ESc201: Introduction to Electronics

Circuit Fundamentals

A *quick* Recap

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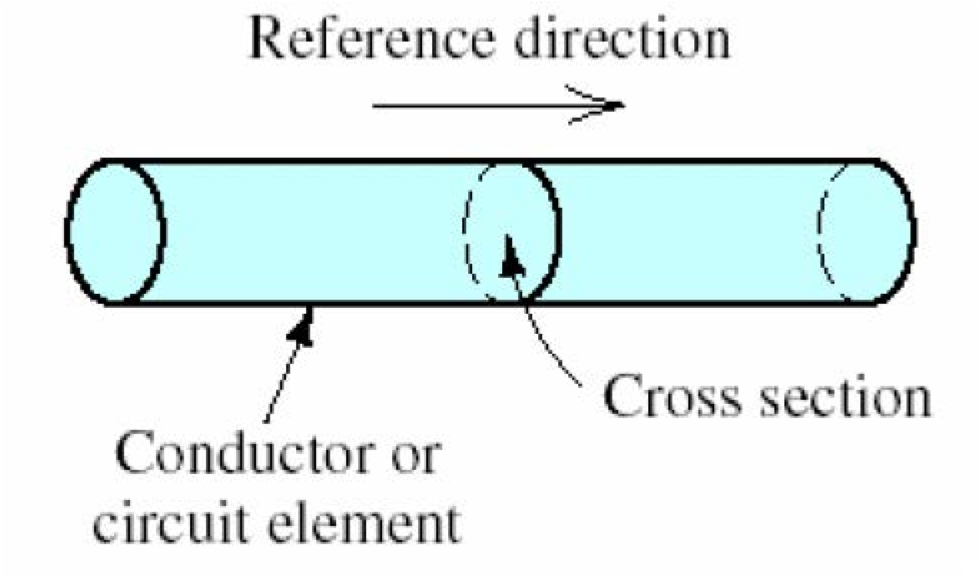
Concepts

- Charge, Current, Voltage, Power, and Energy
- Ohm’s Law
- KCL
- KVL

Electrical Current

The time rate of flow of electrical charge

– The units are amperes (A), which are equivalent to coulombs per second (*C/s*)



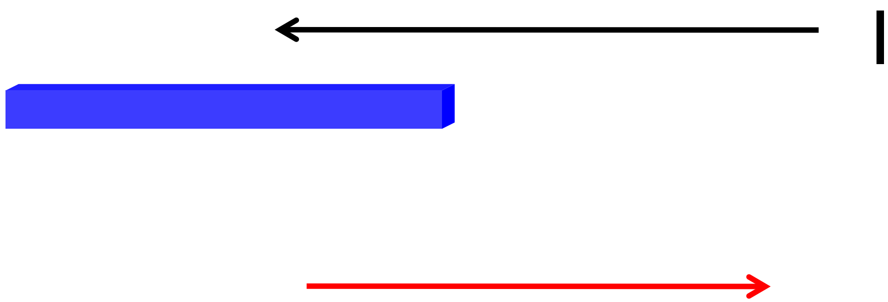
$$i(t) = \frac{dq(t)}{dt}$$

André-Marie Ampère
1775-1836

Flow of electrons through a wire or other electrical conductor gives rise to current

- Electrons are negatively charged particles

The charge per electron is **-1.602×10^{-19} *C***

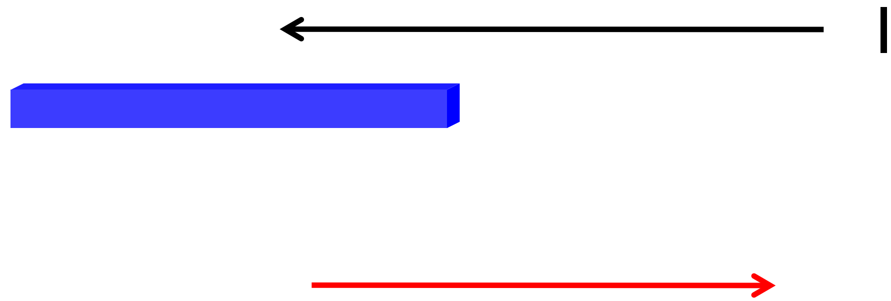


10^{16} electrons flow per second

How much current flows? $i(t) = \dfrac{dq(t)}{dt}$

$$I = \frac{Q}{t} = \frac{-1.6\times10^{-19}\times10^{16}}{1} = -1.6\times10^{-3}\,A$$

