BFF1303: ELECTRICAL / ELECTRONICS ENGINEERING

Direct Current Circuits : Basic Law

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Direct Current Circuit (DC)- Basic Laws

BFF1303 ELECTRICAL/ELECTRONICS ENGINEERING

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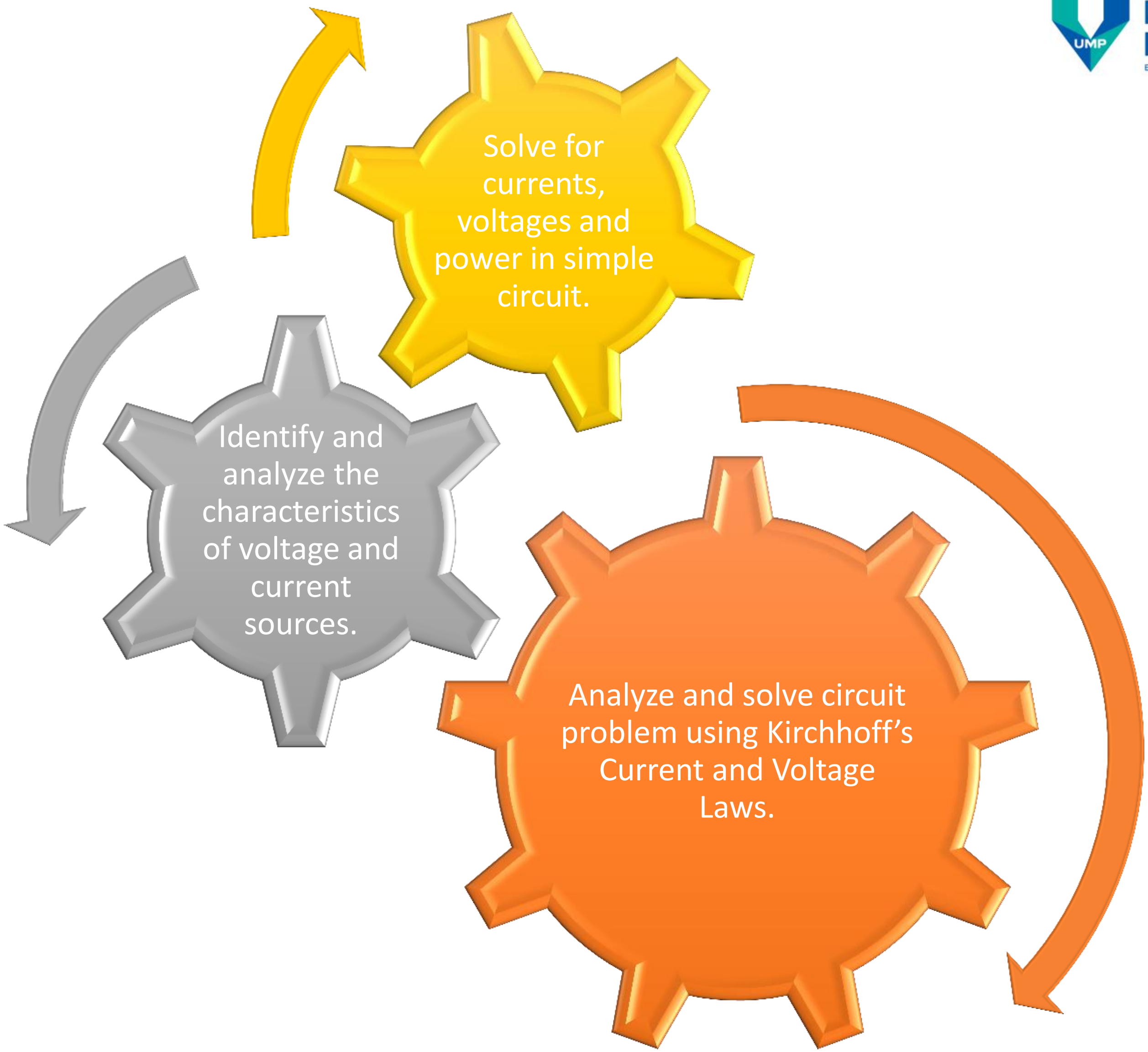
Contents:

- Ohm' Law
- Resistor
- Capacitor
- Inductor
- Kirchhoff's Law
- Series Resistors and Voltage Division
- Parallel Resistors and Current Division

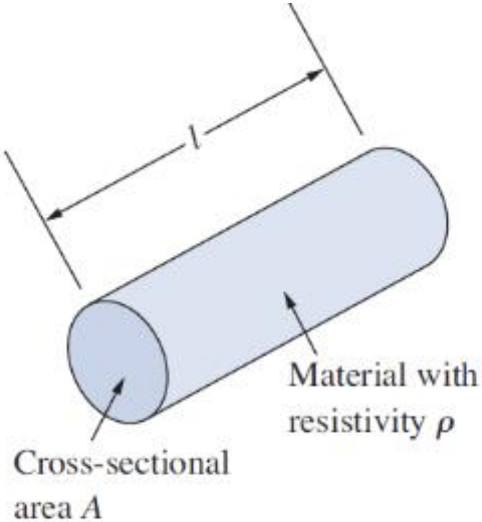
Outcomes


Solve for currents, voltages and power in simple circuit.
Identify and analyze the characteristics of voltage and current sources.
Analyze and solve circuit problem using Kirchhoff's Current and Voltage Laws.

Ohm's Law

- Most material have a characteristic behavior of **resisting** the flow of electric charge.
- The physical property to resist current known as **resistance** and is represented by the symbol R .
- The resistance of any material with a uniform cross-sectional area A depends on A and its length l

$$R = p\frac{l}{A}$$



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Resistivities of common materials

Material	Resistivity (Ω•m)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminium	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

Ohm's Law

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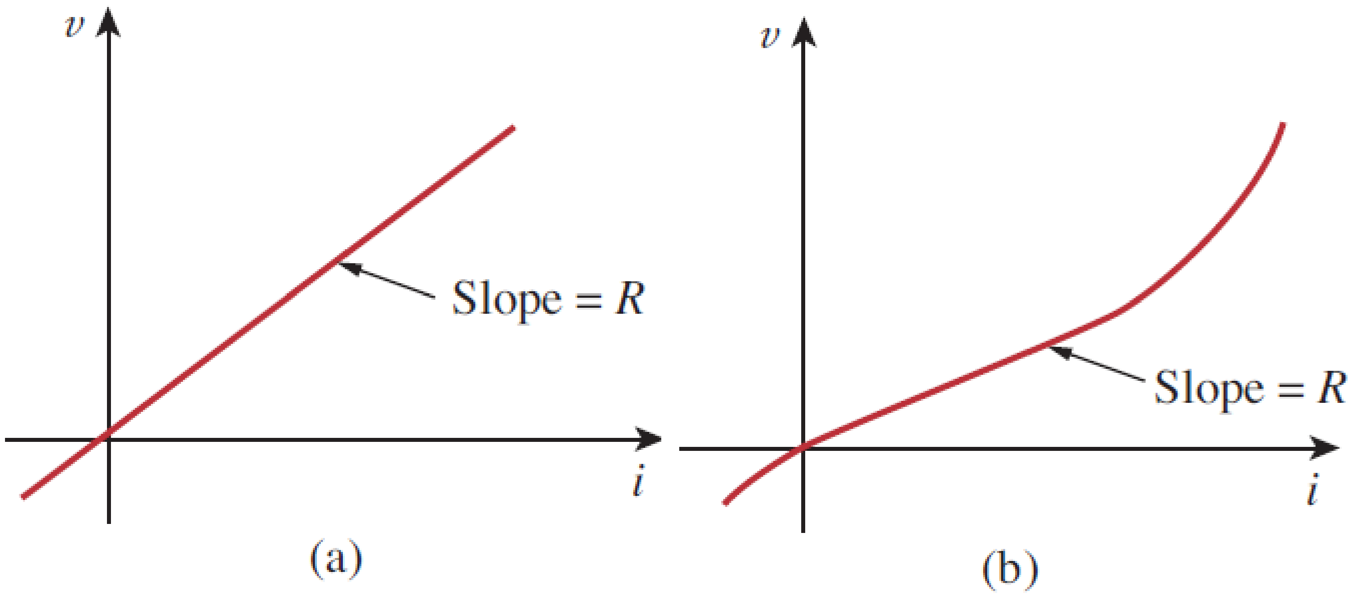
- **Ohm's Law** states that the voltage v across a resistor is directly proportional to the current i flowing through the resistor.

$$v \propto i$$

$$\therefore v = Ri$$



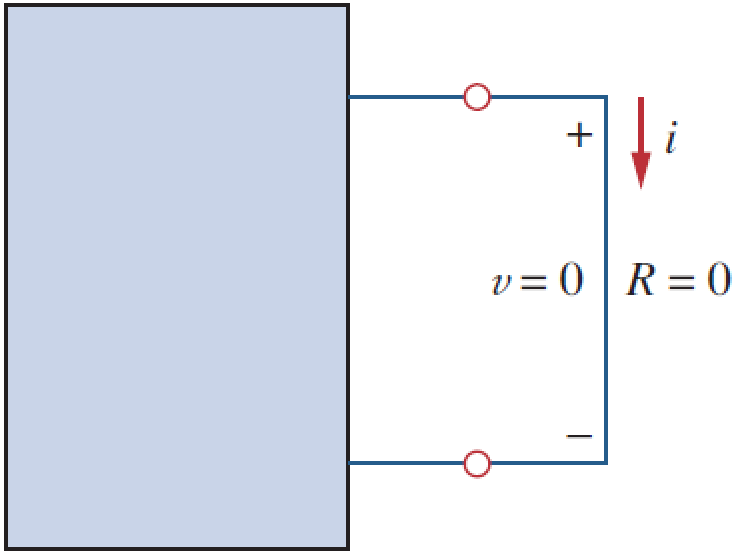
- The **resistance** R of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).

Ohm's Law

- The direction of current and the polarity of voltage must conform with the **passive sign convention**
  - Current enter at **positive** terminal $v = iR$
  - Current enter at **negative** terminal $v = -iR$

- R can be ranged from zero to infinity

$$v = iR = 0$$



- An element with $R = 0$:- **short circuit**.

