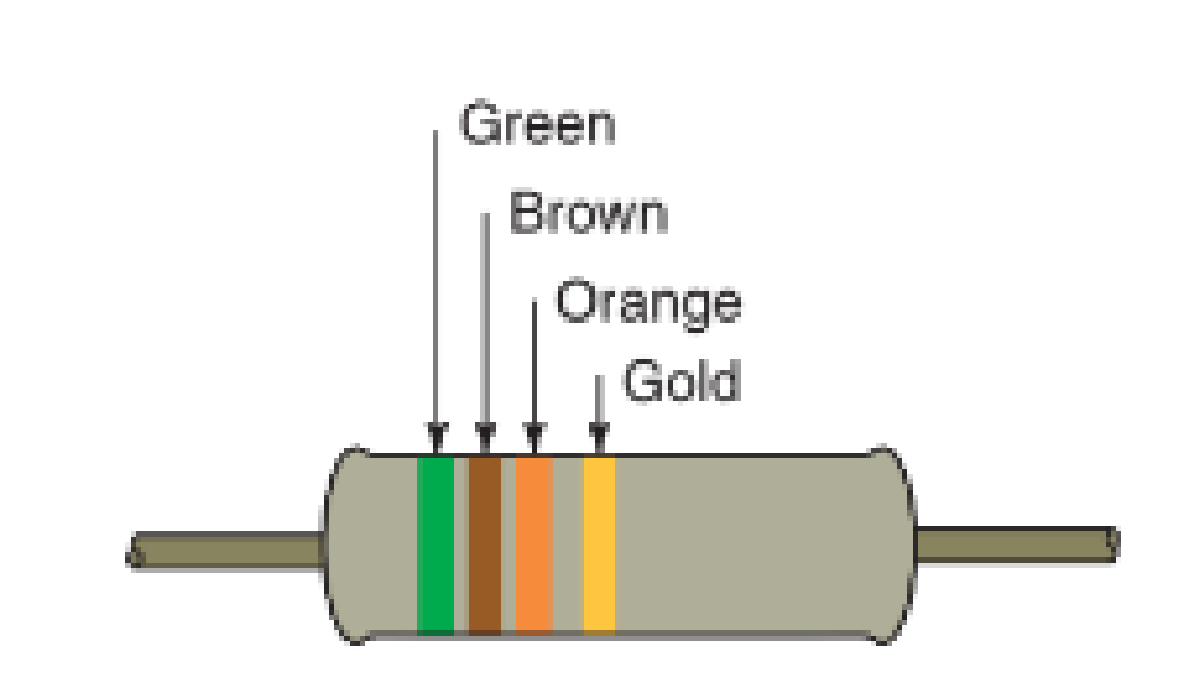
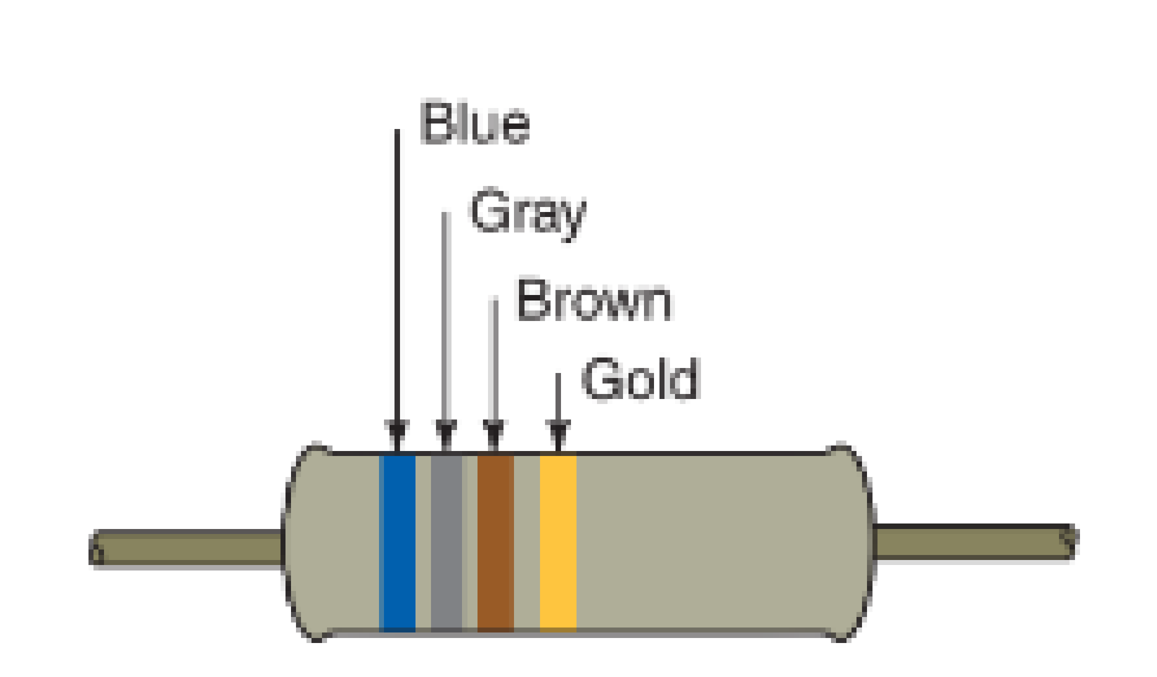
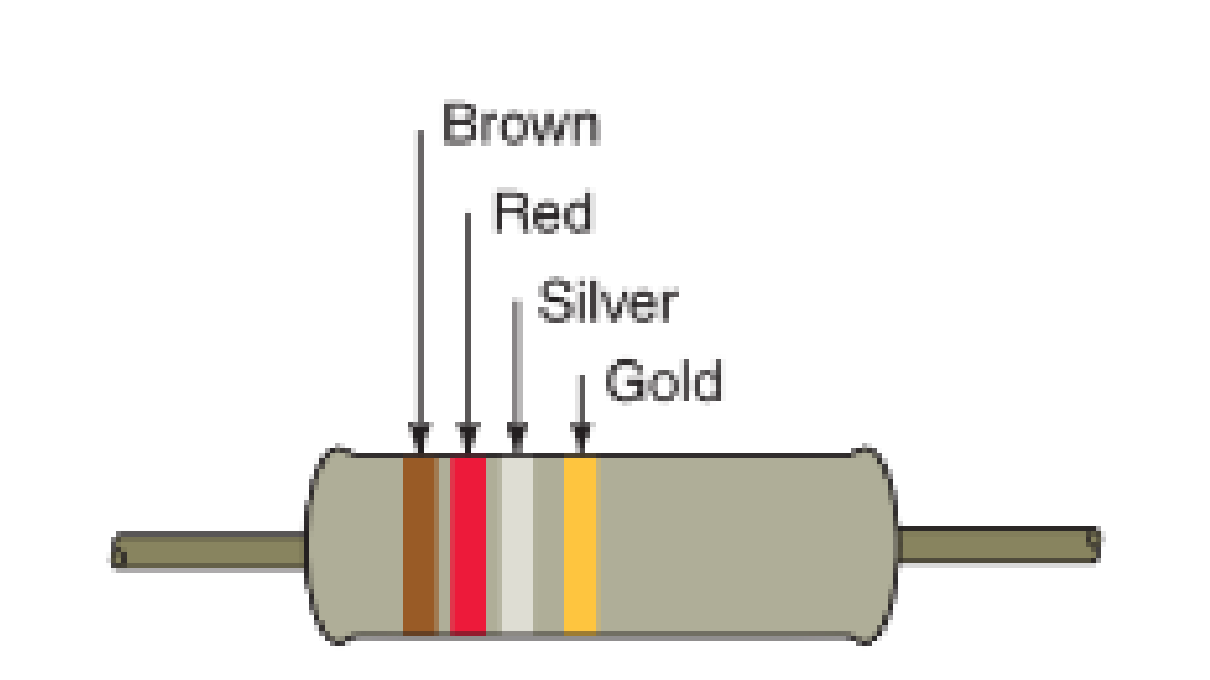
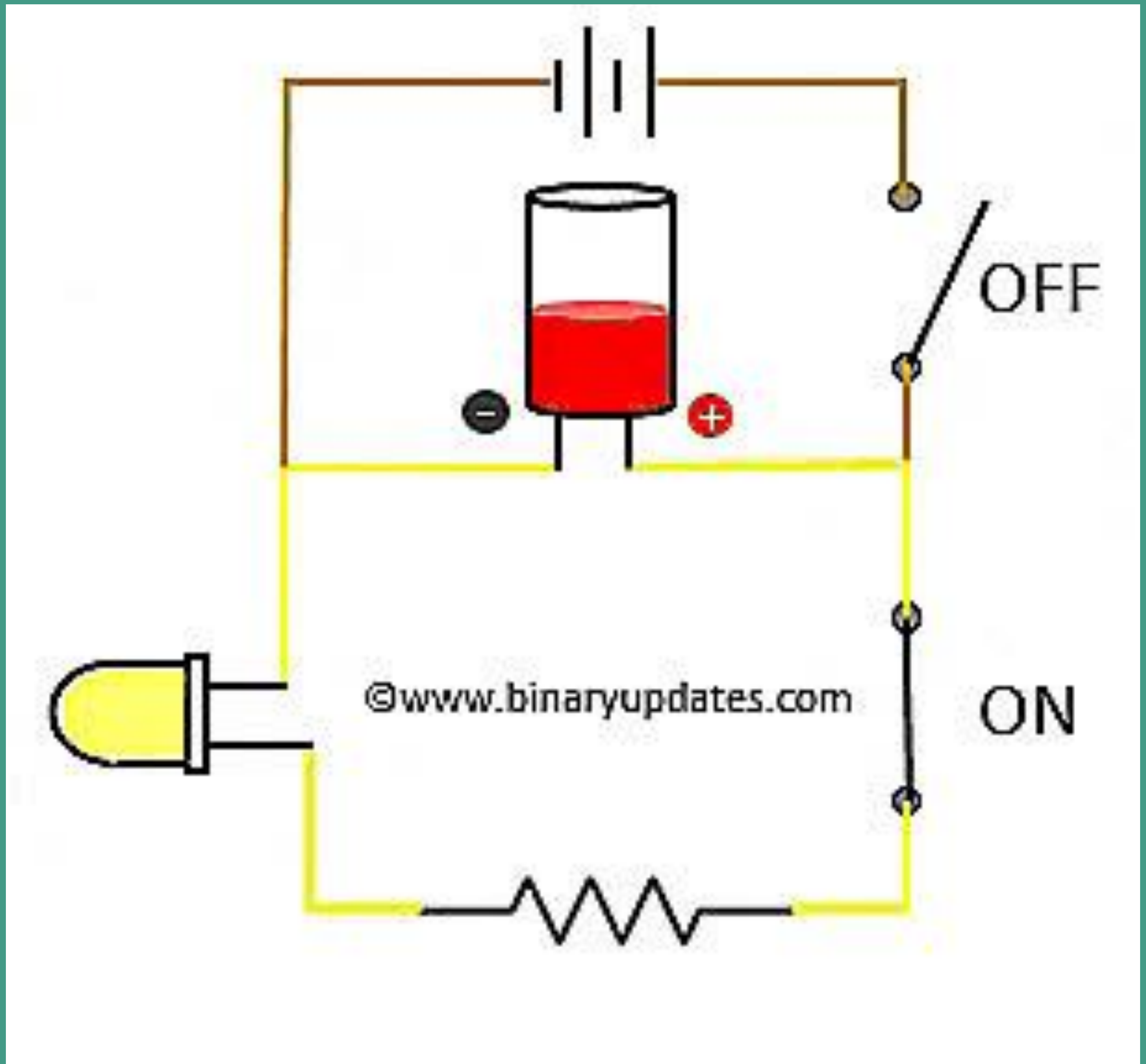






Capacitor



Capacitor Functions

Capacitors are essential electronic components that store electrical energy in an electric field for later use. Their primary functions include:

- **Energy Storage:** Capacitors can store energy when a voltage is applied across their terminals and release it when the circuit requires power. This ability is crucial in various applications, such as power smoothing and timing circuits.
- **Filtering Signals:** In power supply circuits, capacitors help smooth out fluctuations in voltage, ensuring a steady output. They filter out unwanted frequencies in audio and RF applications, allowing only desired signals to pass.
- **Signal Coupling and Decoupling:** Capacitors couple AC signals from one stage of a circuit to another while blocking DC voltage. This function is essential in amplifiers and signal processing circuits. They can also decouple noise from power lines, ensuring stable operation of sensitive components.

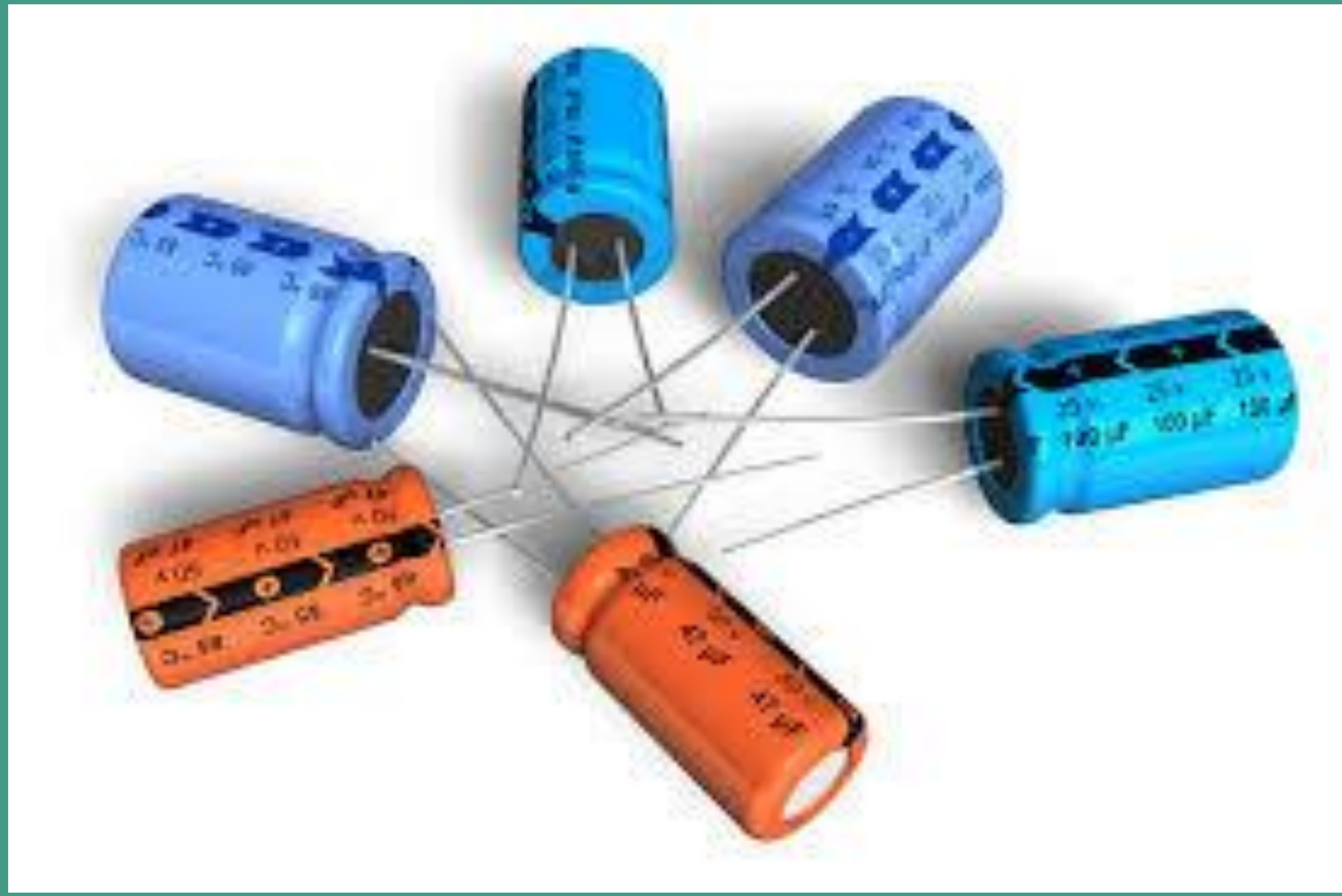
Types of Capacitors

Ceramic Capacitors:

- **Description:** Made from ceramic materials, these capacitors are small and offer high-frequency performance.
- **Characteristics:**
  - Non-polarized, allowing them to be used in AC applications.
  - Stable capacitance over a range of temperatures and frequencies.
- **Applications:**
  - Used in bypass and coupling applications in RF circuits, oscillators, and filters.

Types of Capacitors

Electrolytic Capacitors:



- **Description:** These capacitors use an electrolyte to achieve high capacitance values in relatively small packages.

- **Characteristics:**

  - Polarized, meaning they must be connected in the correct direction.
  - High capacitance values, typically ranging from 1 µF to several thousand µF.

- **Applications:**
  - Commonly used for power supply filtering, energy storage in power supplies, and decoupling applications in digital circuits.

Types of Capacitors

Tantalum Capacitors:

- Description: Made from tantalum oxide, these capacitors are known for their high capacitance in small sizes.
- Characteristics:
  - Polarized, with a stable capacitance and low leakage current.
  - Excellent frequency response and reliability.
- Applications:
  - Used in compact electronics, such as mobile devices, laptops, and medical equipment, where space is limited and performance is critical.

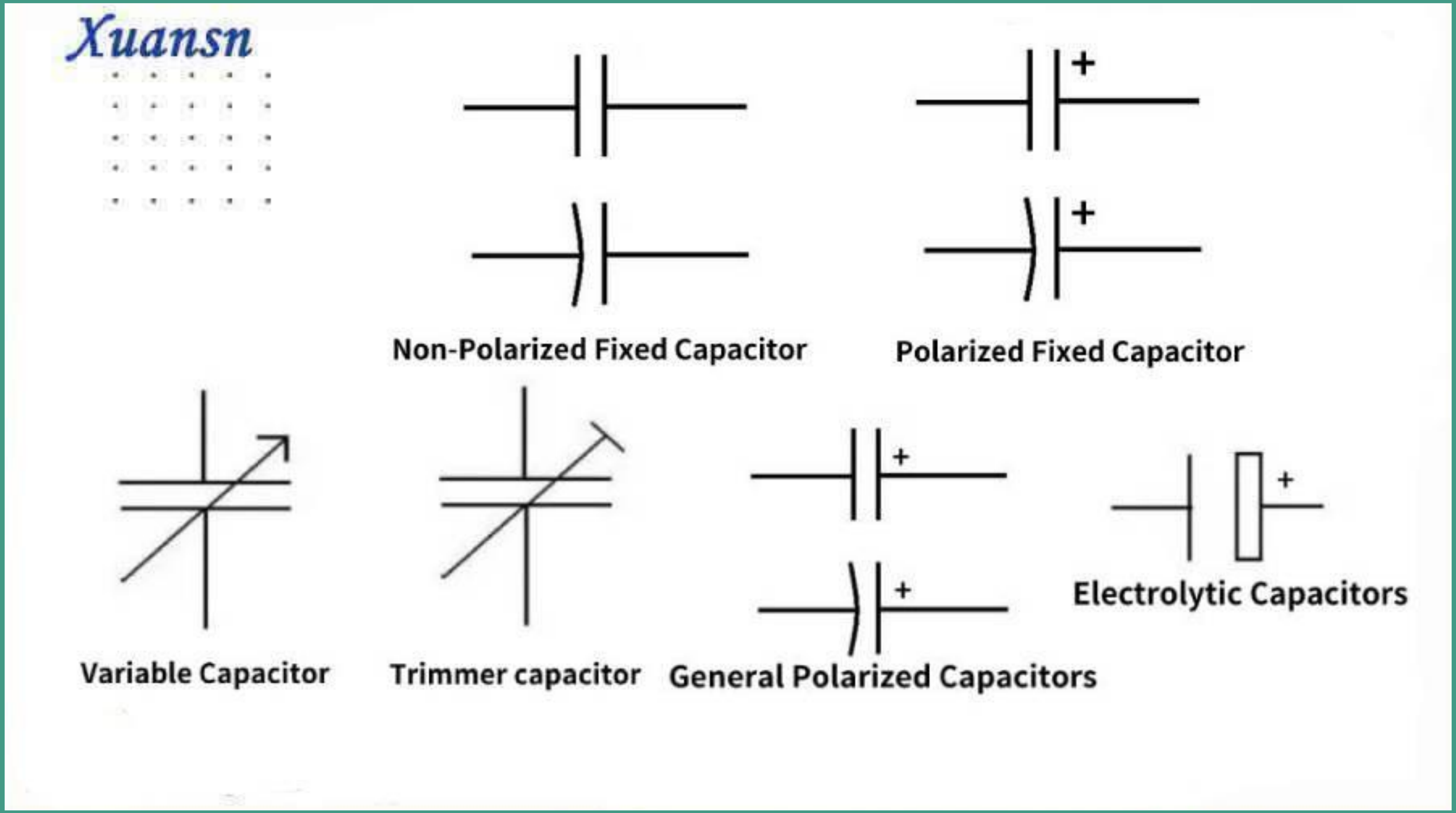
Applications of Capacitor

- **Timing Circuits:** Capacitors are integral to timing applications in oscillators and timers, working with resistors to determine time delays based on the RC time constant ($T=R\times C$).

