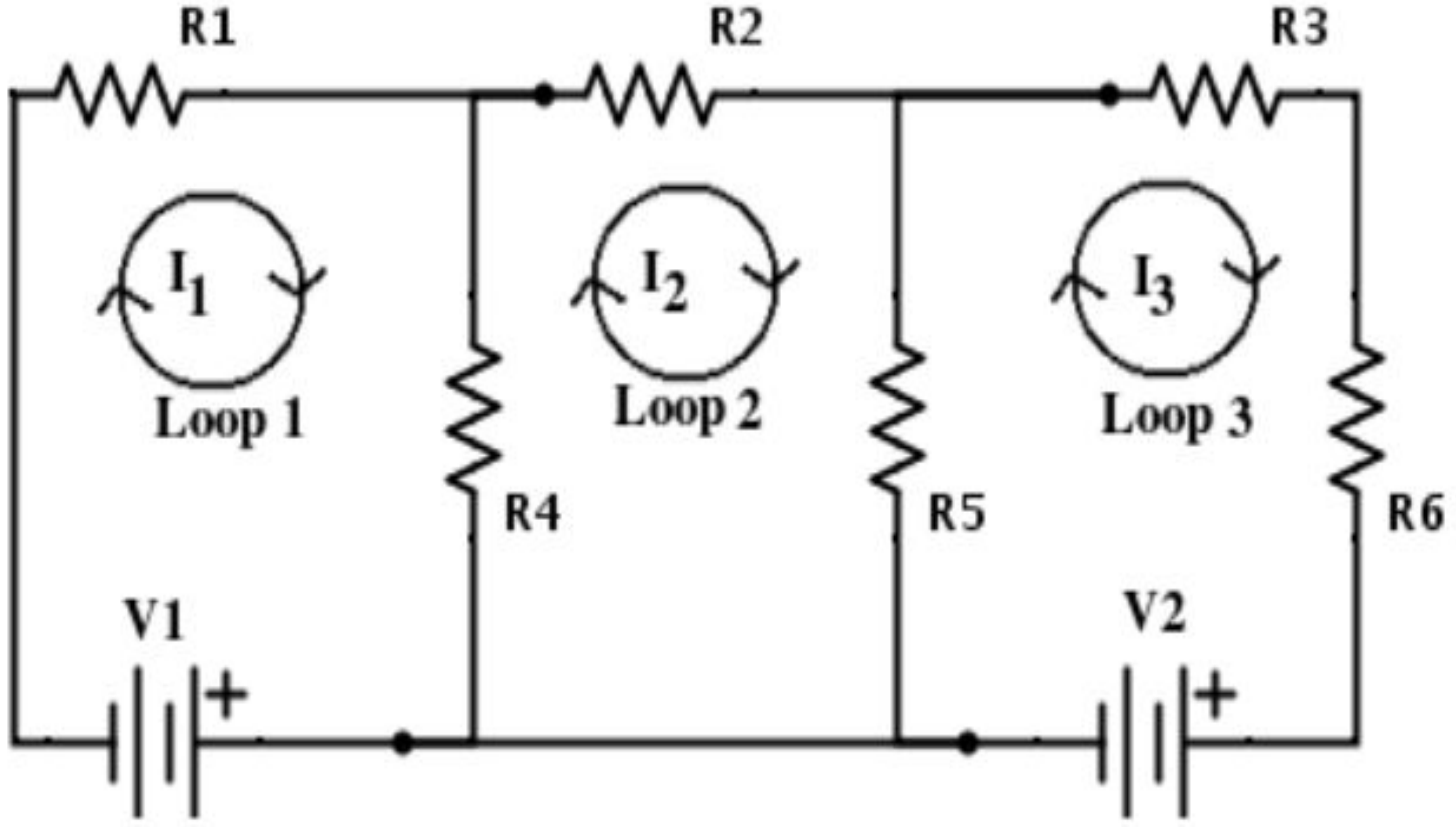
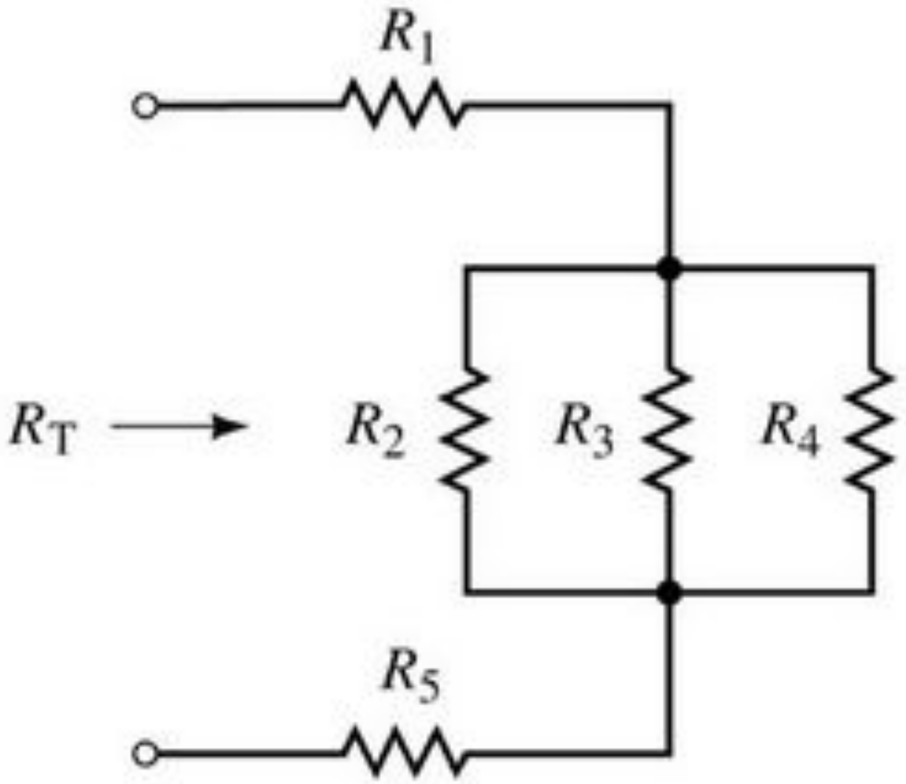
RV College of Engineering®

Department of Electrical and Electronics Engineering

Basics of Electrical Engineering - (22ES14D)

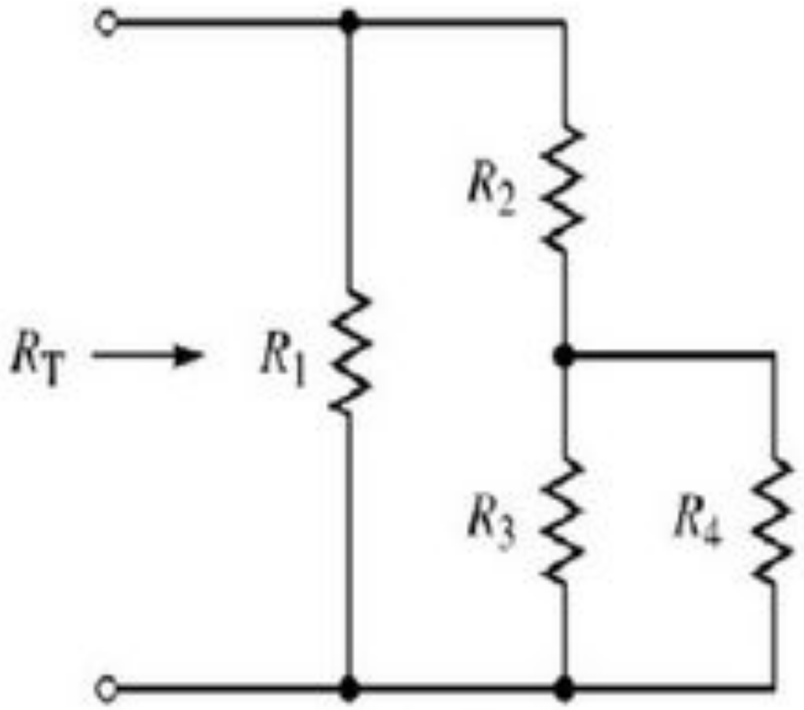
UNIT 1 – DC Circuits





(a)

$R_T = R_1+(R_2||R_3||R_4)+R_5$



(b)

$R_T = R_1||(R_2+(R_3||R_4))$

4

CHARGE AND CURRENT

- **Charge**
  - most basic quantity in an electric circuit
  - is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).
  - charge e *on an electron is* negative and equal in magnitude to 1.602×10^{-19} C, *while a proton carries* a positive charge of the same magnitude as the electron. The presence of equal numbers of protons and electrons leaves an atom neutrally charged.

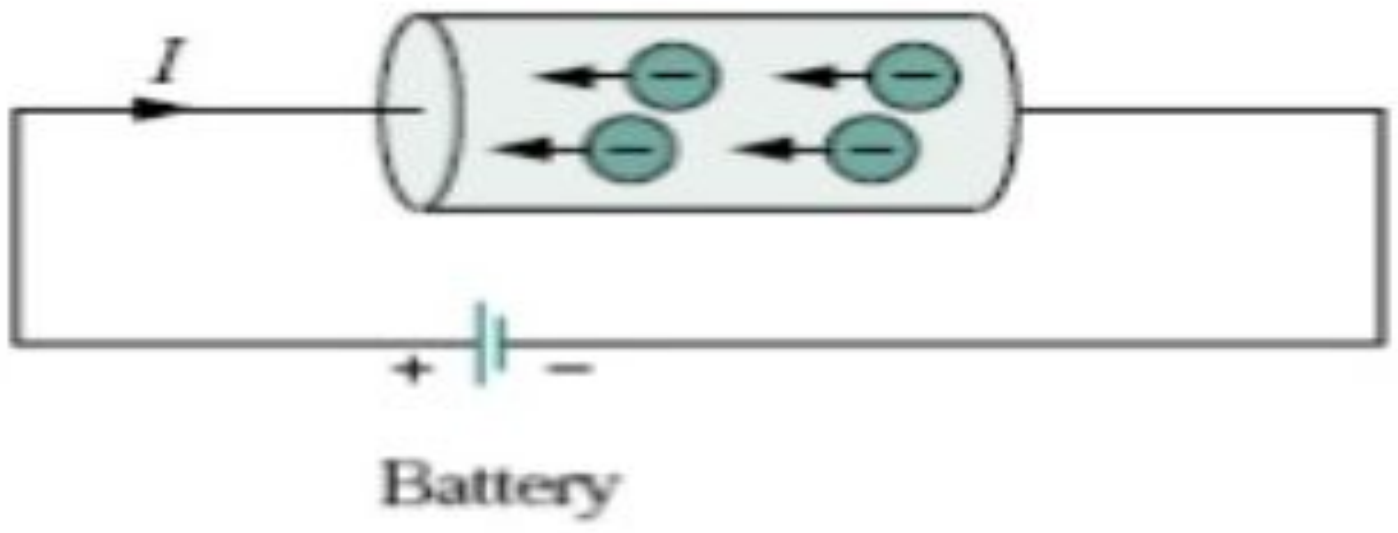
CHARGE AND CURRENT

- Points should be noted about electric charge:
  - The coulomb is a large unit for charges. In 1 C of charge, there are $1/(1.602 \times 10^{-19}) = 6.24 \times 10^{18}$ *electrons. Thus realistic* or laboratory values of charges are on the order of pC, nC, or μC.
  - According to experimental observations, the only charges that occur in nature are integral multiples of the electronic charge $e = -1.602 \times 10^{-19}\ C$.
  - The ***law of conservation of charge*** states that charge can neither be created nor destroyed, only transferred. Thus the algebraic sum of the electric charges in a system does not change.

CHARGE AND CURRENT

- Electric charge or electricity is mobile

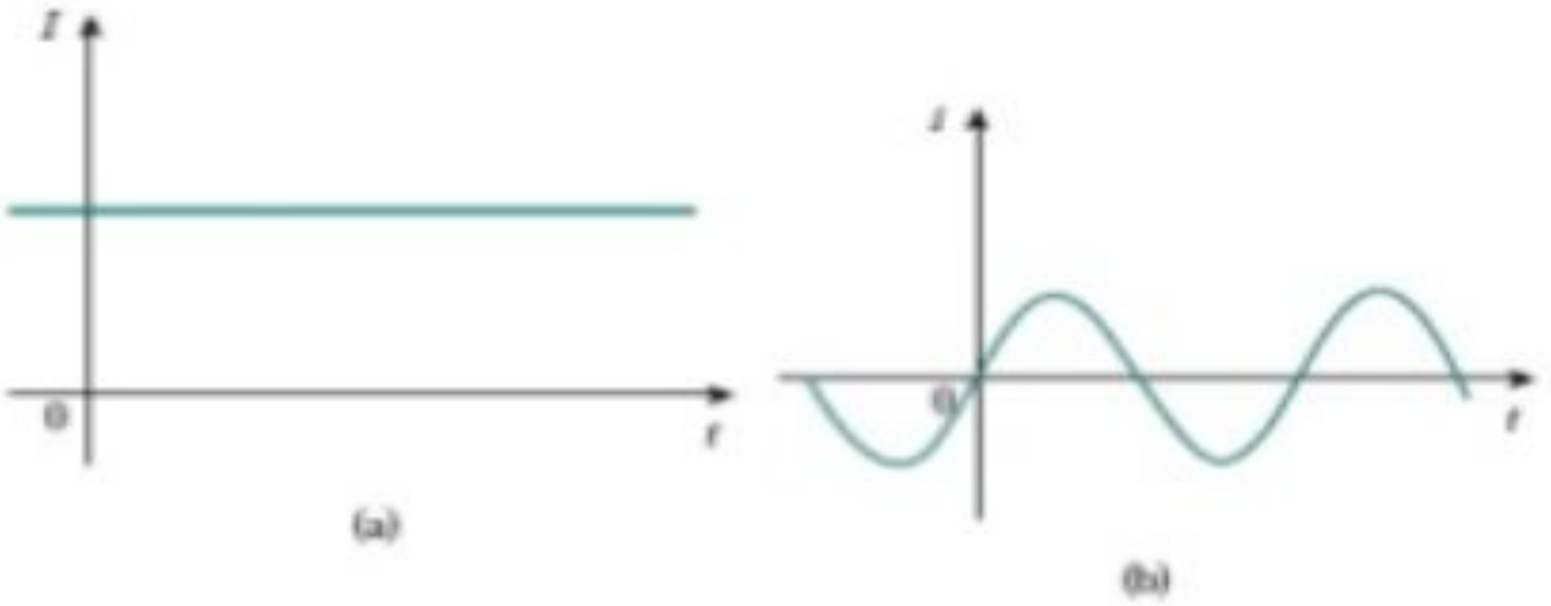
- Positive charges move in one direction while negative charges move in the opposite direction
- Motion of charges creates electric current
- **Conventionally** take the current flow as the movement of positive charges, that is, opposite to the flow of negative charges.



CHARGE AND CURRENT

- **Electric current** is the time rate of change of charge, measured in amperes (A). **1 ampere = 1 coulomb/second**

$$\boxed{i = \frac{dq}{dt}} \qquad \boxed{q = \int_{t_0}^{t} i\,dt}$$



- **Direct Current (DC)** is a c with time.
- **Alternating Current (AC)** is a current that varies sinusoidally with time.

VOLTAGE

- **Voltage** (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).
- Voltage $\boldsymbol{v_{ab}}$ *between two points a and b in* an electric circuit is the energy (or work) needed to move a unit charge from *a to b; mathematically,*

$$v_{ab} = \frac{dw}{dq}$$

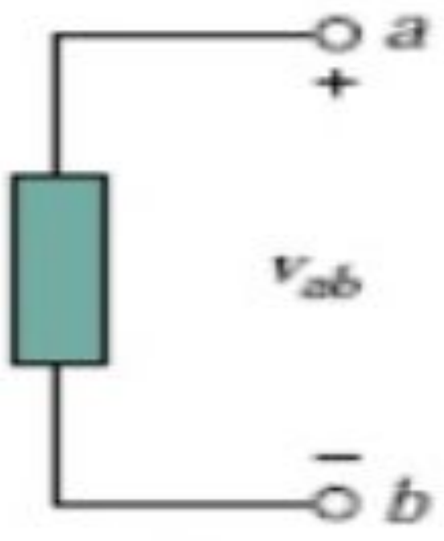
  - where *w is energy in joules (J) and q is charge in coulomb*
  - Voltage $\boldsymbol{v_{ab}}$ *or simply v is measured in volts (V)*

1 volt = 1 joule/coulomb = 1 newton meter/coulomb

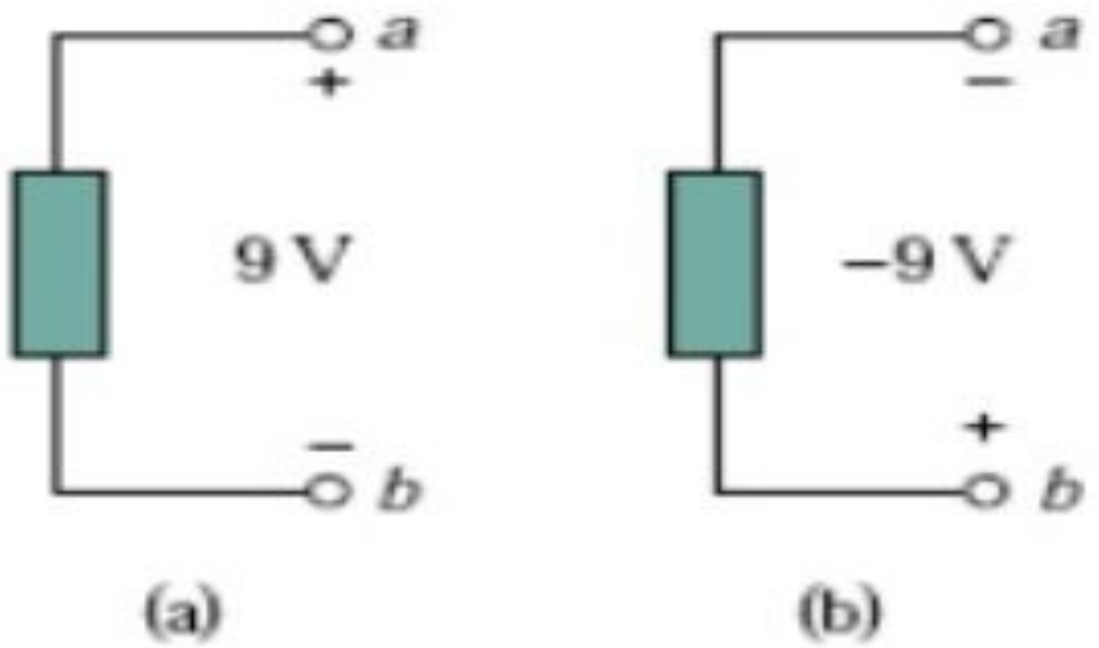
VOLTAGE

- The plus *(+) and minus (–) signs are used to define reference direction or voltage polarity.*

(1) point *a is at a potential of vab* volts higher than point *b*
(2) the potential at point a with respect to point b *is vab*



$$v_{ab} = -v_{ba}$$



(a), there is a 9-V *voltage drop from a to b or equivalently a 9-V voltage rise from* b *to a.*
(b), point *b is* –9 V above point *a.*

<u>A voltage drop from *a to b is equivalent to a voltage rise from b to a.*</u>

<u>*constant voltage*</u> is called a <u>*dc voltage*</u> *and is represented by* <u>*V*</u>*, whereas a* <u>sinusoidally time-varying voltage</u> is called an <u>*ac voltage*</u> *and is represented by*

POWER AND ENERGY

- **Power** is the time rate of expending or absorbing energy, measured in watts (W).

$$\boxed{p = \frac{dw}{dt}} \qquad p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi \qquad \boxed{p = vi}$$

  - where p … watts (W), w is energy in joules (J), and t is time in seconds (s).
  - power p *is a time-varying quantity and is called the instantaneous power.*
- If the power has a **+ sign**, power is being **delivered to or absorbed** by the element. If, on the other hand, the power has a **− sign**, power is being **supplied** by the element.

POWER AND ENERGY

- **Passive sign convention** is satisfied when the current enters through the positive terminal of an element and $p = +vi$. *If the current* enters through the negative terminal, $p = -vi$.

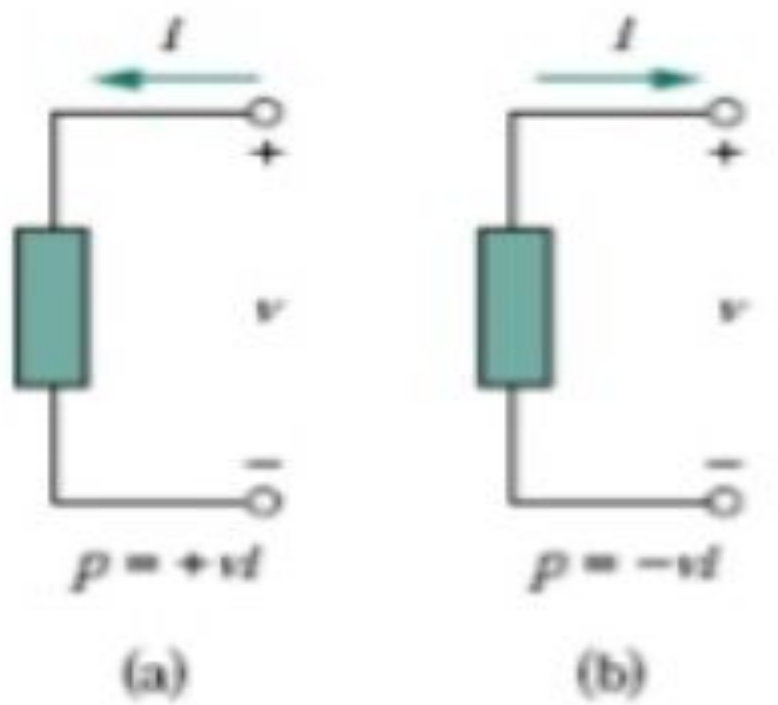


Figure 1.8 Reference polarities for power using the passive sign convention: (a) absorbing power, (b) supplying power.