Current has a magnitude and a direction



10^{16} electrons flow per second

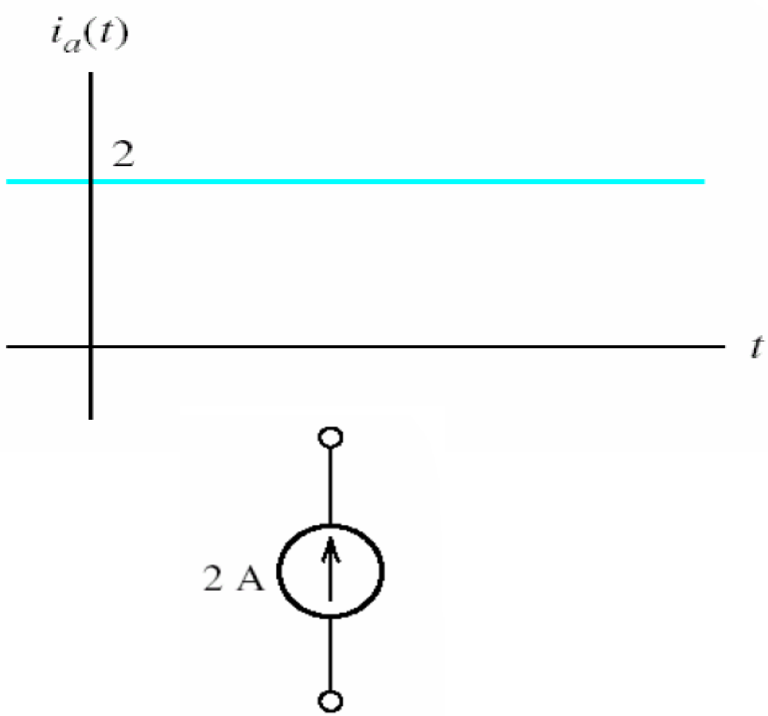
Direction of current flow is opposite to direction of electron flow

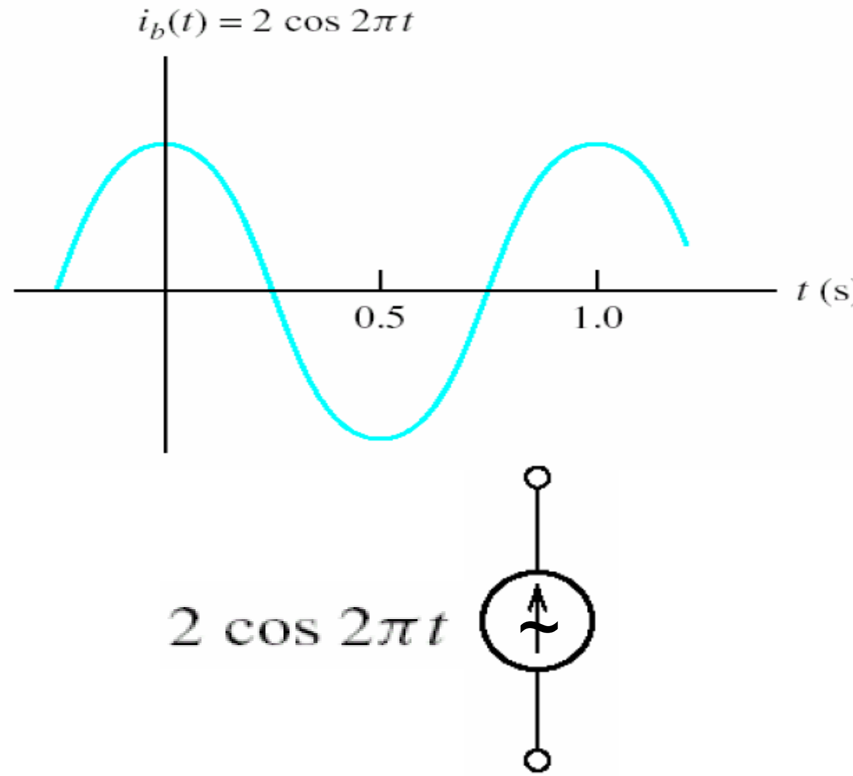
Large number of electrons have to flow for appreciable current

Exercise 1: For $q(t) = 2 - 2e^{-100t}$, $t > 0$ *and* $q(t) = 0$ *for* $t < 0$, *find* $i(t)$

Direct Current (DC) & Alternating Current (AC)

When current is constant with time, we say that we have direct current, abbreviated as DC.