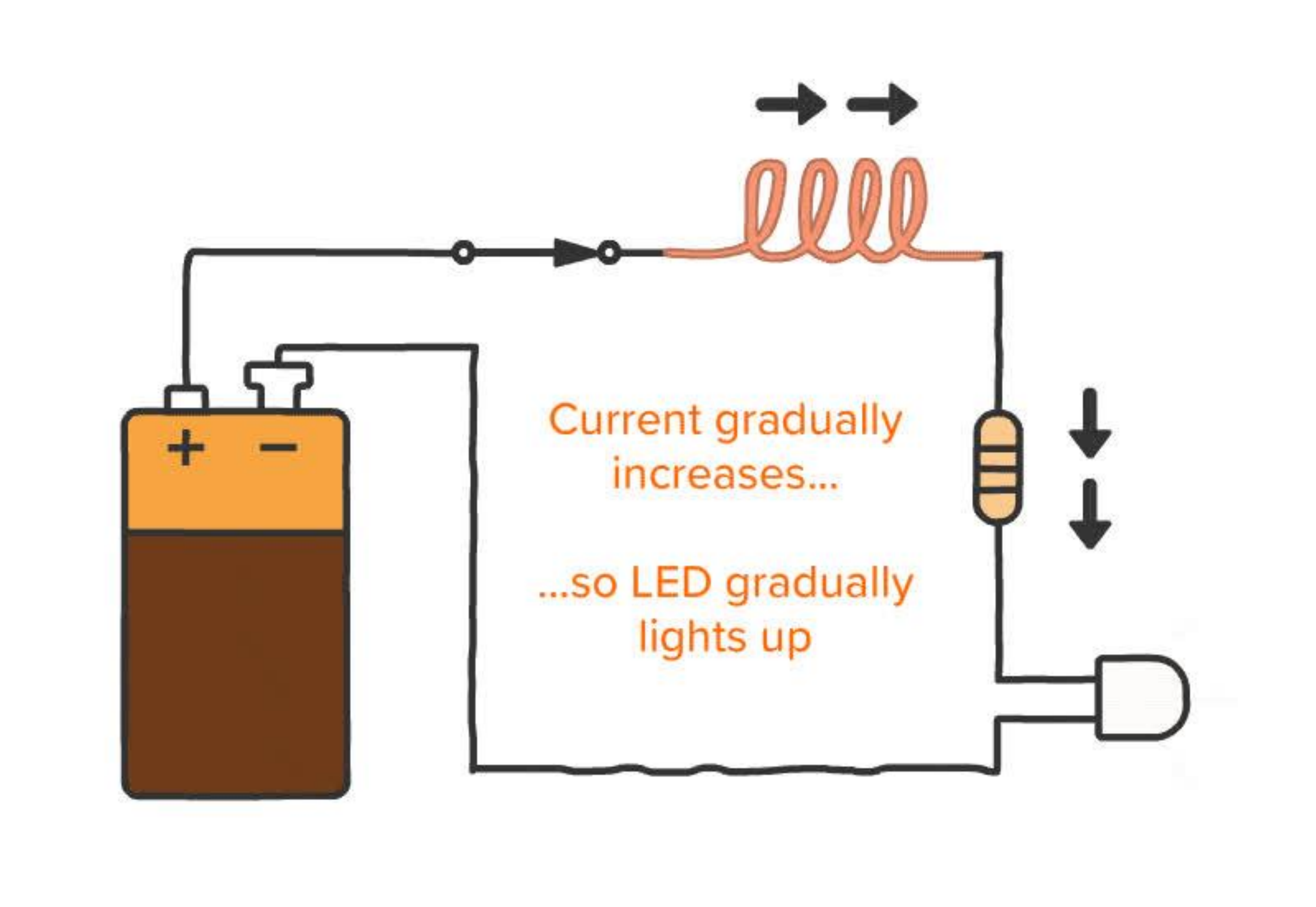
- **Signal Coupling:** In amplifier circuits, capacitors are used to couple signals from one stage to another, allowing AC signals to pass while blocking DC components.

- **Filtering Applications:** Capacitors filter out noise in power supplies, stabilize voltage levels, and ensure smooth operation of sensitive electronic devices by providing necessary energy during voltage dips.

Capacitor Symbols



Inductors



Inductor Functions

Inductors are passive electrical components that store energy in a magnetic field when an electric current flows through them. Their primary functions include:

- Resisting Changes in Current Flow: Inductors oppose rapid changes in current, making them valuable in circuits where stable current levels are critical. They exhibit the property of inductance, which causes them to generate a counter-electromotive force (back EMF) when the current through them changes.

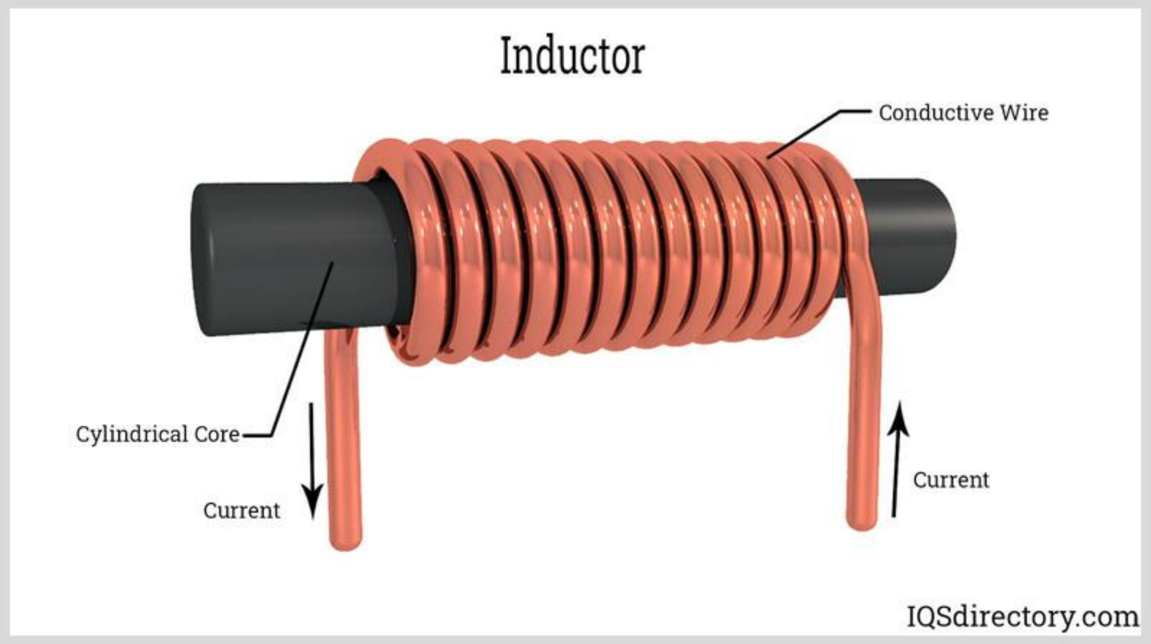
- Creating Magnetic Fields: When current passes through an inductor, it creates a magnetic field around it. This magnetic field is proportional to the amount of current flowing and the number of turns in the coil. This property is utilized in transformers and inductive coupling.

- Filtering and Energy Storage: Inductors are used in filtering applications to smooth out voltage fluctuations. They can store energy temporarily, releasing it when required, which is particularly useful in power supply circuits and energy conversion applications.

Types of Inductor

Air-Core Inductors:

- Description: These inductors are constructed without a core material, relying on air as the medium for inductance.
- Characteristics:
  - Simple design and construction, making them cost-effective.
  - Minimal energy losses, suitable for high-frequency applications.
- Applications:
  - Commonly used in RF (radio frequency) applications, such as antennas, oscillators, and high-frequency filters.



Types of Inductor

Iron-Core Inductors:

- Description: These inductors use a core made of iron or ferrite to enhance the inductance.
- Characteristics:
  - Higher inductance values compared to air-core inductors due to the magnetic properties of the core material.
  - Greater energy storage capacity but can experience core saturation at high currents.
- Applications:
  - Frequently used in power applications, such as transformers, power supplies, and inductive loads in AC circuits.

Types of Inductor

Toroidal Inductors:

- Description: Toroidal inductors are shaped like a doughnut and use a ring-shaped core made of ferromagnetic material.
- Characteristics:
    - Efficient design with minimal electromagnetic interference and magnetic flux leakage.
    - High inductance values in a compact size, suitable for various applications.
- Applications:
    - Widely used in power supply circuits, inductive components in filters, and audio equipment where low noise is critical.

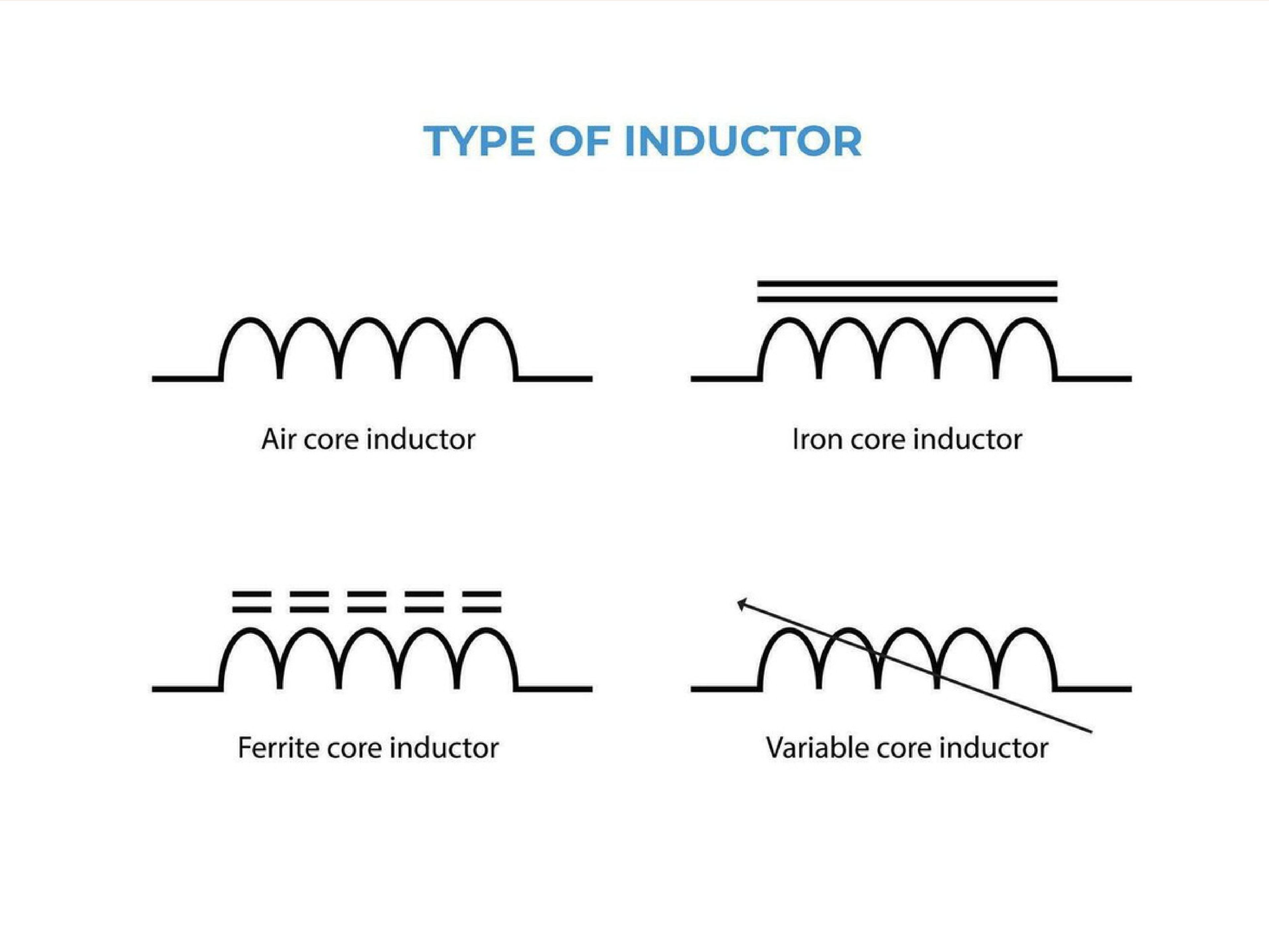
Applications of Inductor

- Transformers: Inductors are fundamental components in transformers, where they transfer energy between circuits through magnetic coupling. This is essential for voltage regulation and energy conversion in power distribution systems.

- Filters: Inductors are used in various types of filters (low-pass, high-pass, band-pass) to control the frequency response of circuits. They work in conjunction with capacitors to attenuate unwanted frequencies while allowing desired signals to pass.

- Power Supply Circuits: Inductors play a vital role in switching power supplies, where they store energy during the ON phase and release it to the output during the OFF phase, helping to maintain stable voltage levels.

Inductor Symbols



Ohm's Law

Ohm's Law is a fundamental principle in electrical engineering and physics that describes the *relationship between current (I), voltage (E), and resistance (R) in direct current (DC) circuits.* It is named after *Georg Simon Ohm*, a German physicist who first formulated this law in the 1820s. Understanding Ohm's Law is essential for analyzing and designing electrical circuits.

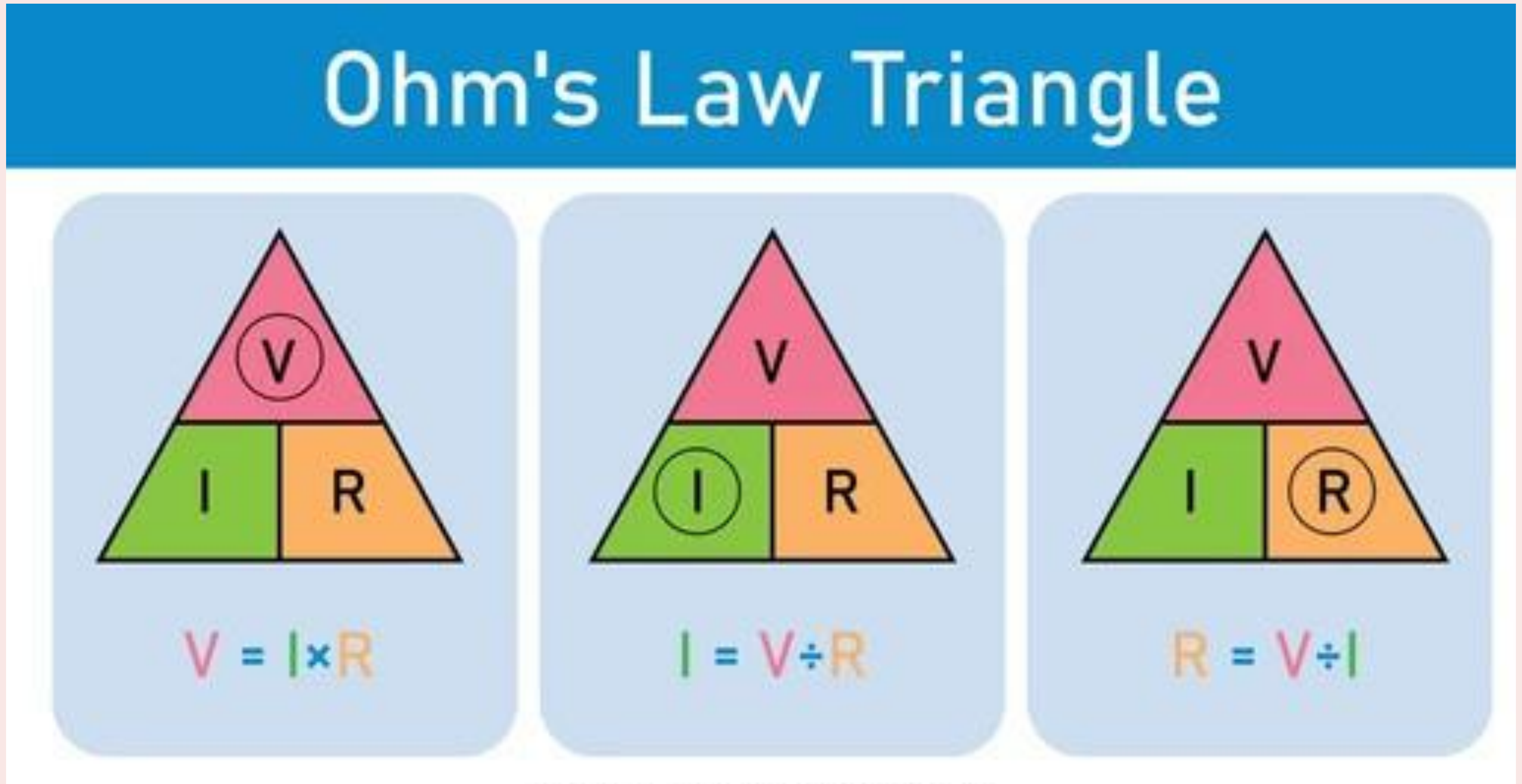
Ohm's Law Formula

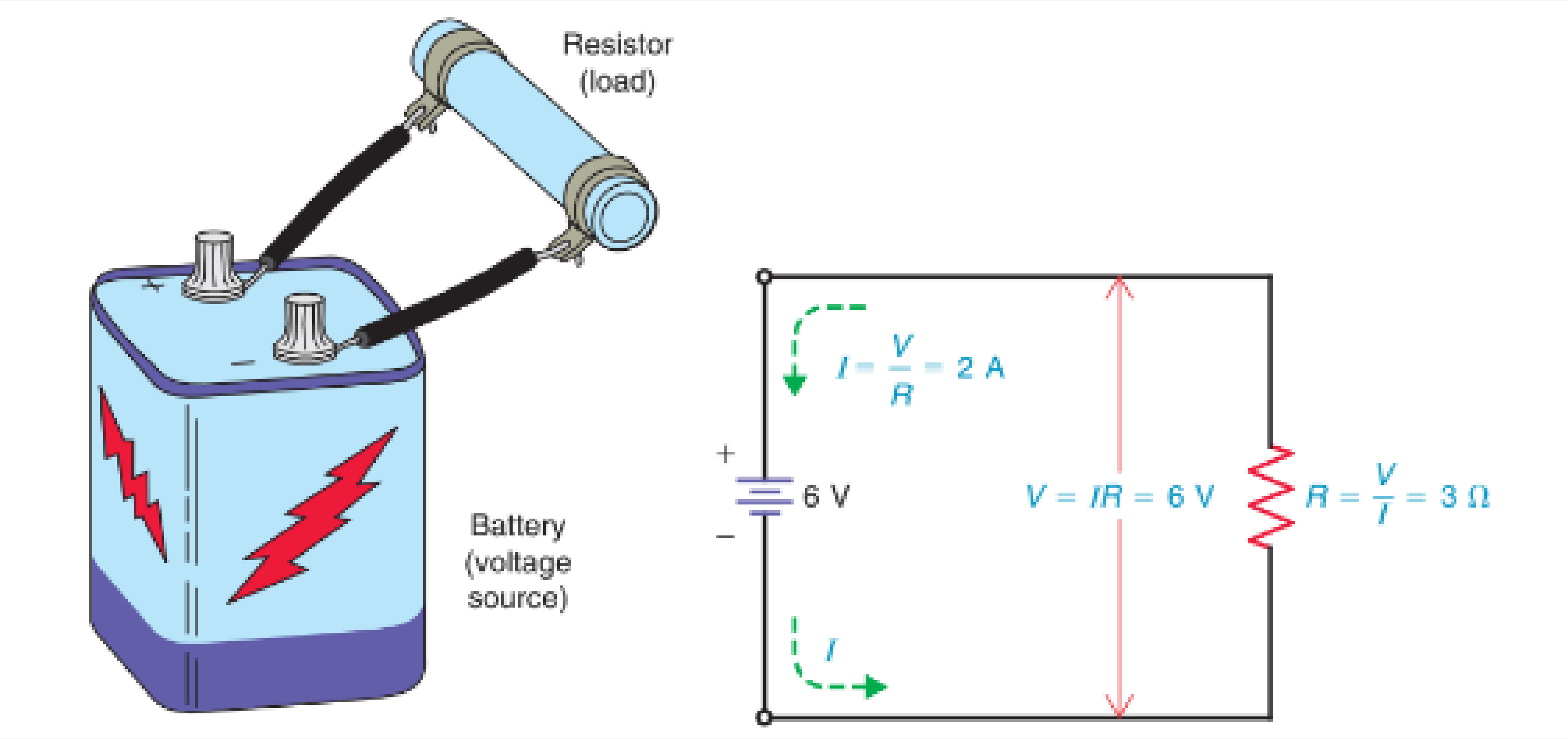
Equation:

$$I = V/R$$

Where:

I = Current (in amperes, A)
V = Voltage (in volts, V)
R = Resistance (in ohms, Ω)





Decimal SI Table

Symbol	Name	Factor	Symbol	Name	Factor
Y	yotta	10^{24}	y	yokto	10^{-24}
Z	zetta	10^{21}	z	zepto	10^{-21}
E	exa	10^{18}	a	atto	10^{-18}
P	peta	10^{15}	f	femto	10^{-15}
T	tera	10^{12}	p	pico	10^{-12}
G	giga	10^{9}	n	nano	10^{-9}
M	mega	10^{6}	μ	micro	10^{-6}
k	kilo	10^{3}	m	milli	10^{-3}
h	hecto	10^{2}	c	centi	10^{-2}
da	deka	10^{1}	d	deci	10^{-1}

Current Calculation

Problem 1.1 Suppose that the dc generator in Fig. 1 produces 10 V and the potentiometer is set to a value of 10 Ω. What is the current?

Problem 1.2 Imagine that dc generator in Fig. 1 produces 100 V and the potentiometer is set to 10 kΩ. What is the current?

Problem 1.3 Suppose that dc generator in Fig. 1 is set to provide 88.5 V, and the potentiometer is set to 477 MΩ. What is the current?