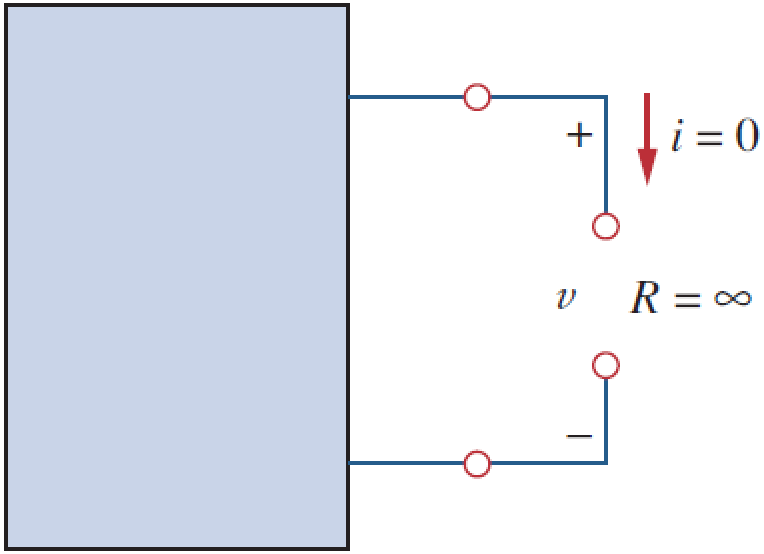
- In short circuit, the **voltage is always** is not.

- In practice, a short circuit is always connecting wire assumed to be a conductor.

Ohm's Law

- An element with $R = \infty$:- open circuit.
- In open circuit, the current is always zero but the voltage is not.

$$i = \lim_{R \to \infty} \frac{v}{R} = 0$$



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Ohm's Law

- Another quantity in circuit analysis – conductance, denoted by *G*.

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

- Conductance is a measure of how well an element will conduct electric current.

- The unit of conductance – mho, ℧ or siemens, S.

- The power dissipate by the resistor can expressed in term of *R*:

$$p = vi = i^2 R = \frac{v^2}{R} \qquad p = vi = v^2 G = \frac{i^2}{G}$$

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Ohm's Law

- The power dissipated in a resistor is always positive.
- Thus resistors always absorbed power from the circuit.
- This shows that the resistor is a passive element.

Resistor

- The resistor is far and away the simplest circuit element.
- In a resistor, the voltage *v* is proportional to the current *i*, with the constant of proportionality *R* known as the resistance.

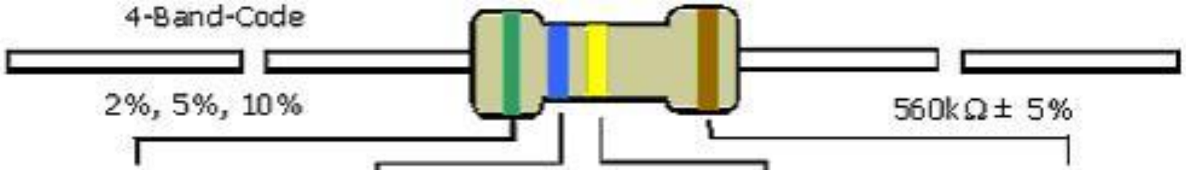
$$v \propto i$$

$$v = iR$$

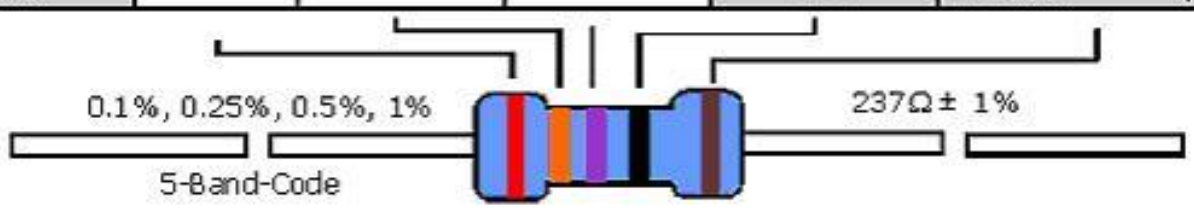
$$R = \frac{v}{i}$$

- Resistor is an element denotes its ability to resist the flow of electric current, it is measured in ohms (Ω).

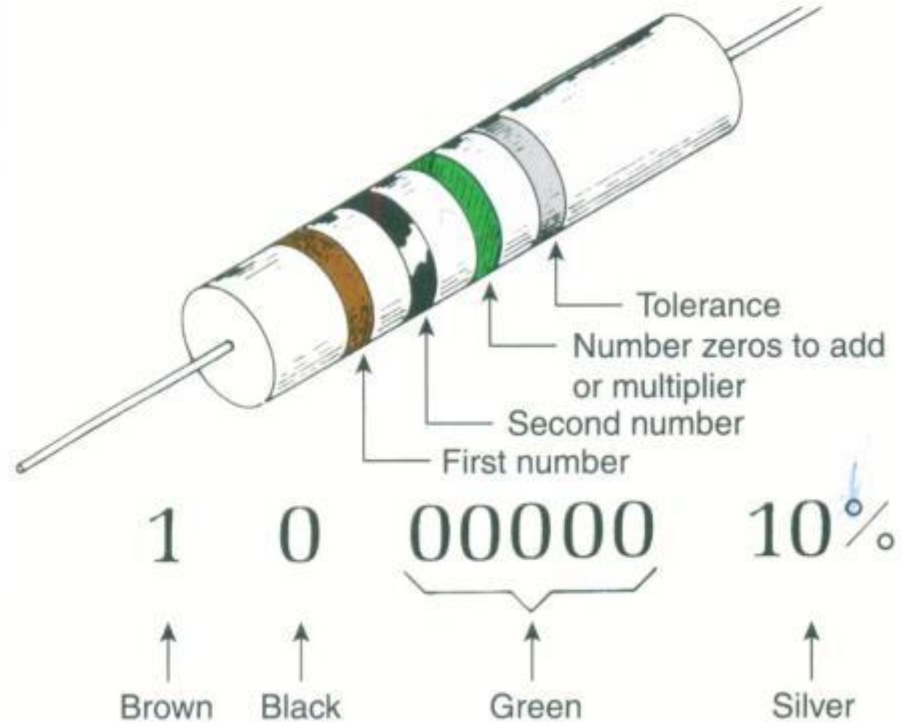
Resistor



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)

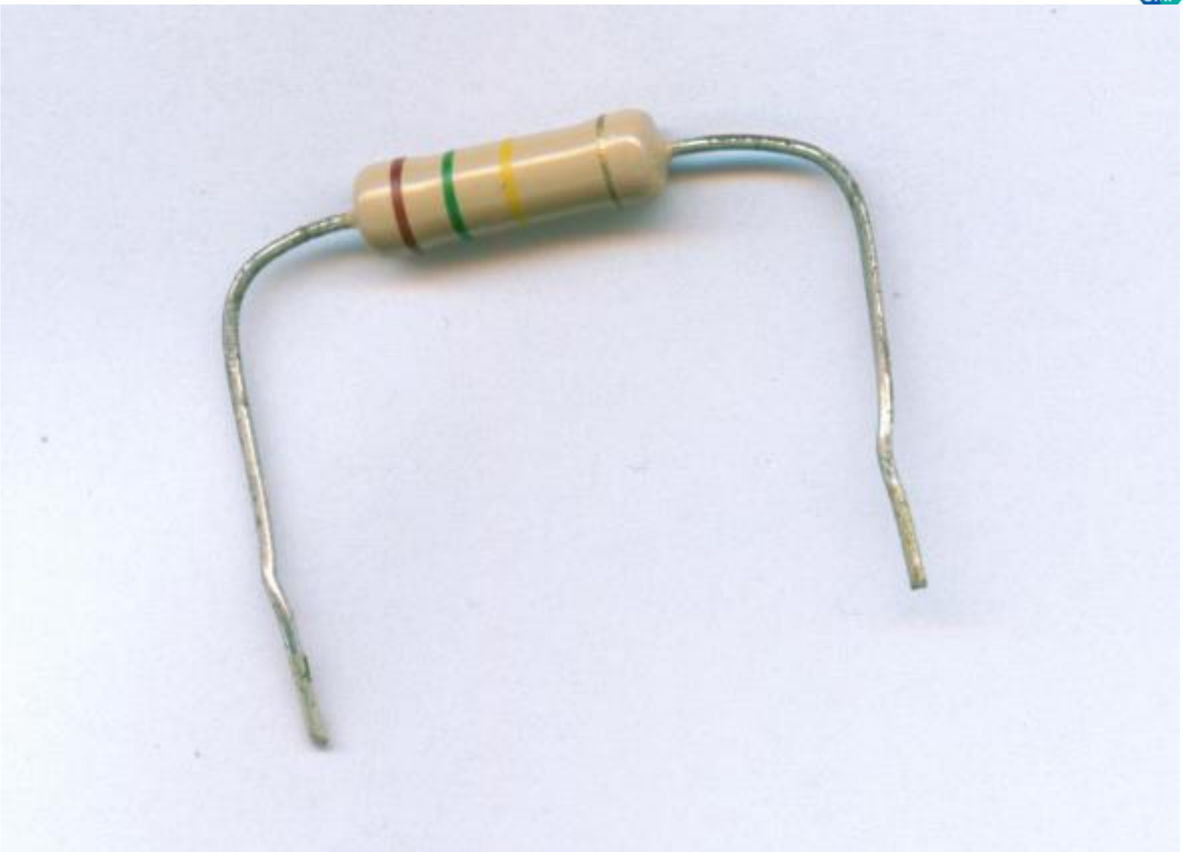


Resistor



- The above resistance is 1,000,000 Ω or 1MΩ.
- The 10% means the actual resistance is between 1.1M Ω and 900kΩ.

Resistor



- The above resistance is 150,000 Ω or 150kΩ.
- The 5% means the actual resistance is between 157.5kΩ and 142.5kΩ.

Example #1

The essential component of a toaster is an electrical element (a resistor that converts electrical energy to heat energy. How much current is drawn by a toaster with resistance 15 Ω at 110 V?

Solution

$$i = \frac{v}{R}$$

$$= \frac{110}{15}$$

$$= 7.333\,\text{A}$$

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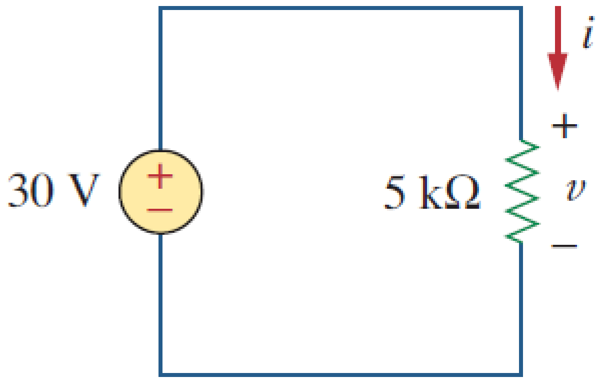
Example #2

In the given circuit, calculate the current *i*, the conductance *G* and the power *p*.