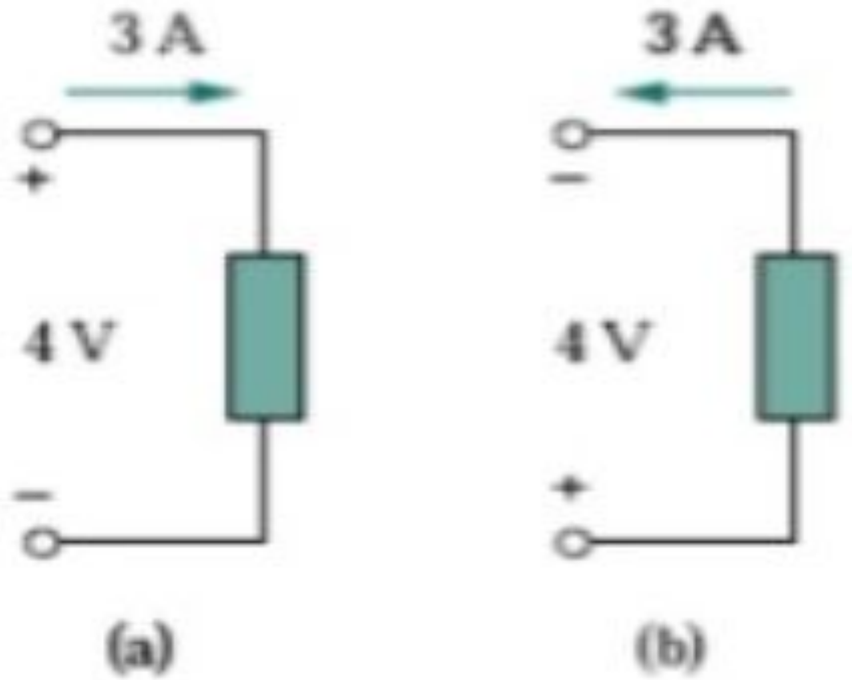


Figure 1.9 Two cases of an element with an absorbing power of 12 W:
(a) $p = 4 \times 3 = 12$ W,
(b) $p = 4 \times 3 = 12$ W.

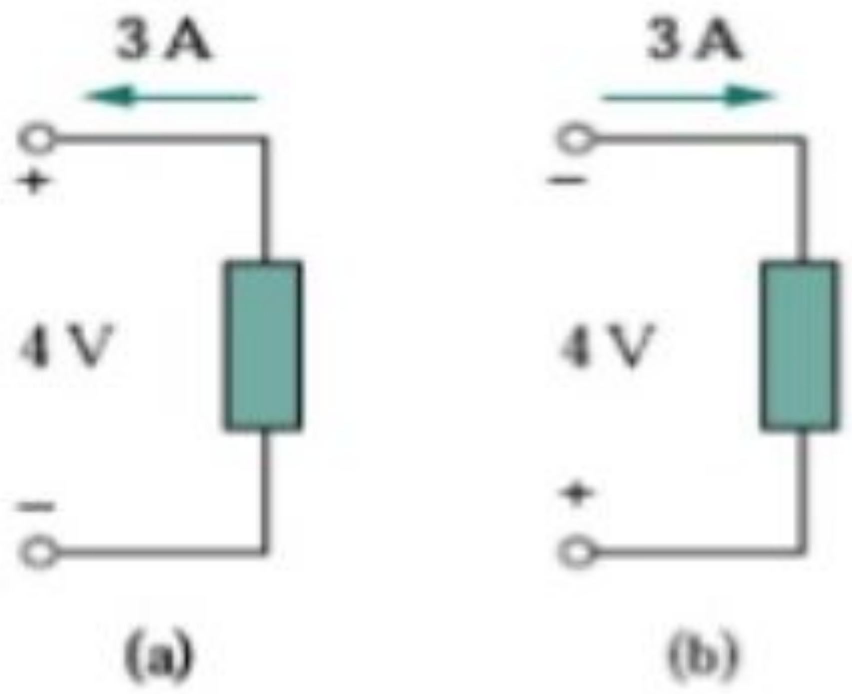


Figure 1.10 Two cases of an element with a supplying power of 12 W:
(a) $p = 4 \times (-3) = -12$ W,
(b) $p = 4 \times (-3) = -12$ W.

POWER AND ENERGY

- ***law of conservation of energy*** *must be obeyed:*

$$\boxed{\sum p = 0}$$

  - algebraic sum of power i any instant of time, must be zero.
- Energy absorbed or supplied by an element from time $\boldsymbol{t_0}$ *to time* $\boldsymbol{t}$ *is*
- **Energy** is the capacity to do work, measured in joules (J).
  - electric power utility compar -hours (Wh)

$$w = \int_{t_0}^{t} p\, dt = \int_{t_0}^{t} vi\, dt$$

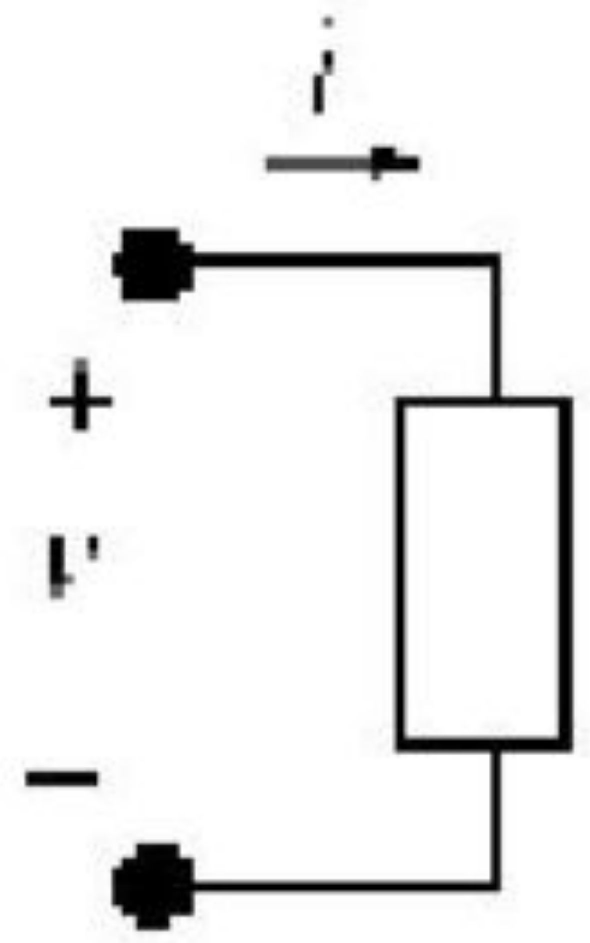
$$1 \text{ Wh} = 3{,}600 \text{ J}$$

Electric Circuit

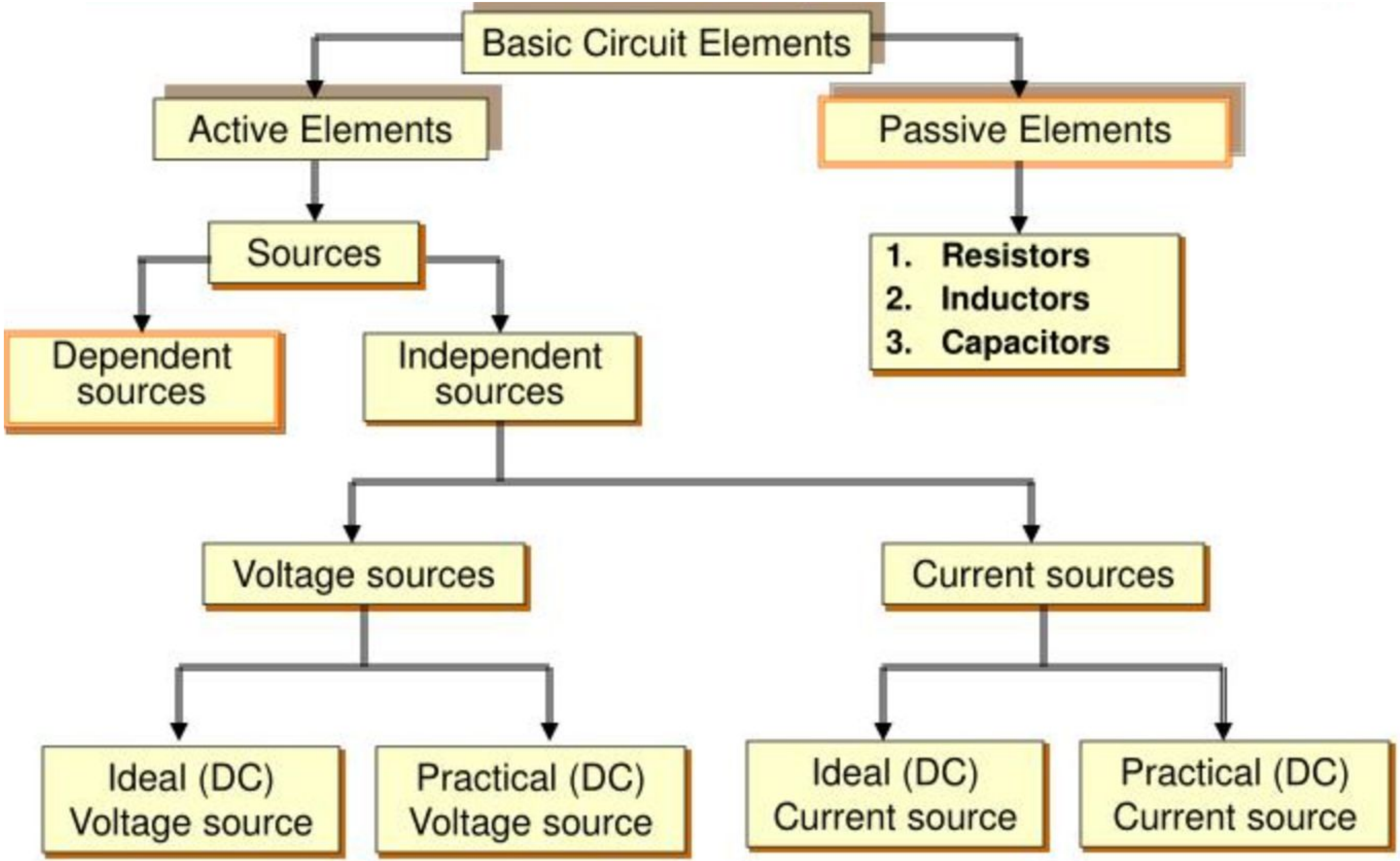
- An interconnection of simple electrical devices with at least one closed path in which current may flow

Circuit Elements

- Active Elements
  - Voltage and Current sources
- Passive Elements
  - Resistors, Inductors and Capacitors



Circuit Elements



Passive Elements

- **Resistance (R):**

Property of opposition to flow of current

- The voltage across the resistor is proportional to the current flowing through it
- $V_R = IR$
- 'R' = V_R/I
- **Unit - Ohm**

Passive Elements

- **Inductance (L):**

Property of opposition to the rate of change of current

- The voltage induced in the inductor is <u>proportional</u> to the rate of change of current flowing through it
- $e_L = L\,(di/dt) = N\,(d\Phi/dt)$
- $L = N\,(d\Phi/di)$
- **Unit – Henry (H)**

Passive Elements

- **Capacitance (C):**

Property which opposes the rate of change of voltage

- The capacitive current is proportional to the rate of change of voltage across it
- $i_c = C\,(dv/dt)$
- Unit – **Farad (F).**

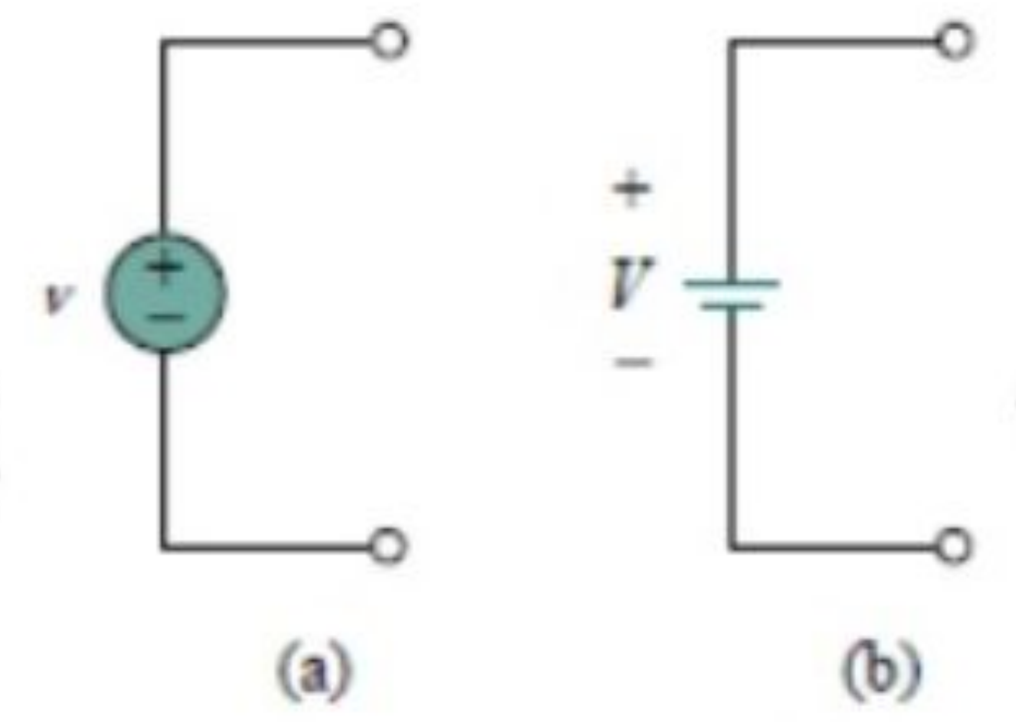
CIRCUIT ELEMENTS

- Two types of elements found in electric circuits:
  - **Passive element** – not capable of generating energy (resistors, capacitors, and inductors)
  - **Active element** - capable of generating energy (generators, batteries, and operational amplifiers)
- Two kinds of sources:
  - **Independent Sources** - an active element that provides a specified voltage or current that is completely independent of other circuit variables
  - **Dependent Sources** - an active element in which the source quantity is controlled by another voltage or current. (transistors, operational amplifiers and integrated circuits)

CIRCUIT ELEMENTS

- **Ideal Independent Voltage Source** delivers to the circuit whatever current is necessary to maintain its terminal voltage (batteries and generators).

- Symbols for inde ed for constant or time-varying voltage, (b) used



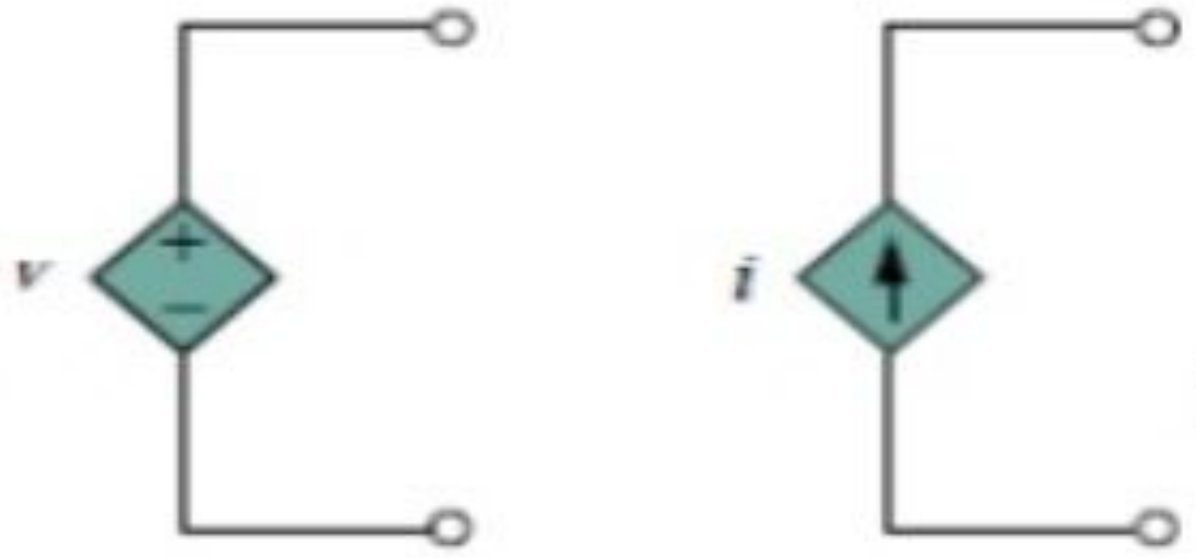
CIRCUIT ELEMENTS

- **Ideal Independent Current Source** is an active element that provides a specified current completely independent of the voltage across the source.

- Symbol for independent cu

CIRCUIT ELEMENTS

- Four possible types of dependent sources:
  - Voltage-Controlled Voltage Source (VCVS).
  - Current-Controlled Voltage Source (CCVS).
  - Voltage-Controlled Current Source (VCCS).
  - Current-Controlled Current Source (CCCS).



(a) (b)

- Symbols for: (a) dep … pendent current source.

OHM'S LAW

- ***Resistance (R)*** –of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).
- The resistance of any material with a uniform cross-sectional area *(A) depends on A and* its length (l)

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

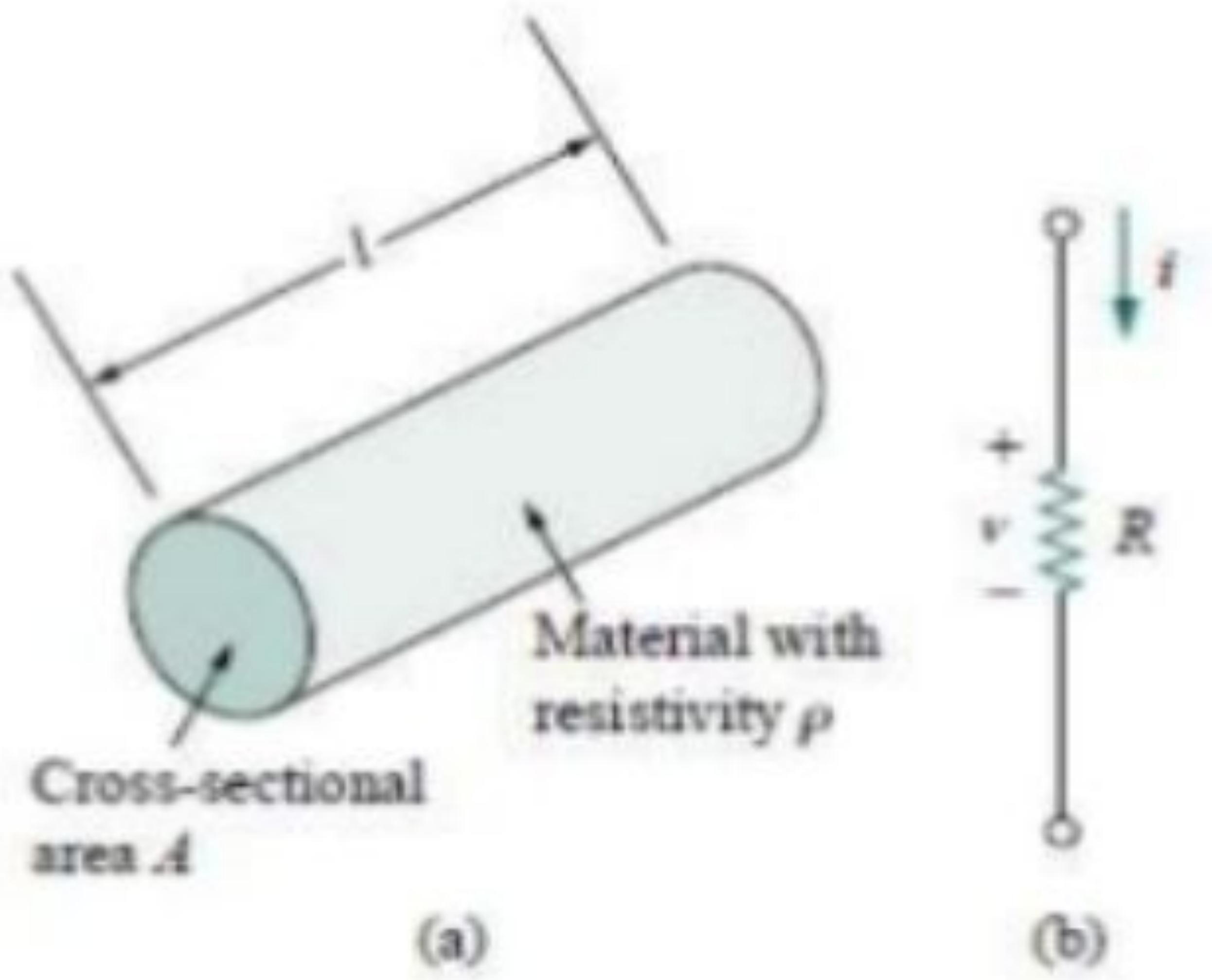
Where, rho is the resistivity of the material.