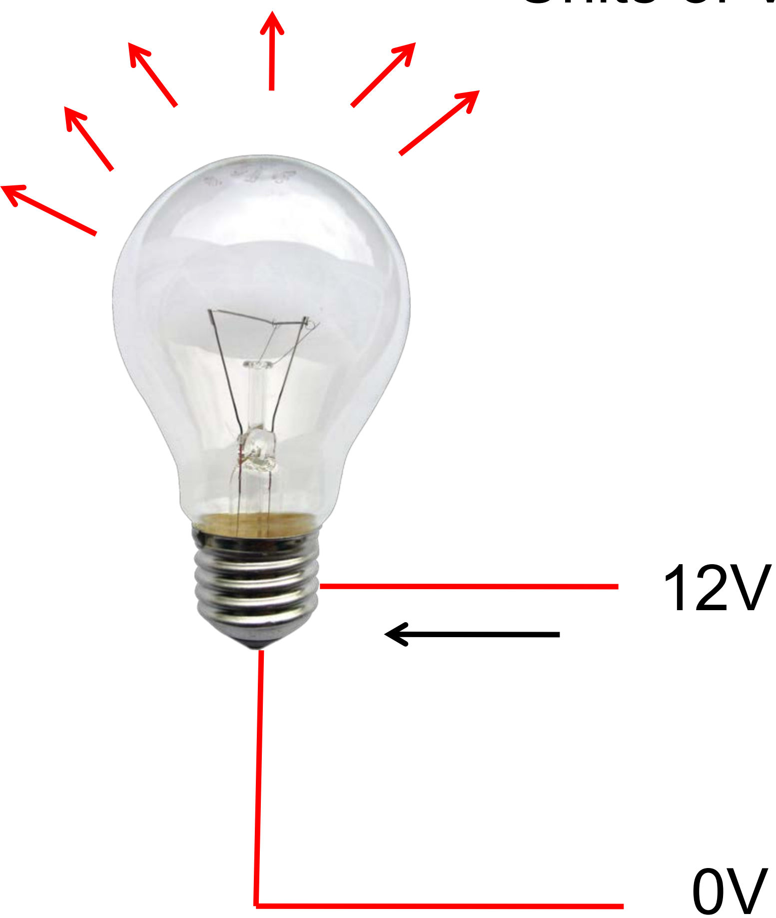
On the other hand, a current that varies with time, reversing direction periodically, is called alternating current, abbreviated as **AC**

Voltage

Voltage difference is a Source of current flow

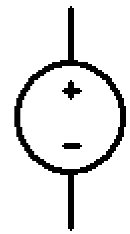
Units of Voltage: Volts (V)

Alessandro Giuseppe Antonio Anastasio Volta 1745-1827

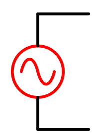


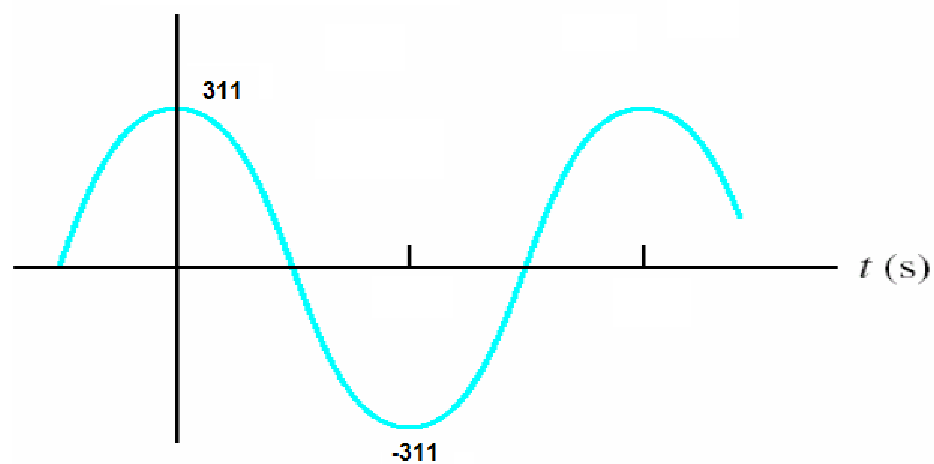
Voltage Sources

DC and AC voltages

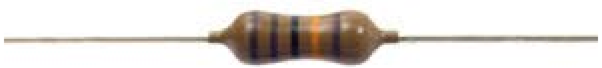


$$V_+ - V_- = 12V$$

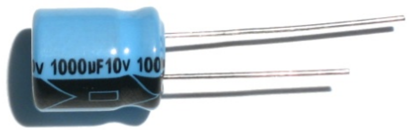




Electrical Systems are made of Voltage sources, wires and a variety of **electrical elements**