Solution

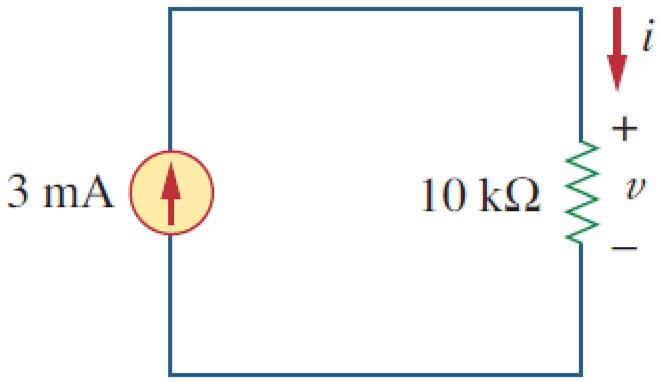
$$i = \frac{v}{R} = \frac{30}{5\text{k}} = 6\,\text{mA}$$

$$p = vi = 30(6\,\text{m}) = 180\,\text{mW}$$

$$G = \frac{1}{R} = \frac{1}{5\text{k}} = 0.2\,\text{mS}$$

Example #3

For the given circuit, calculate the voltage v, the conductance G and the power p.



Solution

$$v = iR = (30\,\text{m})(10\text{k}) = 30\,\text{V}$$

$$G = \frac{1}{R} = \frac{1}{10\text{k}} = 100\,\mu\text{S}$$

$$p = i^2 R = (30\text{m})^2 (10\text{k}) = 90\,\text{mW}$$

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Capacitor

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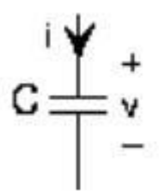
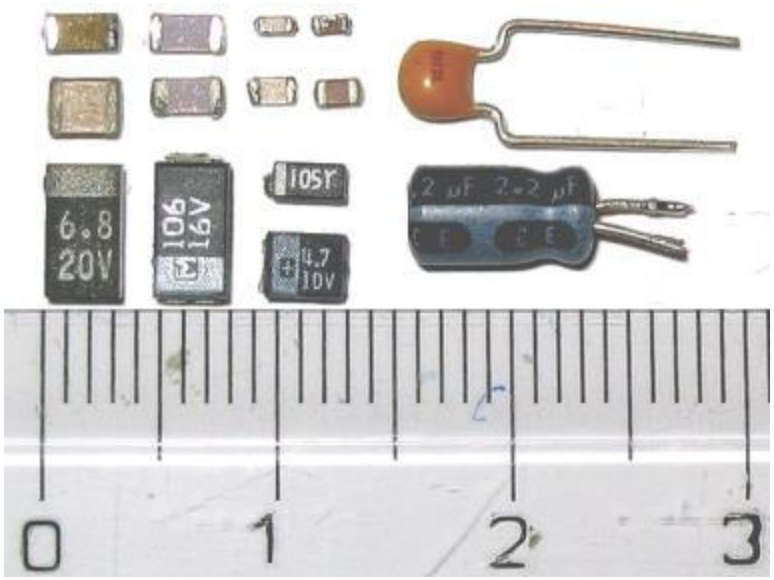
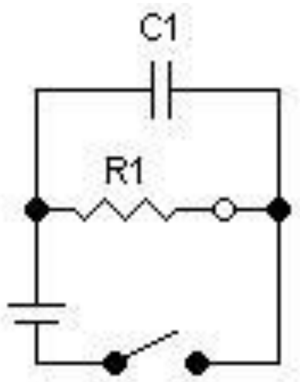
- Unlike resistor which dissipate energy, capacitor store energy, which can be retrieved at later time.
- Also called storage elements. The energy is stored in its electric field.
- It is a passive elements.



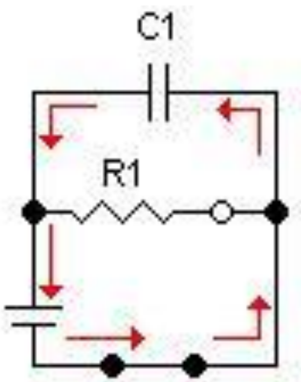


Capacitor

- Capacitor acts as a storage element:

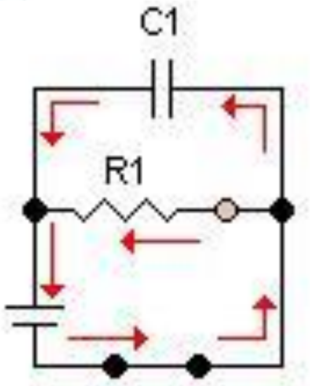


i. There is a capacitor in parallel with the resistor and light bulb. The way the capacitor functions is by acting as a very low resistance load when the circuit is initially turned on. This is illustrated below:

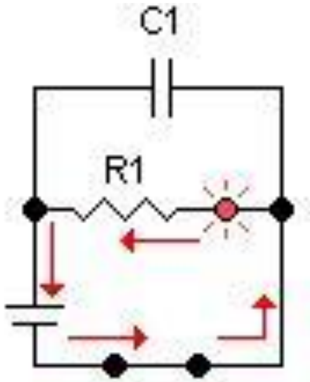


ii. Initially, the capacitor has a very low resistance, almost 0. Since electricity takes the path of least resistance, almost all the electricity flows through the capacitor, not the resistor, as the resistor has considerably higher resistance.

Capacitor

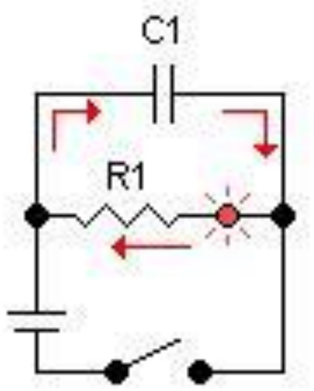


iii. As a capacitor charges, its resistance increases as it gains more and more charge. As the resistance of the capacitor climbs, electricity begins to flow not only to the capacitor, but through the resistor as well:

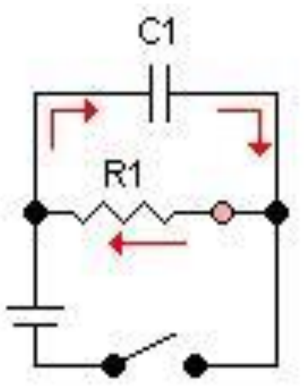


iv. Once the capacitor's voltage equals that of the battery, meaning it is fully charged, it will not allow any current to pass through it. As a capacitor charges its resistance increases and becomes effectively infinite (open connection) and all the electricity flows through the resistor.

Capacitor

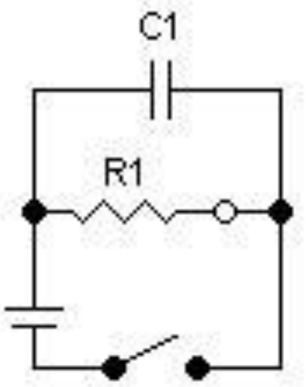


v. Once the voltage source is disconnected, however, the capacitor acts as a voltage source itself:



vi. As time goes on, the capacitor's charge begins to drop, and so does its voltage. This means less current flowing through the resistor:

Capacitor



vii. Once the capacitor is fully discharged, you are back to square one:

- The unit to measure the capacitance of a capacitor is **farad (F)**.

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Capacitor

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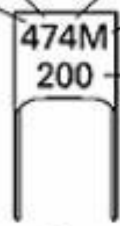
CAPACITOR GUIDE

The Result of Capacitor Code is Given in pF

1st Digit Of Value — 2nd Digit Of Value — Multiplier — Tolerance (±%)



Max. Voltage

474 =
47 x 10,000 pF
= .47 μF

F = 1%
G = 2%
J = 5%
K = 10%
M = 20%
Z = +80%/–20%

On some capacitors the value is shown as a straight number (4.7pF). On others the decimal point is replaced with the first letter of the prefix (4p7 = 4.7pF).

Prefix	Abbr.	Multiplier
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}

1000 pico = 1 nano
1 nano = .001 micro
1000 nano = 1 micro

EXAMPLES:

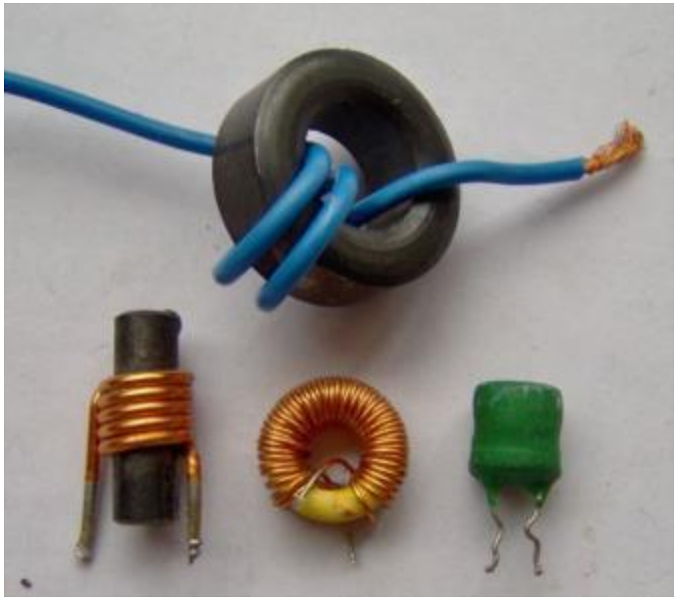
223J = 22 x 10^3pF = 22nF = 0.022μF   5%

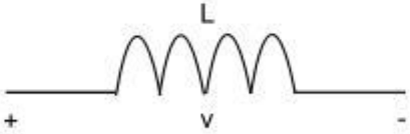
151K = 15 x 10^1pF = 150pF   10%

Inductor

- It is a passive element designed to store energy in its magnetic field.