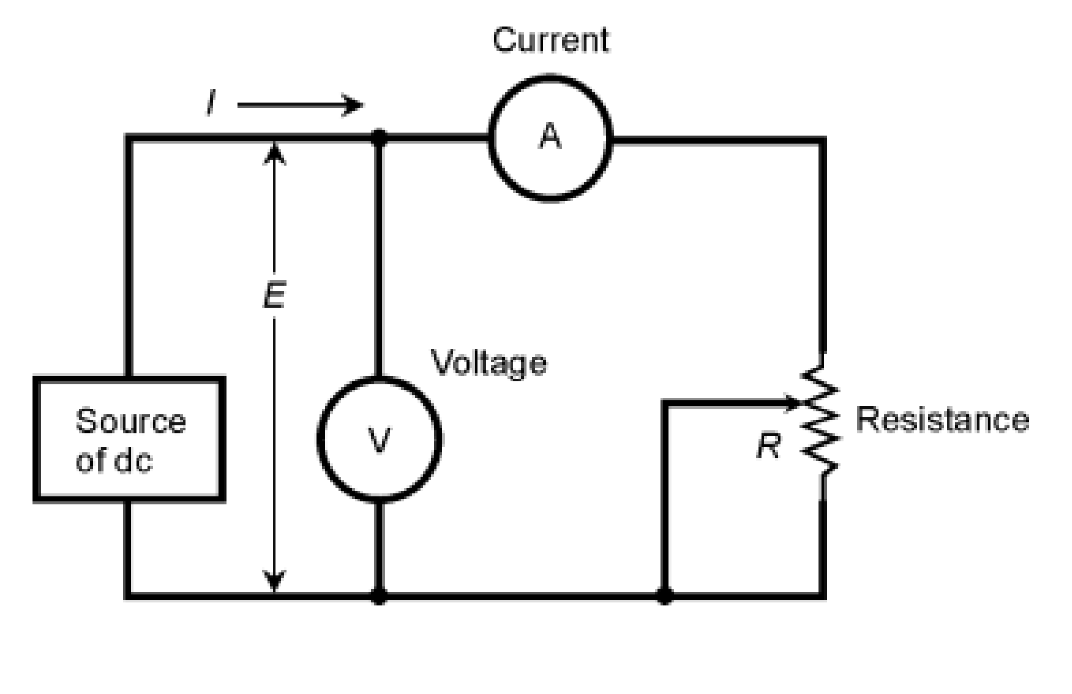
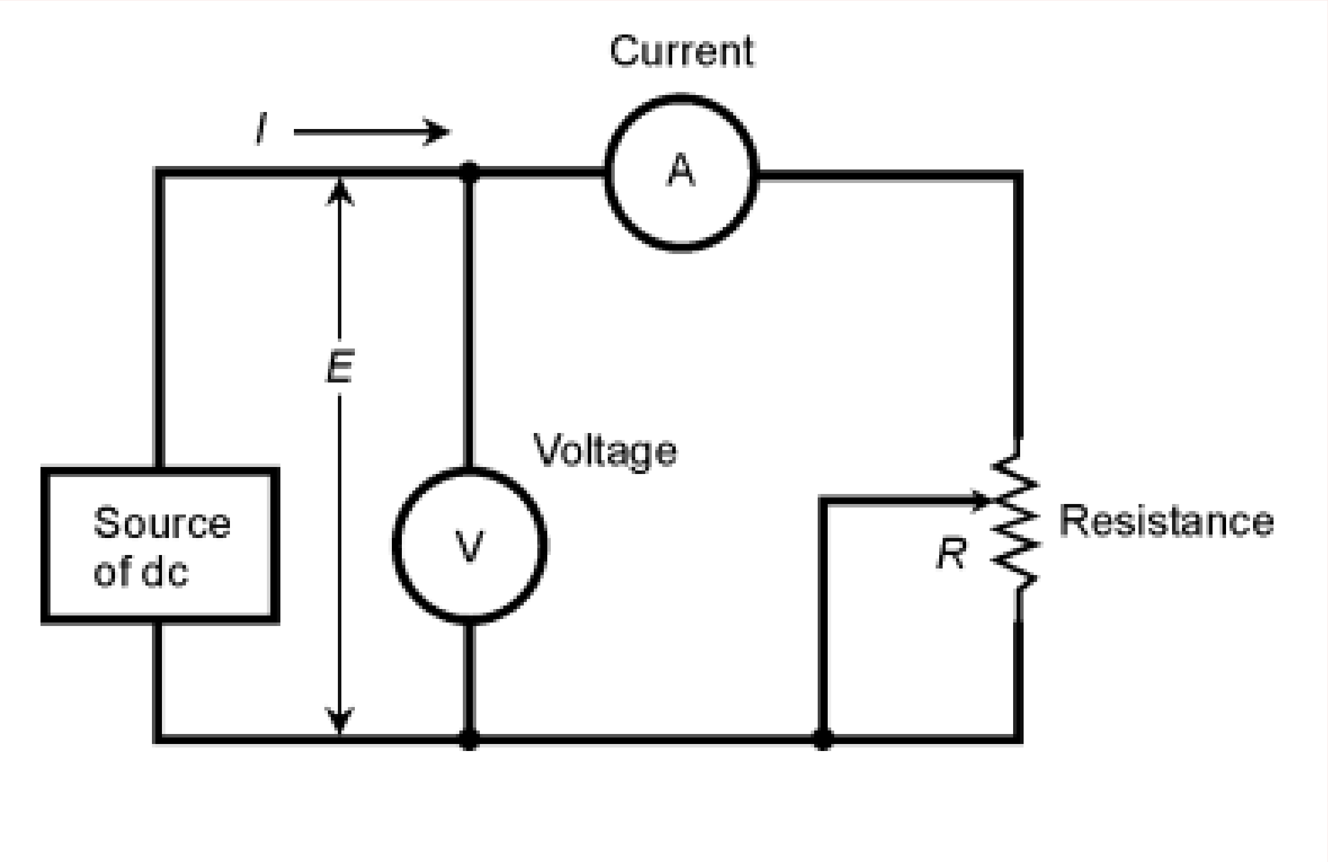


Figure 1
A sample circuit for working Ohm's Law problems.

Voltage Calculation



Problem 1.4 Suppose the potentiometer in Fig. 1 is set to 100 Ω, and the measured current is 10 mA. What is the dc voltage?

Problem 1.5 Adjust the potentiometer in Fig. 1 to a value of 157 kΩ, and suppose the current reading is 17.0 mA. What is the voltage of the source?

Problem 1.6 Suppose you set the potentiometer in Fig. 1 so that the meter reads 1.445 A, and you observe that the potentiometer scale shows 99 Ω. What is the voltage?

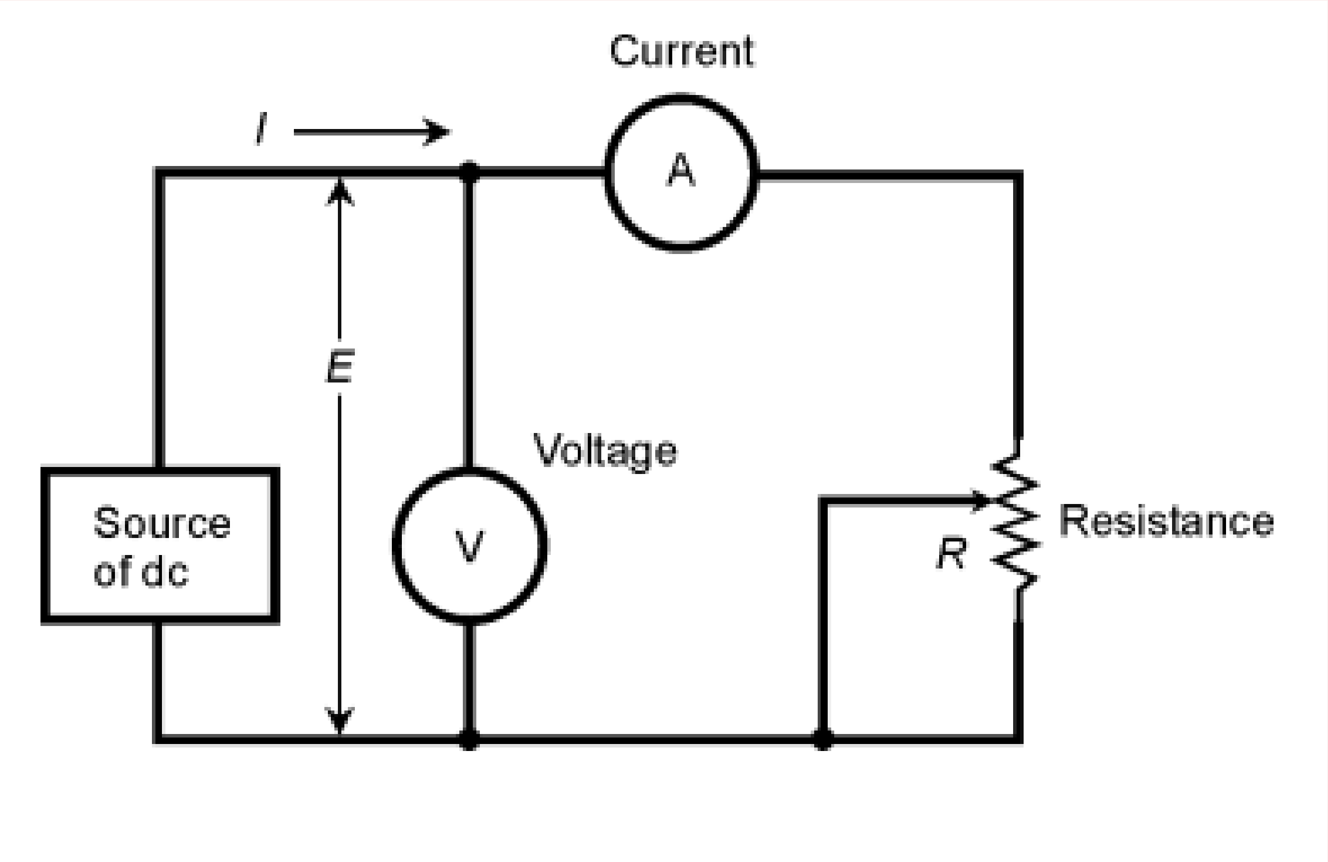
Voltage Calculation

Problem 1.4 Suppose the potentiometer in Fig. 1 is set to 100 Ω, and the measured current is 10 mA. What is the dc voltage? 1V

Problem 1.5 Adjust the potentiometer in Fig. 1 to a value of 157 kΩ, and suppose the current reading is 17.0 mA. What is the voltage of the source?

Problem 1.6 Suppose you set the potentiometer in Fig. 1 so that the meter reads 1.445 A, and you observe that the potentiometer scale shows 99 Ω. What is the voltage?

Resistance Calculation



Problem 1.7 If the voltmeter in Fig. 1 reads 24 V and the ammeter shows 3.0 A, what is the resistance of the potentiometer?

Problem 4.8 What is the value of the resistance in Fig. 1 if the current is 18 mA and the voltage is 229 mV?

Problem 1.9 Suppose the ammeter in Fig. 1 reads 52 µA and the voltmeter indicates 2.33 kV. What is the resistance?

Resistance Calculation

Problem 1.7 If the voltmeter in Fig. 1 reads 24 V and the ammeter shows 3.0 A, what is the resistance of the potentiometer?

Problem 4.8 What is the value of the resistance in Fig. 1 if the current is 18 mA and the voltage is 229 mV?

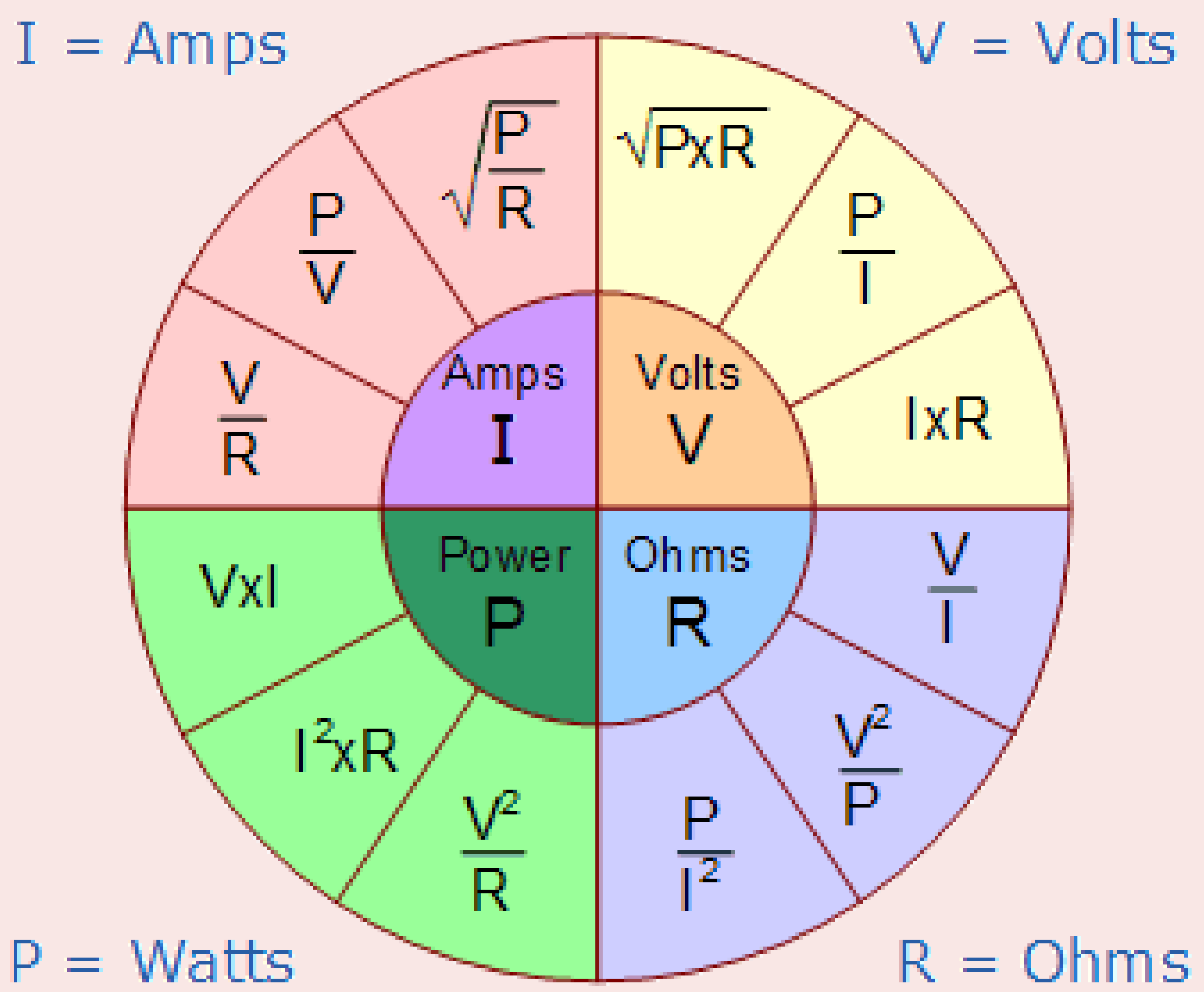
Problem 1.9 Suppose the ammeter in Fig. 1 reads 52 µA and the voltmeter indicates 2.33 kV. What is the resistance?

Electric Power

The unit of electric power is the watt (W), named after James Watt (1736–1819). One watt of power equals the work done in one second by one volt of potential difference in moving one coulomb of charge. Remember that one coulomb per second is an ampere.

Therefore power in watts equals the product of volts times amperes. Power in watts = volts x amperes

$$P = V \times I$$



Power Calculations

Problem 1.10 Suppose that the voltmeter in Fig. 1 reads 12 V and the ammeter shows 50 mA. What is the power dissipated by the potentiometer?

Problem 1.11 If the resistance in the circuit of Fig. 1 is 999 Ω and the voltage source delivers 3 V, what is the power dissipated by the potentiometer?

Problem 1.12 Suppose the resistance in Fig. 1 is 47 kΩ and the current is 680 mA. What is the power dissipated by the potentiometer?

Problem 1.13 How much voltage would be necessary to drive 680 mA through a resistance of 47 kΩ, as is described in the previous problem?

Try It Yourself!

1. A circuit has a voltage supply of 12 volts and a resistor with a resistance of 4 ohms. Calculate the current flowing through the circuit.

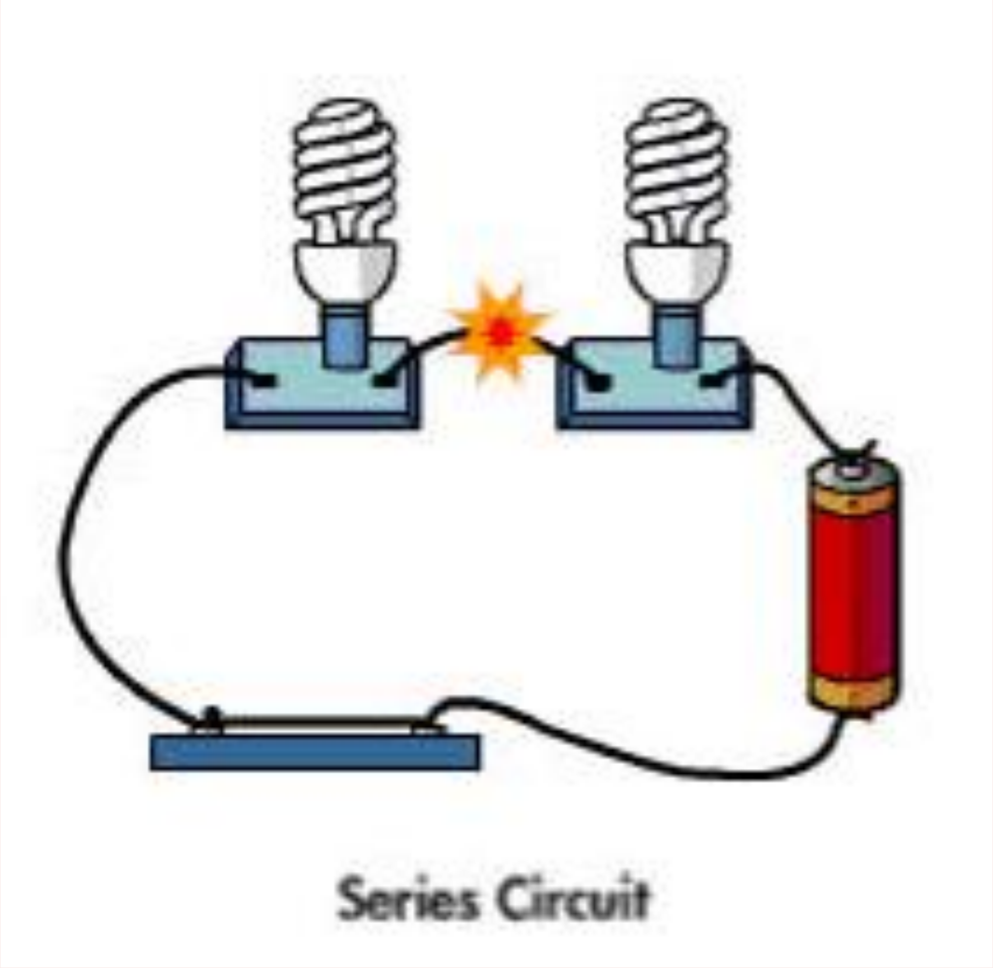
2. A device operates with a current of 2.5 A through a resistor of 10 Ω. What is the voltage across the resistor?

3. A circuit has a voltage supply of 30 V and the current flowing through the circuit is measured at 5 A. Calculate the resistance in the circuit.

4. A resistor in a circuit has a resistance of 20 Ω and a current of 3 A is flowing through it. Calculate the power consumed by the resistor.

Series Circuits

A series circuit connects components one after another in a single path. This means that the same current flows through each component, creating a consistent electrical flow.



Series Circuits

Key Concepts:

- Total Resistance: The total resistance (Rtotal) in a series circuit is simply the sum of all individual resistances. This can be expressed mathematically as:

$$R_{Total} = R_1 + R_2 + R_3 + \cdots + R_n$$

where R1,R2,R3,...,Rn are the resistances of the individual components.

- Current: The current (I) through each component in a series circuit remains the same. This is because there is only one path for the current to take. If the circuit is interrupted at any point (e.g., one component fails), the entire circuit stops functioning.

- Voltage: The total voltage (E) across the series circuit is equal to the sum of the voltages across each component:

$$E_{Total} = E_1 + E_2 + E_3 + \cdots + E_n$$

where $E_1, E_2, E_3, ..E_n$ are the voltages across each resistor.

Series Circuits

Key Concepts:

- Capacitance in Series: The total capacitance (C_{Total}) in a series circuit is given by:

$$\frac{1}{C_{Total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n}$$

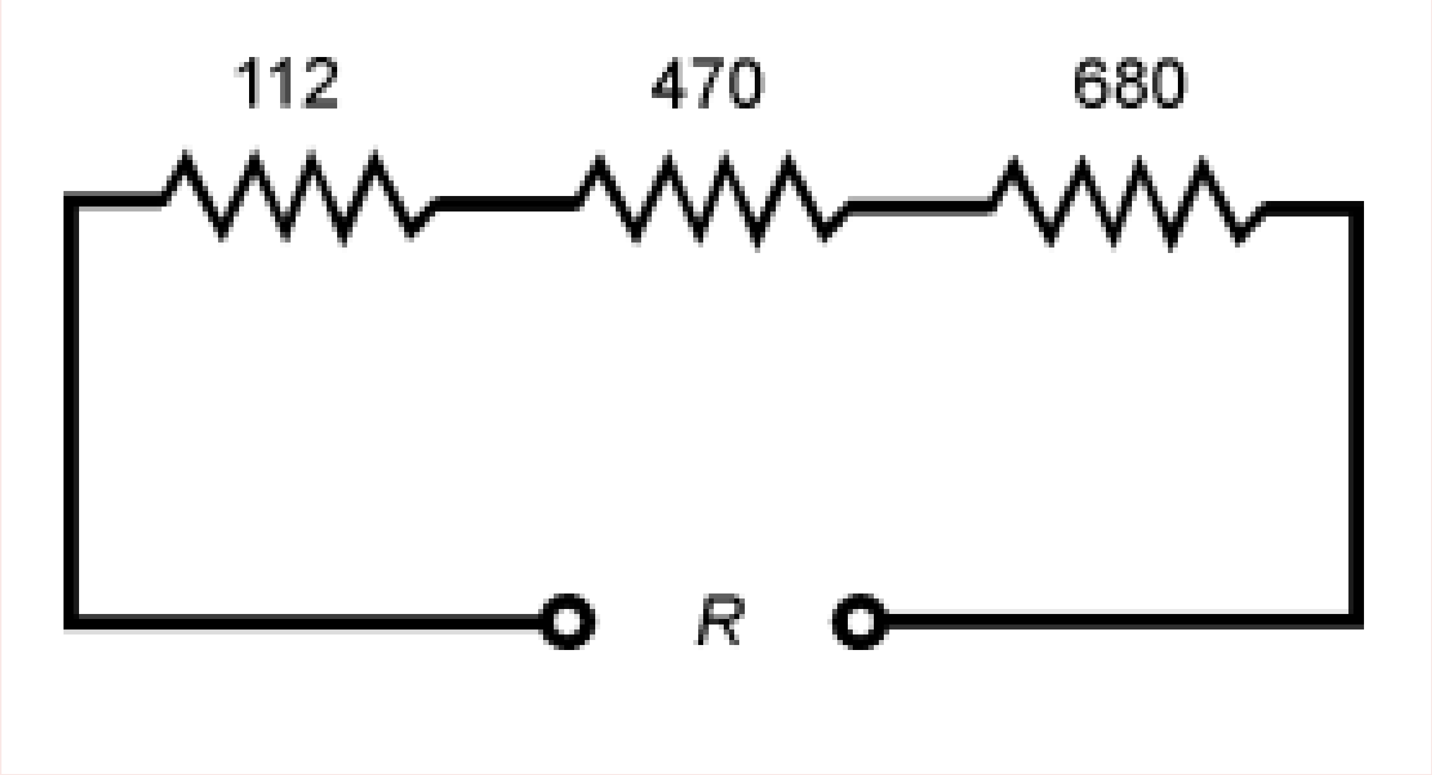
This means that adding capacitors in series results in a total capacitance that is less than any individual capacitor's capacitance.