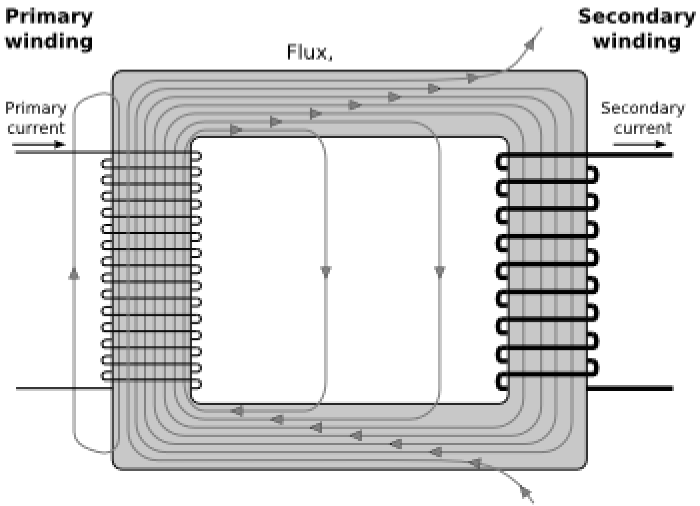


Resistor



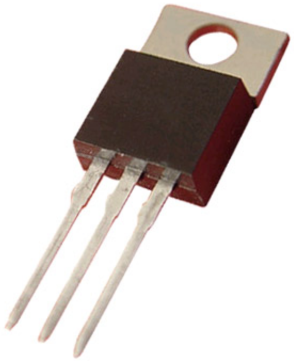
Capacitor

Inductor



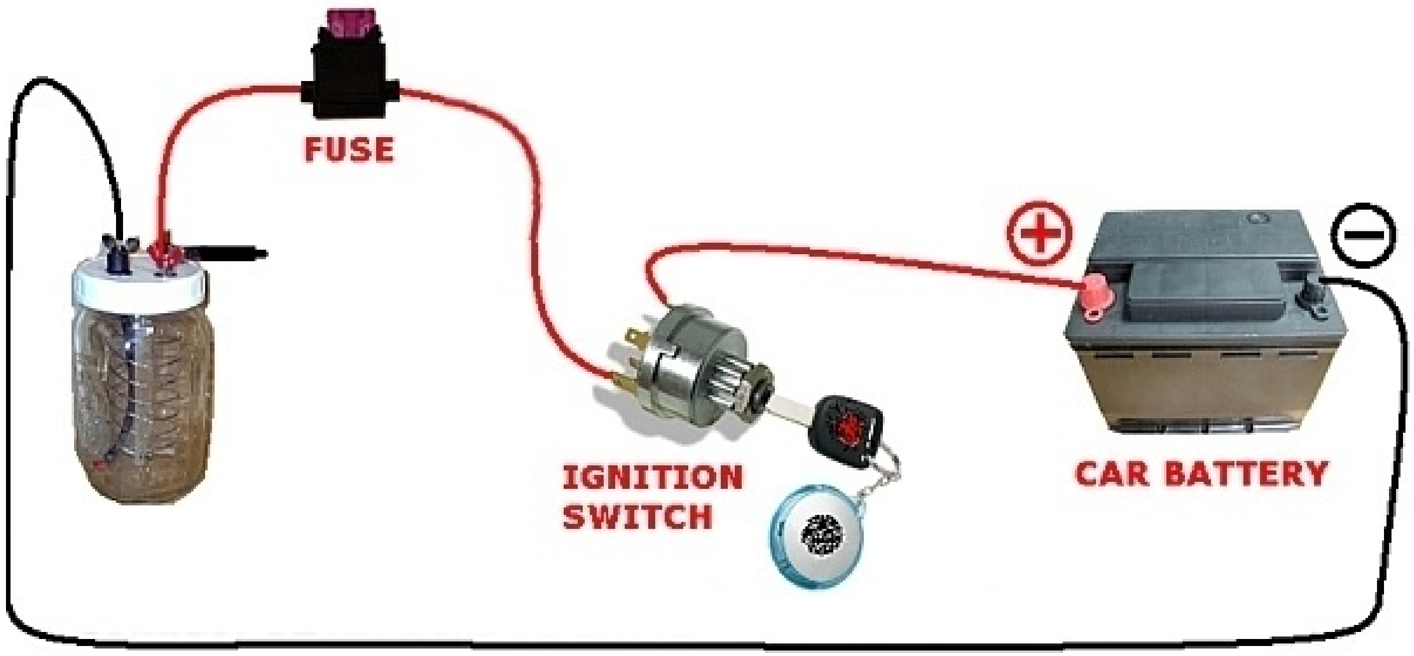
Transformer

Diode



Transistor

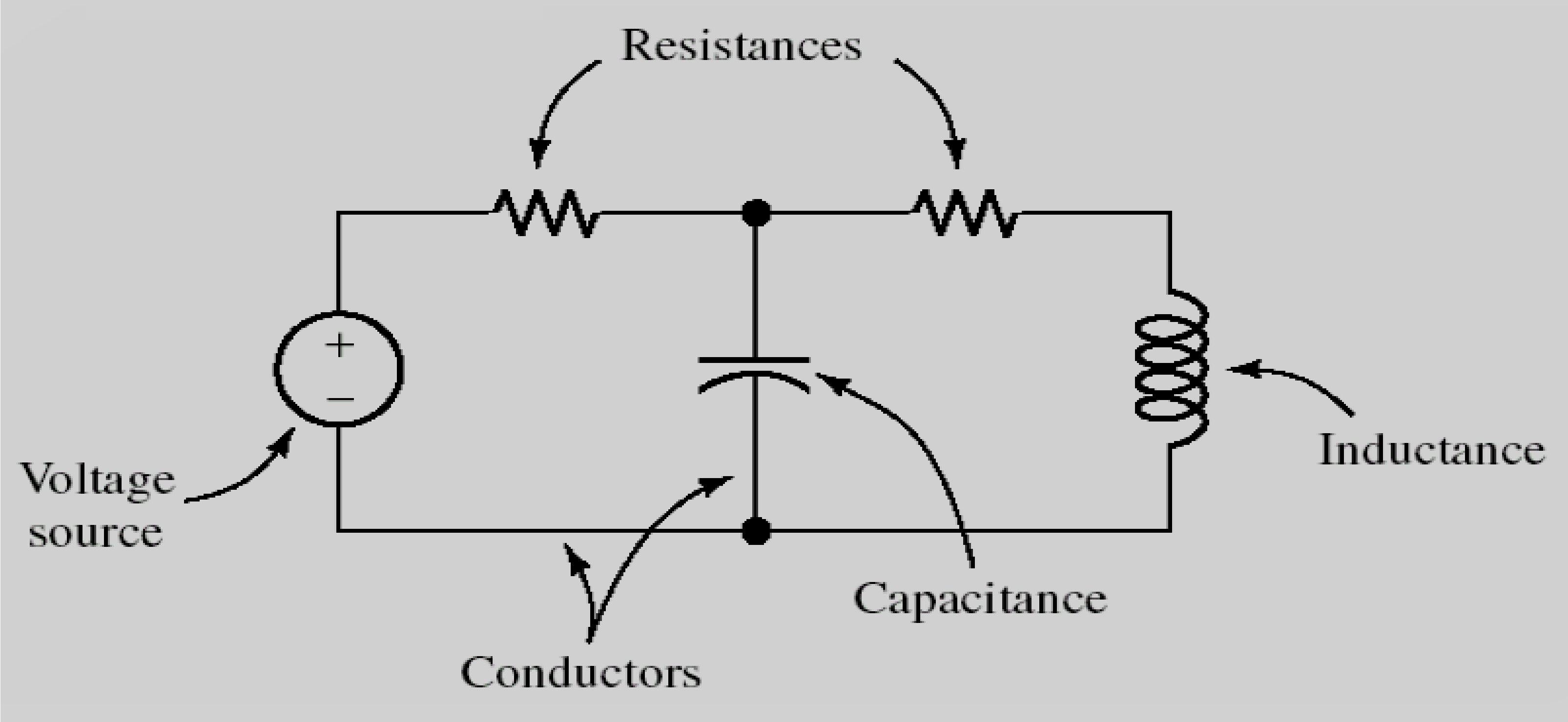
Current flows in a loop



Electrical systems are called electrical circuits

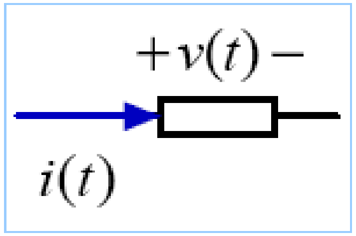
Electrical Circuit

Connection of several circuit elements in closed paths by conductors



Before we learn how to analyze and design circuits, we must become familiar with some basic circuit elements.