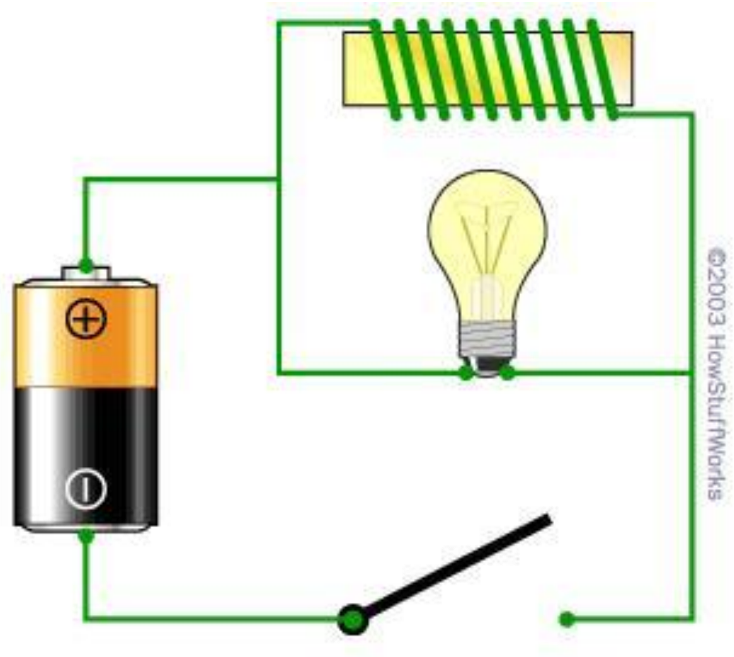
- Inductor consists of a coil of conducting wire.





Inductor

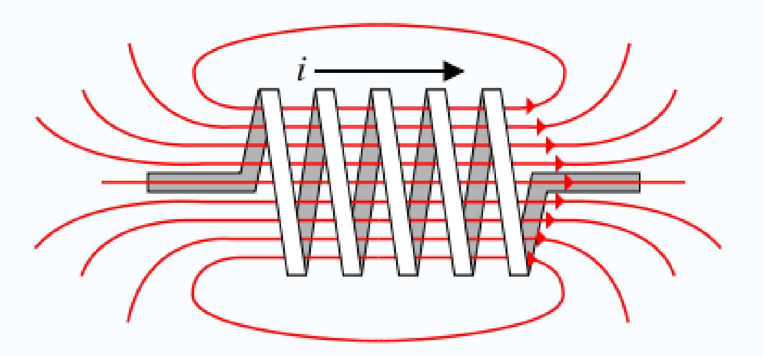
- Inductance is measured in **henrys (H)**.



- For example:
  - What you see here is a battery, a light bulb, a coil of wire around a piece of iron (yellow) and a switch. The coil of wire is an **inductor**.

Inductor

- Without the inductor in this circuit, what you would have is a normal flashlight. You close the switch and the bulb lights up.
- If there is an inductor, when the switch is closed the bulb burns brightly and then gets dimmer. When the switch is opened, the bulb burns very brightly and then quickly goes out.
- The reason for this strange behavior is the inductor. When current first starts flowing in the coil, the coil wants to build up a magnetic field.



Inductor

- While the field is building, the coil inhibits the flow of current. Once the field is built, current can flow normally through the wire (coil).

- A large amount of current will flow through this coil let only a small amount of current flow to the light bulb. This is why the bulb gets dimmer.

- When the switch gets opened, the magnetic field around the coil keeps current flowing in the coil until the field collapses. This current keeps the bulb lit for a period of time even though the switch is open. In other words, an inductor can **store energy** in its magnetic field, and an inductor tends to resist any change in the amount of current flowing through it.

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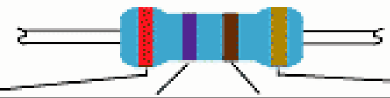
Inductor

- Analogy
  - One way to visualize the action of an inductor is to imagine a narrow channel with water flowing through it, and a heavy water wheel that has its paddles dipping into the channel. Imagine that the water in the channel is not flowing initially. Now you try to start the water flowing. The paddle wheel will tend to prevent the water from flowing until it has come up to speed with the water. If you then try to stop the flow of water in the channel, the spinning water wheel will try to keep the water moving until its speed of rotation slows back down to the speed of the water. An inductor is doing the same thing with the flow of electrons in a wire - an inductor resists a change in the flow of electrons.

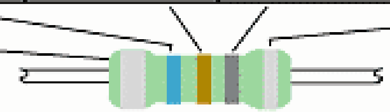
Inductor

INDUCTOR COLOR GUIDE

Result Is In µH



COLOR	1st BAND	2nd BAND	MULTIPLIER	TOLERANCE
BLACK	0	0	1	± 20%
BROWN	1	1	10	Military ± 1%
RED	2	2	100	Military ± 2%
ORANGE	3	3	1,000	Military ± 3%
YELLOW	4	4	10,000	Military ± 4%
GREEN	5	5		
BLUE	6	6		
VIOLET	7	7		
GREY	8	8		
WHITE	9	9		
NONE				Military ± 20%
GOLD			0.1 / Mil. Dec. Pt.	Both ± 5%
SILVER			0.01	Both ±10%



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Kirchhoff's Law

- The foundation of circuit analysis is:
  - The defining equations for circuit elements (e.g. Ohm's law)
  - Kirchhoff's current law (KCL)
  - Kirchhoff's voltage law (KVL)

- Kirchhoff's laws tell how the voltage and current within a circuit element are related.

- Kirchhoff's first law is based on the law of conservation of charge, which required that the algebraic sum of charges within a system cannot change.

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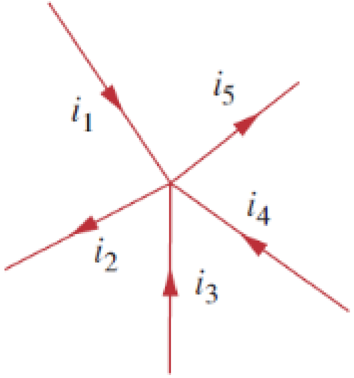
- **Kirchhoff's current law (KCL)** – that the **algebraic sum** of **currents entering a node** (or a closed boundary) is **zero**.

$$\sum_{n=1}^{N} i_n = 0$$ N = number of branches connected to a node.

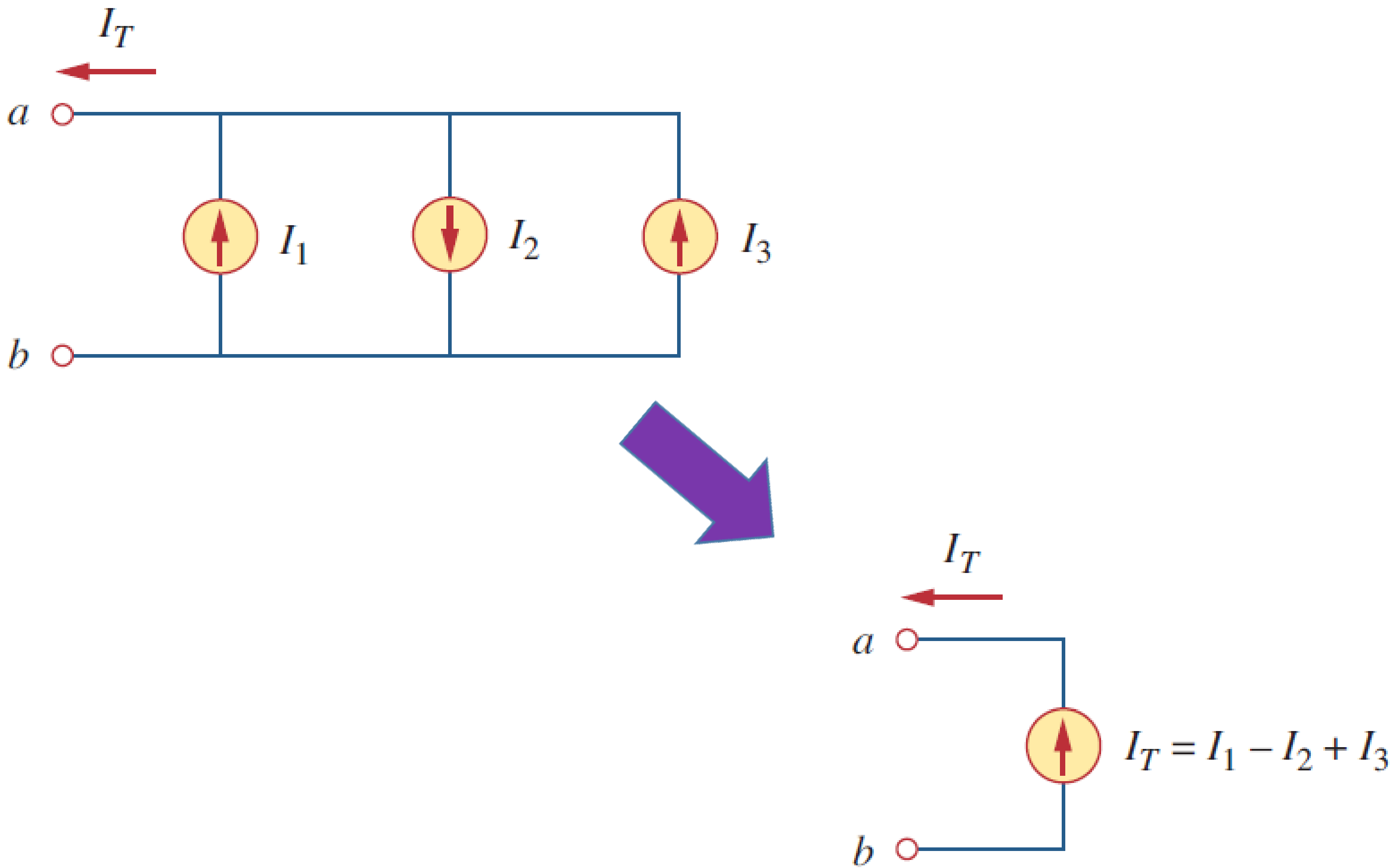
- One can assume that **currents entering a node** as **positive** while **leaving the node** as **negative** or vice versa.



$$i_1 + (-i_2) + i_3 + i_4 + (-i_5) = 0$$

$$i_1 + i_3 + i_4 = i_2 + i_5$$

Kirchhoff's Law



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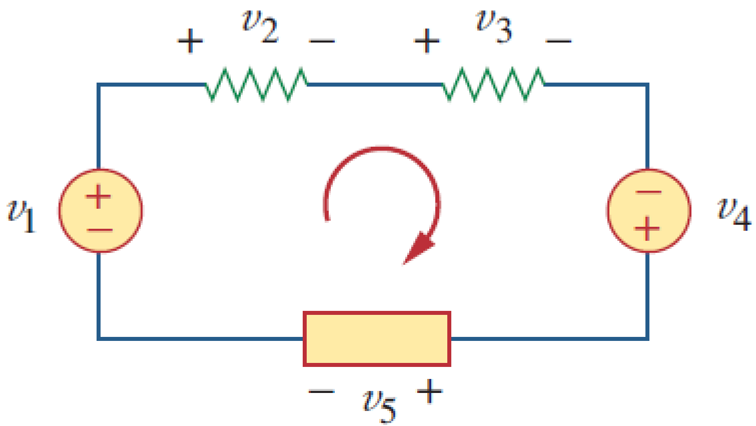
- **Kirchhoff's second law** is based on the principle of conservation energy.