Good conductors like Copper and Aluminium have low resistivity while insulators such as Mica, Paper have high resistivities.

OHM'S LAW

TABLE 2.1 Resistivities of common materials.

Material	Resistivity (Ω·m)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
Silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}	Insulator
Glass	10^{12}	Insulator
Teflon	3×10^{12}	Insulator



(a) Resistor, (b) Circuit symbol for resistance.

OHM'S LAW

- **Ohm's law** states that the voltage "v" *across a resistor is directly proportional* to the current "i" *flowing through the resistor.*

$$\boxed{v = iR}$$

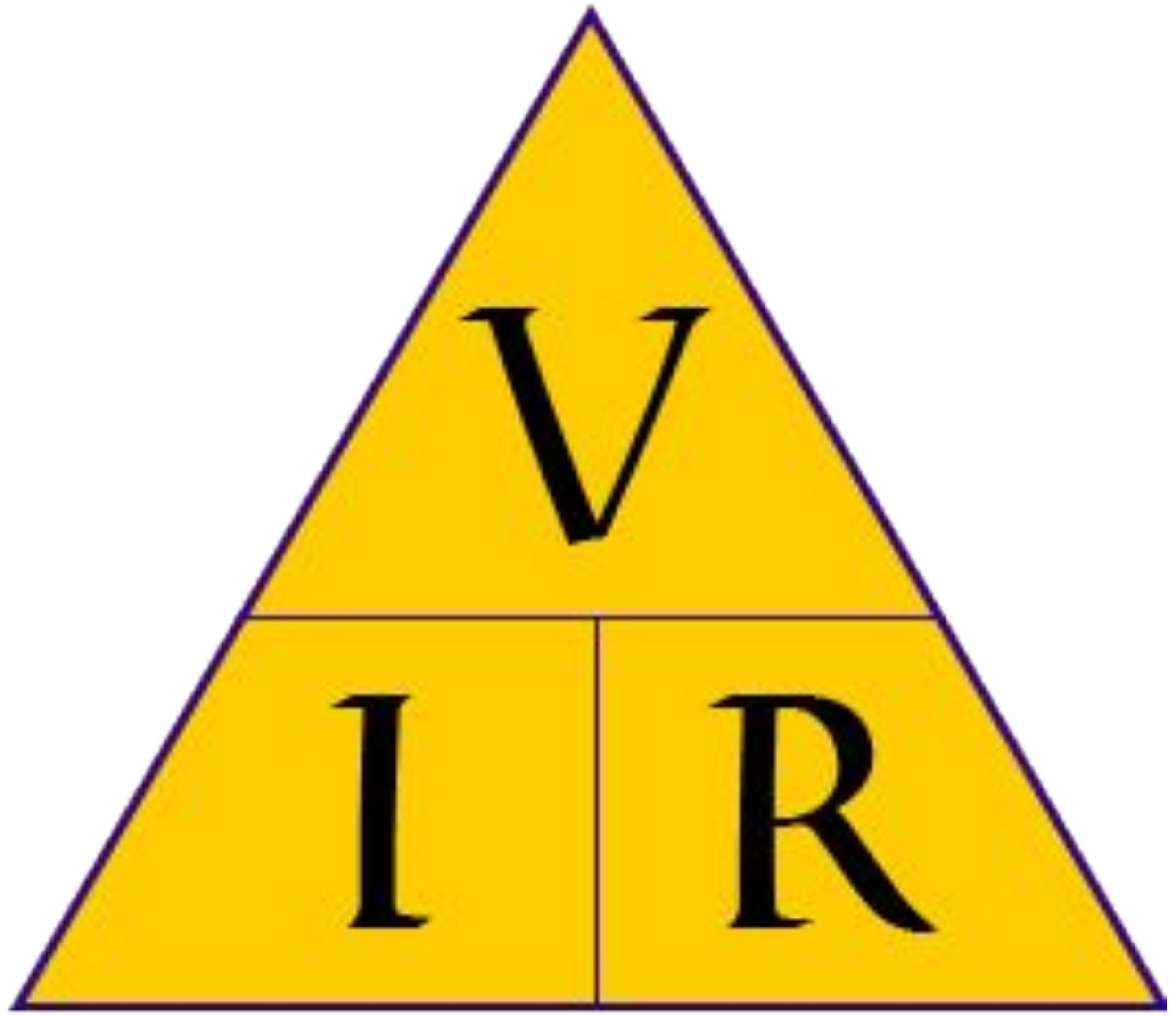
Short Circuit : is a circuit element where, resistance approaches to zero.

Open Circuit : is a circuit element where, resistance approaches to infinity.

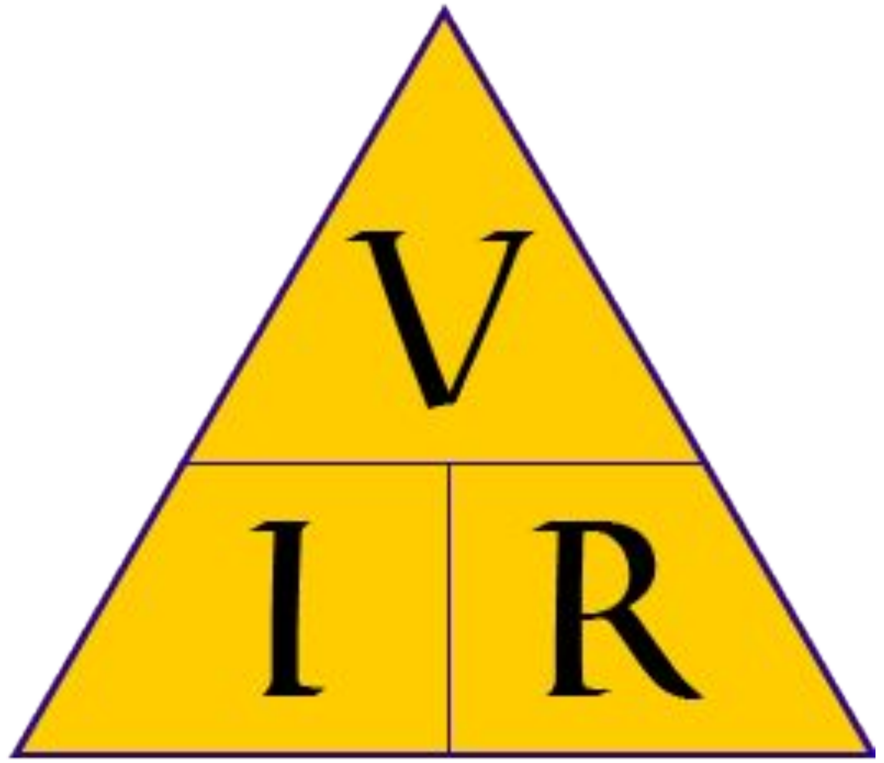
Ohm's law Magic Triangle

$$E = I R$$

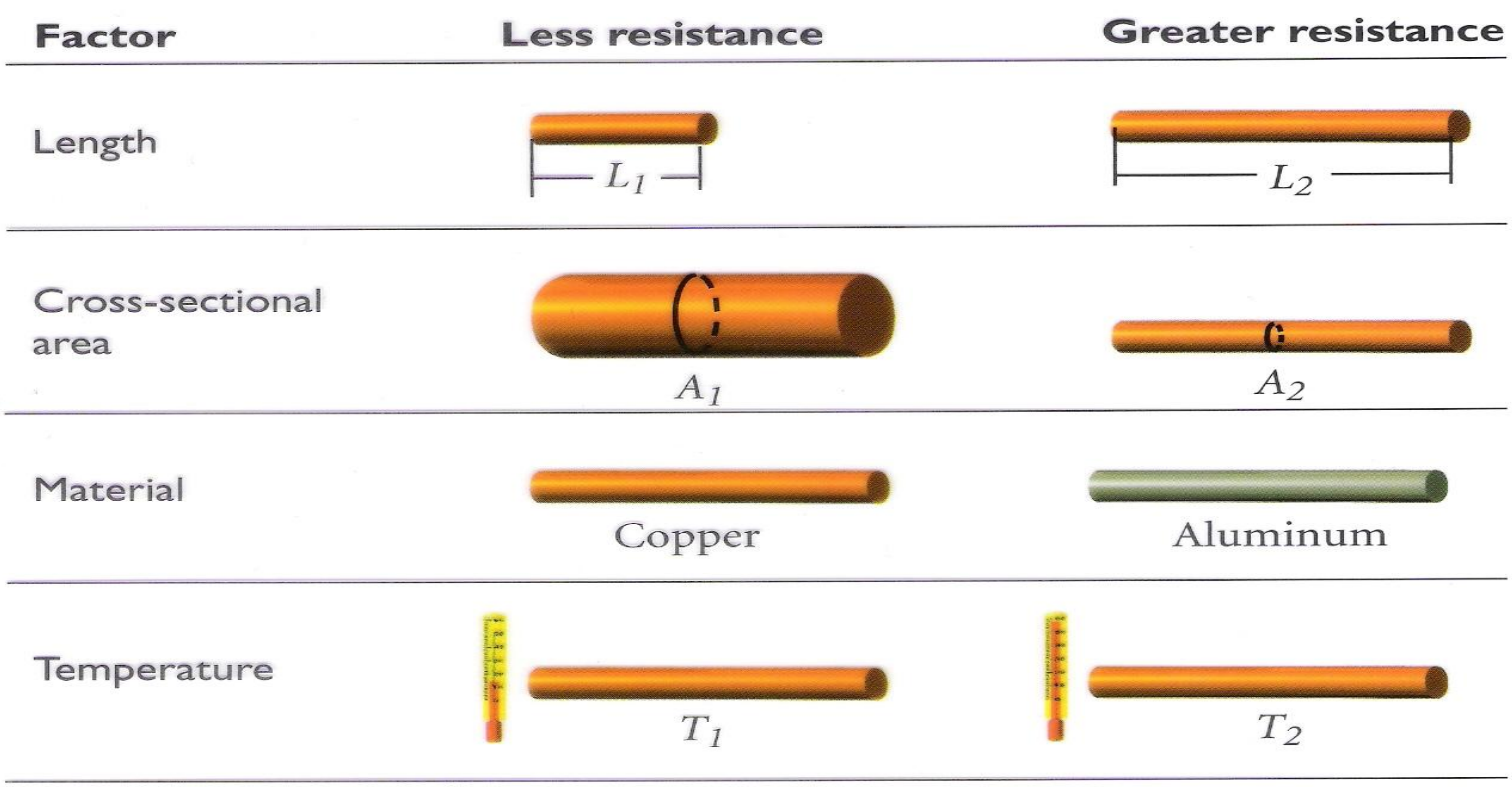
$$I = \frac{E}{R} \qquad R = \frac{E}{I}$$



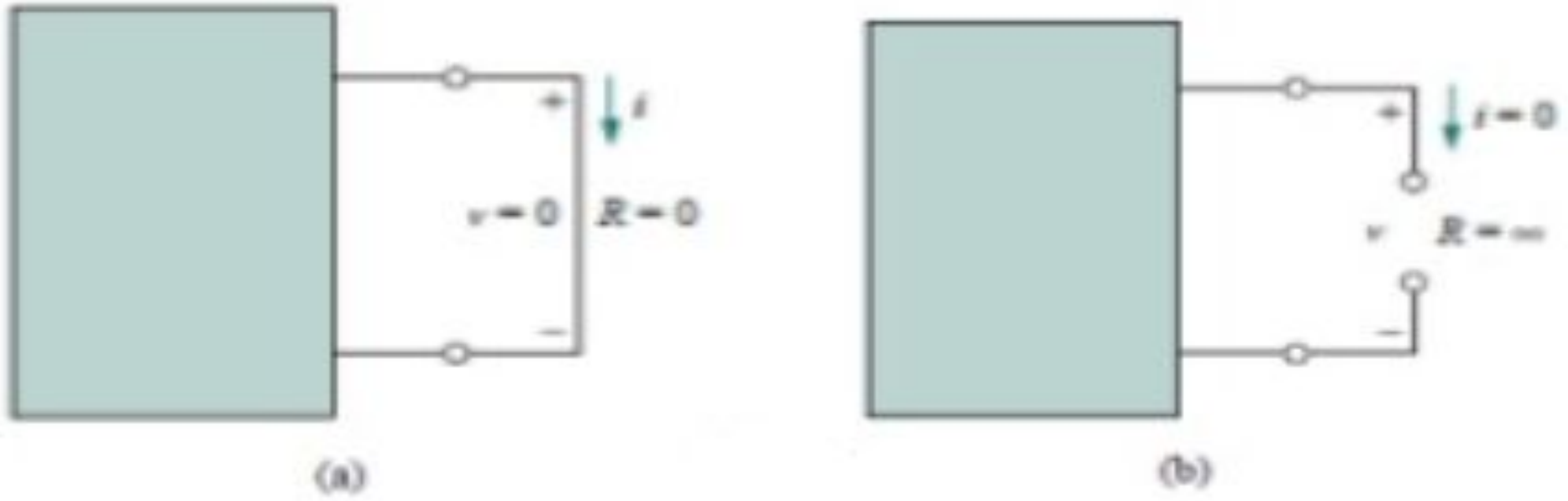
Quantity	Symbol	Unit of Measurement	Unit Abbreviation
Current	I	Ampere ("Amp")	A
Voltage	E *or* V	Volt	V
Resistance	R	Ohm	Ω



Factors Affecting Resistance



OHM'S LAW



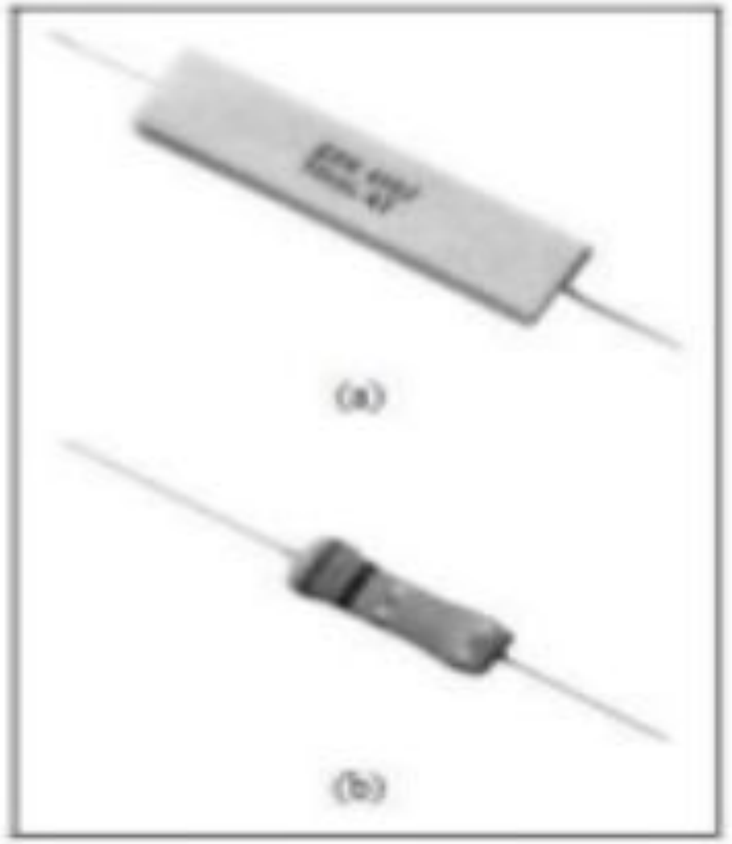


Figure 2.3 Fixed resistors: (a) wire-wound type, (b) carbon film type.

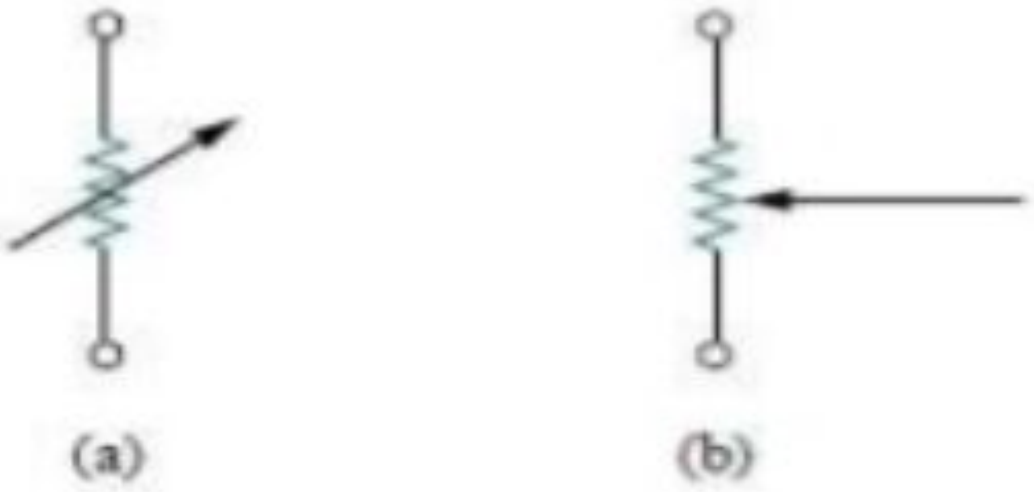


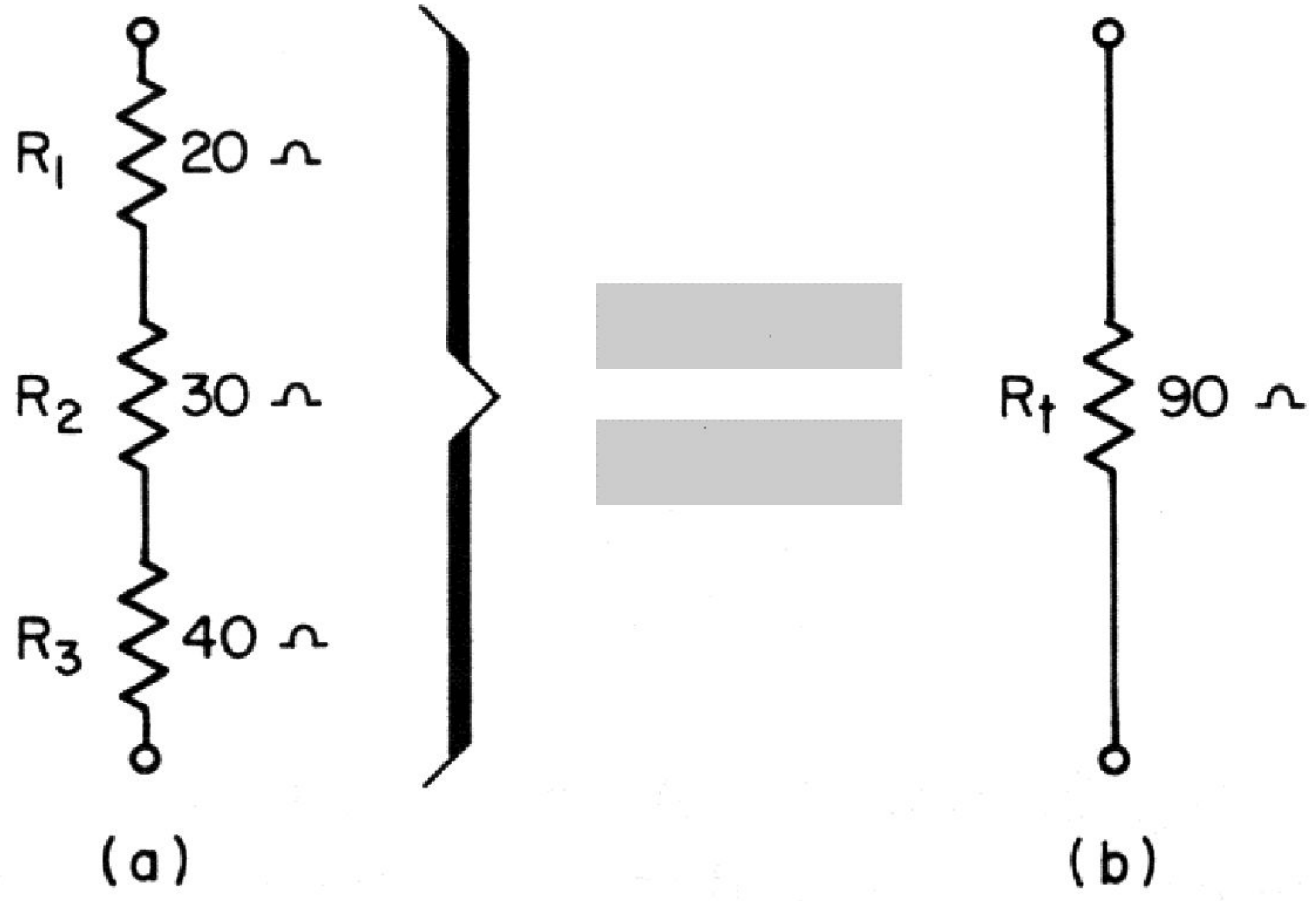
Figure 2.4 Circuit symbol for: (a) a variable resistor in general, (b) a potentiometer.