Resistance



$$v(t) = R \times i(t)$$

Ohm's law

The constant, *R, is called the resistance of the component and is* measured in units of Ohm (Ω)

Standard Multiples of Ohm

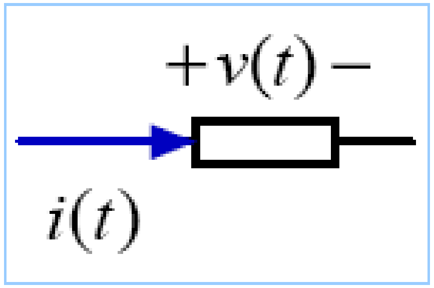
$M\Omega$ Mega Ohm ($10^6\,\Omega$)

$k\Omega$ Kilo Ohm ($10^3\,\Omega$)

Georg Simon Ohm
1789-1854

Resistor Symbol:

Conductance



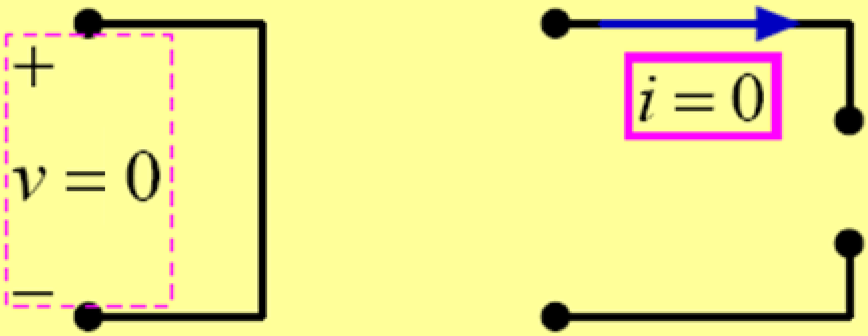
$$v(t) = R \times i(t)$$

$$i(t) = \frac{v(t)}{R} = G \times v(t)$$

Ernst Werner von Siemens
1816-1892

G = 1/R is called conductance and its unit is Siemens (S)