- **Kirchhoff's voltage law (KVL)** – the **algebraic sum** of all **voltages around a closed path** (or loop) is **zero**.

$$\sum_{m=1}^{M} v_m = 0$$

M = number of voltages on the loop.



i. Start at any branch and go around the loop either clockwise / counterclockwise.
ii. Check which terminal the loop encounter first,
   a) If positive terminal then $+v$.
   b) If negative terminal then $-v$.

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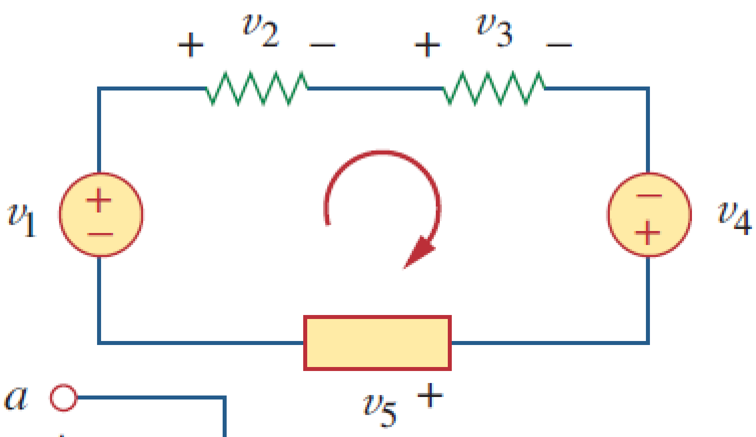
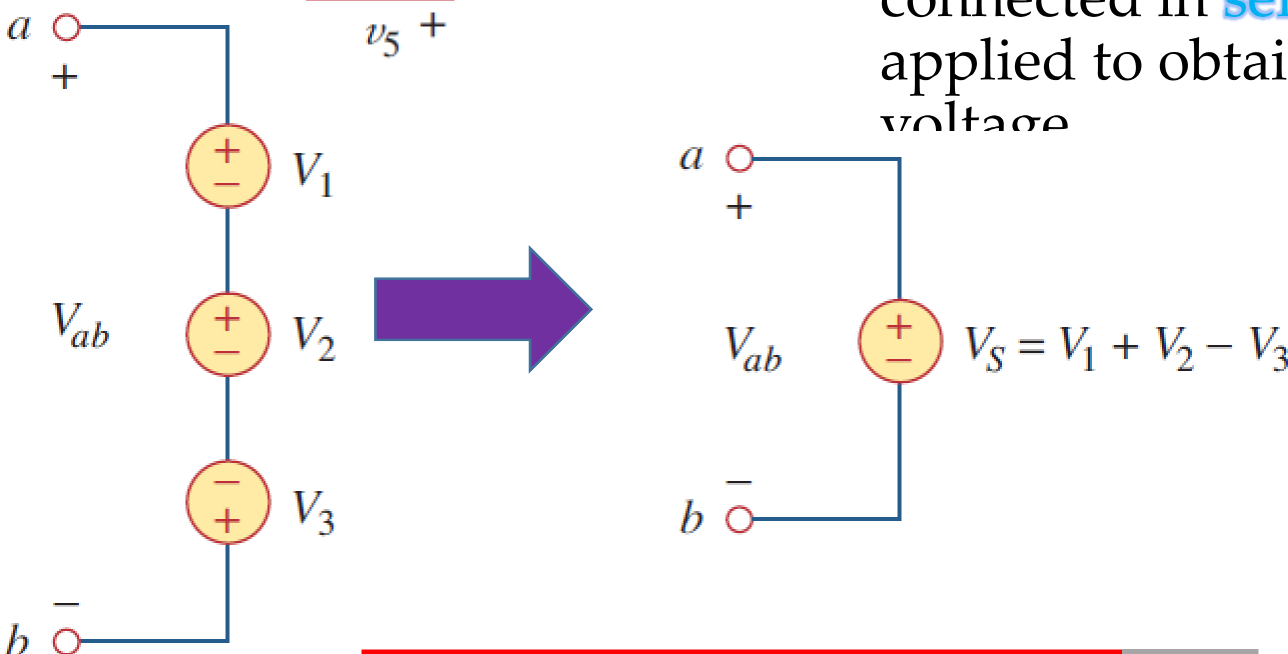


$$-v_1 + v_2 + v_3 - v_4 + v_5 = 0$$

$$v_2 + v_3 + v_5 = v_1 + v_4$$

- When voltage source are connected in series, KVL can be applied to obtained the total voltage



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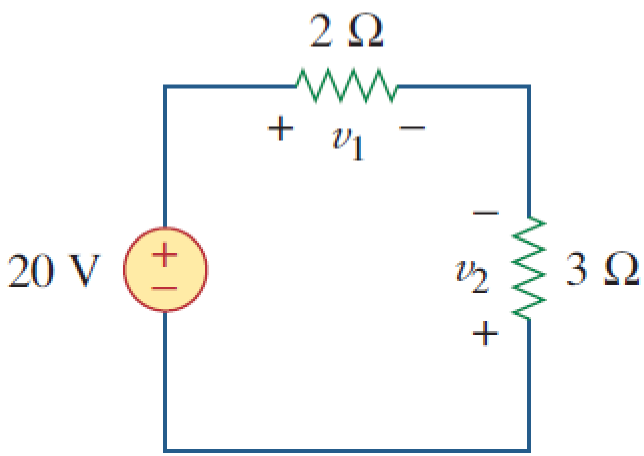
- Steps for Kirchhoff's laws:
  - Determine the direction of current flowing through the passive elements (resistors).
  - Obtain the voltage across each elements. If the current flow through:
  - Positive terminal, thus $v = +iR$
  - Negative terminal, thus $v = -iR$

- For KCL, obtain the equation by assuming if a current:
  - Enter a node, $+i$
  - Leaving a node, $-i$

- Obtain the KVL equation based on the chosen loop (clockwise or counterclockwise). If the loop enter:
  - Positive terminal, $+v$
  - Negative terminal, $-v$

Example #4

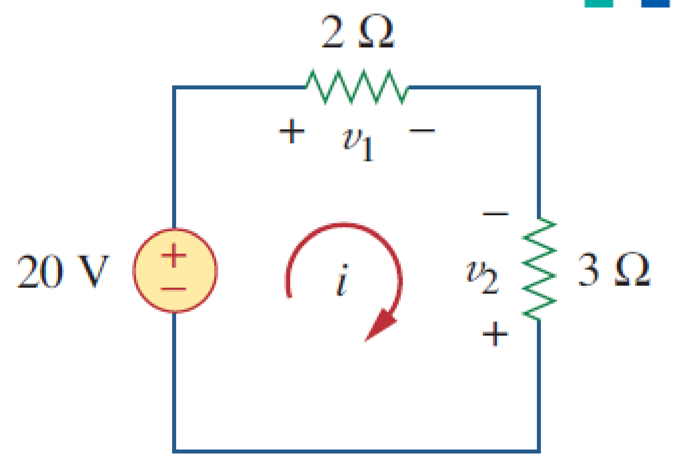
Find voltage v_1 and v_2 for the given circuit.



Solution

Apply Ohm's law & KVL. Assume the current i flow through the loop as shown below.

Example #4



From Ohm's law,

$$v_1 = 2i, \qquad v_2 = -3i$$

Applying KVL around a loop.

$$-20 + v_1 - v_2 = 0$$

$$-20 + 2i - (-3i) = 0$$

Thus

$$i = 4\,\text{A}$$

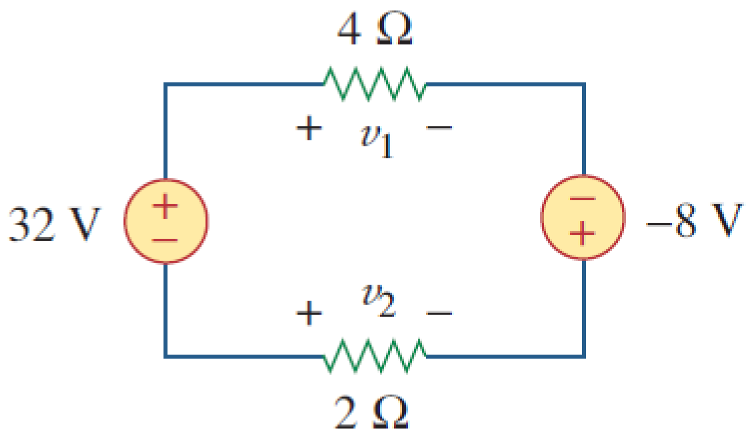
Then, the of value of v_1 and v_2

$$v_1 = 2(4), \qquad v_2 = -3(4)$$

$$v_1 = 8\,\text{V}, \qquad v_2 = -12\,\text{V}$$

Example #5

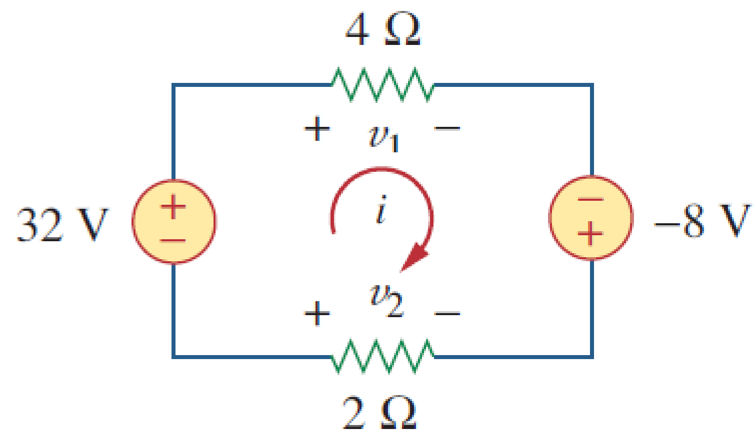
Find voltage v_1 and v_2 for the given circuit.