Figure 2.5 Variable resistors: (a) composition type, (b) slider pot.

Series circuits
and
Parallel circuits

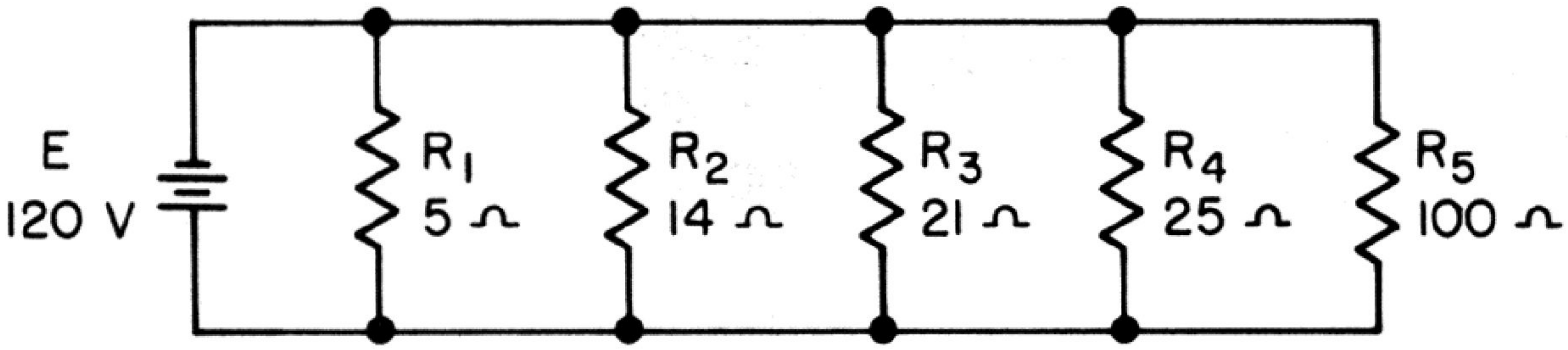
Series Circuits

- Series Circuits are the simplest to work with.
- Here we have three resistors of different resistances.
- They share a single connection point.
- When added together the total resistance is 90-Ohms.



Parallel Circuits

- A parallel circuit is shown here and it has TWO common connection points with another component.
- We cannot add the values of each resistor together like we can in the previous series circuit. So what do we need to do?



Calculating Total Resistance of a Parallel Circuit

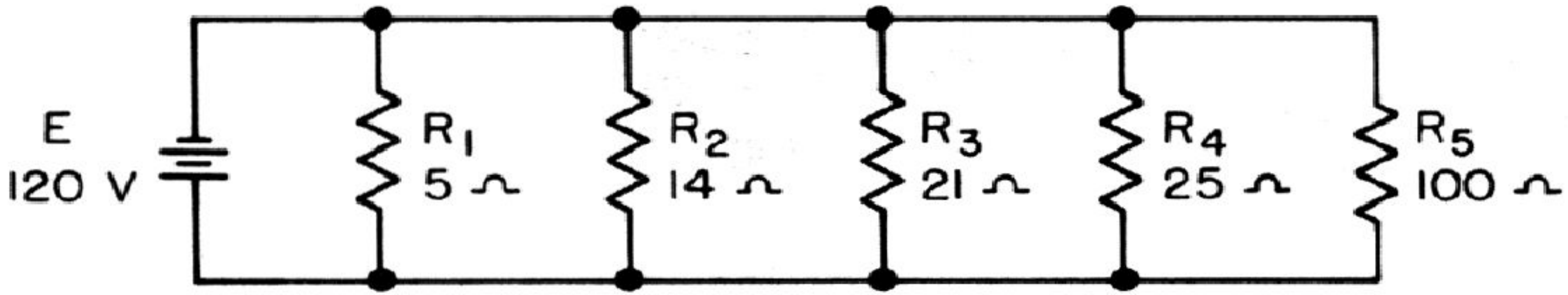
Two methods can be used to calculate the total resistance of the parallel circuit. They are the Product Over Sum equation or the Reciprocal Formula.

Product Over Sum is $R_T = \frac{(R1 \text{ x } R2)}{(R1 + R2)}$

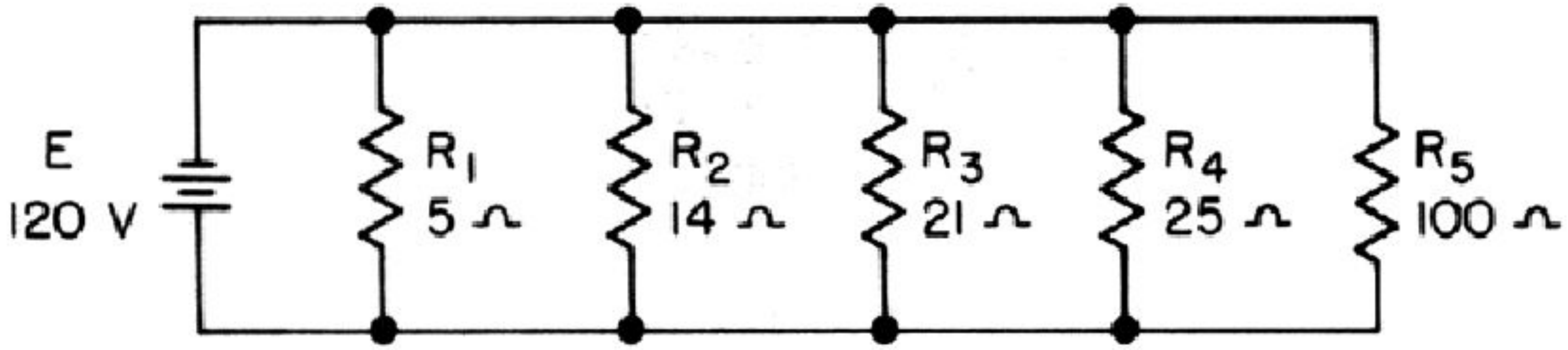
Reciprocal Formula is $R_T = \frac{1}{\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}+\frac{1}{R4}+\frac{1}{R5}}$

Calculating Total Resistance of a Parallel Circuit

- So let use calculate R_T in this circuit.
- $R_T = \frac{1}{\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}+\frac{1}{R4}+\frac{1}{R5}}$



Calculating Total Resistance of a Parallel Circuit



- $R_T = \dfrac{1}{\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}+\frac{1}{R4}+\frac{1}{R5}} = \dfrac{1}{\frac{1}{5}+\frac{1}{14}+\frac{1}{21}+\frac{1}{25}+\frac{1}{100}}$

$$= \frac{1}{0.2 + 0.0714 + 0.0476 + 0.04 + 0.01} = \frac{1}{0.369} = 2.7\Omega$$

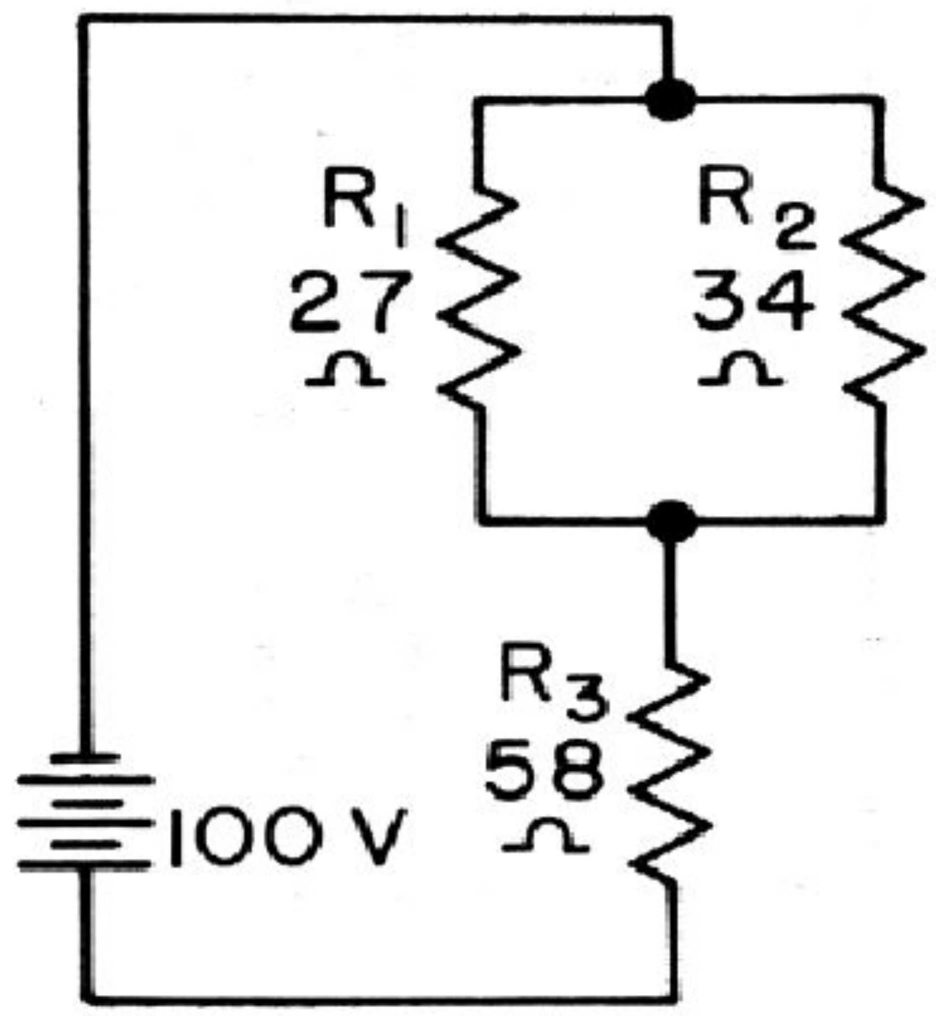
Series-Parallel Circuits

If we combined a series circuit with a parallel circuit we produce a Series-Parallel circuit.

- R1 and R2 are in parallel and R3 is in series with R1 || R2.

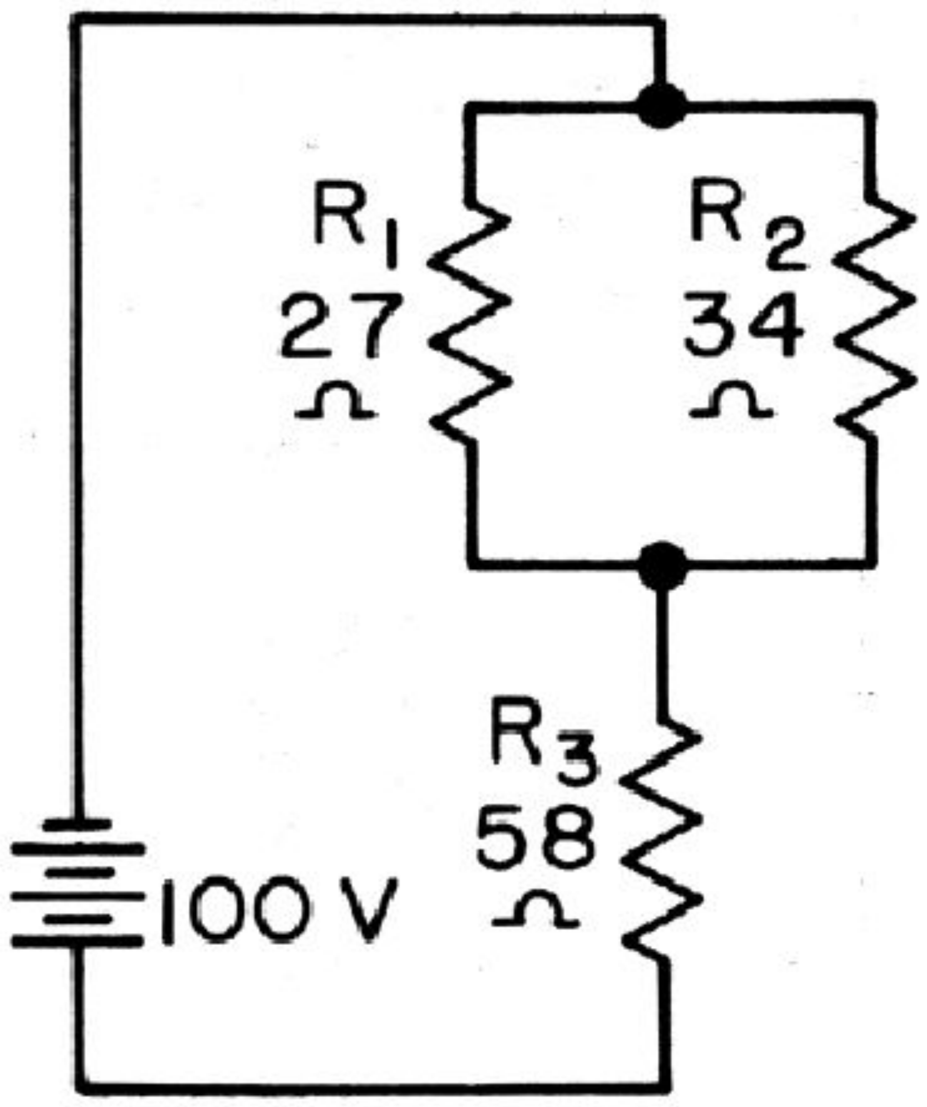
The double lines between R1 and R2 is a symbol for parallel.

We need to calculate R1 || R2 first before adding R3.



Series-Parallel Circuits

- Here we can use the shorter Product Over Sum equation as we only have two parallel resistors.



$$R_{1\,\|\,2} = \frac{(R1 \times R2)}{(R1 + R2)} = \frac{27 \, x \, 34}{27+34} = \frac{918}{61}$$

$R_{1\,\|\,2} = 15.049\Omega + R3 = R_T$

$R_T = 15.049 + 58 = 73.049\Omega$

- $R_T = 73\Omega$

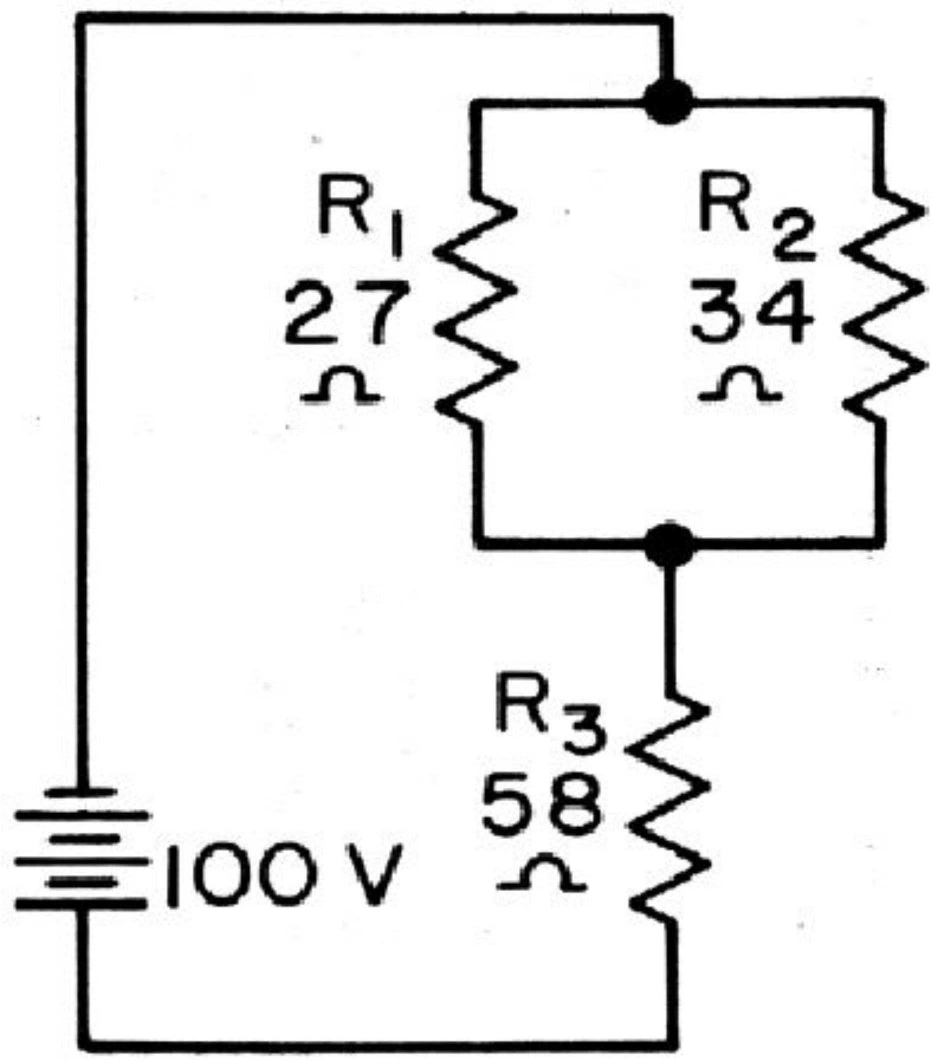
Series-Parallel Circuits

- Now that we have our circuit resistance of RT we can calculate circuit current by using Ohm's Law.

If RT = 73Ω and E = 100V

$$I = \frac{100}{73} = 1.369 \text{ Amps or } 1.37 \text{ A}$$

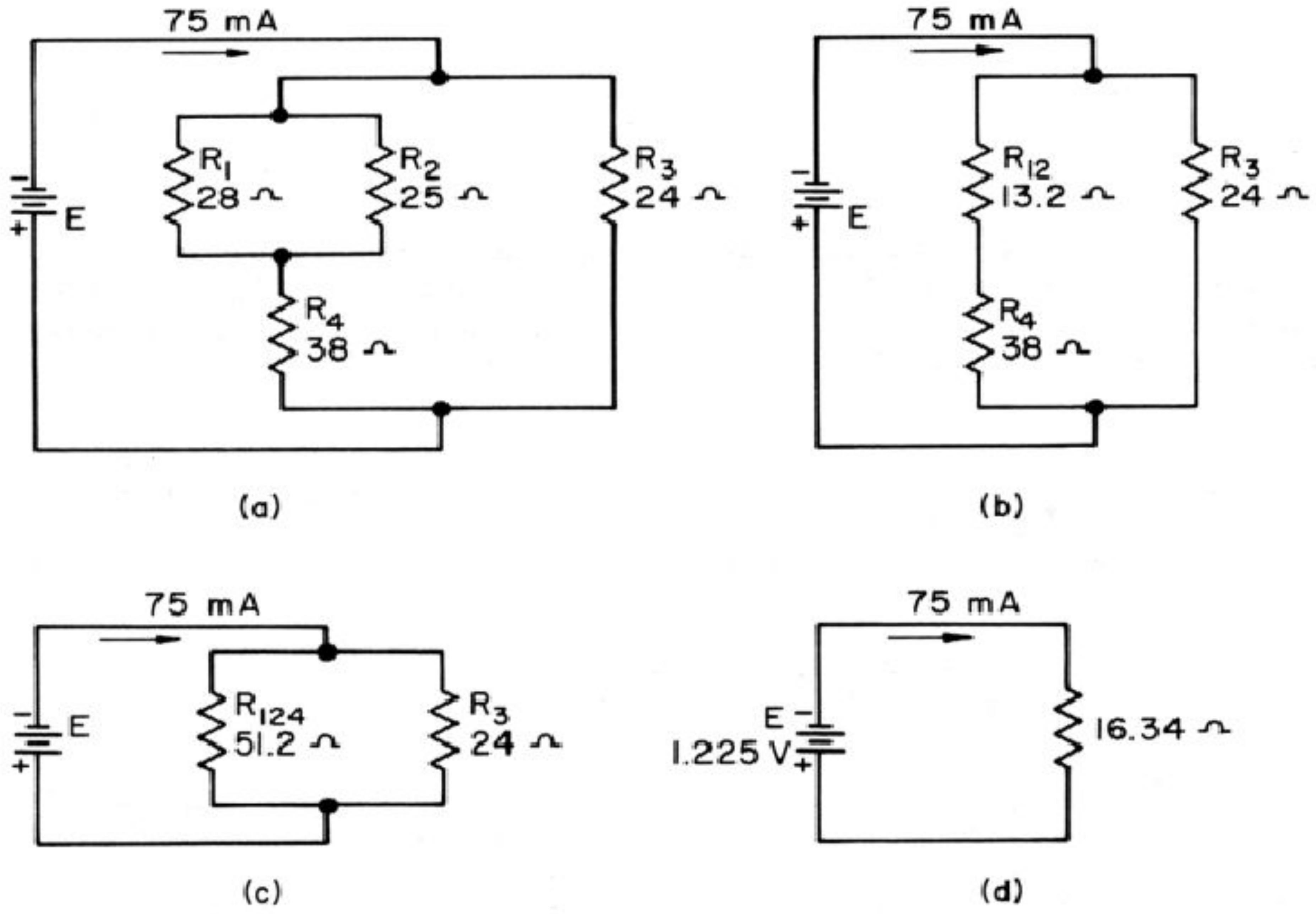
The parallel resistors must be reduced to a single series value before being added to the series resistor.



Series-Parallel Circuits

- Series-Parallel circuits can be more complex as in this case:

In circuit (a) we have our original complex circuit. In circuit (b) we have resistors R_1 and R_2 combined to get 13.2Ω. R_4 is in series with the newly combined R_{12} and their added value is 51.2Ω. And now (c) we are left with R_{124} in parallel with R_3. (d) is our final circuit.