- Inductance in Series: The total inductance (L_{Total}) in a series circuit is simply the sum of the individual inductances:

$$L_{Total} = L_1 + L_2 + L_3 + \cdots + L_n$$

Sample Problems

Problem 1.14: Suppose resistors with the following values are connected in series, as shown in Fig. 2: 112 Ω, 470 Ω, and 680 Ω. What is the total resistance of the series combination?



Try It Yourself!

1. You have three resistors connected in series, $R1=4\,\Omega$, $R2=6\,\Omega$ and $R3=10\,\Omega$. What is the total resistance of the circuit?

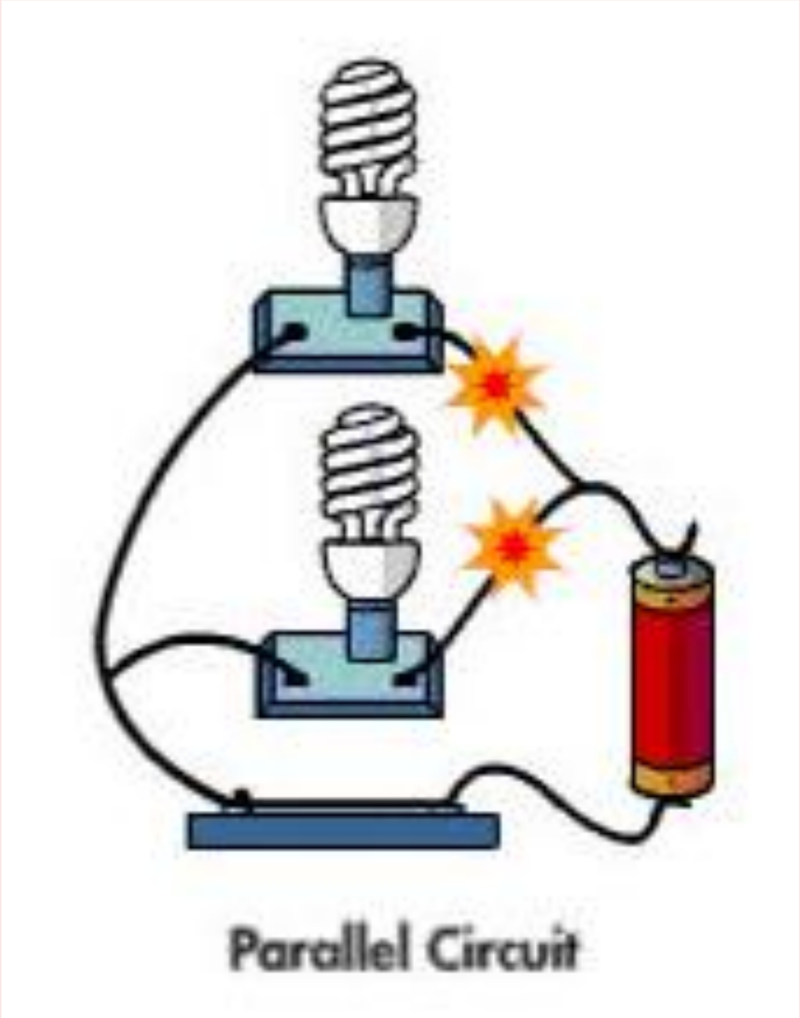
2. Using the same resistors from Sample Problem 1, if a voltage of 40 V is applied across the series circuit, what is the current flowing through the circuit?

3. You have three capacitors connected in series, $C1=4\,\mu F$, $C2=6\,\mu F$, $C3=12\,\mu F$. What is the total capacitance of the circuit?

4. You have three inductors connected in series with the following inductance values: $L1=2\,H$, $L2=3\,H$ and $L3=5\,H$. Calculate the total inductance Ltotal of the series circuit.

Parallel Circuits

In a parallel circuit, components are connected across the same voltage source. This setup allows the current to split and flow through multiple paths, which can be beneficial for ensuring that each component receives the same voltage.



Parallel Circuits

Key Concepts:

- Total Resistance: The total resistance (R_{Total}) in a parallel circuit is calculated using the inverse of the sum of the reciprocals of each individual resistance:

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}$$

  This means that adding more resistors in parallel actually decreases the total resistance.

- Current: The total current (Itotal) entering the parallel circuit is the sum of the currents flowing through each branch. The voltage across each branch is the same, and can be calculated using Ohm's Law:

$$\boldsymbol{I_{Total} = I_1 + I_2 + I_3 + \cdots + I_n}$$

- Voltage: The voltage across each component is equal to the source voltage (E):

$$\boldsymbol{E_{Total} = E_1 = E_2 = E_3 = \cdots = E_n}$$

Parallel Circuits

Key Concepts:

- Capacitance in Parallel: The total capacitance (C_{Total}) in a parallel circuit is the sum of all individual capacitances:

$$C_{Total} = C_1 + C_2 + C_3 + \cdots + C_n$$

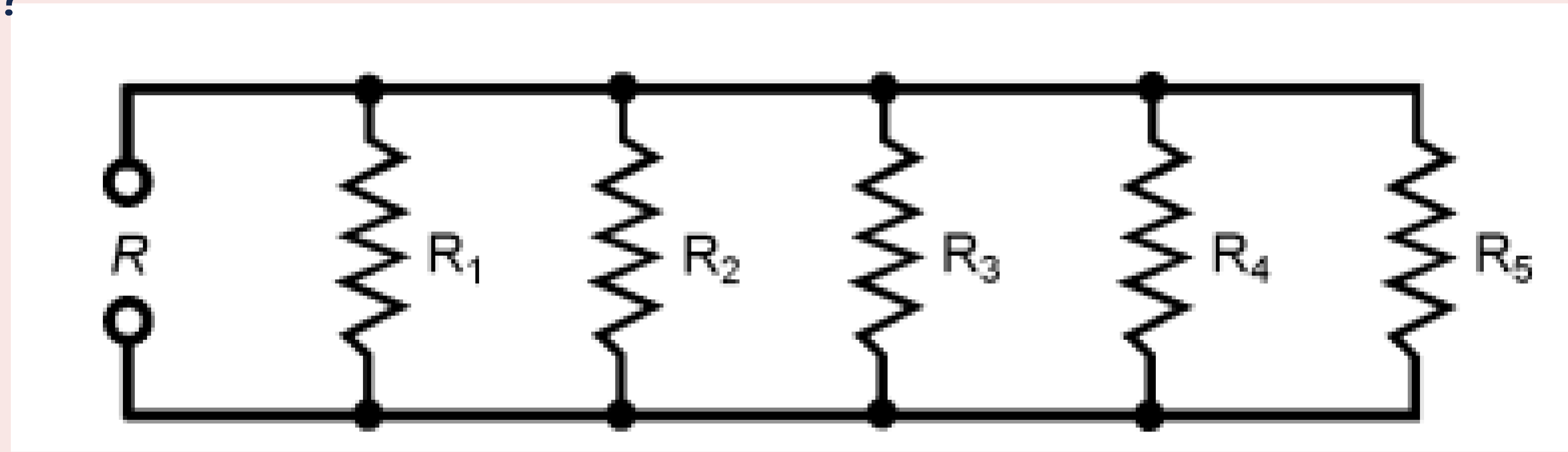
This means that adding capacitors in parallel increases the total capacitance.

- Inductance in Parallel: The total inductance (L_{Total}) in a parallel circuit is given by:

$$\frac{1}{L_{Total}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots + \frac{1}{L_n}$$

Sample Problems

Problem 1.15: Consider five resistors in parallel. Call them R1 through R5, and call the total resistance R as shown in Fig. 3. Let the resistance values be as follows: R1 = 100 Ω, R2 = 200 Ω, R3 = 300 Ω, R4 = 400 Ω, and R5 = 500 Ω. What is the total resistance, R, of this parallel combination?



Problem 1.16 Suppose you have five resistors, called R1 through R5, connected in parallel as shown in Figure. Suppose all the resistances, R1 through R5, are 4.70 kΩ. What is the total resistance, R, of this combination?

Try It Yourself!

1. Calculate the total resistance Rtotal in a parallel circuit with the following resistors: R1=8 Ω, R2=4 Ω and R3=2 Ω.

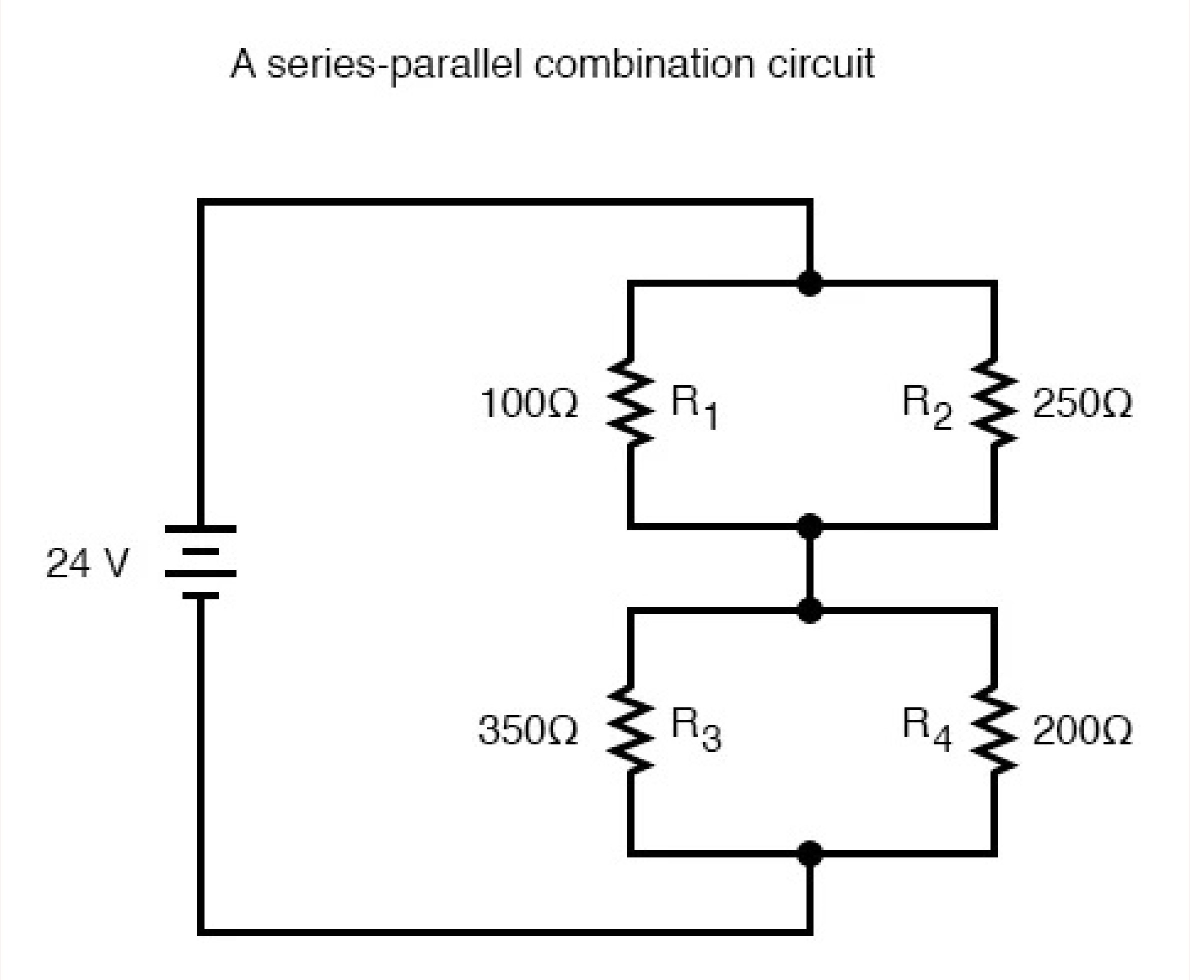
2. In a parallel circuit with resistors R1=5 Ω, R2=10 Ω, and R3=20 Ω, a voltage of 12 V is applied across the circuit. Calculate the total current supplied by the voltage source.

3. In a parallel circuit, there are three capacitors: C1=5 µF, C2=10 µF and C3=15 µF. Calculate the total capacitance Ctotal.

4. Calculate the total inductance Ltotal in a parallel circuit with the following inductors: L1=10 mH, L2=20 mH and L3=30 mH.

Series - Parallel Circuits

A series-parallel combination circuit integrates both series and parallel configurations. Some components are connected in series, while others are connected in parallel. This arrangement allows for more complex current and voltage behavior and can optimize power distribution in a circuit.



Series - Parallel Circuits

Key Concepts:

1. Current Flow:
   - In a series-parallel circuit, the total current is divided among the parallel branches while remaining the same within each series segment.
   - Current flowing into a parallel branch divides among the components connected in that branch.
2. Voltage Distribution:
   - The voltage across series components adds up to the total voltage supplied by the source.
   - The voltage across parallel components remains the same as the source voltage, but the total voltage in the circuit can vary depending on the series configuration.
3. Total Resistance:
   - The total resistance of a combination circuit is not straightforward and requires careful calculation.
   - First, calculate the equivalent resistance of the parallel sections and then add this to the series resistance.

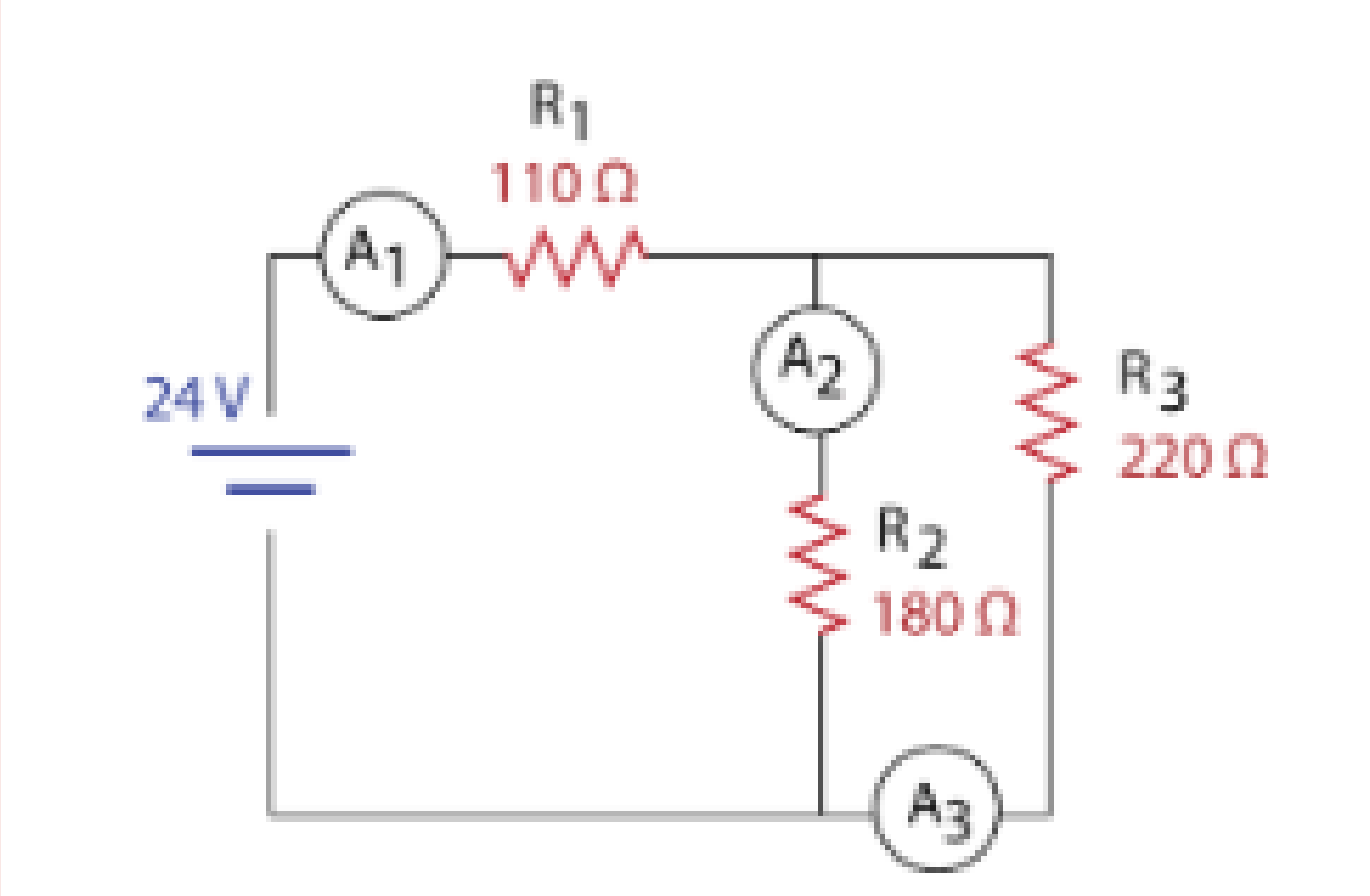
Series - Parallel Circuits

To analyze series-parallel circuits, follow these steps:

1. Identify Series and Parallel Components:
    - Look for groups of resistors (or other components) that are clearly in series or parallel.
2. Calculate Equivalent Resistances:
    - Simplify the circuit step by step:
        - Calculate the equivalent resistance of parallel components.
        - Combine the equivalent resistances with any series resistances to find the total resistance.
3. Use Ohm's Law:
    - Apply Ohm's Law ($V=I \cdot R$) to find currents and voltages across individual components.
4. Backtrack to Find Individual Currents and Voltages:
    - Once you have the total current or voltage, backtrack through the circuit to find individual component values.

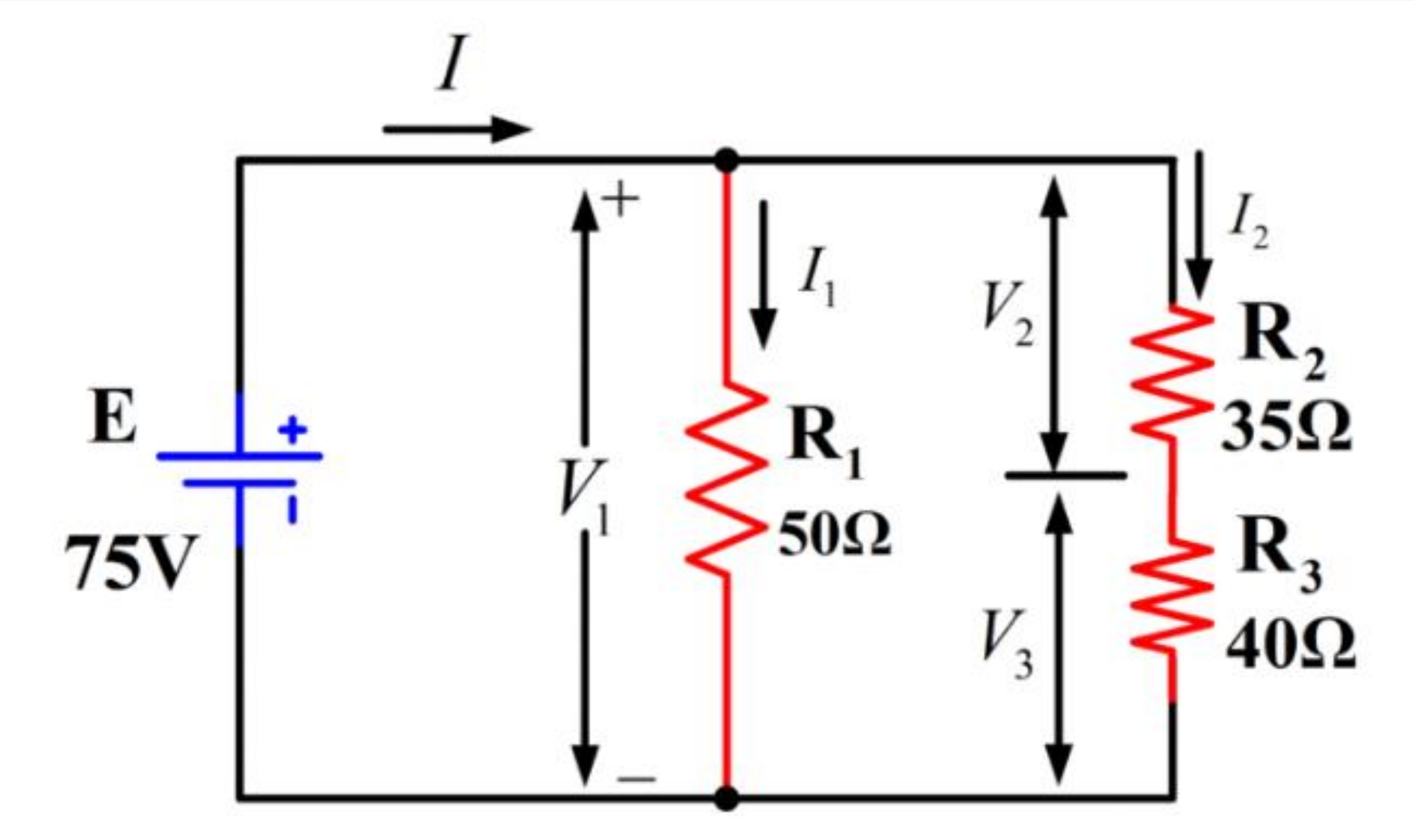
Sample Problem

1. In the combination circuit sketched below, find the equivalent resistance for the circuit, find the total current through the circuit, and find the current through each individual resistor.