Solution

Apply Ohm's law & KVL. Assume the current *i* flow through the loop as shown below.

Example #5



From Ohm's law,

$$v_1 = 4i, \qquad v_2 = -2i$$

Applying KVL around a loop.

$$-32 + v_1 - (-8) - v_2 = 0$$

$$-32 + 4i + 8 + 2i = 0$$

Thus

$$i = 4\,\mathrm{A}$$

Then, the of value of v_1 and v_2

$$v_1 = 4(4), \qquad v_2 = -2(4)$$

$$v_1 = 16\,\mathrm{V}, \qquad v_2 = -8\,\mathrm{V}$$

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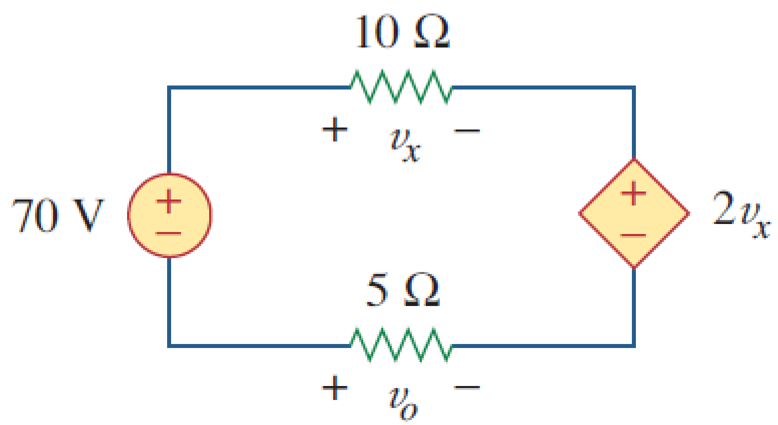
Example #6

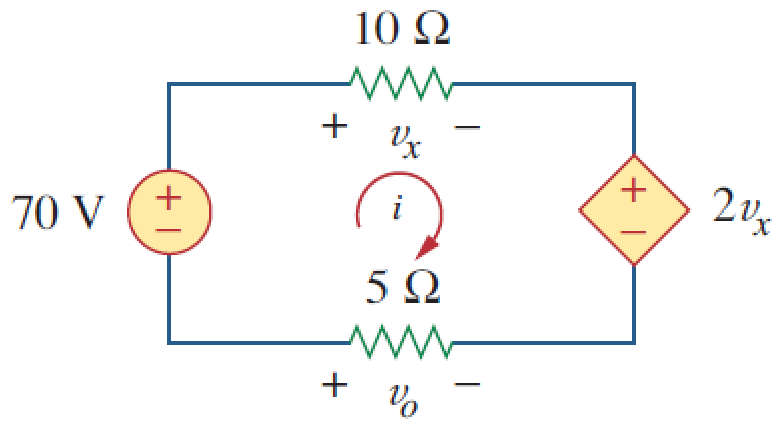
Find v_x and v_o for the given circuit.



<u>Solution</u>

Apply Ohm's law & KVL. Assume the current i flow through the loop as shown below.

Example #6



From Ohm's law,

$$v_x = 10i, \qquad v_o = -5i$$

Applying KVL around a loop.

$$-70 + v_x + 2v_x - v_o = 0$$

$$-70 + 10i + 2(10i) + 5i = 0$$

Thus

$$i = 2\,\text{A}$$

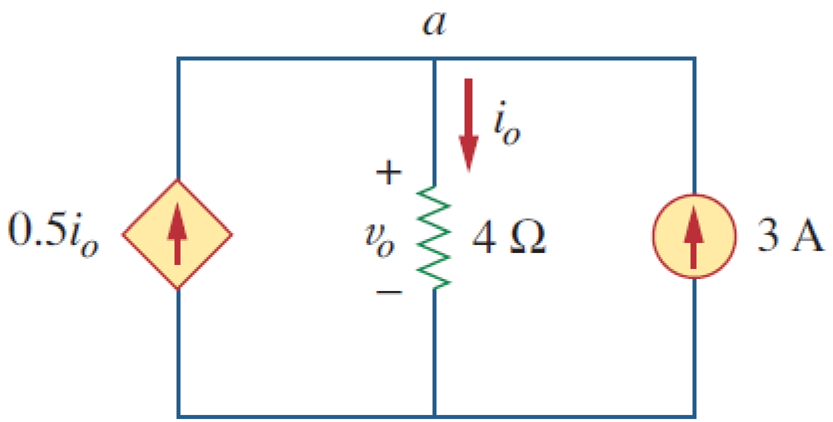
Then, the of value of v_x and v_o

$$v_x = 10(2), \qquad v_o = -5(2)$$

$$v_x = 20\,\text{V}, \qquad v_o = -10\,\text{V}$$

Example #7

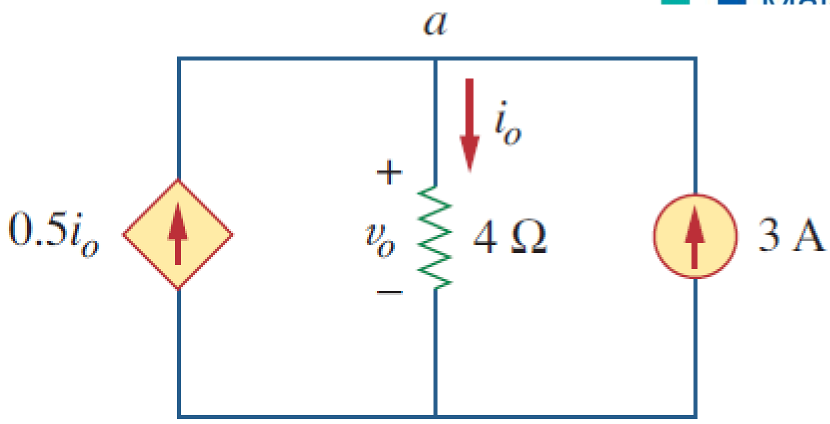
Find current i_o and voltage v_o for the given circuit.



Solution

Apply Ohm's law & KCL.

Example #7



From Ohm's law,

$$v_o = 4i_o$$

Applying KCL to node *a*.

$$0.5i_o - i_o + 3 = 0$$

$$i_o = 6\,\text{A}$$

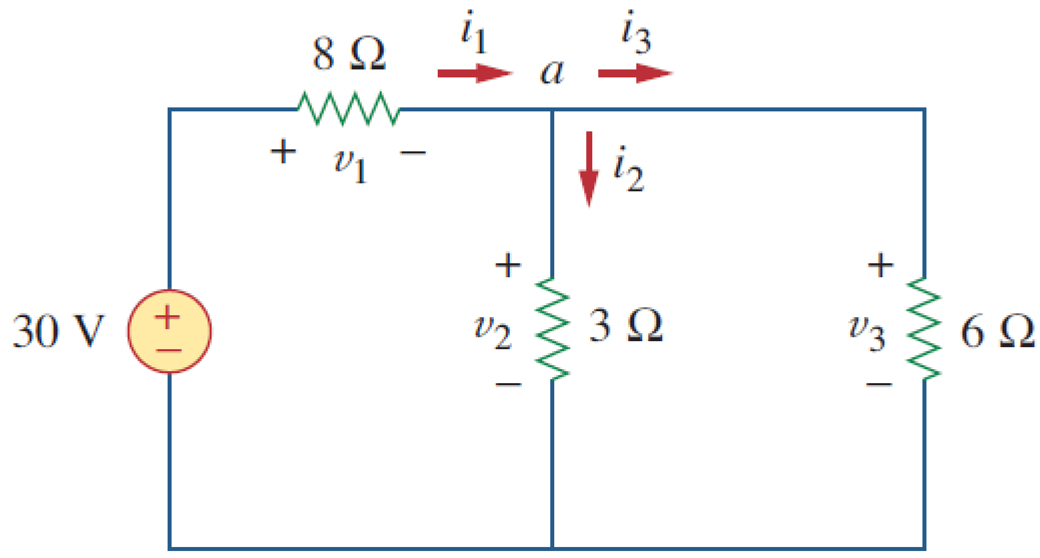
Then, the of value of v_o

$$v_o = 4(6)$$

$$v_o = 24\,\text{V}$$

Example #8

Find currents and voltages for the given circuit.



Solution

Apply Ohm's law & Kirchhoff's Law.

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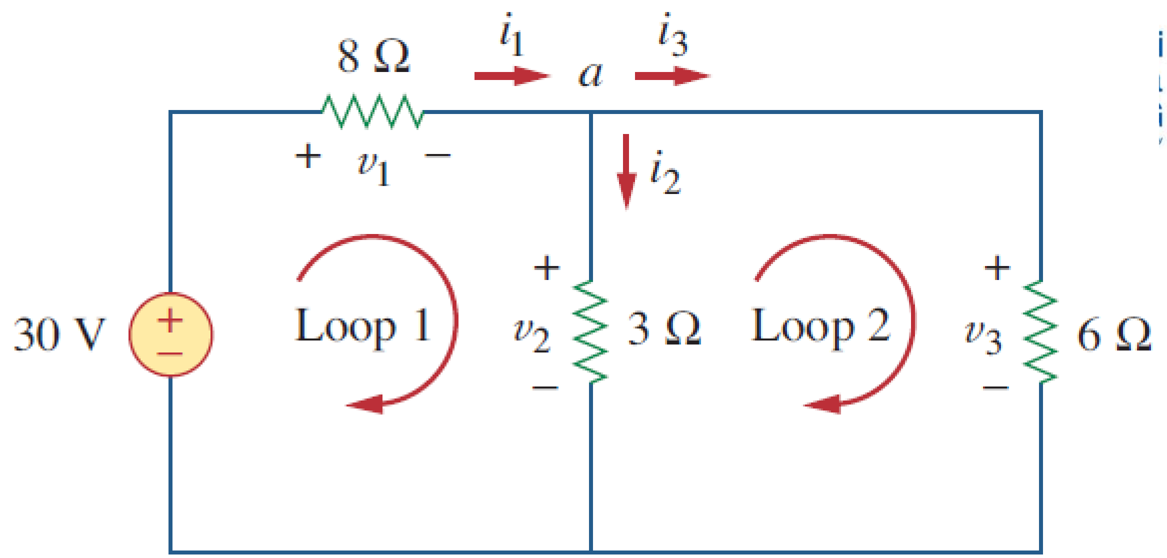
Example #8