Two special resistor values



Short Circuit

$R = 0$

$G = \infty$

Open Circuit

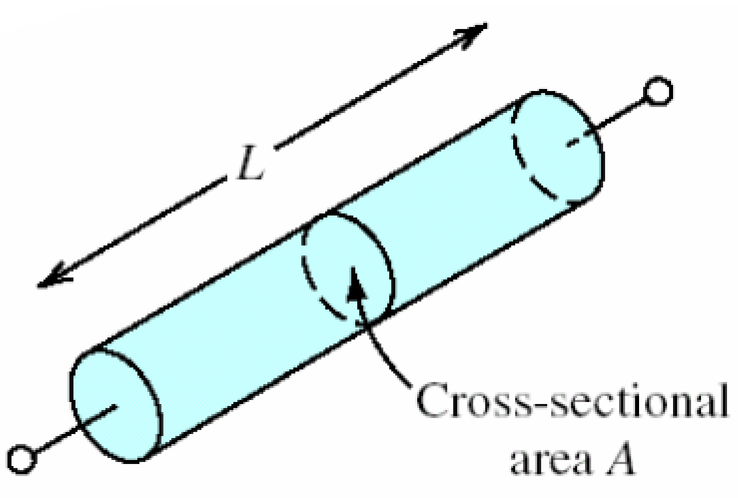
$R = \infty$

$G = 0$

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

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

Resistance Related to Physical Parameters

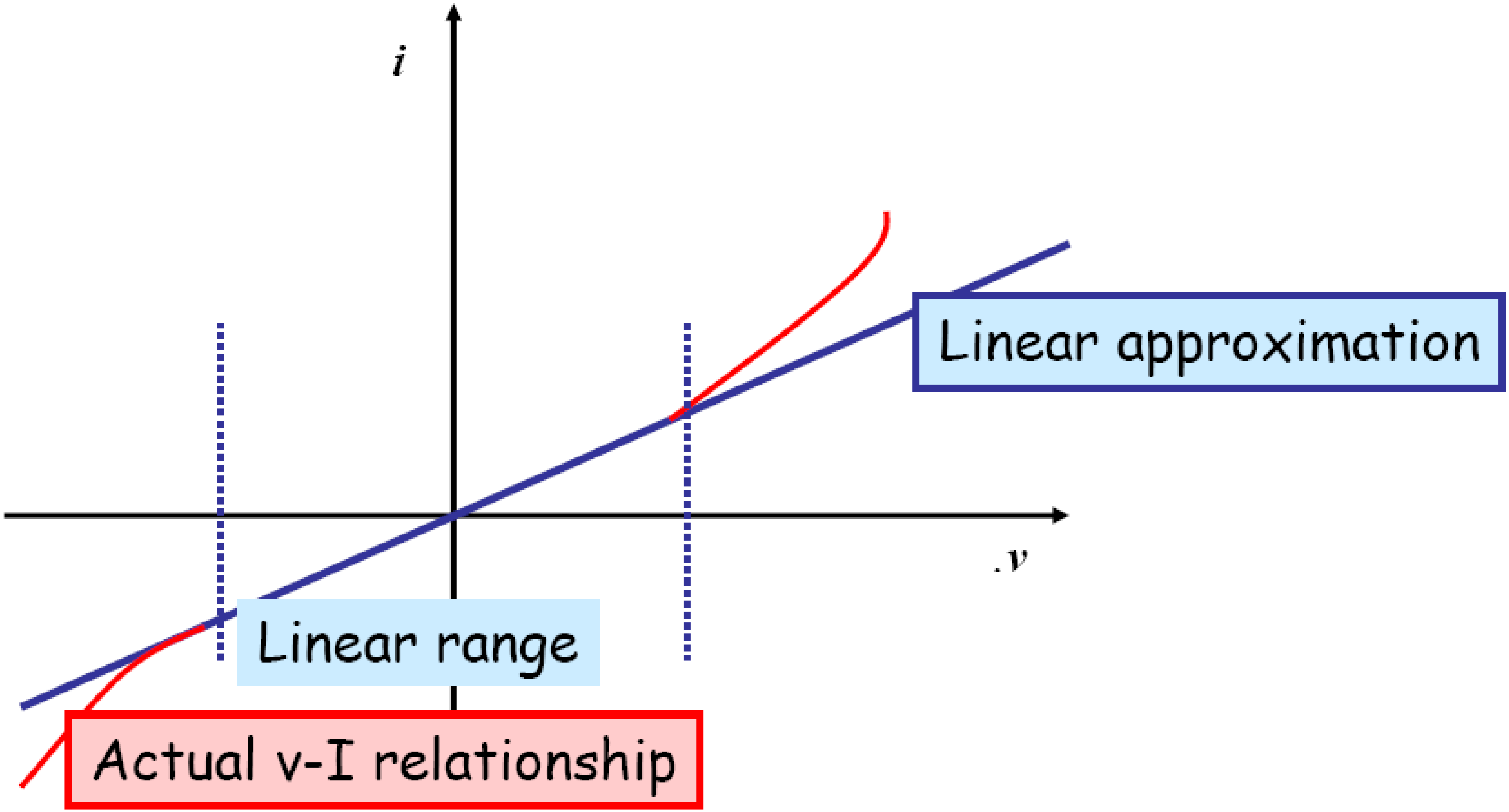


$$R = \rho \times \frac{L}{A}$$

Resistance is affected by the dimensions and geometry of the resistor as well as the particular material used