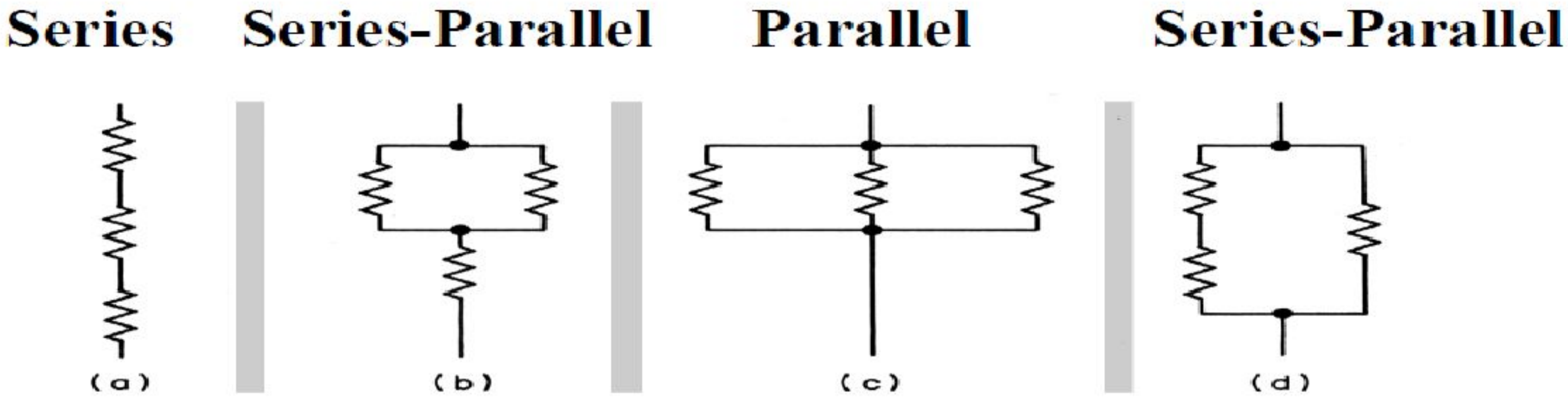


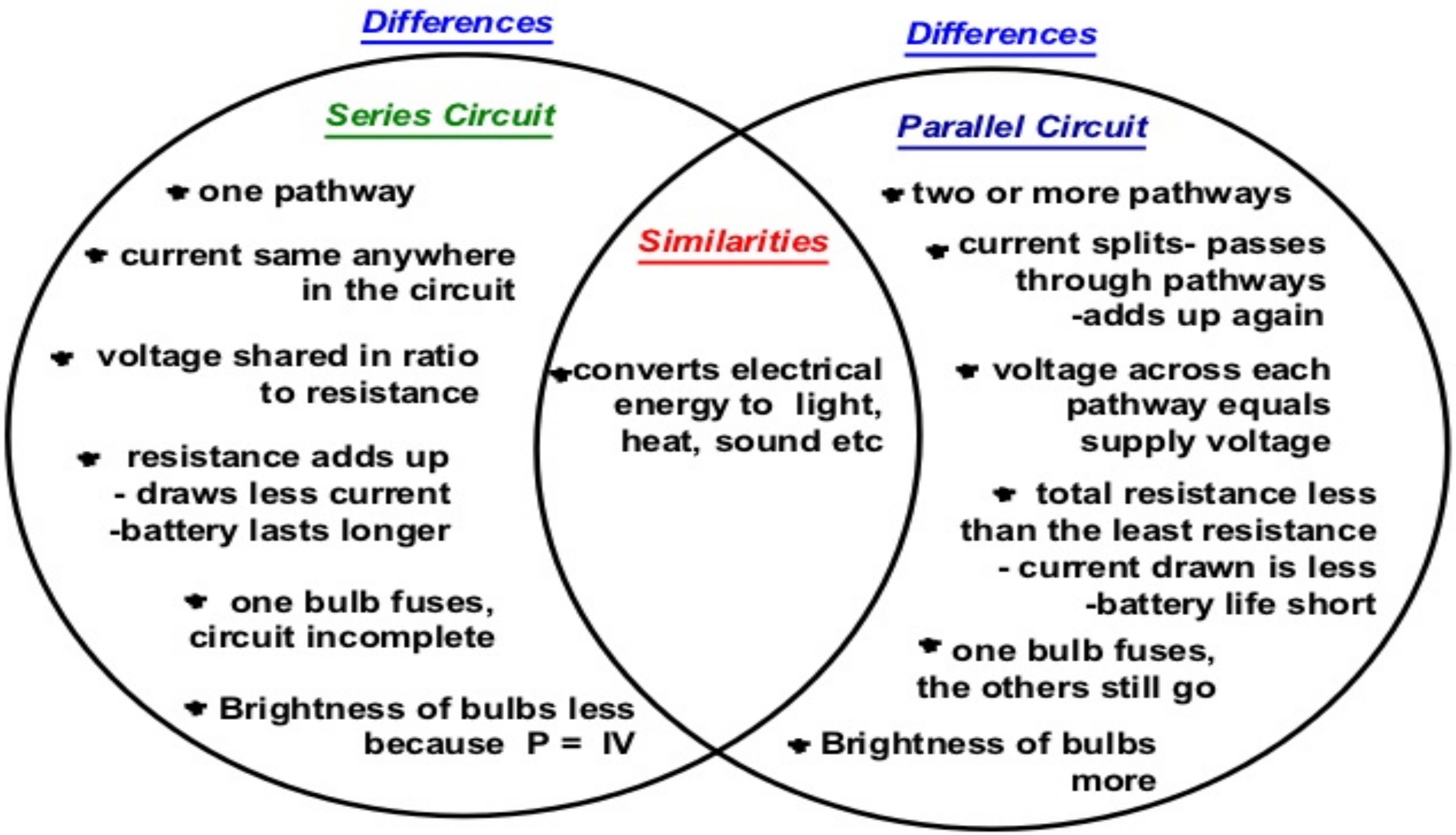
Series-Parallel Circuits

- Series, Parallel and Series-Parallel circuits are our three main types of circuits and they are common in DC and AC supplied circuits.
- A series circuit has one shared connection point between components.
- A parallel circuit has two shared connection points between components.

Series-Parallel Circuits

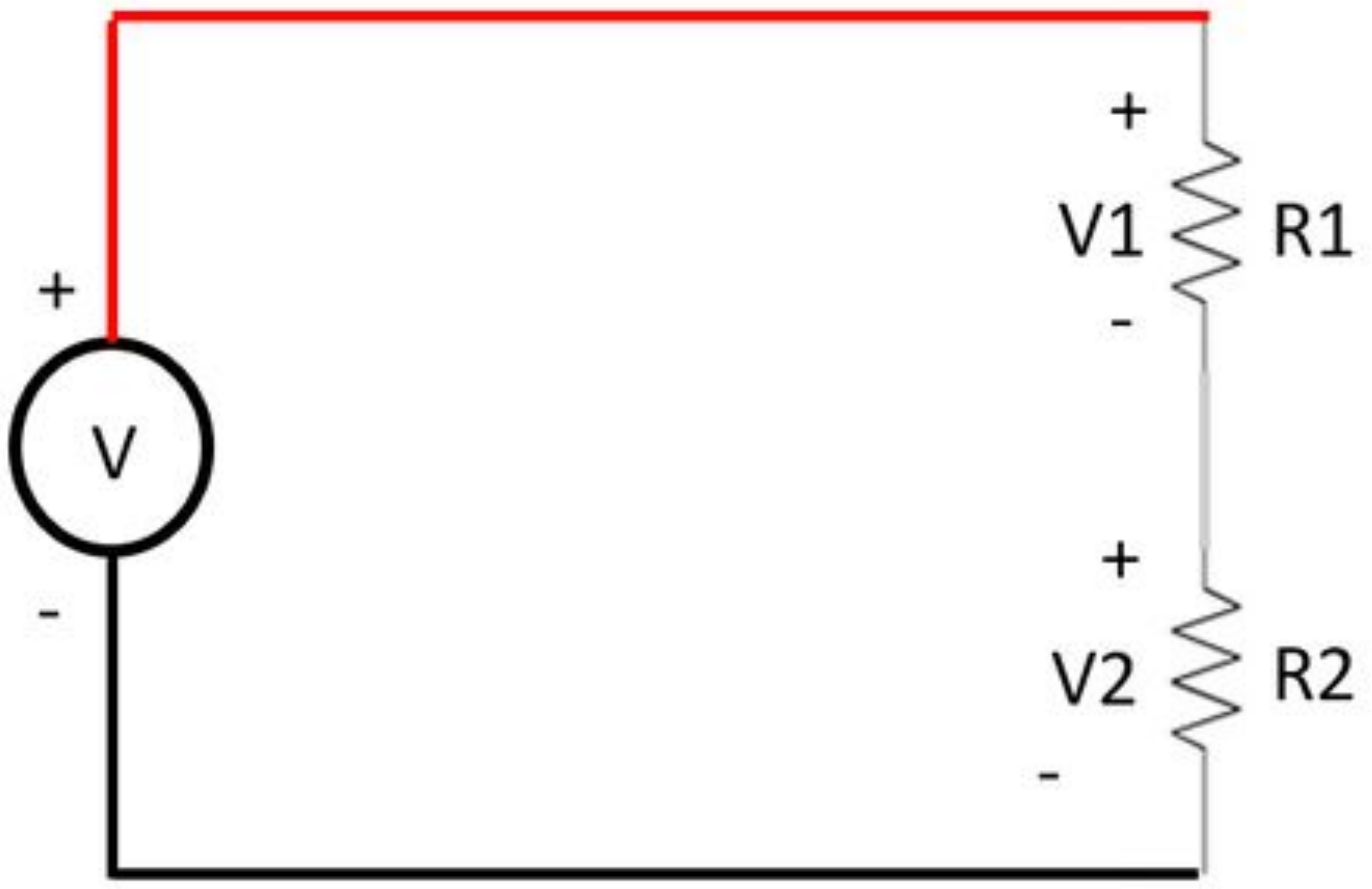
A series-parallel circuit can have two components sharing one connection point with a single component while they have two common connection points between them.




Differences
Differences
Series Circuit
Parallel Circuit
Similarities
one pathway
current same anywhere in the circuit
voltage shared in ratio to resistance
resistance adds up - draws less current -battery lasts longer
one bulb fuses, circuit incomplete
Brightness of bulbs less because P = IV
converts electrical energy to light, heat, sound etc
two or more pathways
current splits- passes through pathways -adds up again
voltage across each pathway equals supply voltage
total resistance less than the least resistance - current drawn is less -battery life short
one bulb fuses, the others still go
Brightness of bulbs more

Voltage Division Rule and Current Division Rule

Voltage Division Rule



V1 is the voltage across R1:

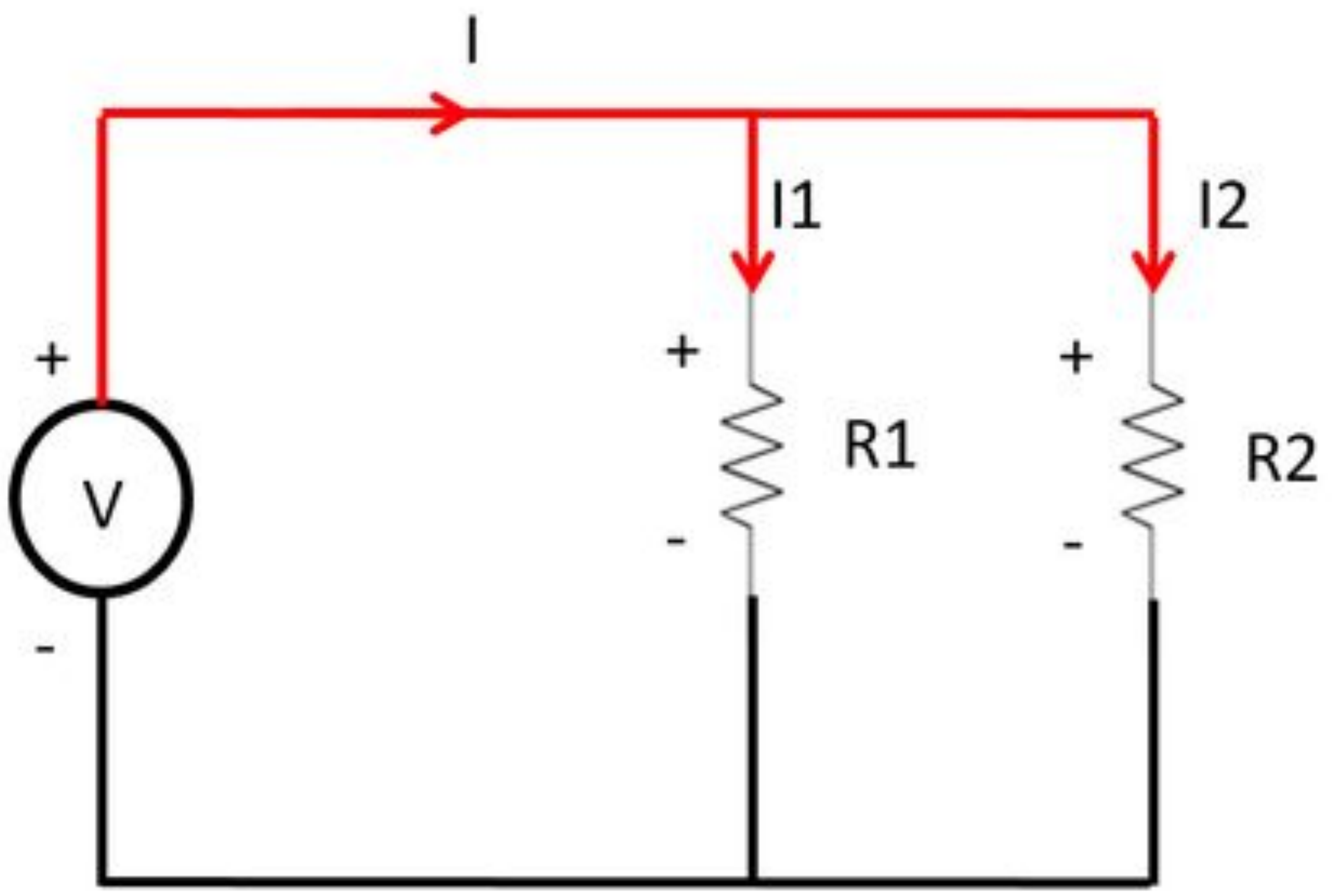
$$V1 = \frac{R1}{R1+R2} * V$$

V2 is the voltage across R2:

$$V2 = \frac{R2}{R1+R2} * V$$

Voltage division rule

Current Division Rule



I1 is the current following through R1:

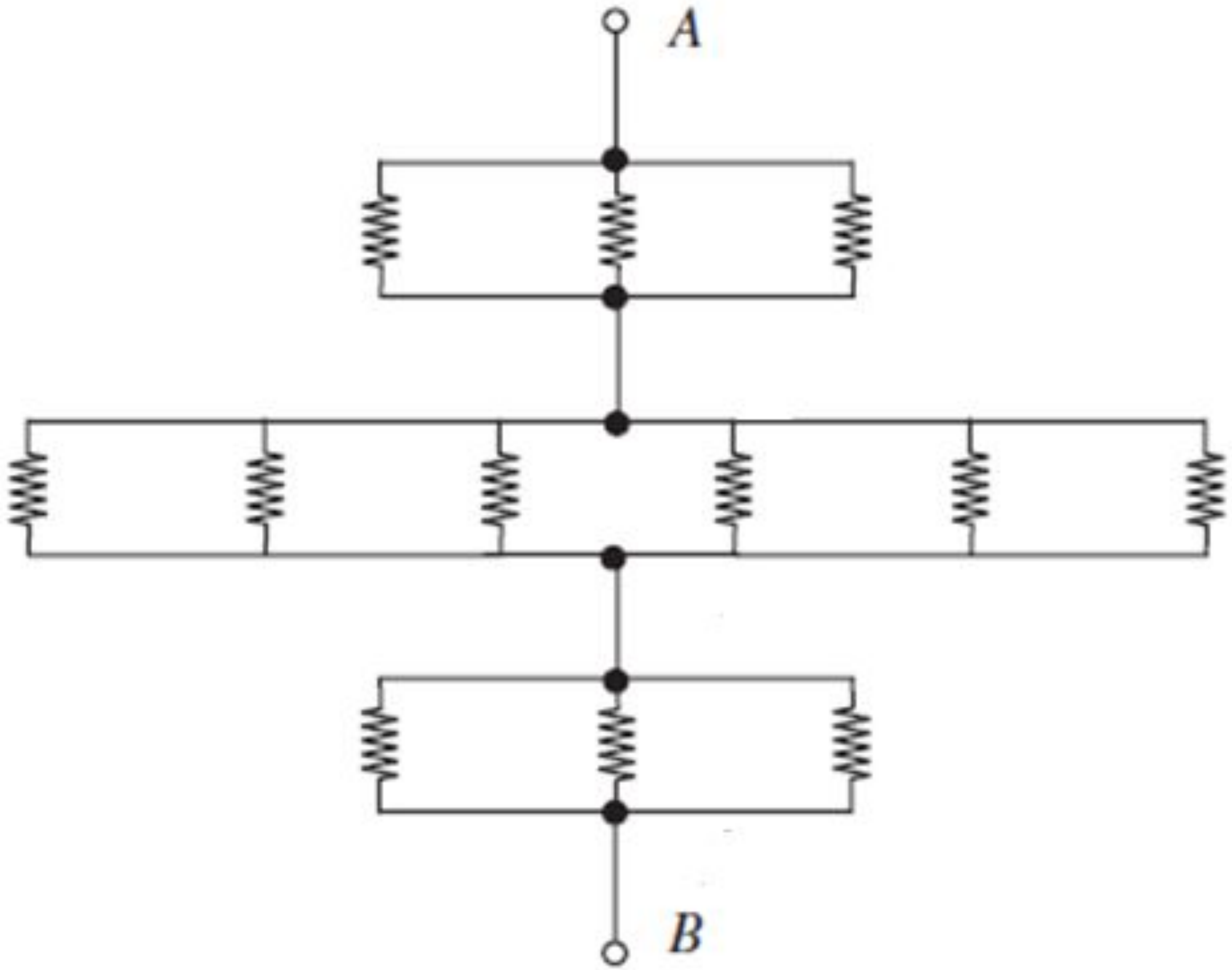
$$I1 = \frac{R2}{R1+R2} * I$$

I2 is the current following through R2:

$$I2 = \frac{R1}{R1+R2} * I$$

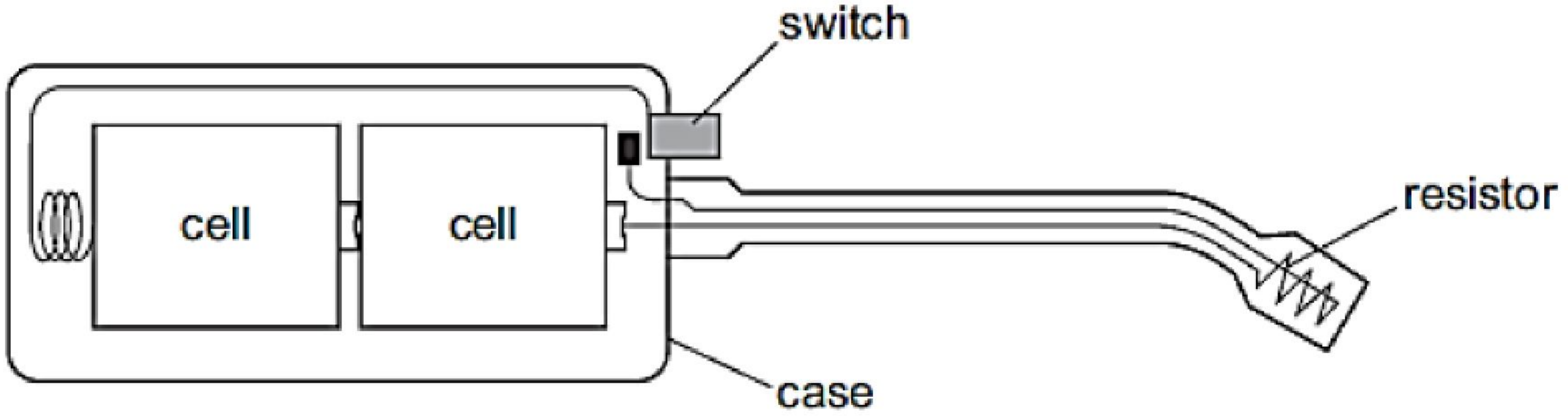
Current division rule

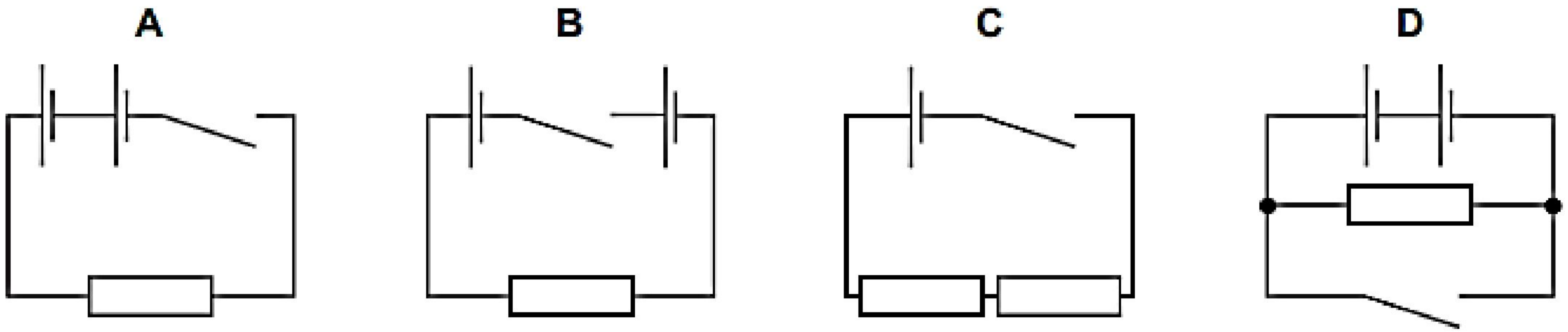
1. Each resistor is of 1Kohm. Calculate equivalent resistance.