From Ohm's law,

$$v_1 = 8i_1$$
$$v_2 = 3i_2$$
$$v_3 = 6i_3$$

Applying KCL to node *a*.

$$i_1 - i_2 - i_3 = 0$$
$$i_1 = i_2 + i_3 \qquad \rightarrow (1)$$

Applying KVL to loop 1.

$$-30 + v_1 + v_2 = 0$$
$$-30 + 8i_1 + 3i_2 = 0$$
$$i_1 = \frac{(30 - 3i_2)}{8} \qquad \rightarrow (2)$$

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Example #8

Applying KVL to loop 2.

$$-v_2 + v_3 = 0$$

$$v_2 = v_3 \qquad \rightarrow (3)$$

$$3i_2 = 6i_3$$

$$i_3 = 0.5i_2 \qquad \rightarrow (4)$$

From the value of i_2, we can obtain another voltages and currents

Subs eq. (2) and (4) into (1).

$$\frac{(30 - 3i_2)}{8} = i_2 + 0.5i_2$$

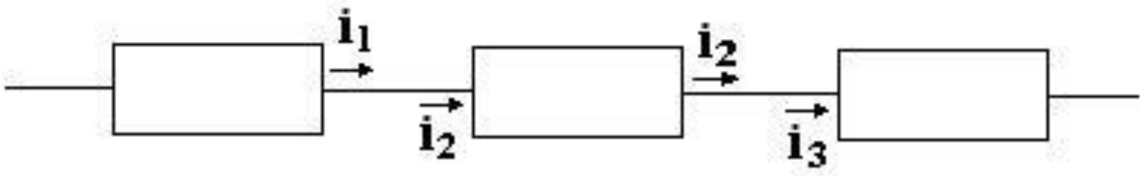
$$i_2 = 2\,\text{A}$$

$$i_1 = 3\,\text{A} \qquad v_1 = 24\,\text{V}$$

$$i_3 = 1\,\text{A} \qquad v_2 = 6\,\text{V}$$

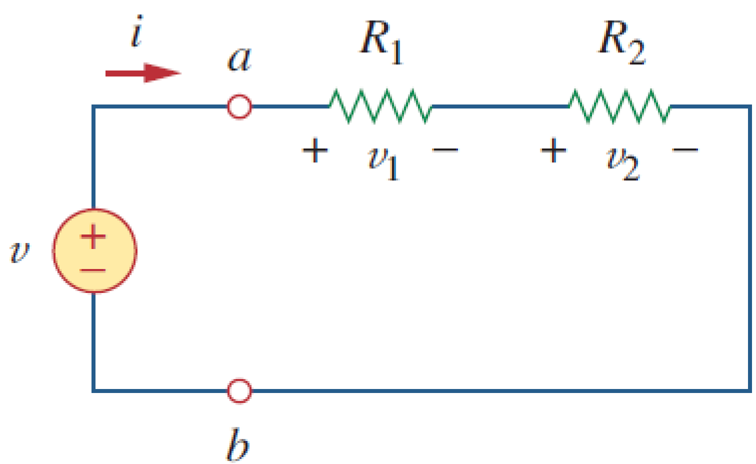
$$v_3 = 6\,\text{V}$$

- Recall: The current that pass through the **series resistors** has the **same value**.



$$i_1 = i_2 = i_3$$

- Consider the following figure:



- Applying Ohm's law to each of the resistors

$$v_1 = iR_1, \qquad v_2 = iR_2 \qquad \rightarrow (1)$$

- Applying KVL to the loop (clockwise).

$$-v+v_1+v_2=0 \qquad \rightarrow (2)$$

Combining Eq. (1) and (2), we get

$$v=v_1+v_2=i\left(R_1+R_2\right) \qquad \rightarrow (3)$$

$$i=\frac{v}{\left(R_1+R_2\right)} \qquad \rightarrow (4)$$

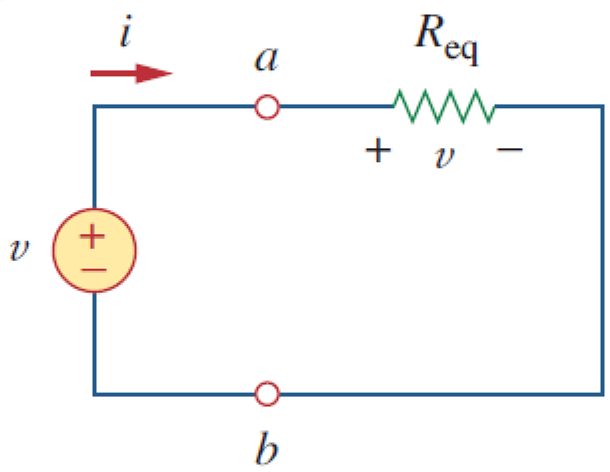
Notice that Eq. (3) can be written as

Where $R_{eq}=R_1+R_2$

$$v=iR_{eq} \qquad \rightarrow (5)$$

Series Resistors and Voltage Division

- Any number of resistors connected in series is the **sum of the individual resistances**.



$$R_{eq} = R_1 + R_2 + \cdots R_N = \sum_{n=1}^{N} R_n$$

N = number of resistors in series

- To determine the voltage across each resistor, substitute Eq. (4) into (1)

Principle of **voltage division**.

$$v_1 = \left(\frac{R_1}{R_1 + R_2}\right) v, \qquad v_2 = \left(\frac{R_2}{R_1 + R_2}\right) v$$

The source voltage v is divided among the resistors in direct proportion to their resistances; **the larger the resistance, the larger the voltage drop**.

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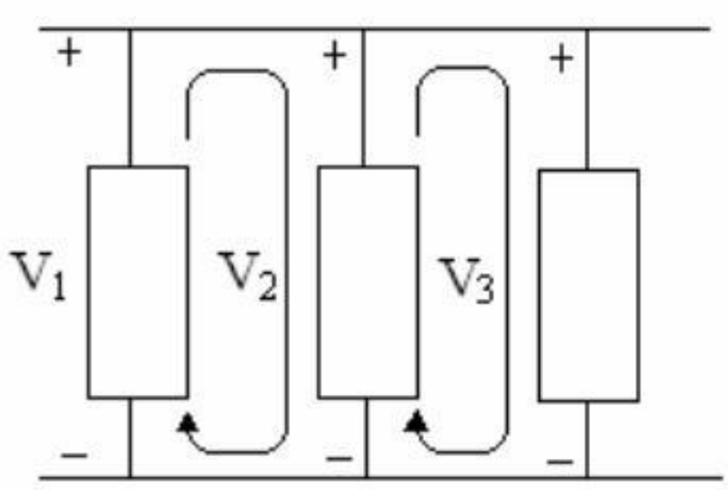
- Recall: Elements in parallel have the same voltage drops across them.



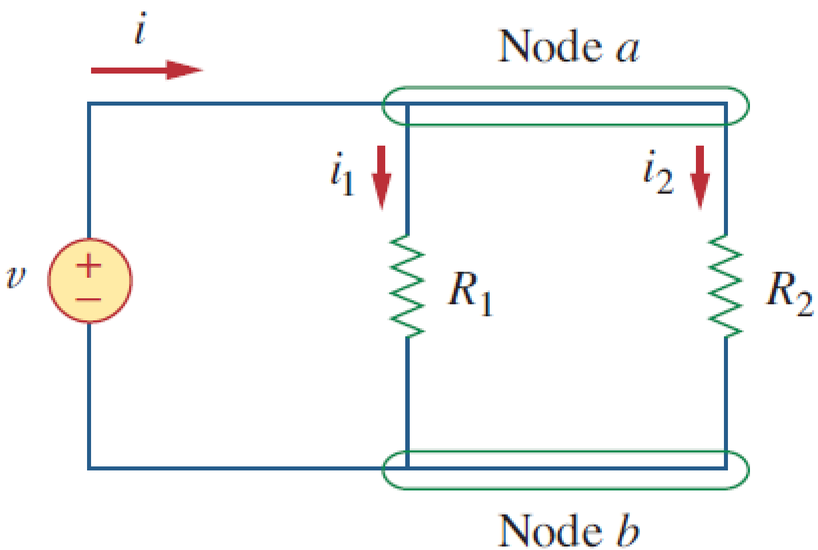
KVL around loop 1 and 2:

$V_1 = V_2$

$V_2 = V_3$

Parallel Resistors and Current Division

- Consider the following figure:



- Applying Ohm's law to each of the resistors

$$v = i_1 R_1, \qquad v = i_2 R_2$$

$$i_1 = \frac{v}{R_1}, \qquad i_2 = \frac{v}{R_2} \qquad \rightarrow (1)$$

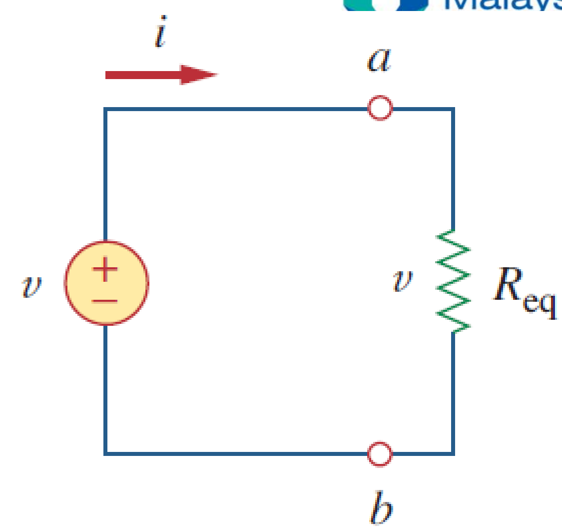
- Applying KCL to node *a* gives the total current *i* as

$$i = i_1 + i_2 \qquad \rightarrow (2)$$

Parallel Resistors and Current Division

Subs Eq. (1) into (2)

$$i=\frac{v}{R_1}+\frac{v}{R_2}=v\left(\frac{1}{R_1}+\frac{1}{R_2}\right)=\frac{v}{R_{eq}} \qquad \rightarrow (3)$$



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

$$R_{eq}=\frac{R_1R_2}{R_{eq}} \qquad \rightarrow (4)$$

The above Eq. (4) only apply for 2 resistor in parallel.