Try it Yourself

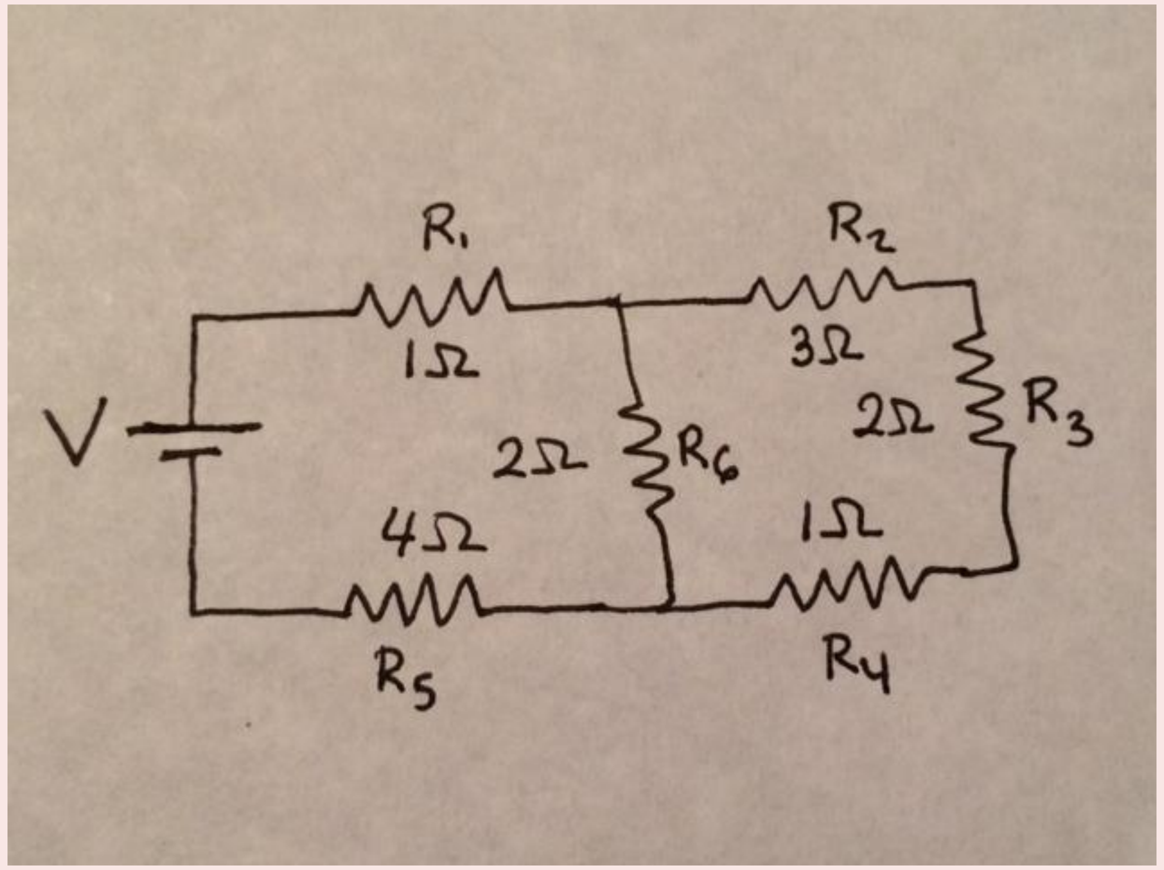
1. In the combination circuit sketched below, find the equivalent resistance for the circuit, find the total current through the circuit, and find the current through each individual resistor.



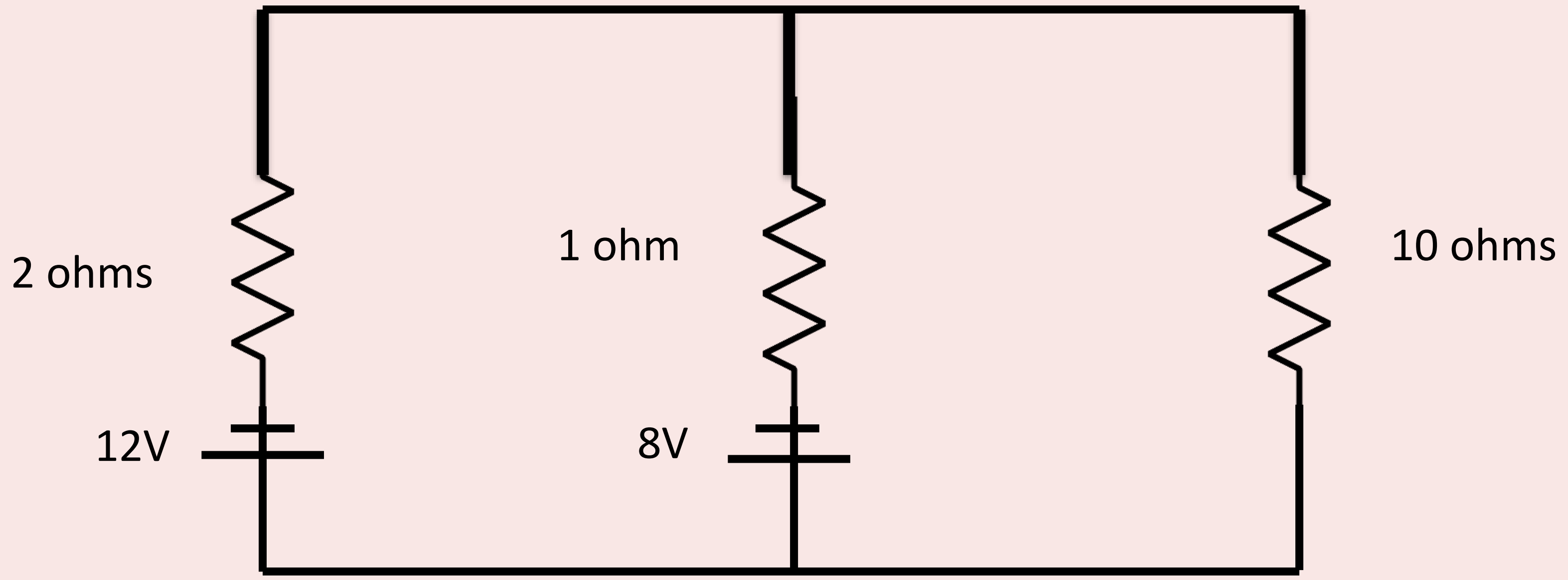
Try It Yourself!

1. A circuit has a resistor with a resistance of 3Ω followed by three parallel branches, each holding a resistor with a resistance of 5Ω. What is the total equivalent resistance of the circuit?

2. What is the effective resistance of this DC circuit?



Electric Network



Nodes – is a junction where two or more circuit elements are connected together.

Branch – part of a network which lies between two junctions.

Loop – is a closed path in a circuit in which no element or node is encountered more than once.

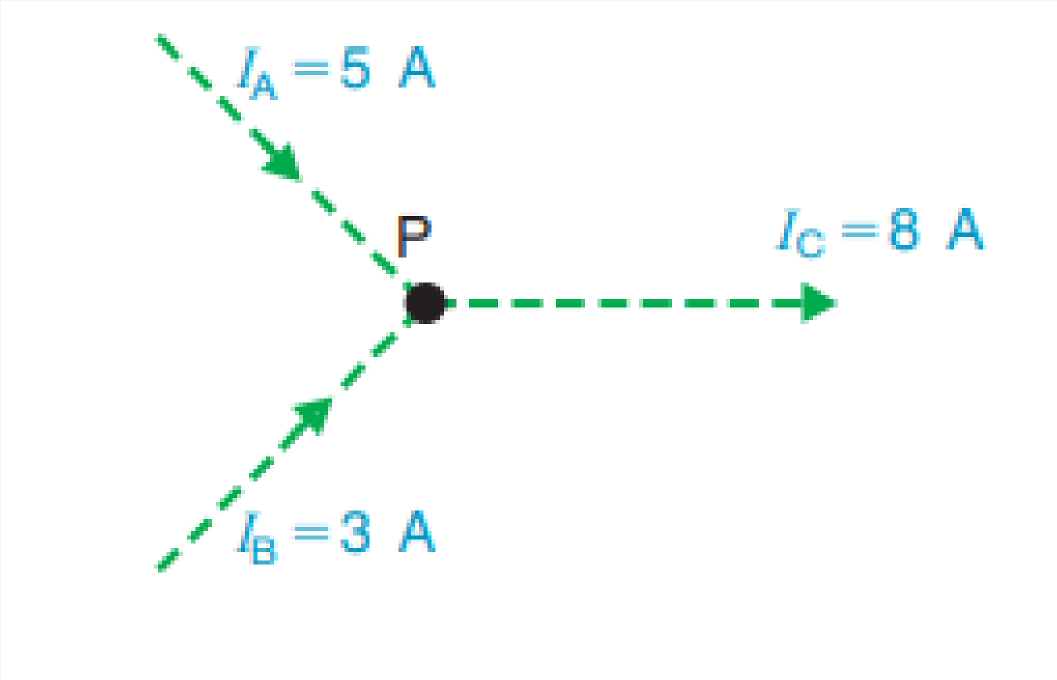
Kirchhoff's Current Law (KCL)

Kirchhoff's Current Law states that *the total current entering any junction in a circuit must equal the total current leaving that junction*. In other words, the algebraic sum of currents at any node (junction) in an electrical circuit is zero.

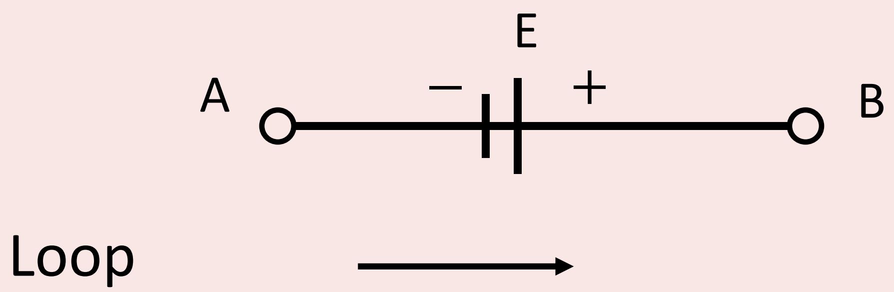
Algebraic Signs

In using Kirchhoff's laws to solve circuits, it is necessary to adopt conventions that determine the algebraic signs for current and voltage terms. A convenient system for currents is to consider all currents into a branch point as positive and all currents directed away from that point as negative.

As an example, in Fig. 4 we can write the currents as
IA + IB - IC = 0 or 5 A + 3 A - 8 A = 0 Currents IA and IB are positive terms because these currents flow into P, but IC , directed out, is negative.

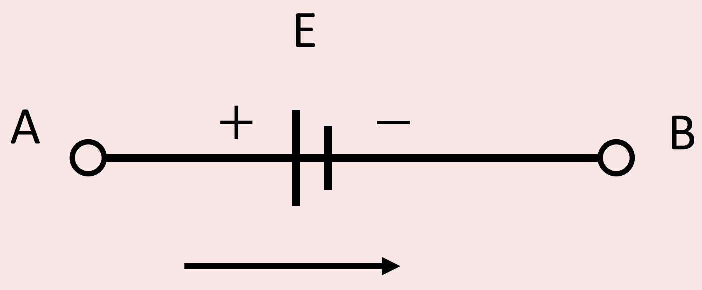


Algebraic Signs



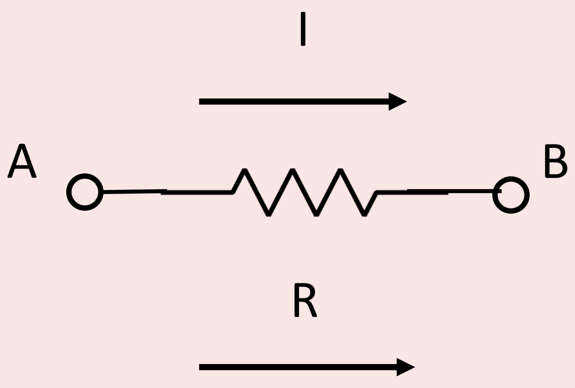
$+\ (\boldsymbol{Positive})$

$+\ \boldsymbol{E}$



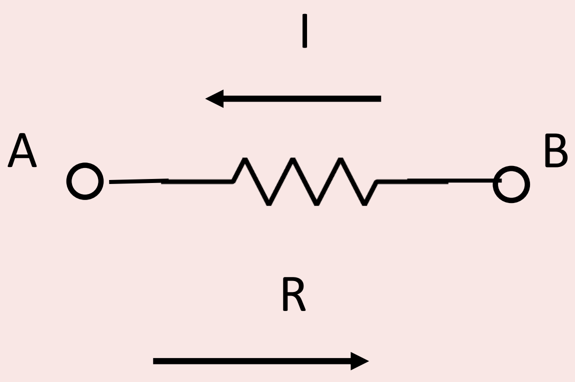
$-\ (\boldsymbol{Negative})$

$-\ \boldsymbol{E}$



$-\ (\boldsymbol{Negative})$

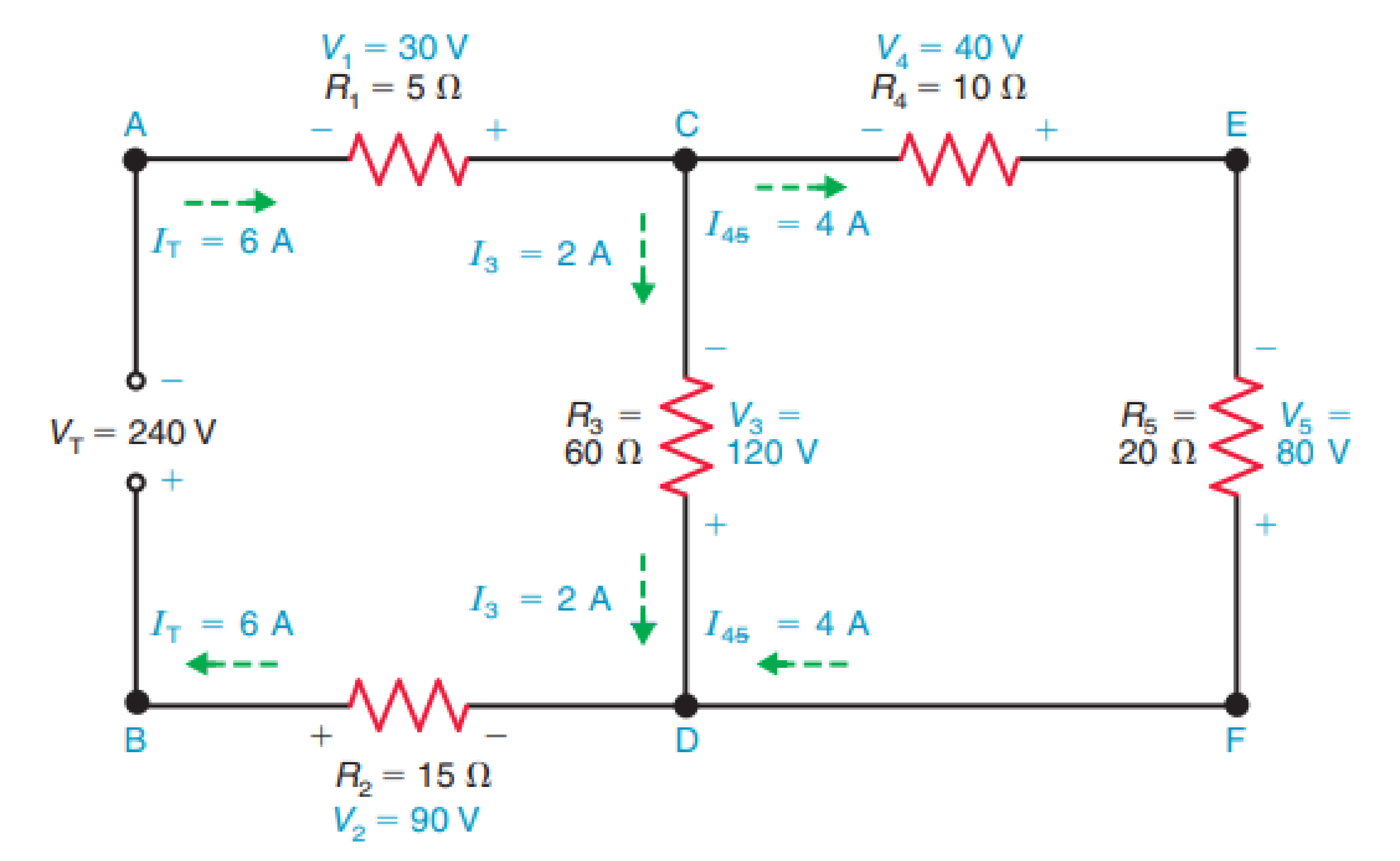
$-\ \boldsymbol{IR}$



$+\ (\boldsymbol{Positive})$

$+\ \boldsymbol{IR}$

Current Equations



$I_{in} = I_{out}$

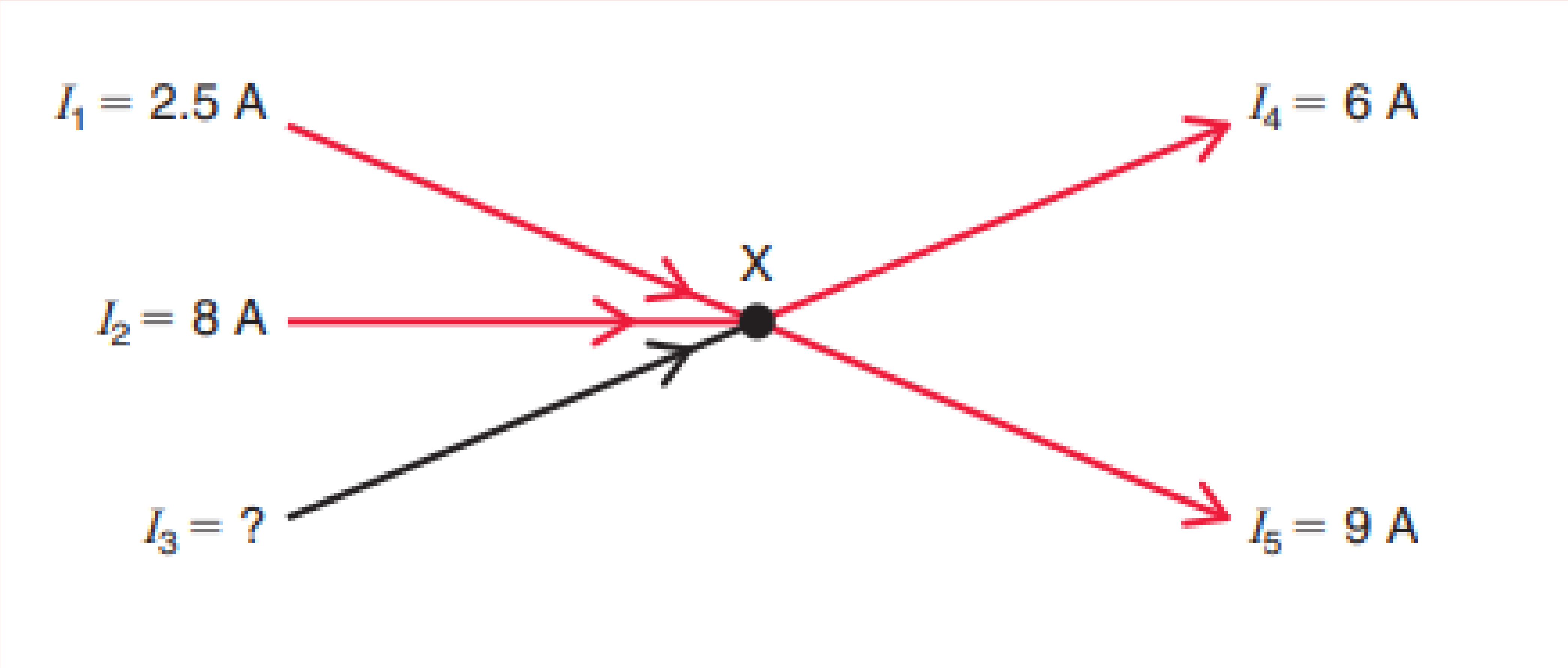
Note that at either point C or point D in Fig. 5, the sum of the 2-A and 4-A branch
currents must equal the 6-A total line current. Therefore, Kirchhoff's current law
can also be stated as $I_{in} = I_{out}$.

For Fig. 5, the equations of current can be written:
At point C: 6 A = 2 A + 4 A
At point D: 2 A + 4 A = 6 A

Kirchhoff's current law is the basis for the practical rule in parallel circuits that the
total line current must equal the sum of the branch currents.