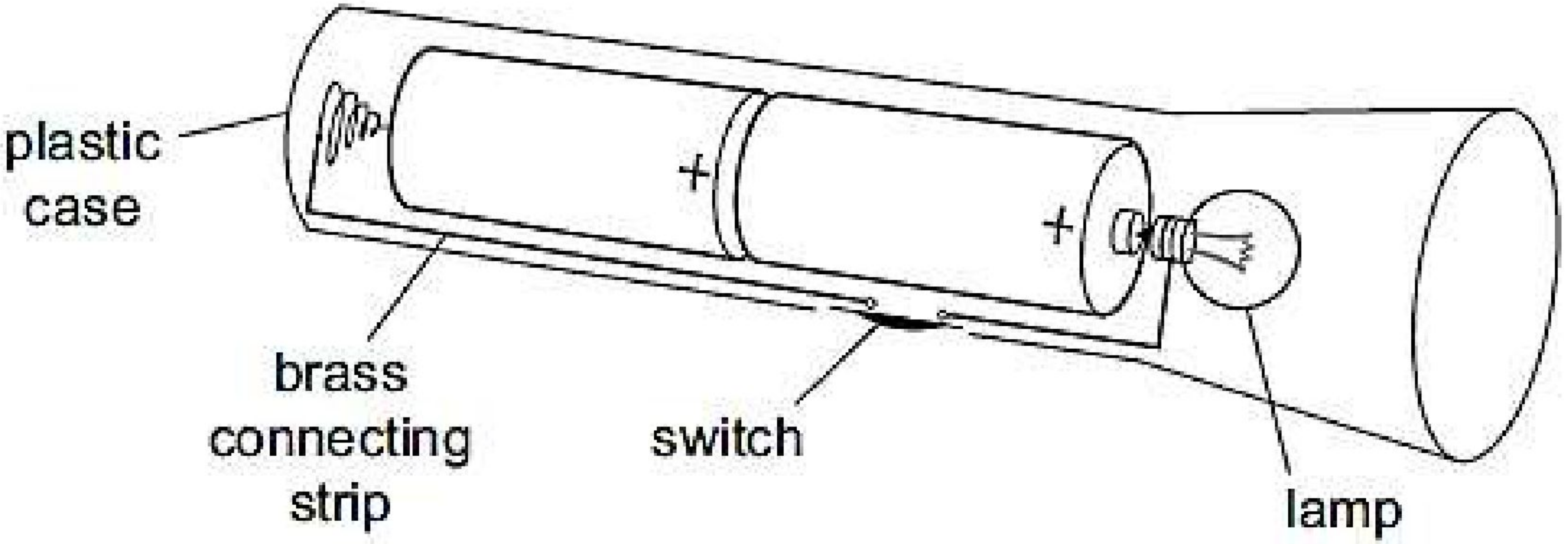
2. The diagram shows the components of a lighter for a gas

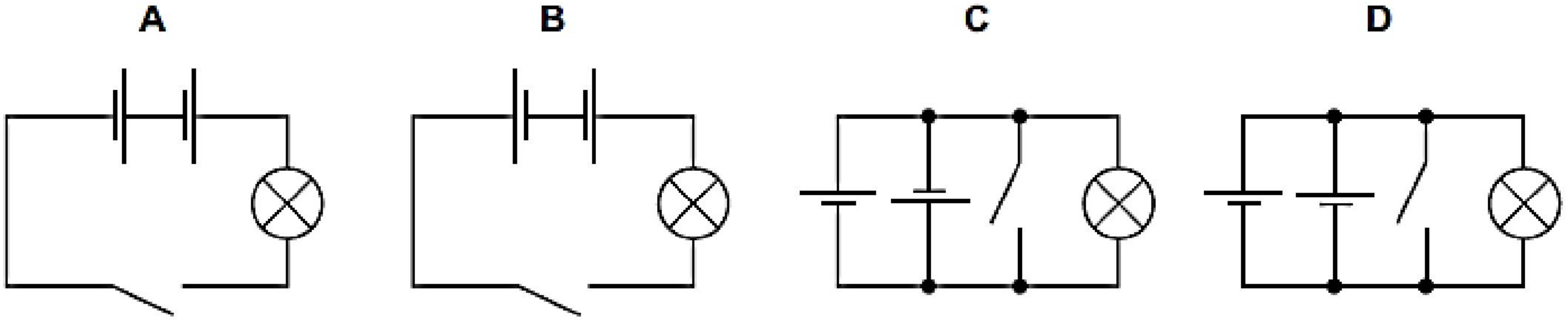
cook lighter?



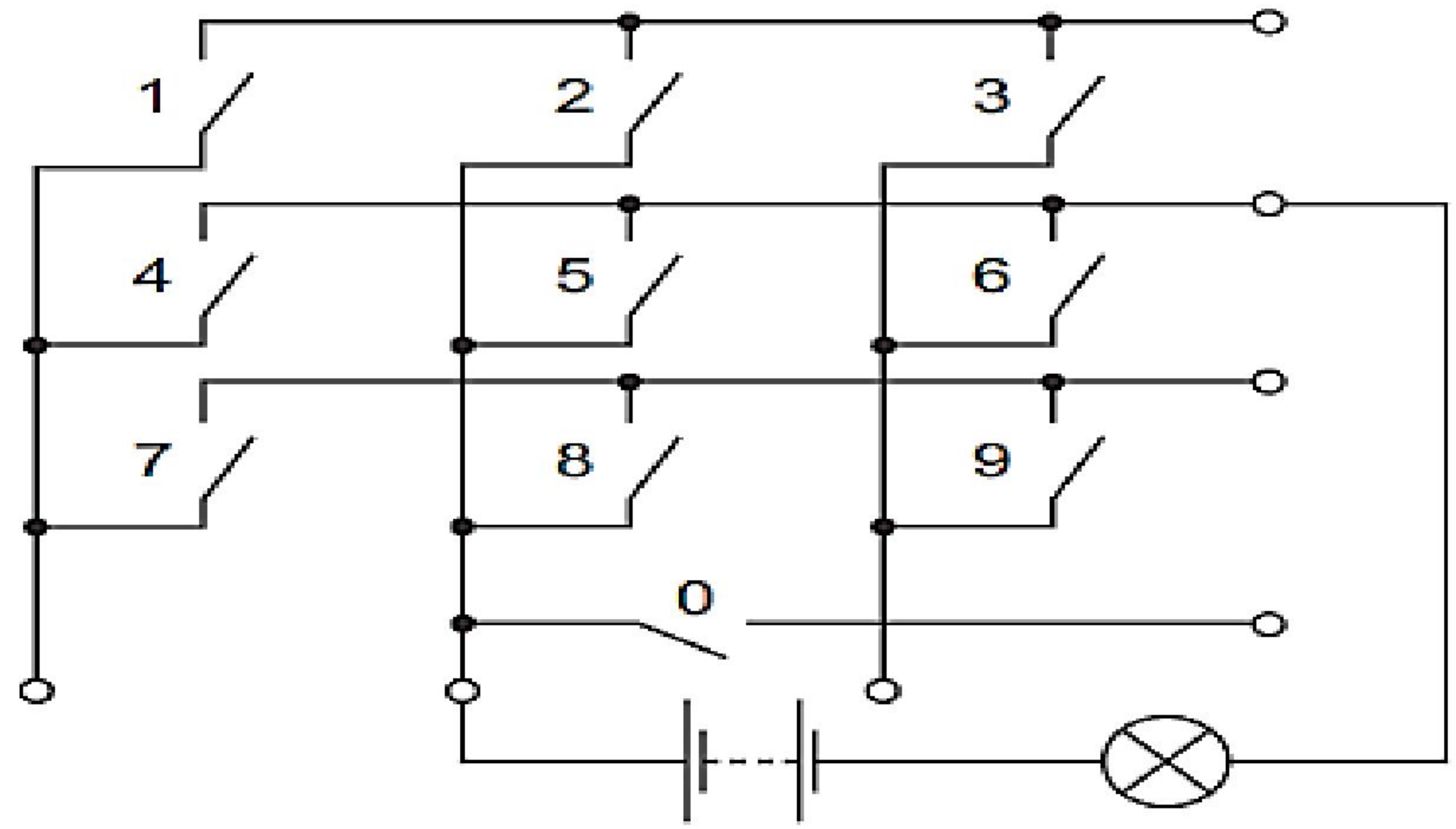


3. The diagram shows a torch containing two cells, a switch
and a lamp. What is the circuit diagram for the torch?



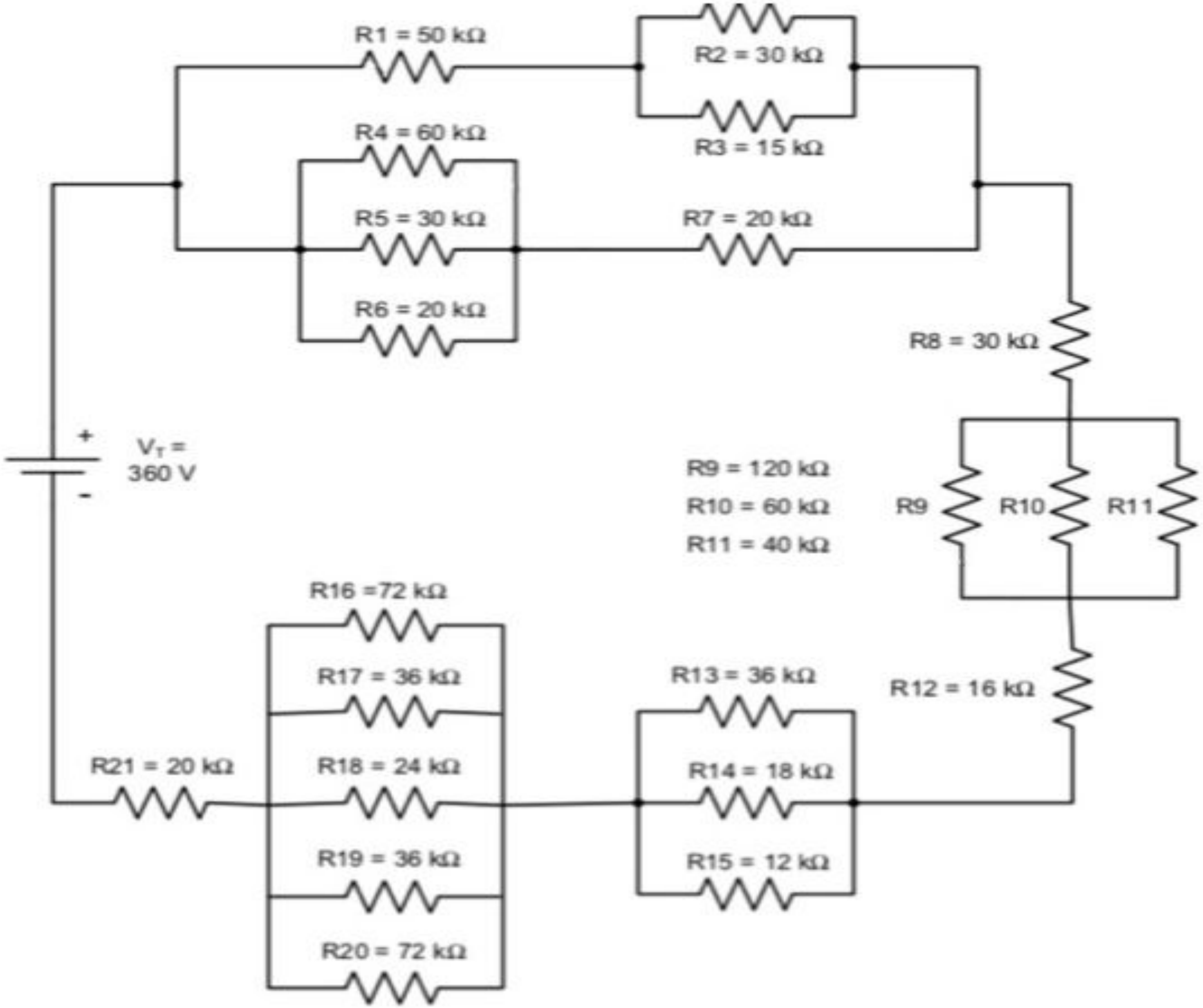


4. A student tests the circuit of a press-button telephone with a lamp and a battery. Which single switch can be pressed to make the lamp light?



A. 0
B. 1
C. 5
D. 6

5. Calculate the total resistance of the given network and calculate the total current in the circuit.



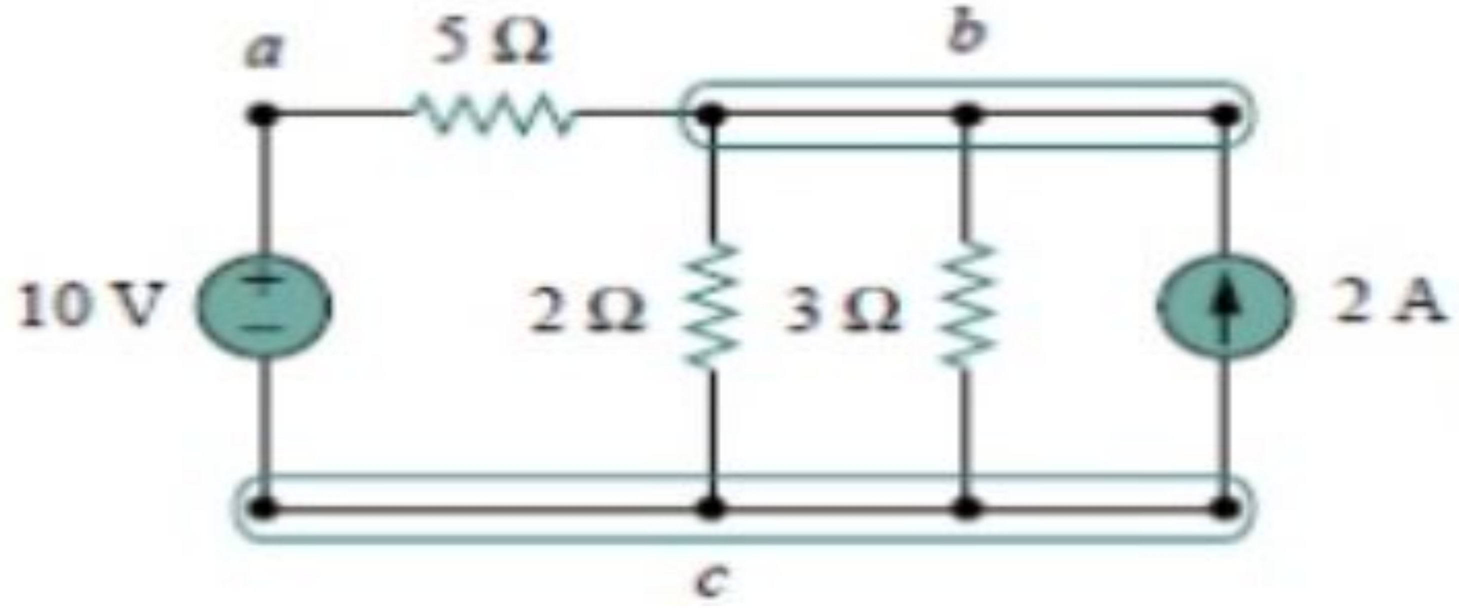
NODES, BRANCHES, AND LOOPS

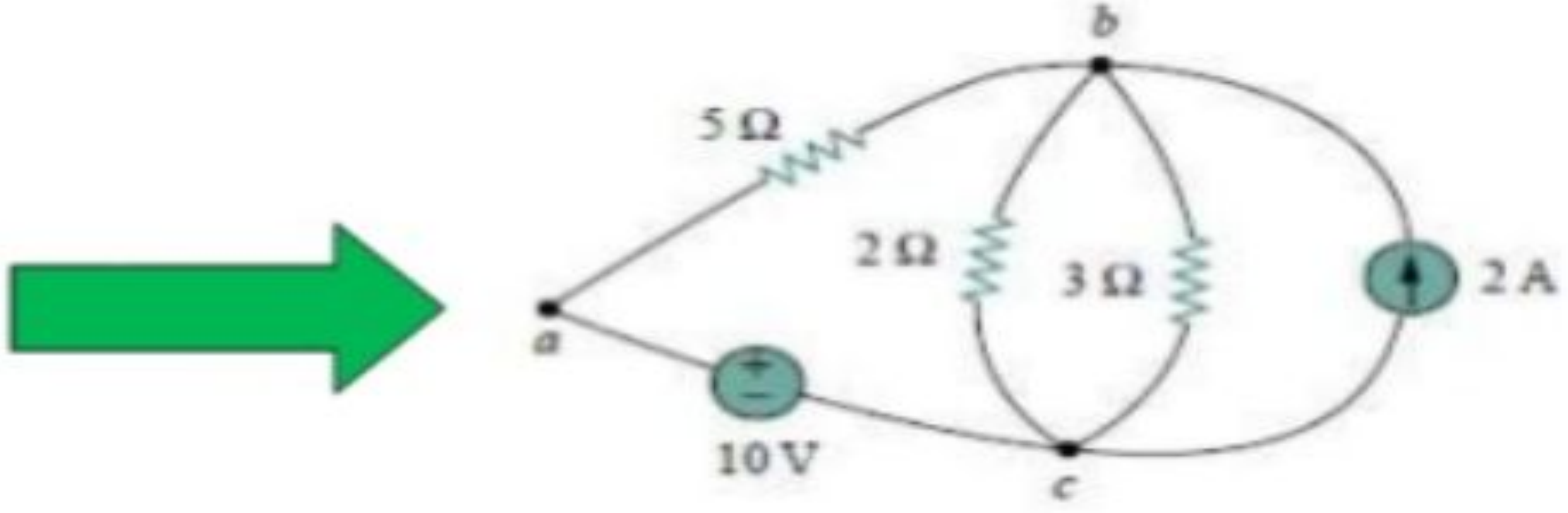
- A **branch** represents a single element such as a voltage source or a resistor
- A **node** is the point of connection between two or more branches
- A **loop** is any closed path in a circuit.
- A network with *b branches, n nodes, and l independent loops will* satisfy the fundamental theorem of network topology:

$$b = l + n - 1$$

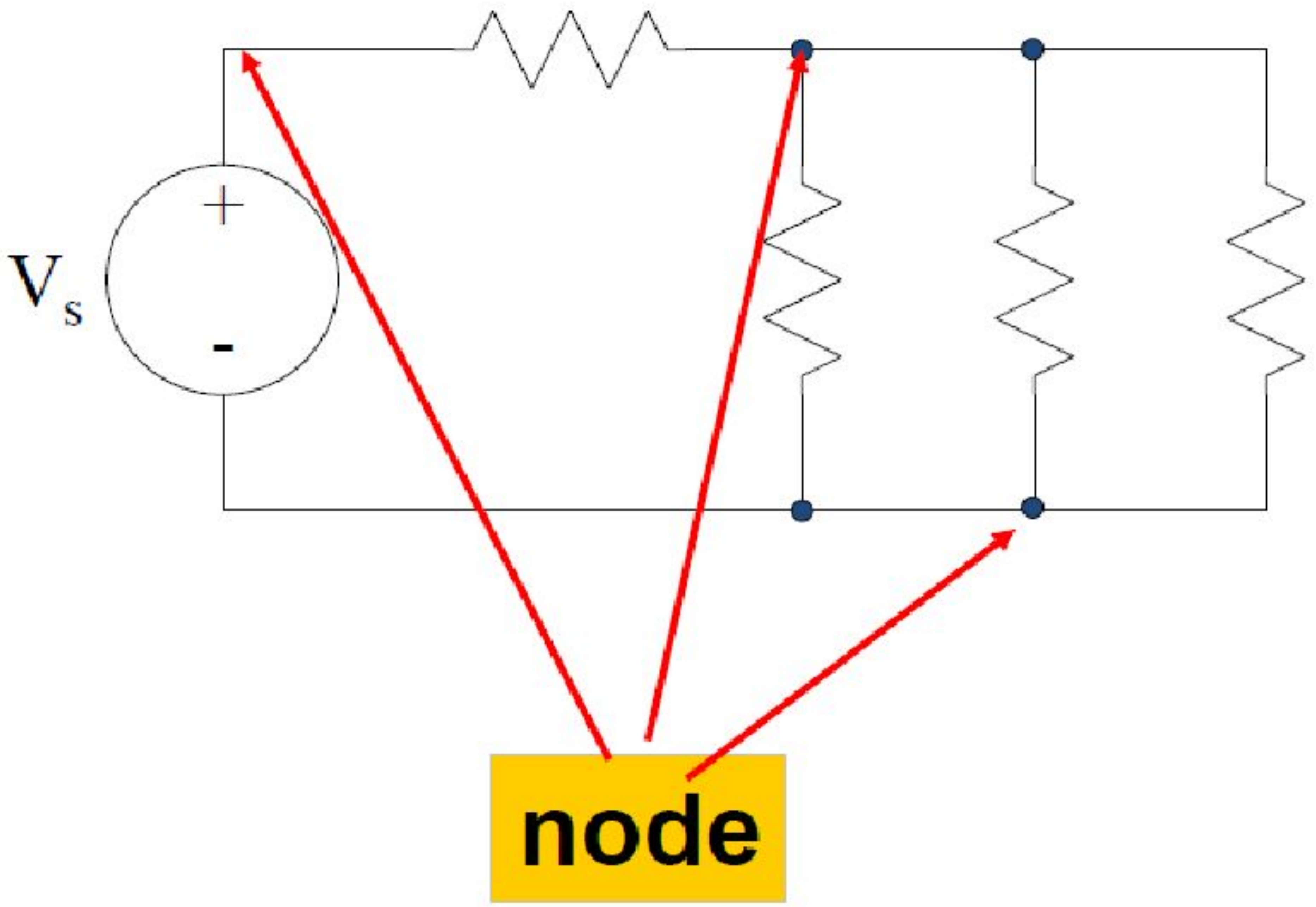
NODES, BRANCHES, AND LOOPS

- Two or more elements are in **series** if they are cascaded or connected sequentially and consequently carry the same current
- Two or more elements are in **parallel** if they are connected to the same two nodes and consequently have the same voltage across them.