Parallel Resistors and Current Division

For N resistors in parallel

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

From Eq. (3) and (4).

$$v = iR_{eq} = i\left(\frac{R_1 R_2}{R_1 + R_2}\right) \quad \rightarrow (5)$$

Subs Eq. (5) into (1)

$$i_1 = i\left(\frac{R_2}{R_1 + R_2}\right), \qquad i_2 = i\left(\frac{R_1}{R_1 + R_2}\right) \quad \rightarrow (6)$$

Principle of current division.

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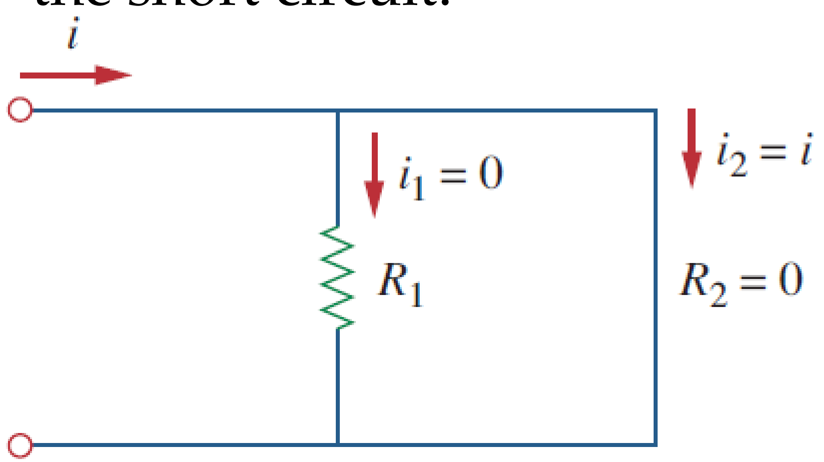
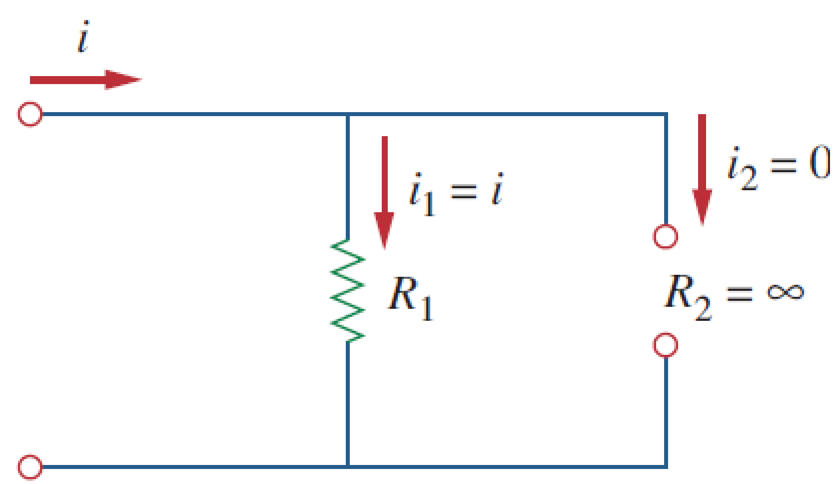
- Notice that larger current flows through smaller resistance.

- In electrical circuit, current will always flow through a path with least resistance.

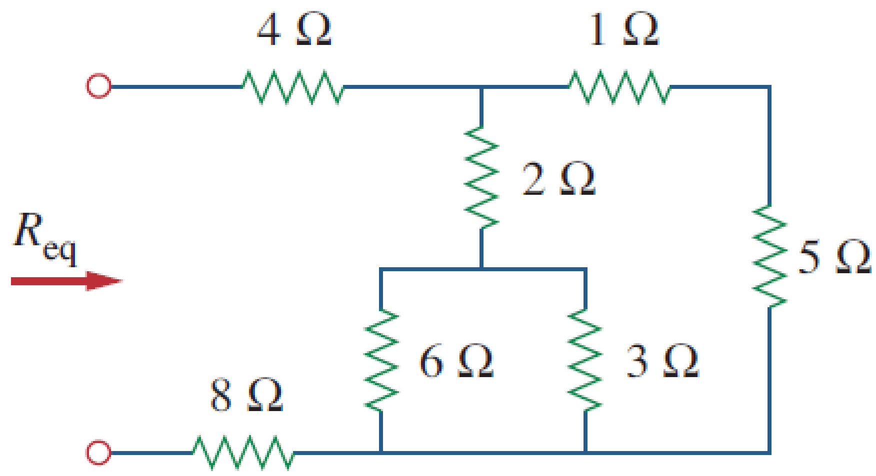
- If there is a short circuit, the entire current will flow through the short circuit.





Example #9

Find R_{eq} for the given circuit.



Solution

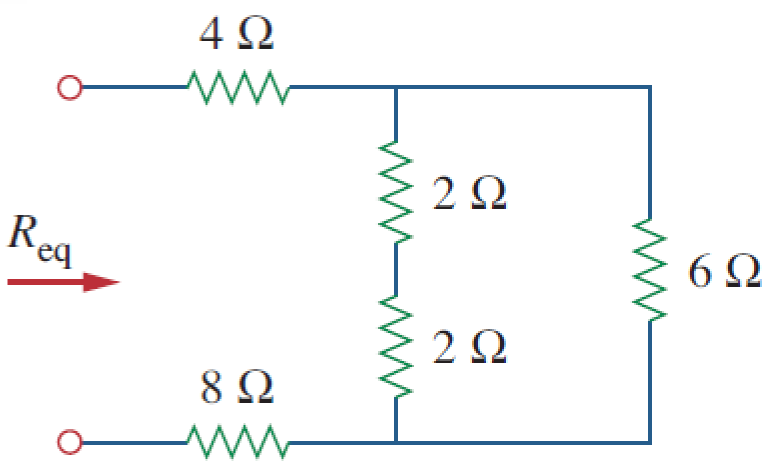
To get R_{eq}, we combine resistors in series and in parallel.

Example #9

$$6\Omega \parallel 3\Omega = \frac{6\times 3}{6+3} = 2\Omega$$

Also 1 Ω in series with 5 Ω

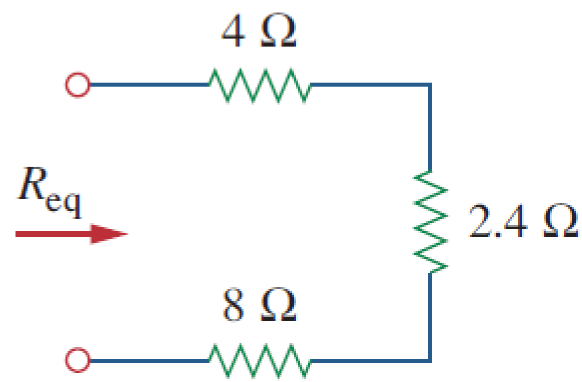
$$1\Omega + 5\Omega = 6\Omega$$



$$2\Omega + 2\Omega = 4\Omega$$

Now 4 Ω in parallel with 6 Ω

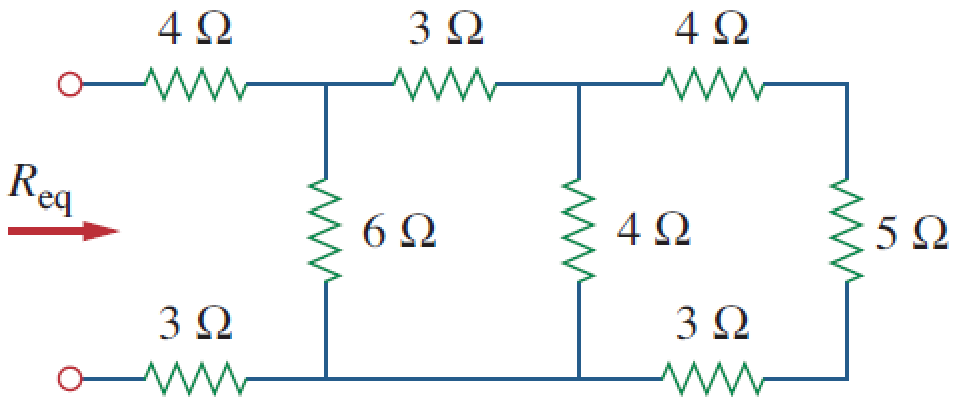
$$4\Omega \parallel 6\Omega = \frac{4\times 6}{4+6} = 2.4\Omega$$



$$R_{eq} = 4\Omega + 2.4\Omega + 8\Omega = 14.4\Omega$$

Example #10

By combining the resistors find R_{eq} for the following circuit.

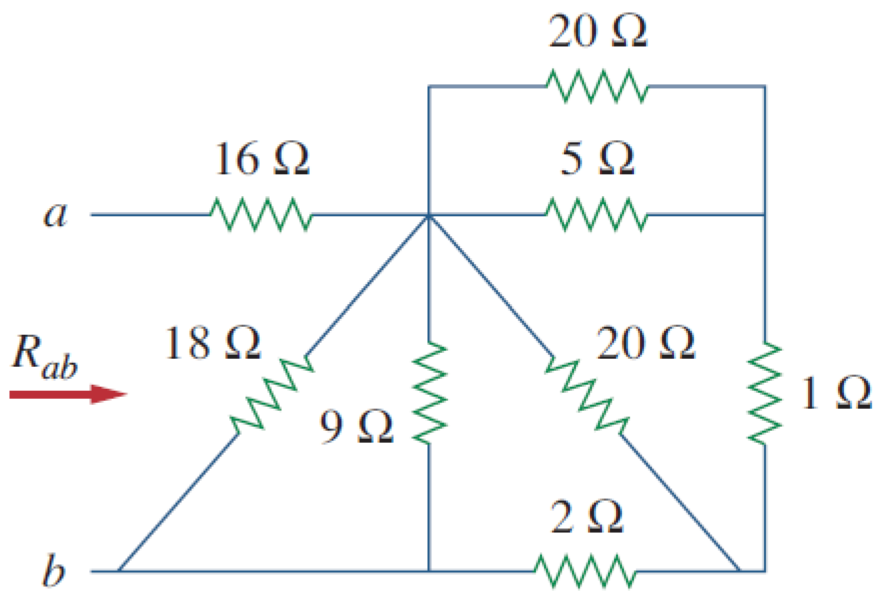


Solution

$$R_{eq} = 10\,\Omega$$

Example #11

Find R_{ab} for the given circuit.



Solution

$$R_{ab} = 19\,\Omega$$