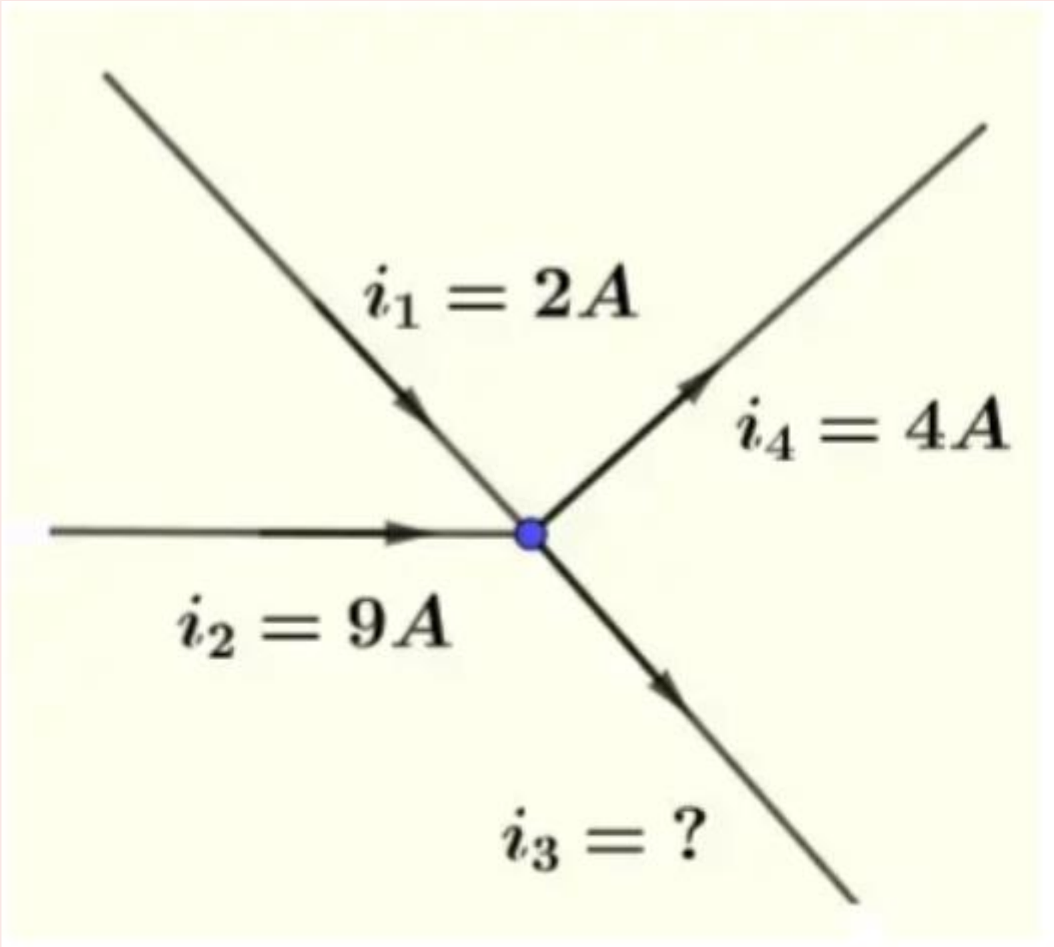
Sample Problems

1. In the Figure below, apply Kirchhoff's current law to solve for the unknown current, I3.



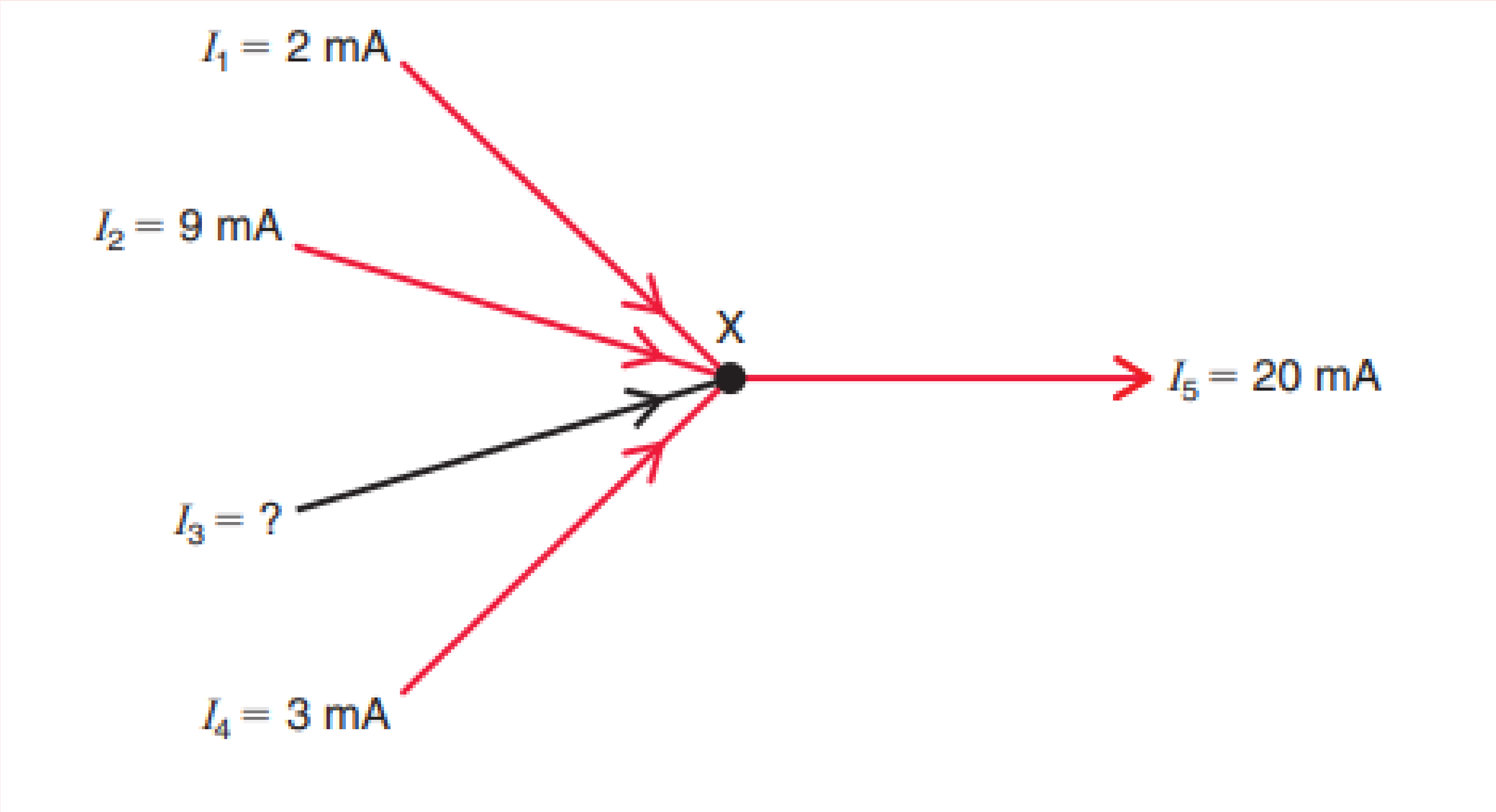
Sample Problems

1. In the Figure below, solve for the following unknown currents: I3



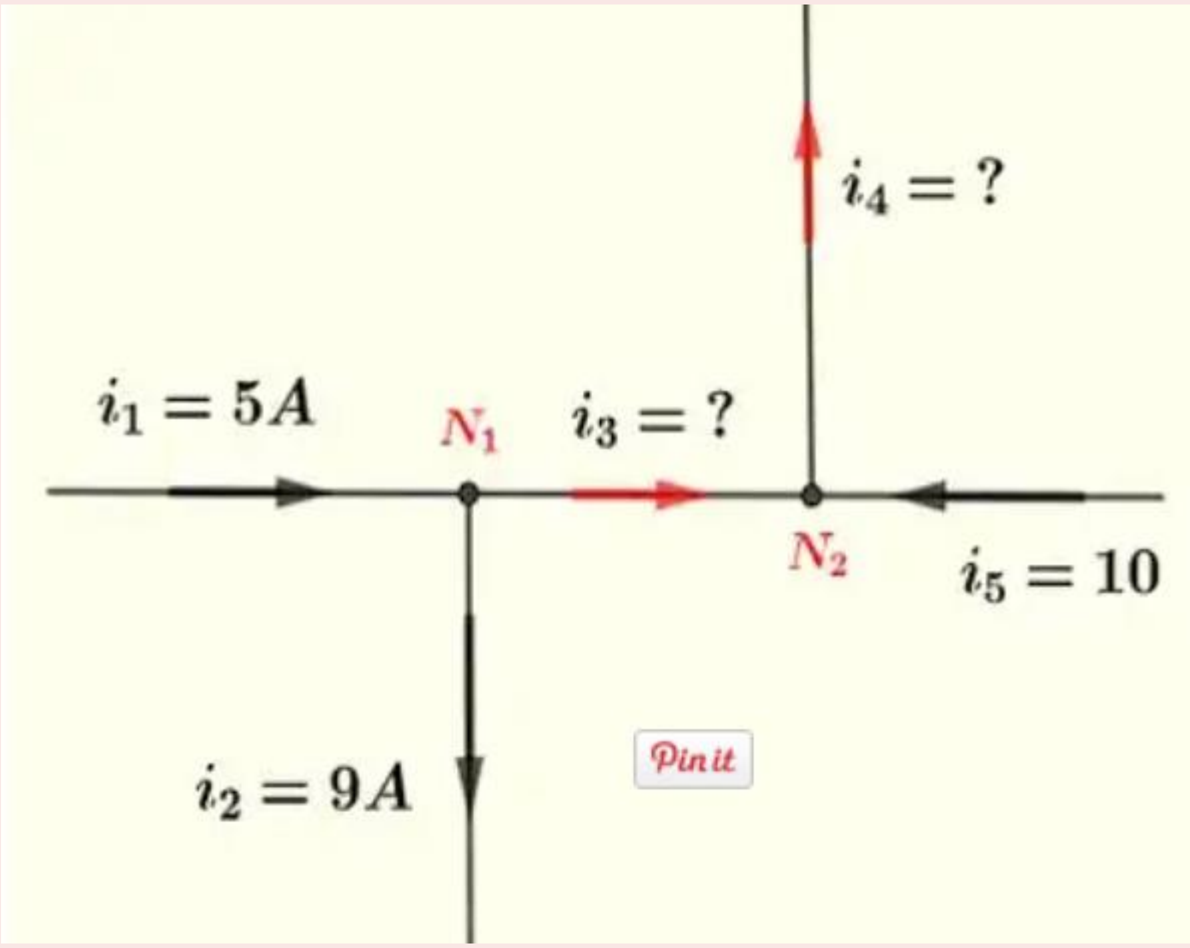
Try It Yourself!

In the Figure below, solve for the unknown current, I3.



Try It Yourself!

In the Figure below, solve for the unknown current, I3 & I4.



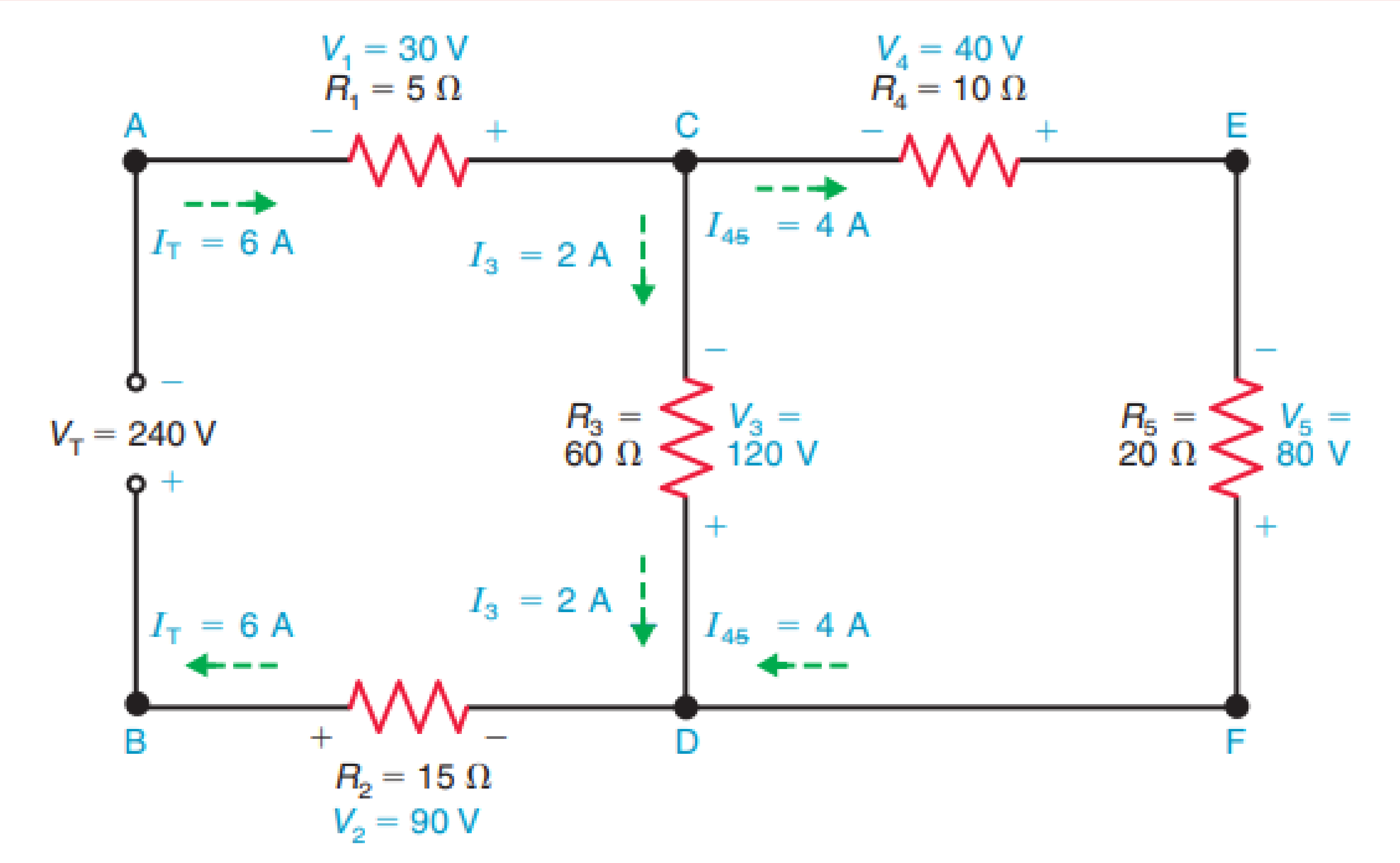
Kirchhoff's Voltage Law (KVL)

The algebraic sum of the voltages around any closed path is zero. If you start from any point at one potential and come back to the same point and the same potential, the difference of potential must be zero.

Algebraic Signs

To determine the algebraic signs for voltage terms in a KVL equation, mark the polarity of each voltage source and voltage drop, considering any voltage whose negative terminal is reached first as negative and those with a positive terminal first as positive. This applies to both IR voltage drops and voltage sources, regardless of the traversal direction (clockwise or counterclockwise). As you complete the closed path, the algebraic sum of all voltage terms must equal zero; if not returning to the starting point, the sum indicates the voltage difference between the start and finish. The voltage between any two points remains the same, irrespective of the path taken in the circuit.

Loop Equations



∑?V =? VT

The Greek letter ∑ means "sum of." In either direction, for any loop, the sum of the IR voltage drops must equal the applied voltage VT . In Fig. 5, for the inside loop with the source VT, going counterclockwise from point B,

90 V + 120 V + 30 V = 240 V

This system does not contradict the rule for algebraic signs. If 240 V were on the left side of the equation, this term would have a negative sign. Stating a loop equation as ∑V = VT eliminates the step of transposing the negative terms from one side to the other to make them positive.

In this form, the loop equations show that Kirchhoff's voltage law is the basis for the practical rule in series circuits that the sum of the voltage drops must equal the applied voltage. When a loop does not have any voltage source, the algebraic sum of the IR voltage drops alone must total zero. For instance, in Fig. 5, for the loop CEFDC without the source VT , going clockwise from point C, the loop equation of voltages is

Notice that V3 is positive now, because its plus terminal is reached fi rst by going clockwise from D to C in this loop.

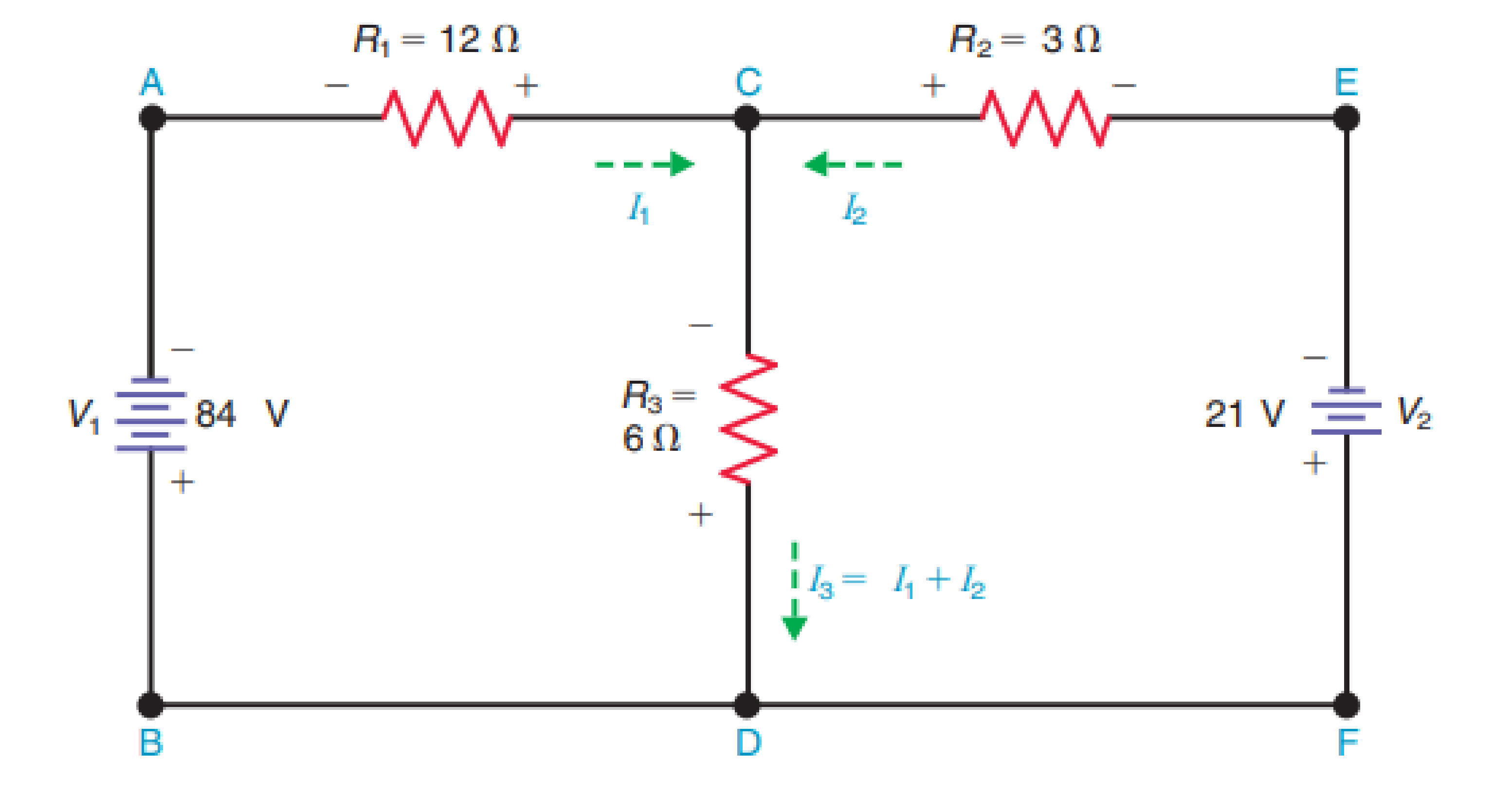
Method of Branch Currents

Now we can use Kirchhoff's laws to analyze the circuit in Fig. 6. The problem is to find the currents and voltages for the three resistors.

First, indicate current directions and mark the voltage polarity across each resistor consistent with the assumed current. Remember that electron flow in a resistor produces negative polarity where the current enters. In Fig. 6, we assume that the source V_1 produces electron flow from left to right through R_1 , and V_2 produces electron flow from right to left through R_2 .

The three different currents in R_1 , R_2 , and R_3 are indicated as I_1 , I_2 , and I_3 . However, three unknowns would require three equations for the solution. From Kirchhoff's current law, $I_3 = I_1 + I_2$, as the current out of point C must equal the current in. The current through R_3 , therefore, can be specified as $I_1 + I_2$.

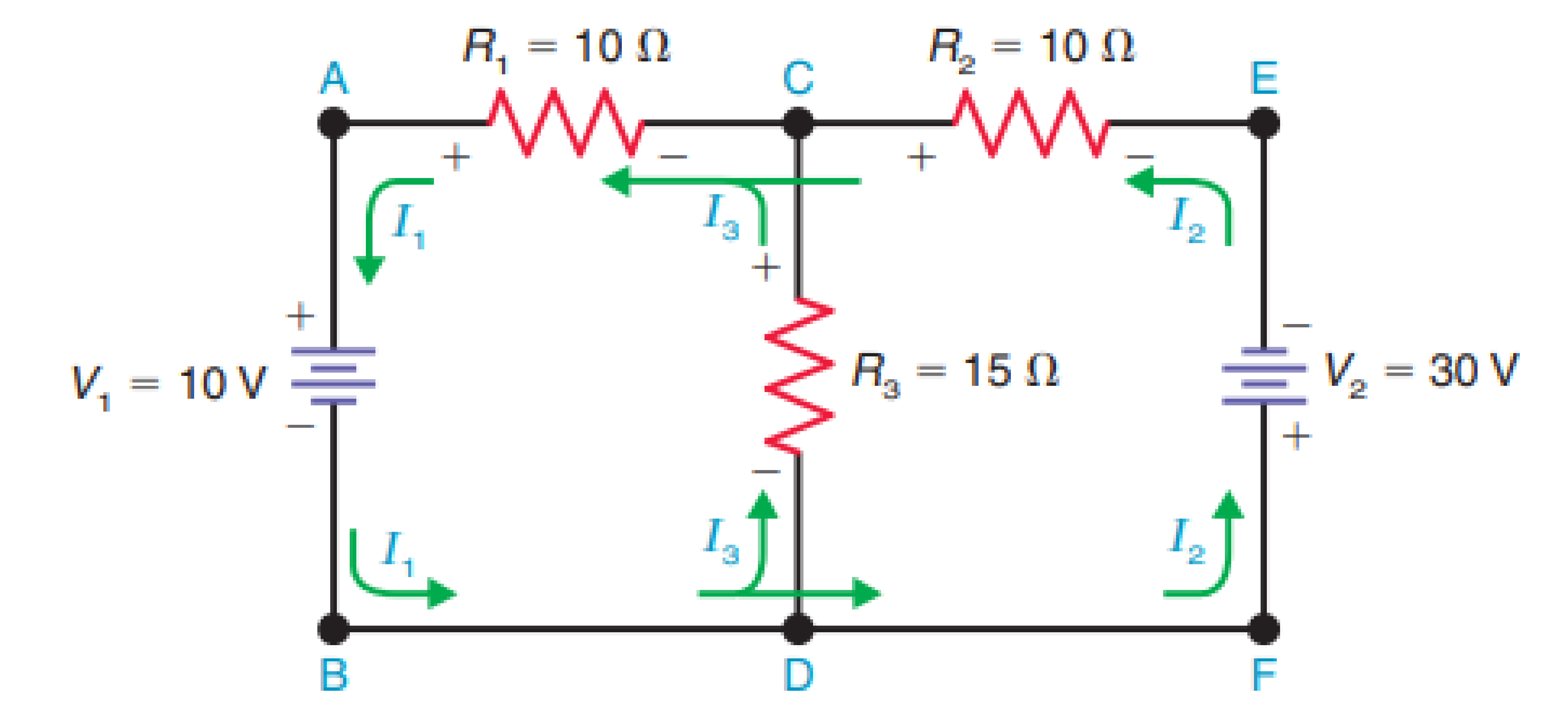
Method of Branch Currents



With two unknowns, two independent equations are needed to solve for I1 and I2 . These equations are obtained by writing two Kirchhoff's voltage law equations around two loops. There are three loops in Fig. 6, the outside loop and two inside loops, but we need only two. The inside loops are used for the solution here.