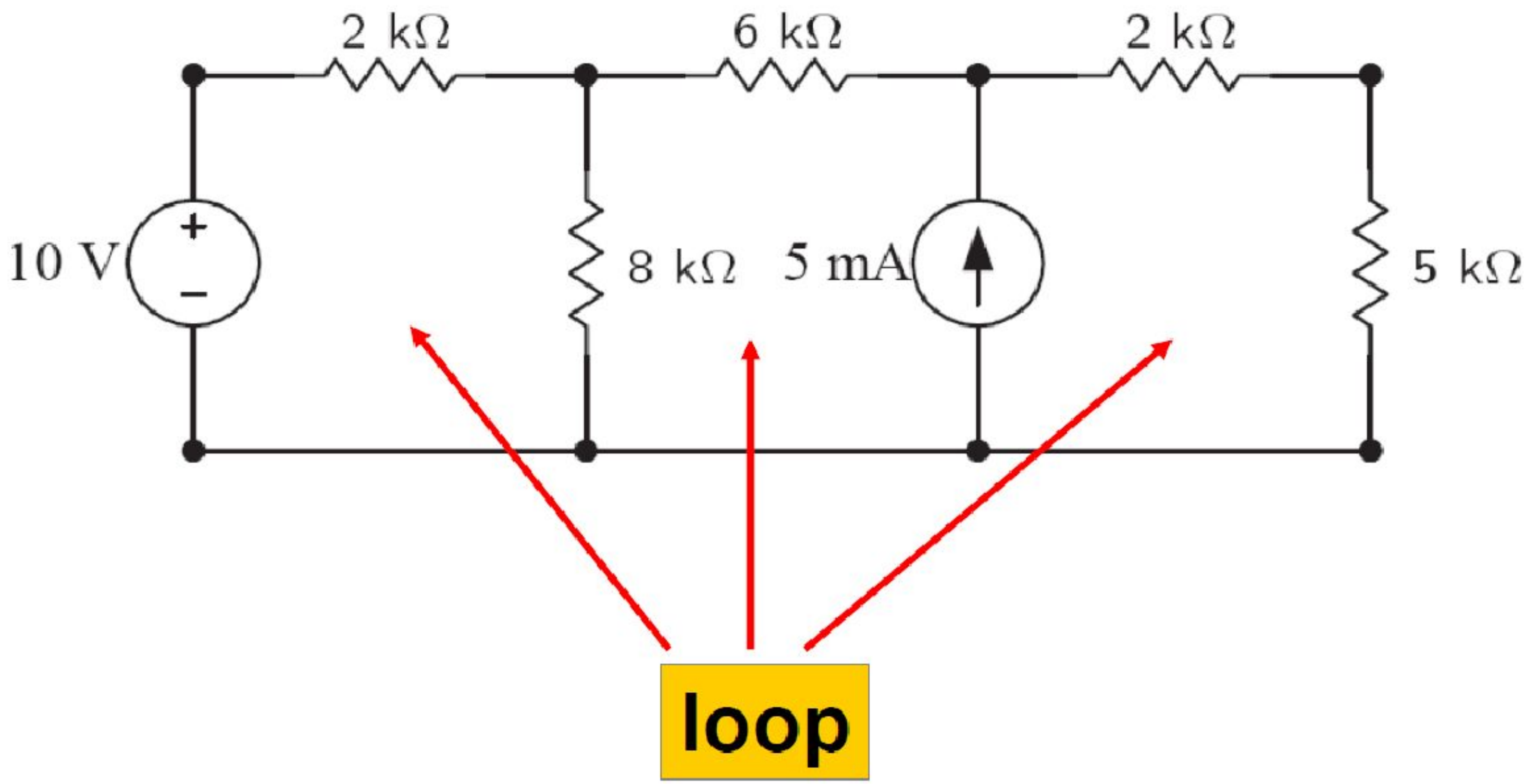




Example: Find the Nodes



Example: Find the loops



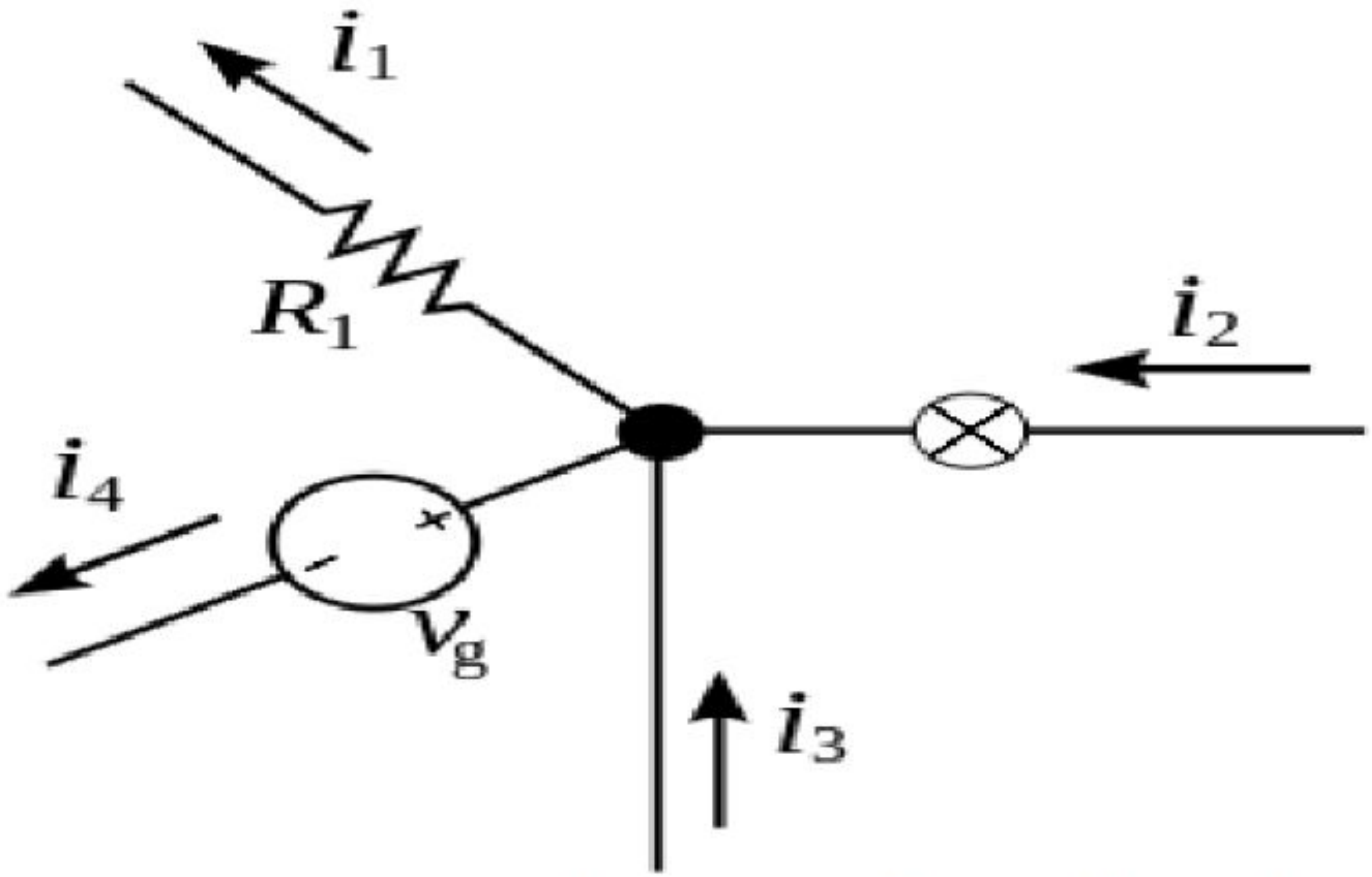
Kirchhoff's laws

- Kirchoff’s current law:-
- This law is also called **Kirchhoff's first law**, **Kirchhoff's point rule**, or **Kirchhoff's junction rule** (or nodal rule).
- The principle of conservation of electric charge implies that:
- At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node, or:The algebraic sum of currents in a network of conductors meeting at a point is zero.Recalling that current is a signed (positive or negative) quantity reflecting direction towards or away from a node, this principle can be stated as:

$$\sum_{k=1}^{n} I_k = 0$$

- *n* is the total number of branches with currents flowing towards or away from the node.
- The law is based on the conservation of charge whereby the charge (measured in coulombs) is the product of the current (in amperes) and the time (in seconds).

Cont..



The current entering any junction is equal to the current leaving that junction. $i_2 + i_3 = i_1 + i_4$

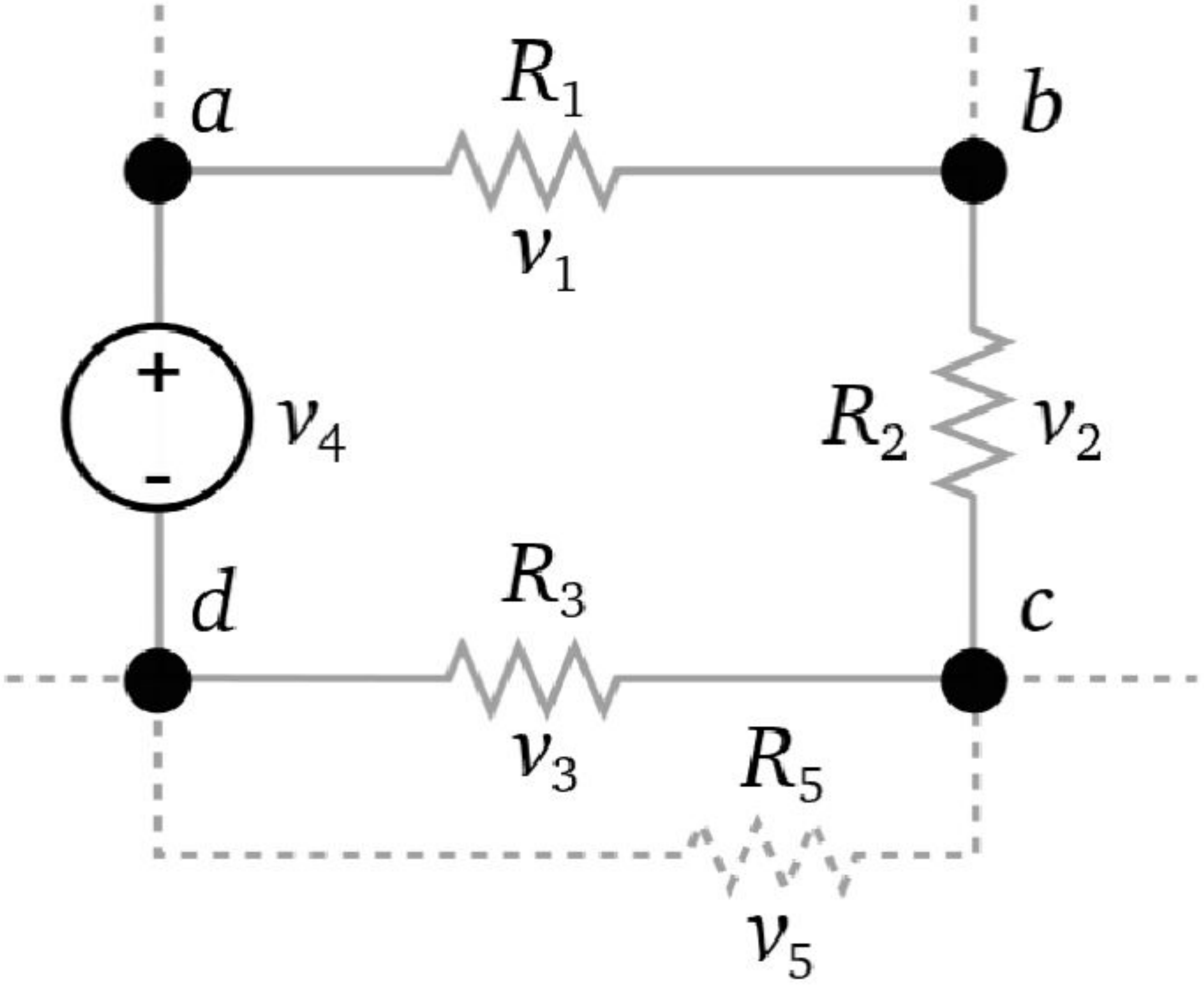
Kirchoff’s voltage law:

This law is also called **Kirchhoff's second law**, **Kirchhoff's loop (or mesh) rule**, and **Kirchhoff’s second rule**.

- ✔The principle of conservation of energy implies that, The directed sum of the electrical potential differences (voltage) around any closed network is zero, or
- ✔More simply, the sum of the emfs in any closed loop is equivalent to the sum of the potential drops in that loop, or
- ✔The algebraic sum of the products of the resistances of the conductors and the currents in them in a closed loop is equal to the total emf available in that loop.

Similarly to KCL, it can be stated as:

Cont..



The sum of all the voltages around the loop is equal to zero.

$v_1 + v_2 + v_3 - v_4 = 0$

Cont..

- Here, n is the total number of voltages measured. The voltages may also be complex:
- This law is based on the conservation of energy whereby voltage is defined as the energy per unit charge. The total amount of energy gained per unit charge must equal the amount of energy lost per unit charge, as energy and charge are both conserved.

Methods of Analysis

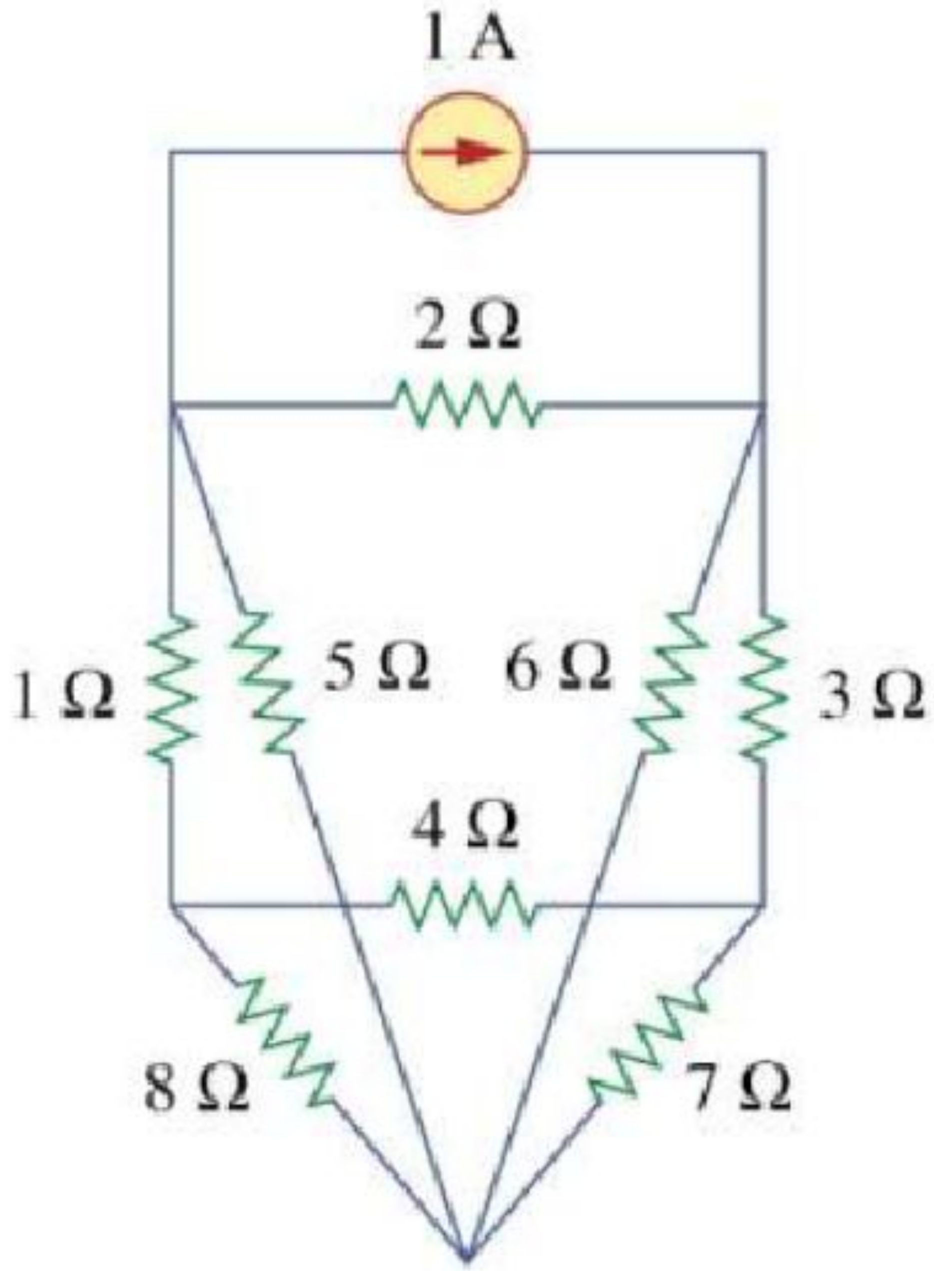
- Introduction
- Nodal analysis
- Nodal analysis with voltage source
- Mesh analysis
- Mesh analysis with current source
- Nodal and mesh analyses by inspection
- Nodal versus mesh analysis

Mesh Analysis

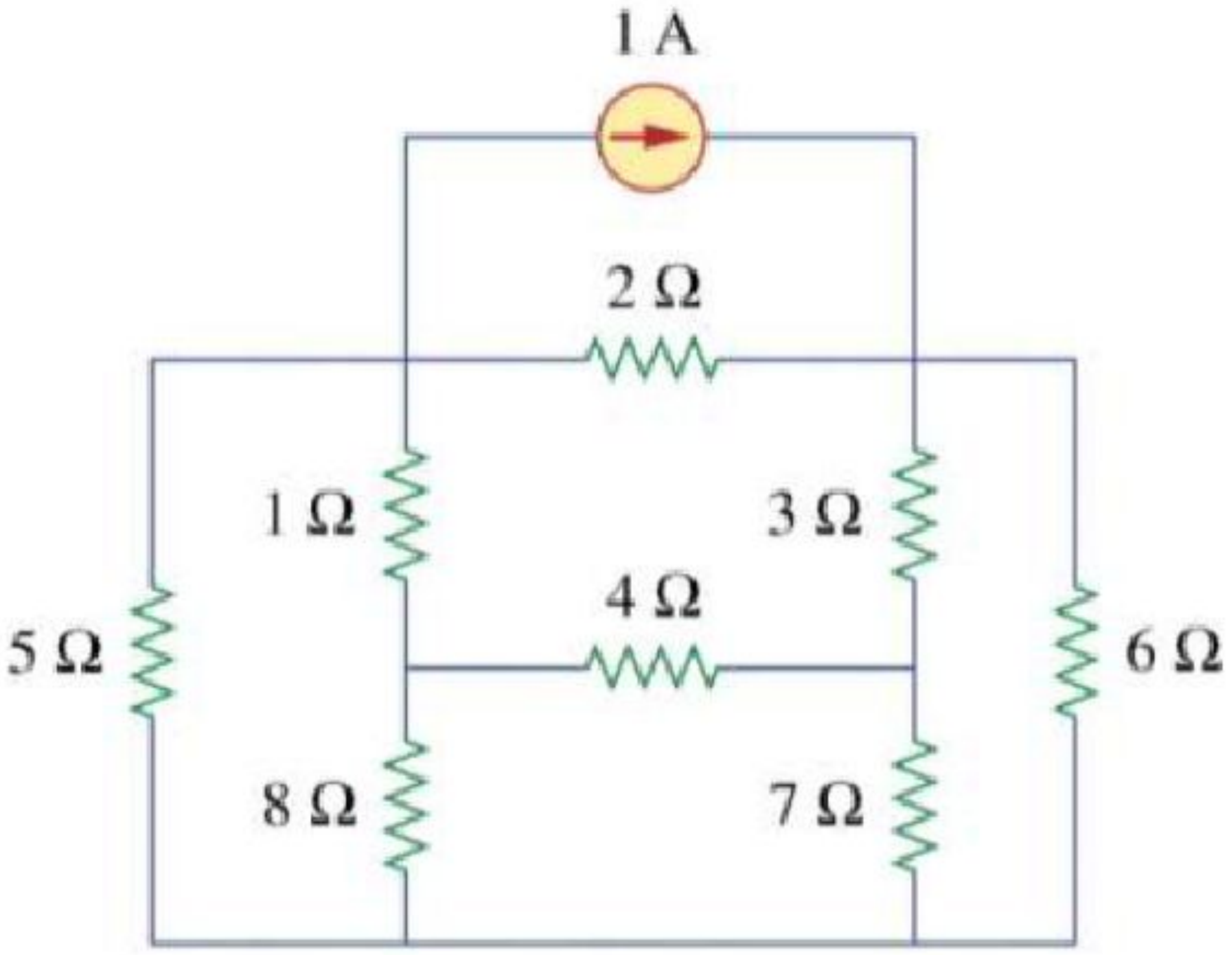
- Mesh analysis: another procedure for analyzing circuits, applicable to planar circuit.
- A Mesh is a loop which does not contain any other loops within it

(a) A Planar circuit with crossing branches,

(b) The same circuit redrawn with no crossing branches.



(a)



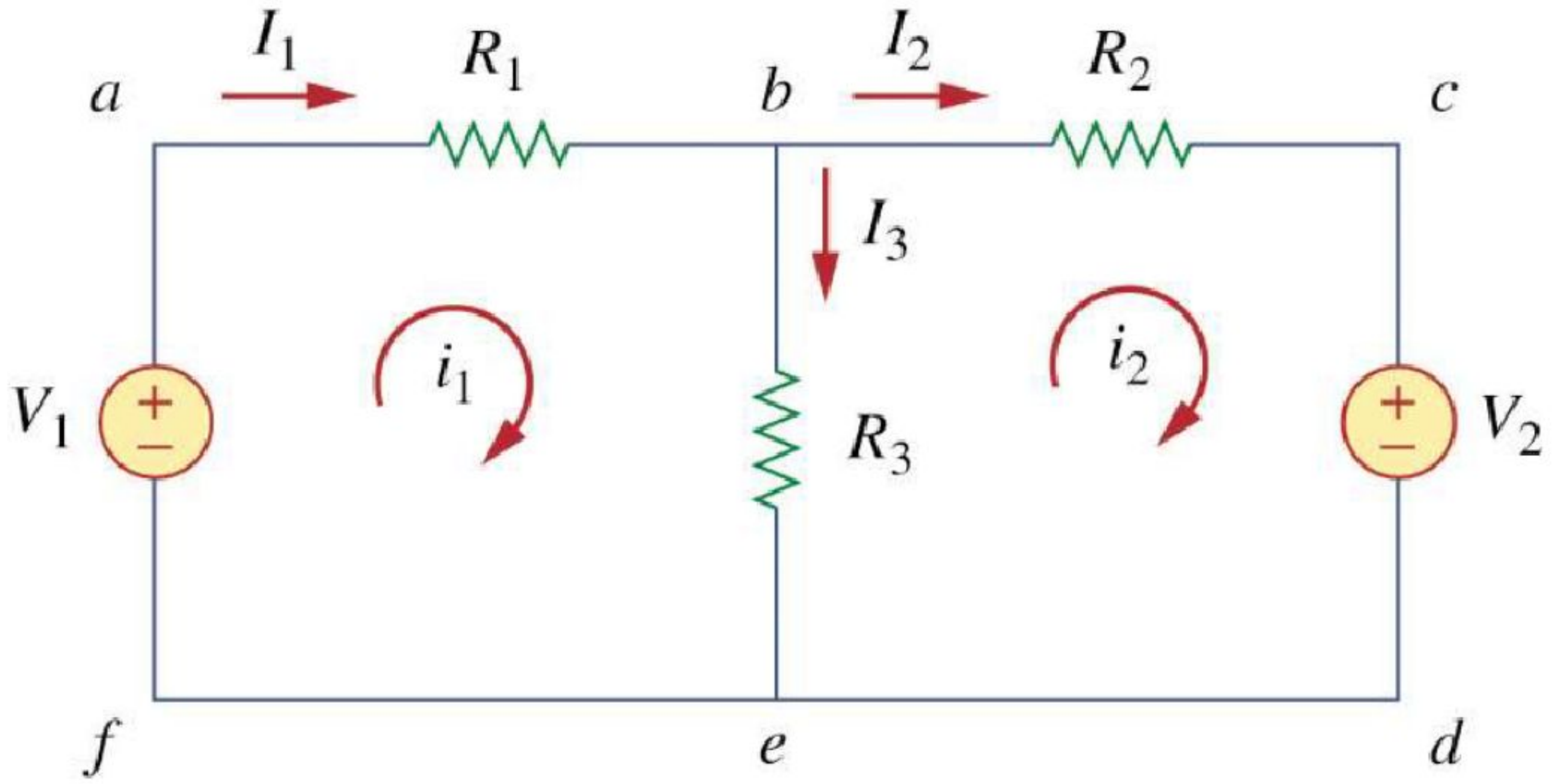
(b)

- Steps to Determine Mesh Currents:

1. Assign mesh currents $i_1, i_2, .., i_n$ to the n meshes.
2. Apply KVL to each of the n meshes. Use Ohm's law to express the voltages in terms of the mesh currents.
3. Solve the resulting *n* simultaneous equations to get the mesh currents.

Figure:

A circuit with two meshes.



- Apply KVL to each mesh. For mesh 1,

$$-V_1 + R_1 i_1 + R_3(i_1 - i_2) = 0$$

$$(R_1 + R_3)i_1 - R_3 i_2 = V_1$$

- For mesh 2,

$$R_2 i_2 + V_2 + R_3(i_2 - i_1) = 0$$

$$-R_3 i_1 + (R_2 + R_3)i_2 = -V_2$$

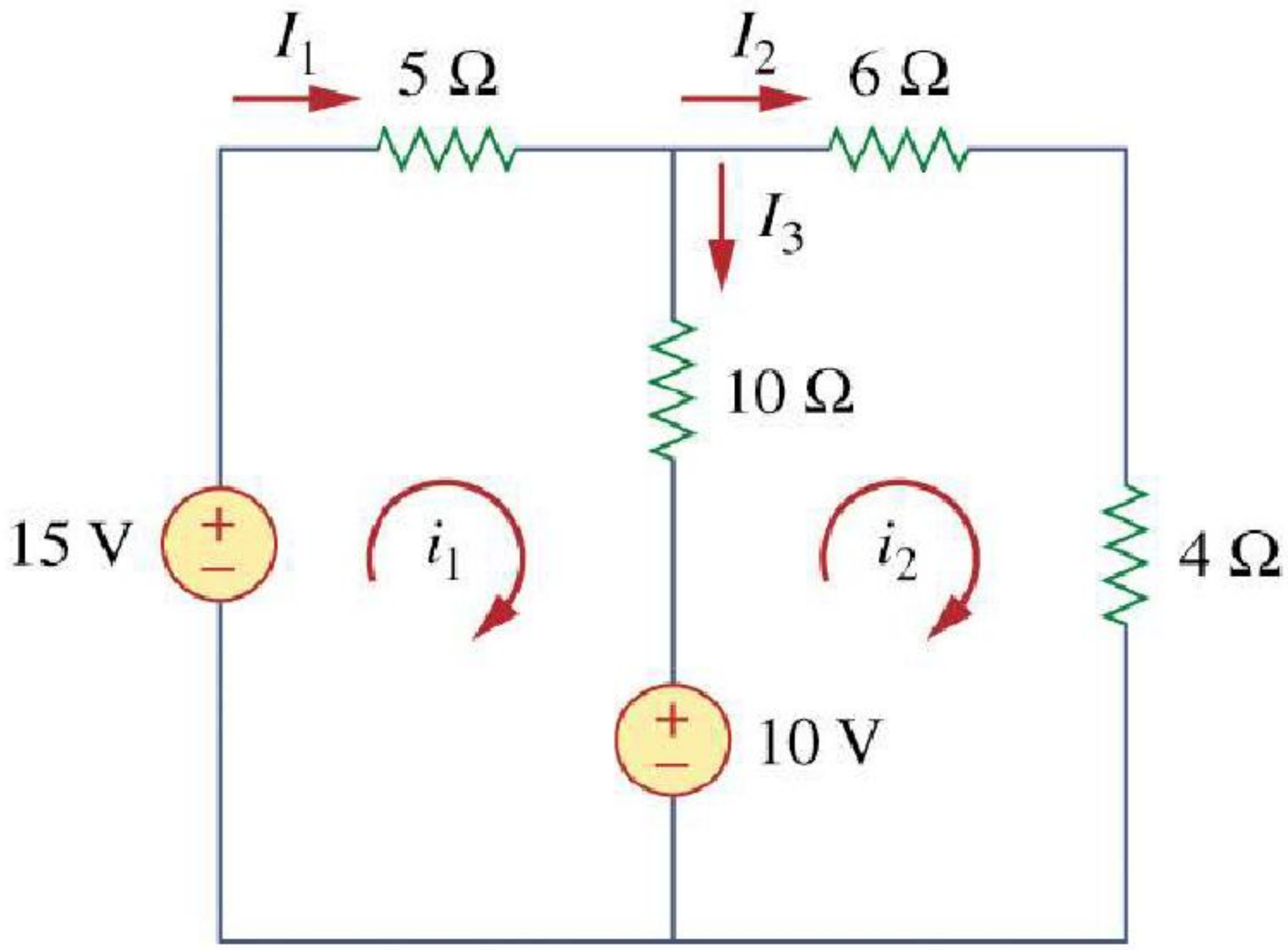
- Solve for the mesh currents.

$$\begin{bmatrix} R_1 + R_3 & -R_3 \\ -R_3 & R_2 + R_3 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} V_1 \\ -V_2 \end{bmatrix}$$

- Use *i* for a mesh current and *I* for a branch current. It’s evident from Fig. 3.17 that

$$\boxed{I_1 = i_1, \quad I_2 = i_2, \quad I_3 = i_1 - i_2}$$

- Find the branch current I_1, I_2, and I_3 using mesh analysis.



- For mesh 1,

$$-15+5i_1+10(i_1-i_2)+10=0$$

$$\boxed{3i_1-2i_2=1}$$

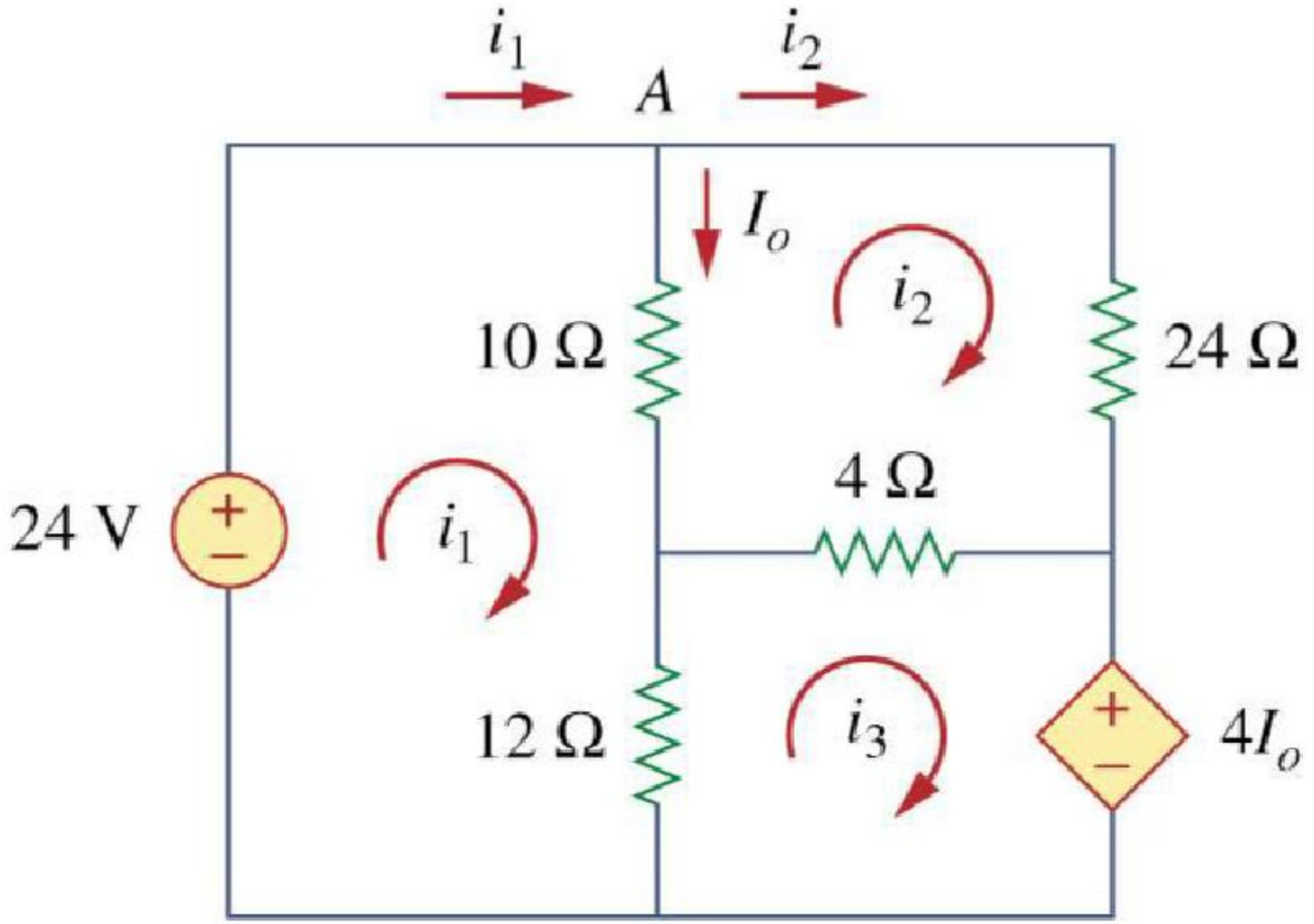
- For mesh 2,

$$6i_2+4i_2+10(i_2-i_1)-10=0$$

$$\boxed{i_1=2i_2-1}$$

- We can find i_1 and i_2 by substitution method or Cramer's rule. Then, $I_1=i_1, \quad I_2=i_2, \quad I_3=i_1-i_2$

- Use mesh analysis to find the current I_0 in the circuit.



- Apply KVL to each mesh. For mesh 1,

$$-24+10(i_1-i_2)+12(i_1-i_3)=0$$

$$\boxed{11i_1-5i_2-6i_3=12}$$

- For mesh 2,

$$24i_2+4(i_2-i_3)+10(i_2-i_1)=0$$

$$\boxed{-5i_1+19i_2-2i_3=0}$$

- For mesh 3,

$$4I_0 + 12(i_3 - i_1) + 4(i_3 - i_2) = 0$$

$$\text{At node A, } I_0 = I_1 - i_2,$$

$$4(i_1 - i_2) + 12(i_3 - i_1) + 4(i_3 - i_2) = 0$$

$$\boxed{-i_1 - i_2 + 2i_3 = 0}$$

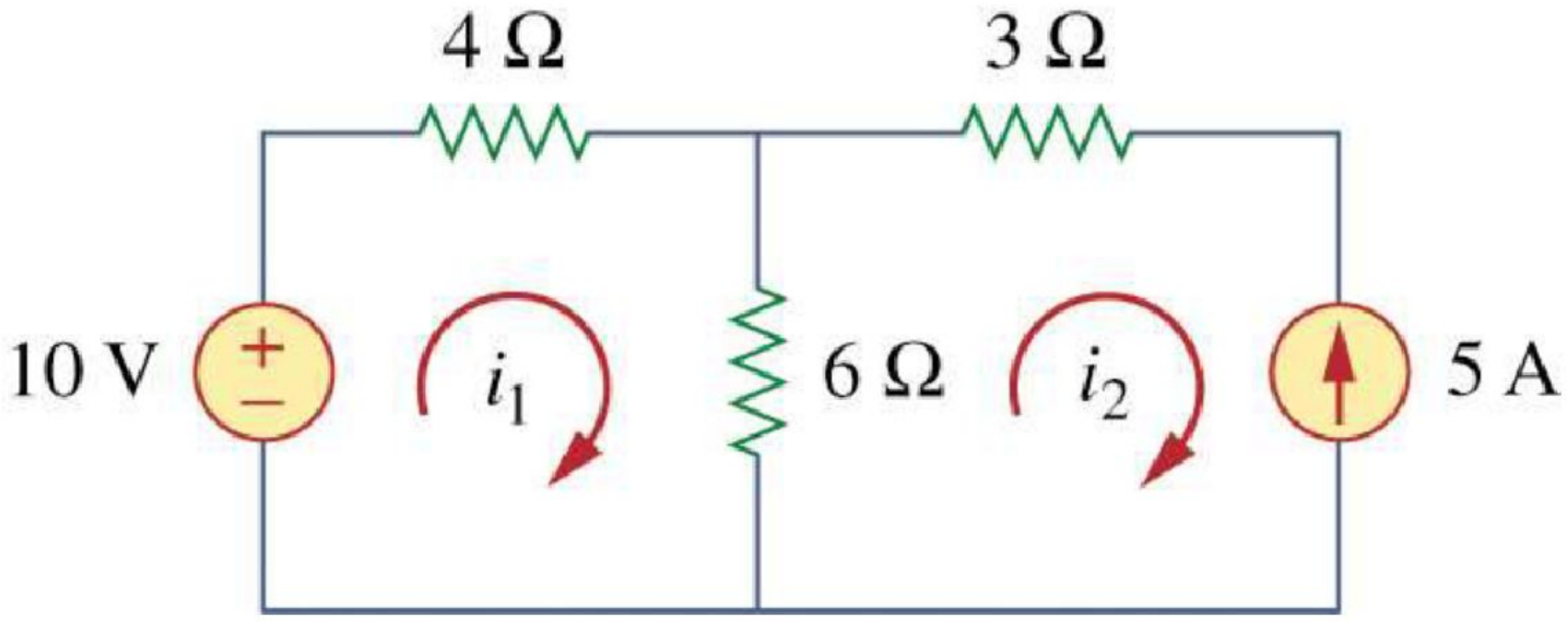
- In matrix from become

$$\begin{bmatrix} 11 & -5 & -6 \\ -5 & 19 & -2 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 12 \\ 0 \\ 0 \end{bmatrix}$$

we can calculus i_1, i_2 and i_3 by Cramer's rule, and find I_0.

Mesh Analysis with Current Sources

A circuit with a current source.



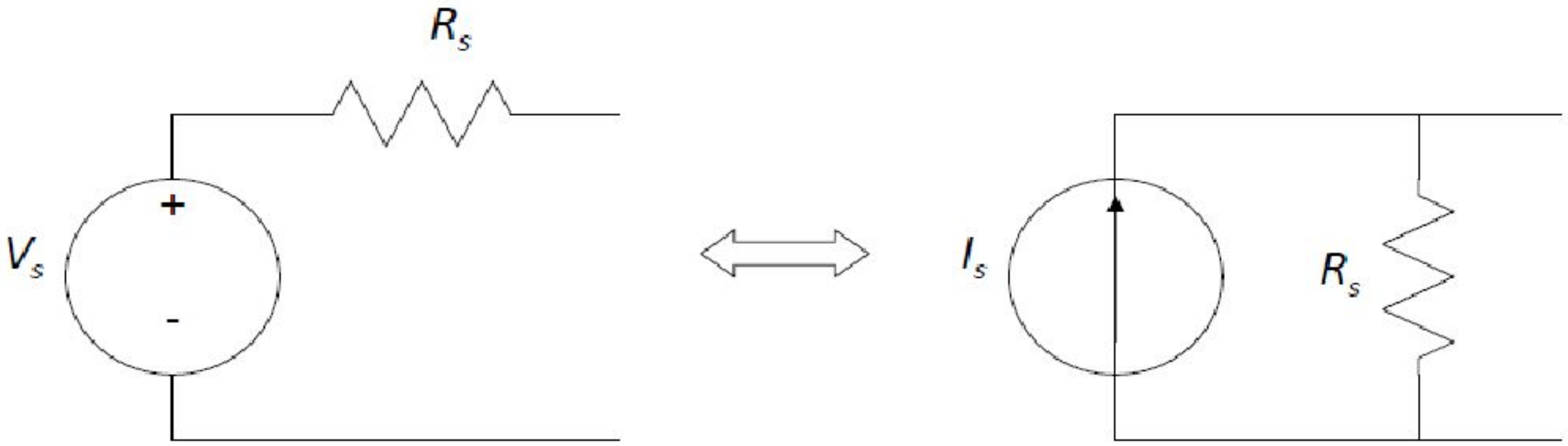
- <u>Case 1</u>
  - Current source exist only in one mesh

$$i_1 = -2\text{A}$$

  - One mesh variable is reduced
- <u>Case 2</u>
  - Current source exists between two meshes, a super-mesh is obtained.

Equivalent Circuits:-

Source Transformation



$$V_s = R_s I_s$$

$$I_s = \frac{V_s}{R_s}$$