Try It Yourself!

Using the method of branch currents, solve for the unknown values of voltage and current in the Figure below.



Nodal Analysis (Node-Voltage Method)

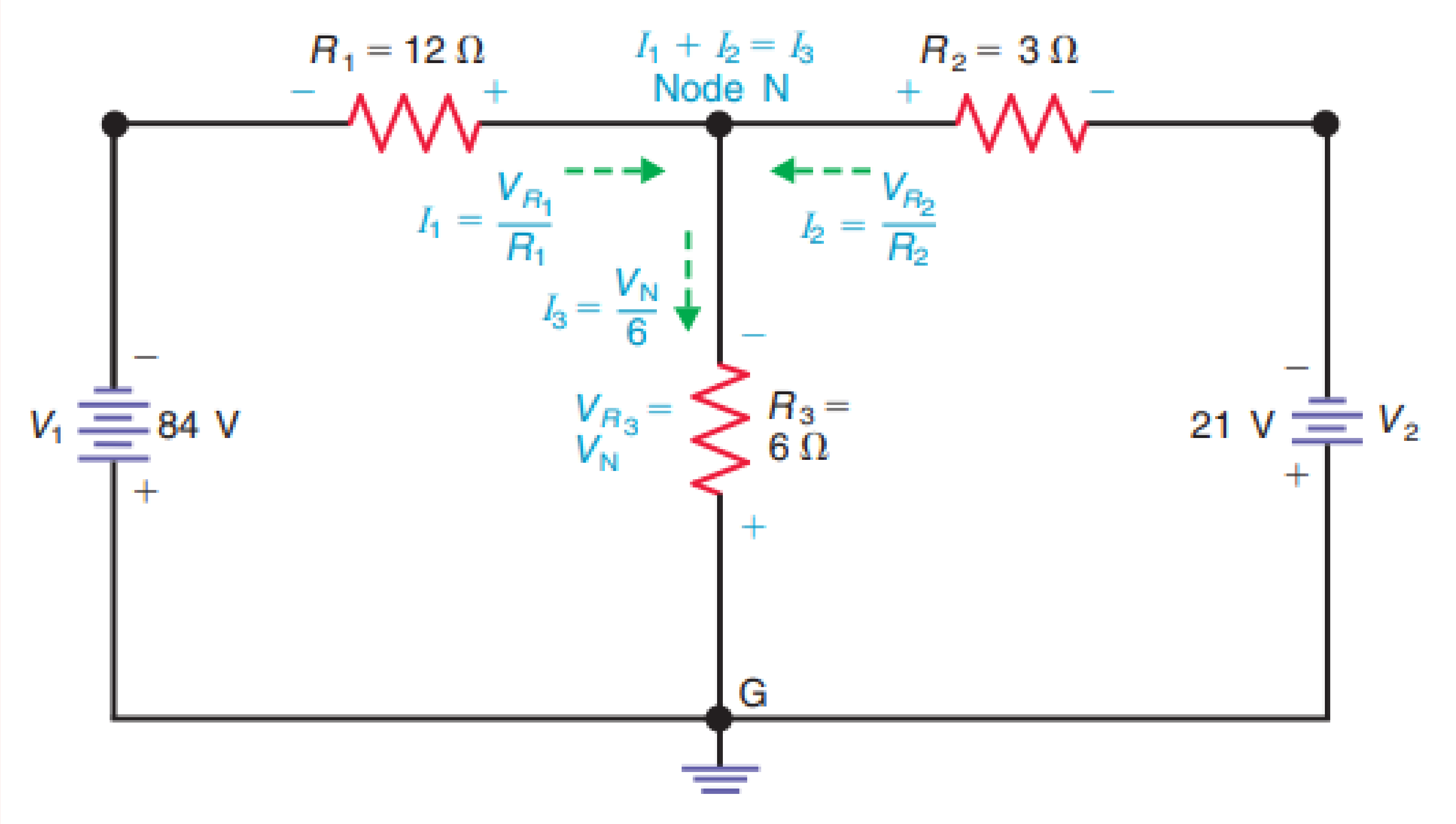
Another method uses voltage drops to specify the currents at a branch point, also called a node. Then node equations of currents are written to satisfy Kirchhoff's current law. Solving the node equations, we can calculate the unknown node voltages. This method of node-voltage analysis often is shorter than the method of branch currents.

A node is simply a common connection for two or more components. A principal node has three or more connections. In effect, a principal node is a junction or branch point where currents can divide or combine. Therefore, we can always write an equation of currents at a principal node. In Fig. 7, points N and G are principal nodes.

However, one node must be the reference for specifying the voltage at any other node. In Fig. 7, point G connected to chassis ground is the reference node. Therefore, we need to write only one current equation for the other node N. In general, the number of current equations required to solve a circuit is one less than the number of principal nodes.

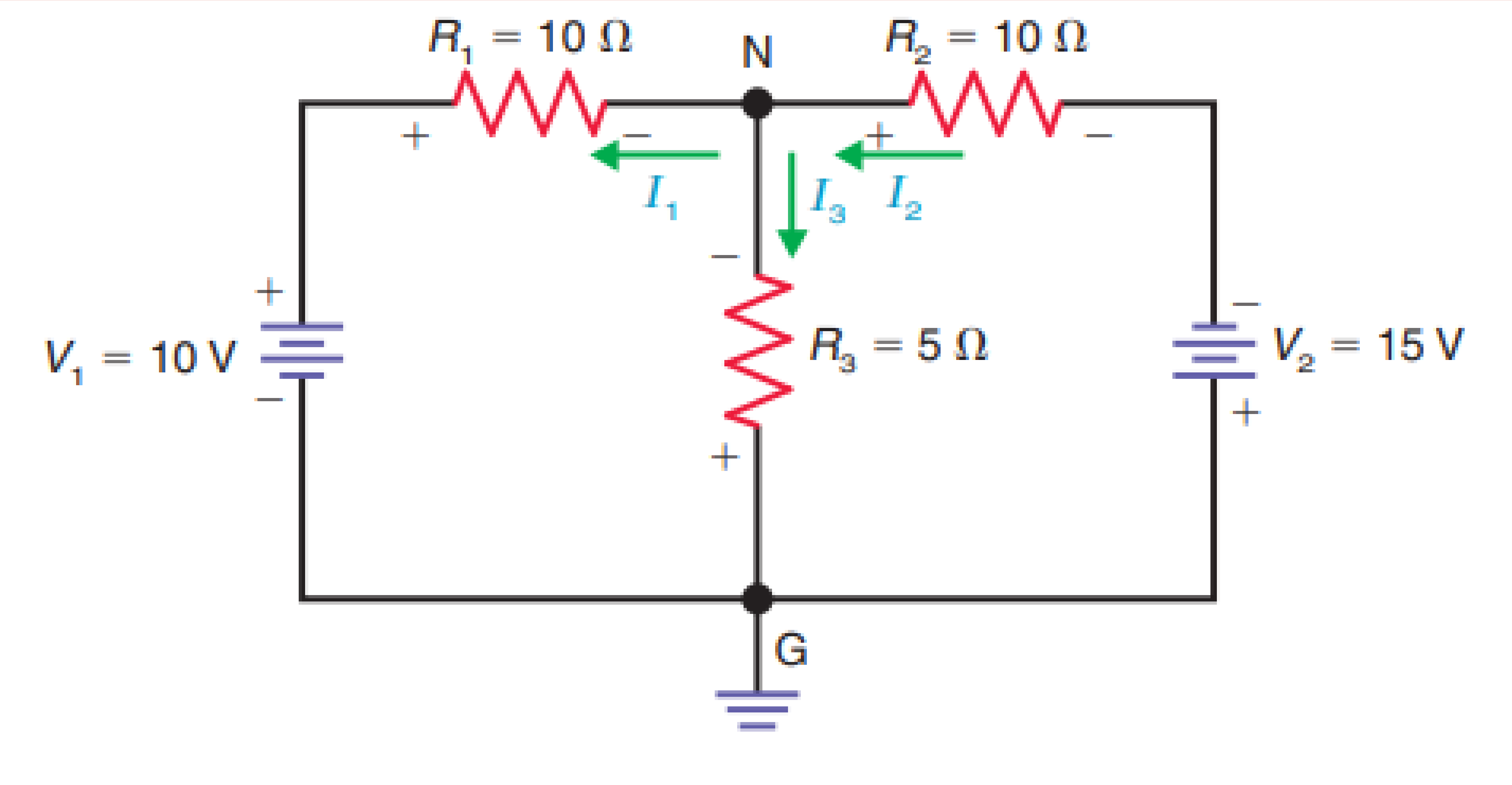
Sample Problem

Using the node-voltage analysis, solve for the unknown values of voltage and current in the Figure below.



Try It Yourself!

Using the node-voltage analysis, solve for the unknown values of voltage and current in the Figure below.



Method of Mesh Currents

A mesh is the simplest possible closed path. The circuit in Fig. 7 has two meshes, ACDBA and CEFDC. The outside path ACEFDBA is a loop but not a mesh. Each mesh is like a single window frame. There is only one path without any branches.

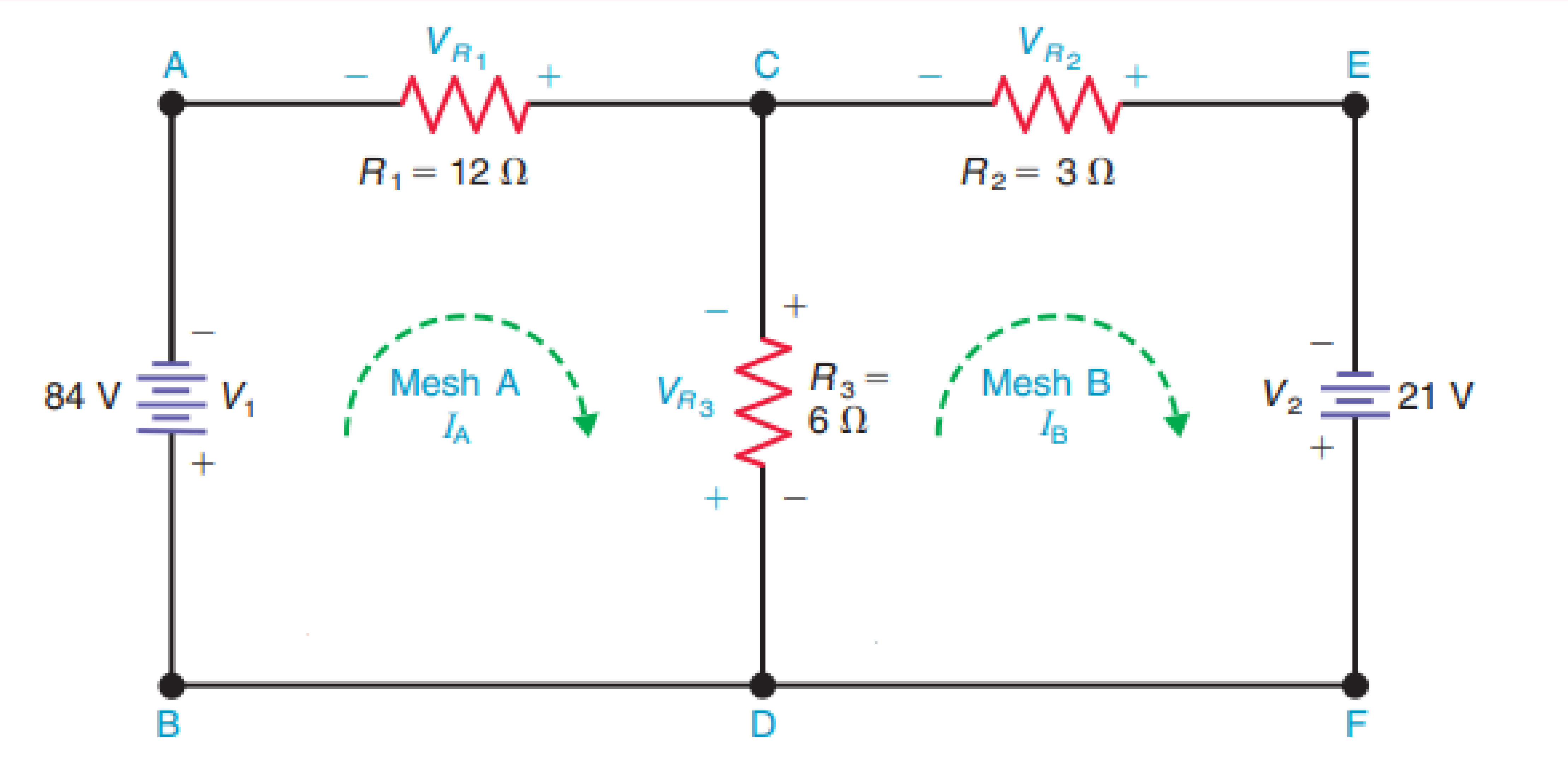
A mesh current is assumed to flow around a mesh without dividing. In Fig. 7, the mesh current IA flows through V1 , R1 , and R3 ; mesh current IB flows through V2 , R2 , and R3 . A resistance common to two meshes, such as R3 , has two mesh currents, which are IA and IB here.

The fact that a mesh current does not divide at a branch point is the difference between mesh currents and branch currents. A mesh current is an assumed current, and a branch current is the actual current. However, when the mesh currents are known, all individual currents and voltages can be determined.

As an example, Fig. 7, which has the same circuit as Fig. 6, will now be solved by using the assumed mesh currents IA and IB . The mesh equations are

Sample Problem

Using the method of mesh currents, solve for the unknown values of voltage and current in the Figure below.

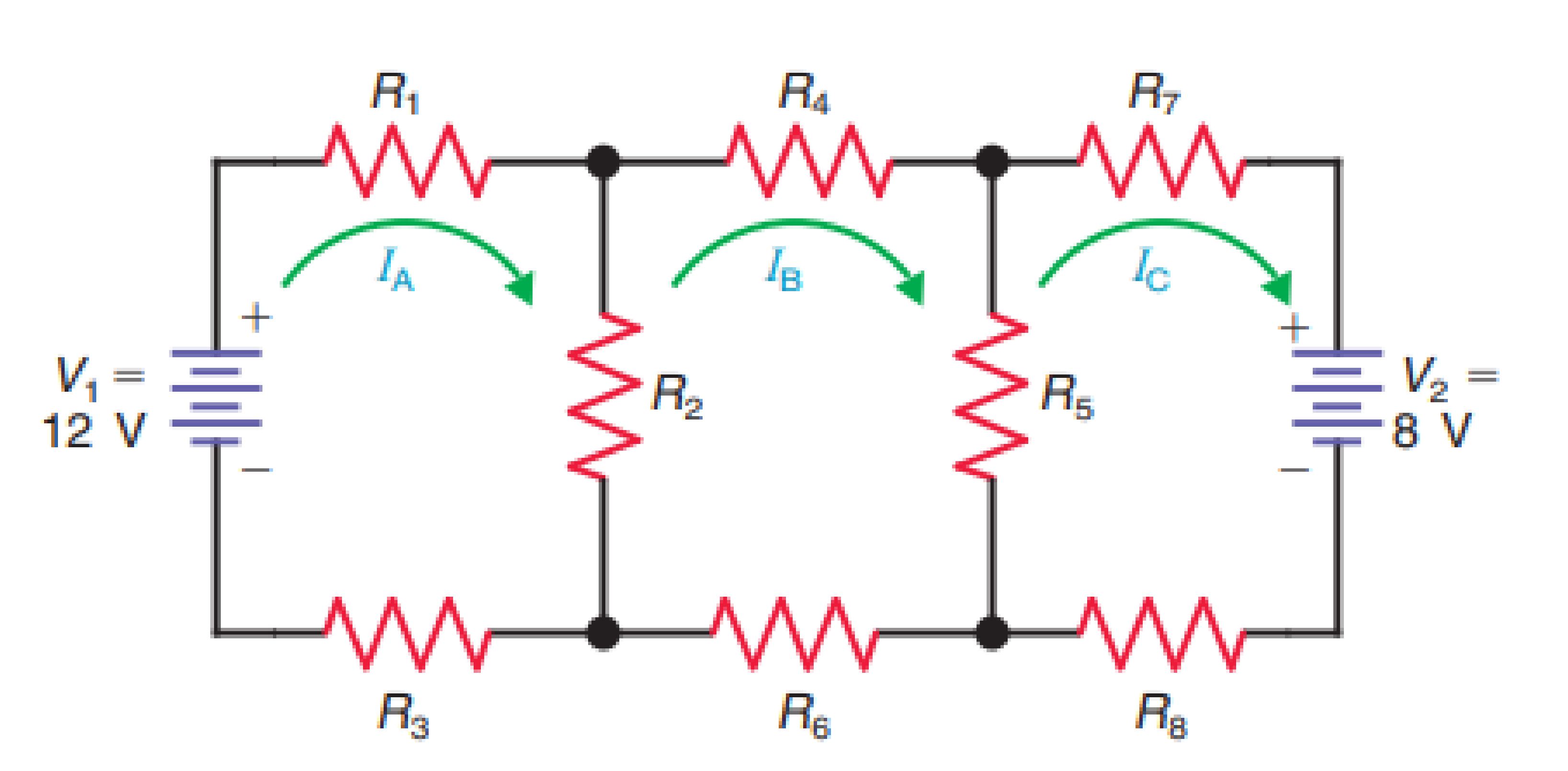


The Set of Mesh Equations

The system for algebraic signs of the voltages in mesh equations is different from the method used with branch currents, but the end result is the same. The advantage of mesh currents is the pattern of algebraic signs for the voltages, without the need for tracing any branch currents. This feature is especially helpful in a more elaborate circuit, such as that in Fig. 8, that has three meshes. We can use Fig. 8 for more practice in writing mesh equations, without doing the numerical work of solving a set of three equations. Each R is 2Ω.

In Fig. 8, the mesh currents are shown with solid arrows to indicate conventional current, which is a common way of analyzing these circuits. Also, the voltage sources V1 and V2 have the positive terminal at the top in the diagram. When the direction of conventional current is used, it is important to note that the voltage source is a positive value with mesh current into the negative terminal. This method corresponds to the normal flow of positive charges with conventional current. For the three mesh equations in Fig. 8,

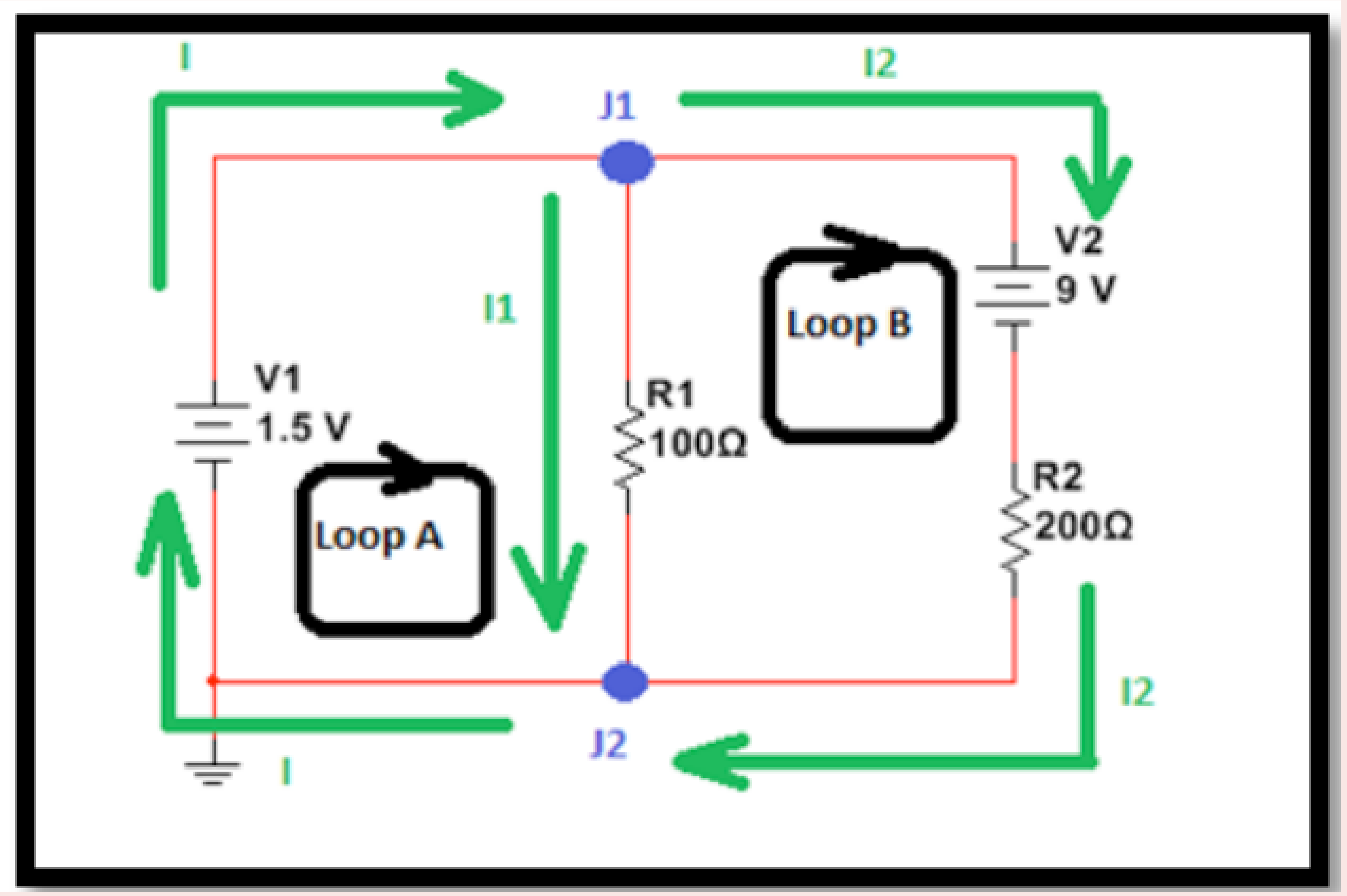
The Set of Mesh Equations



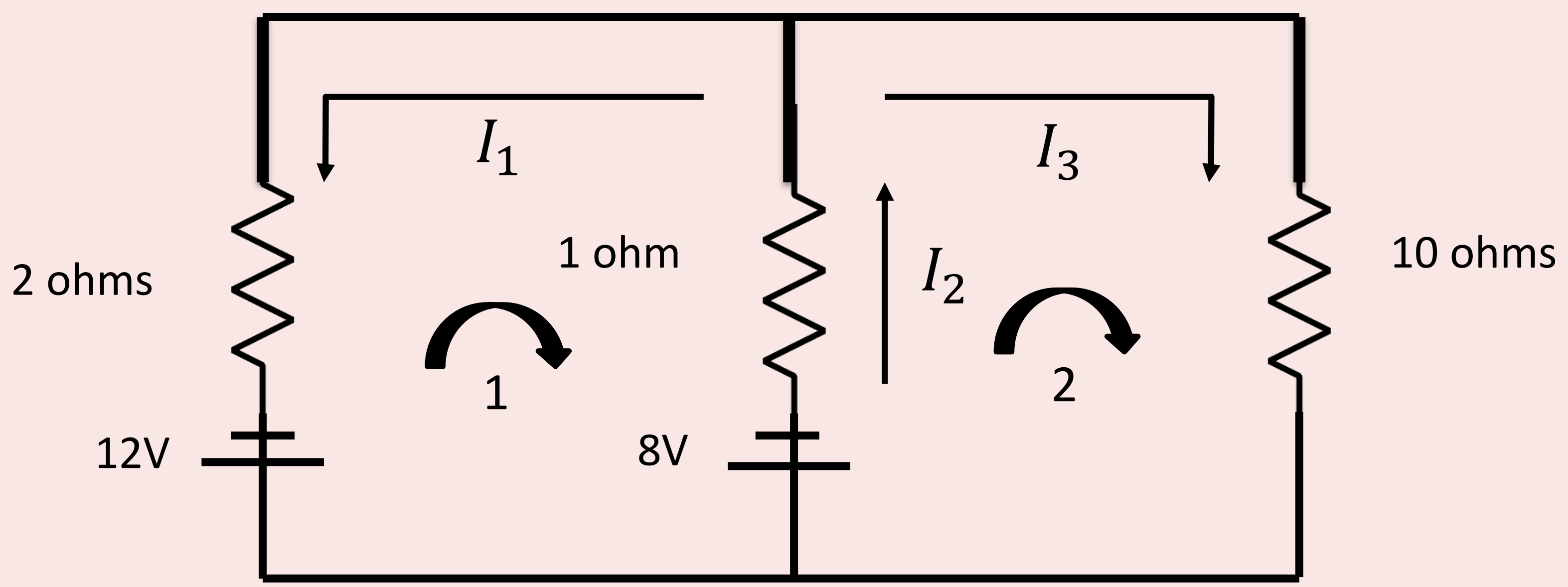
The zero term in equations A and C represents a missing mesh current. Only mesh B has all three mesh currents. However, note that mesh B has a zero term for the voltage source because it is the only mesh with only IR drops. In summary, the only positive IR voltage in a mesh is for the RT of each mesh current in its own mesh. All other voltage drops for any adjacent mesh current across a common resistance are always negative. This procedure for assigning algebraic signs to the voltage drops is the same whether the source voltage in the mesh is positive or negative. It also applies even if there is no voltage source in the mesh.

Sample Problems

Determine the voltage drops V_{R1} and V_{R2} across each resistor.

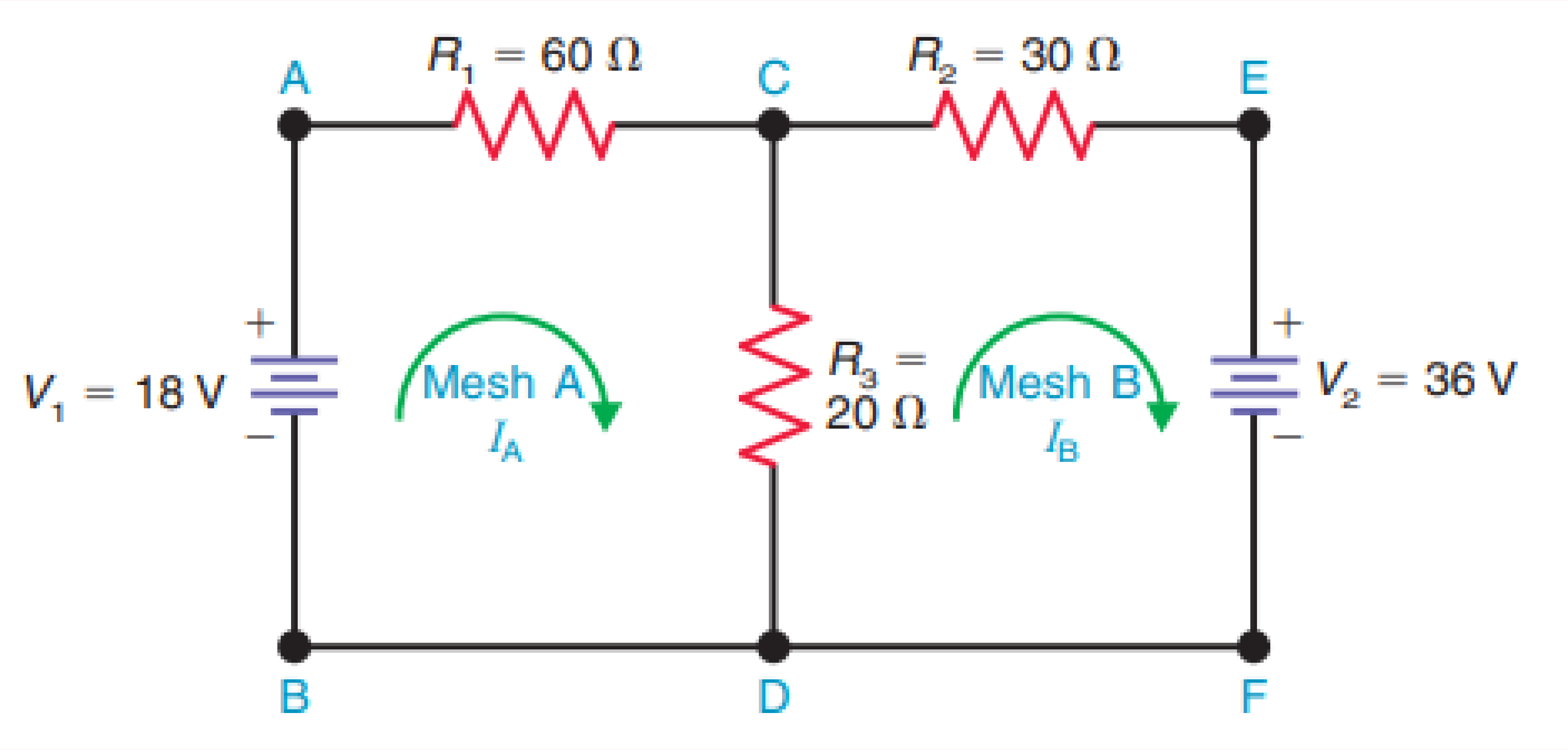


Example



Try It Yourself!

Using the method of mesh currents, solve for the unknown values of voltage and current in the Figure below.



Voltage Divider

In a series circuit, the current is constant through all resistors, and the voltage drop (V) across each resistor is proportional to its resistance (R) based on Ohm's Law (V=I×R). Larger resistances result in larger voltage drops. If one resistor (R1) is double another (R2), the voltage drop across R1 will be double that across R2. This makes the series circuit act as a voltage divider, where each resistor receives a portion of the total applied voltage proportional to its resistance.

$$V = \frac{R}{R_T} \times V_T$$

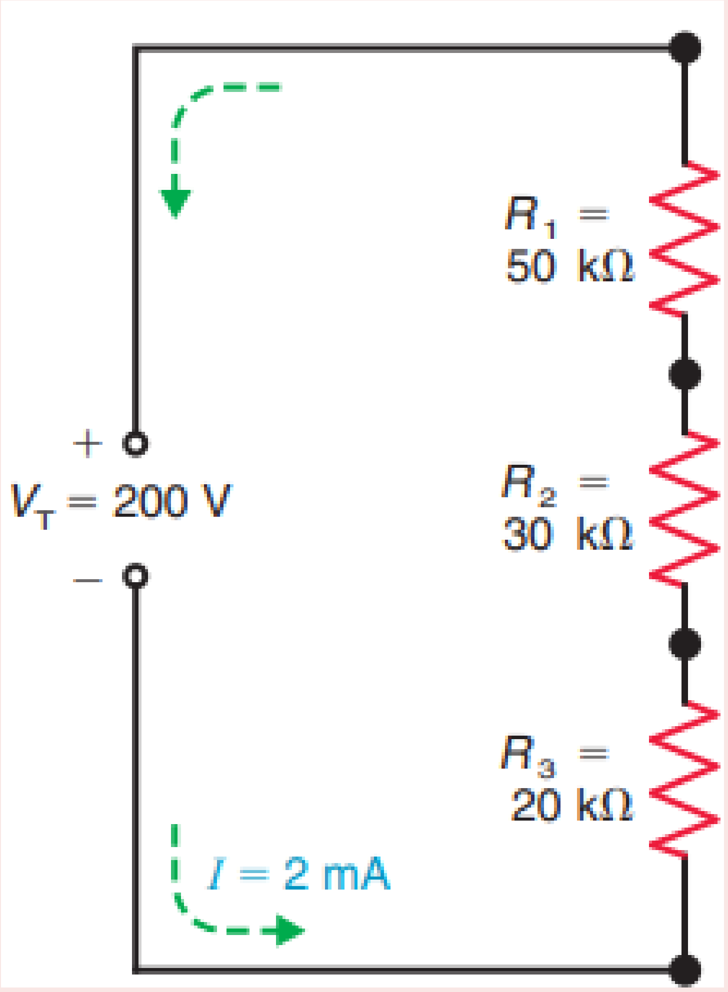
Where:

- V = Voltage drop across the resistor (Volts)
- R = Resistance of the individual resistor (Ohms)
- RT = Total resistance of the series circuit (Ohms)
- VT = Total applied voltage across the series circuit (Volts)

Sample Problems

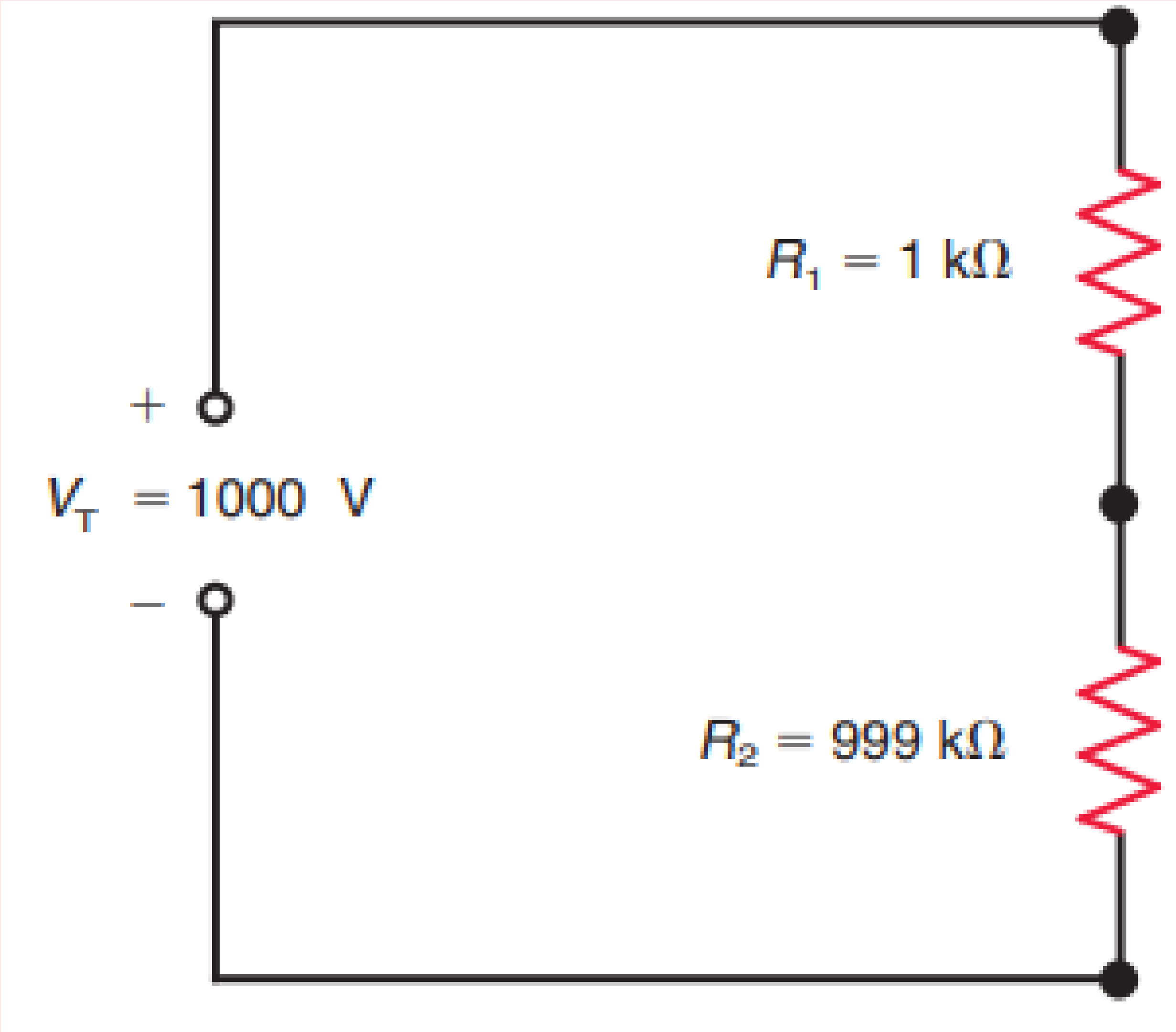
1. Three 50Ω resistors R1 , R2 , and R3 are in series across an applied voltage of 180V. How much is the IR voltage drop across each resistor?

2. Find the voltage across R3.



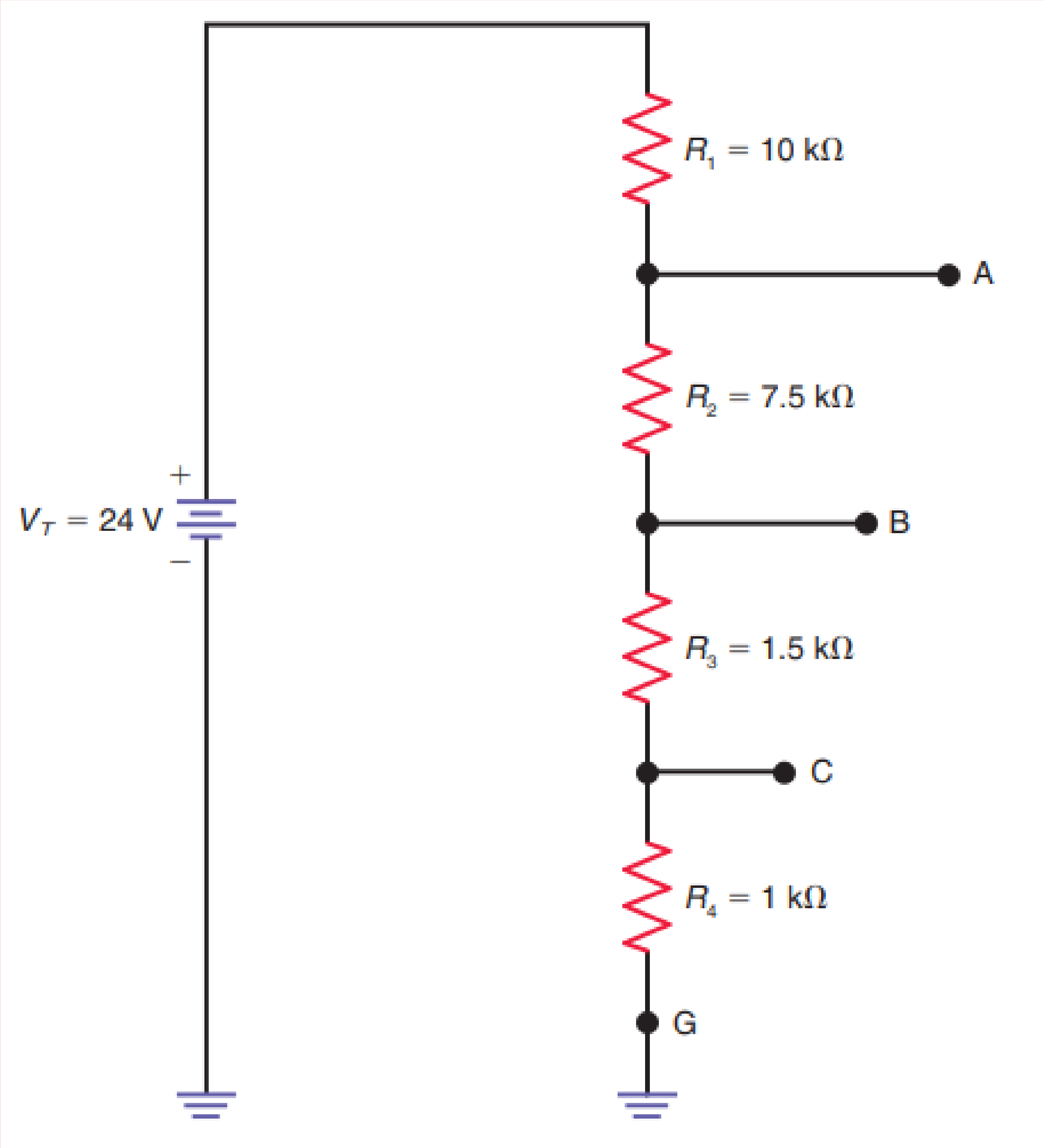
Sample Problems

3. Find the voltage across R1 and R2.



Sample Problems

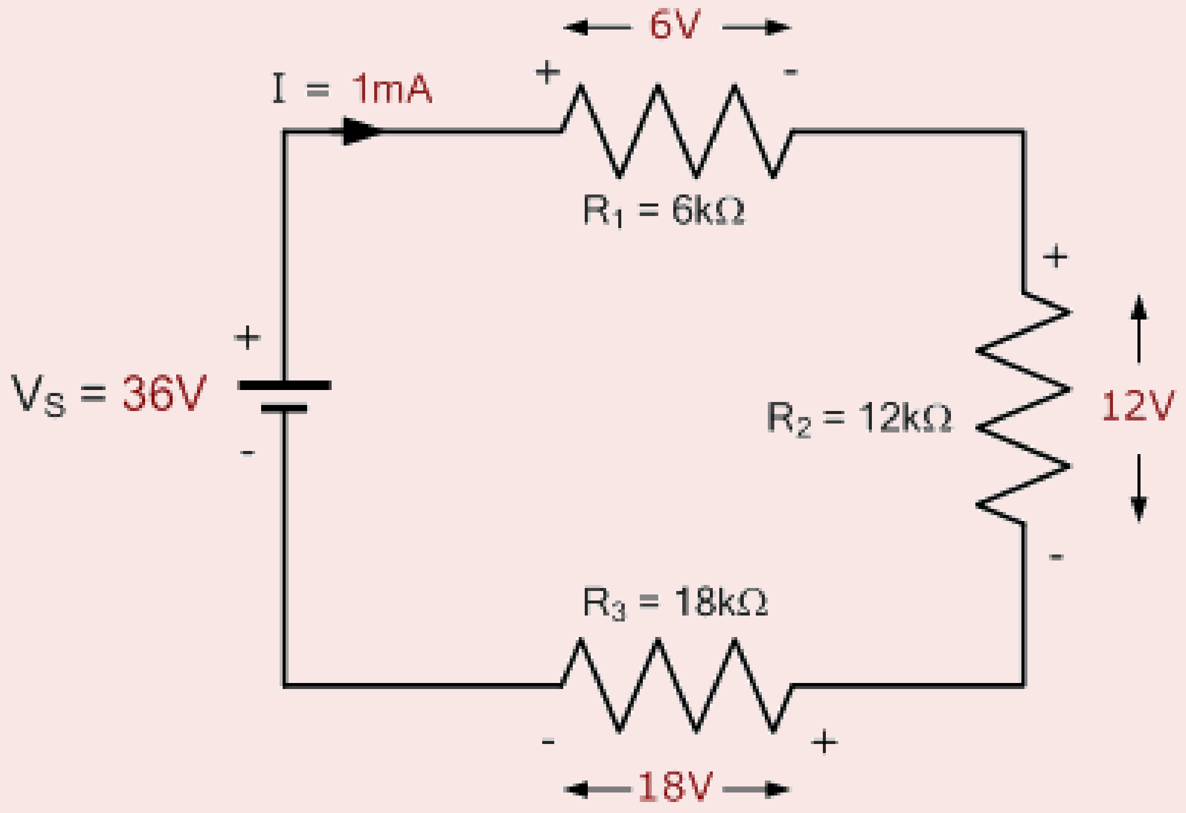
4. Find the voltage across Vcg, Vbg and Vag.



Try It Yourself!

1. How much current will flow through a 20Ω resistor connected in series with a 40Ω resistor when the supply voltage across the series combination is 12 volts dc. Also calculate the voltage drop produced across each resistor.

2. Three resistive elements of 6kΩ, 12kΩ and 18kΩ are connected together in series across a 36 volt supply. Calculate, the total resistance, the value of the current flowing around the circuit, and the voltage drops across each resistor.



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