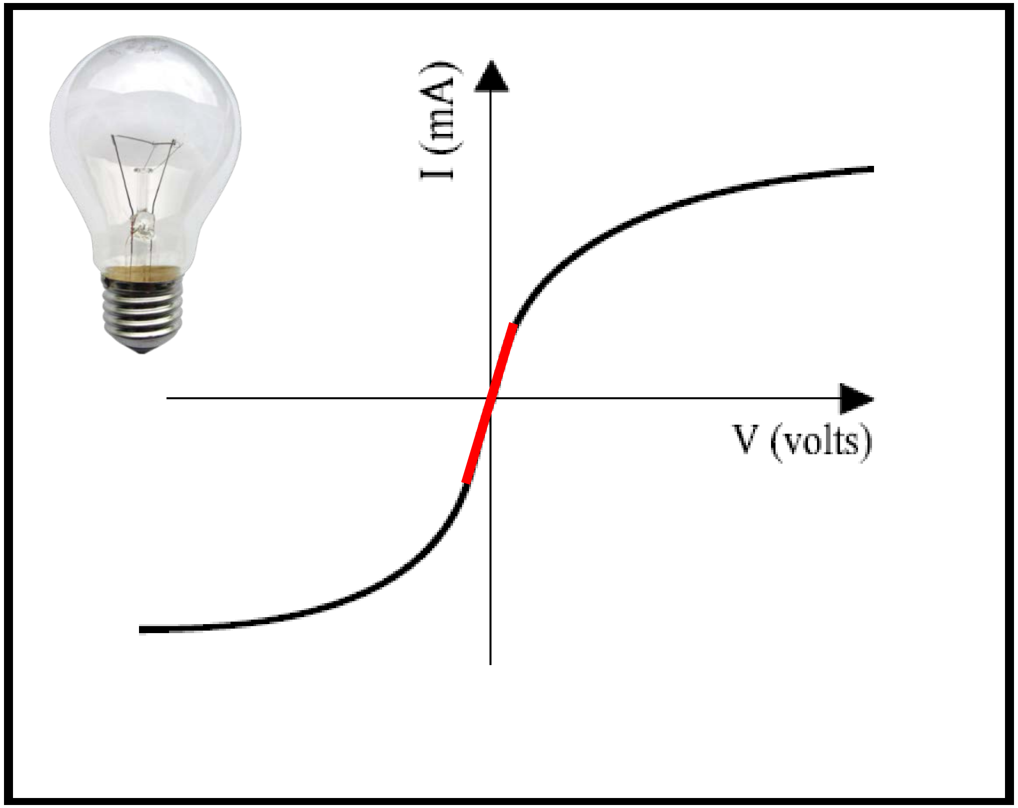
ρ is the resistivity of the material in ohm meters [Ω-m]
– Conductors (Aluminum, Carbon, Copper, Gold)
– Insulators (Glass, Teflon)
– Semiconductors (Silicon)

Any electrical element which obeys ohms law can be modeled as a resistor



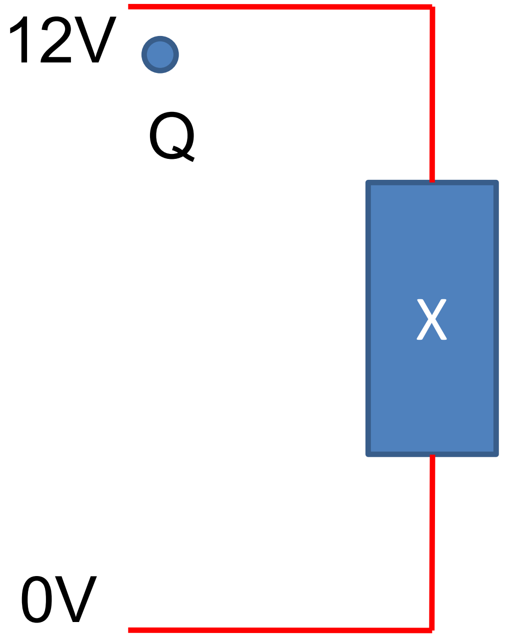
Can we model an electric bulb as a resistor?

Electrical Bulb



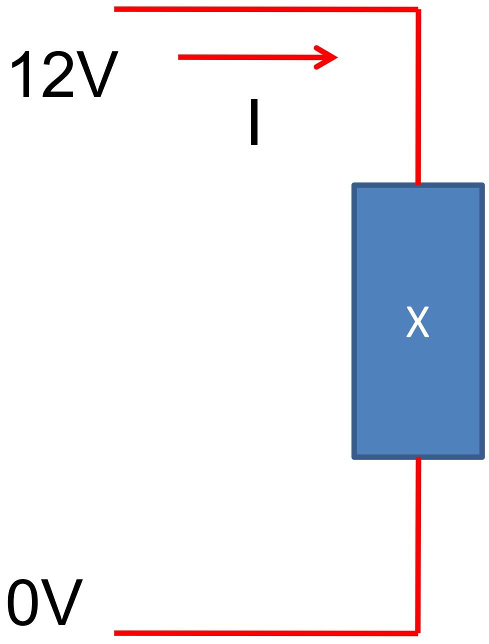
Even though characteristics are non-linear, over a certain range, the bulb can be thought of as a resistor

Power and Energy



The charge loses energy = Q x 12 Joules

This energy is taken from the voltage source and delivered to the circuit element



$$I = \frac{Q}{t}$$

$$Q = I \times t$$

In 1 second, charge equal to Q = *I* flows through the element X

Every time a charge q goes from 12V to 0V it transfers energy qx12 J to the element X

Total Energy transferred in 1 second = *I* x 12 J

Power = Energy/time

Joules/second = watts

P = *I* x 12 Watts

P = *I* x V

A charge of 1 coulomb receives or delivers an energy of 1 joule in moving through a voltage of 1 volt.

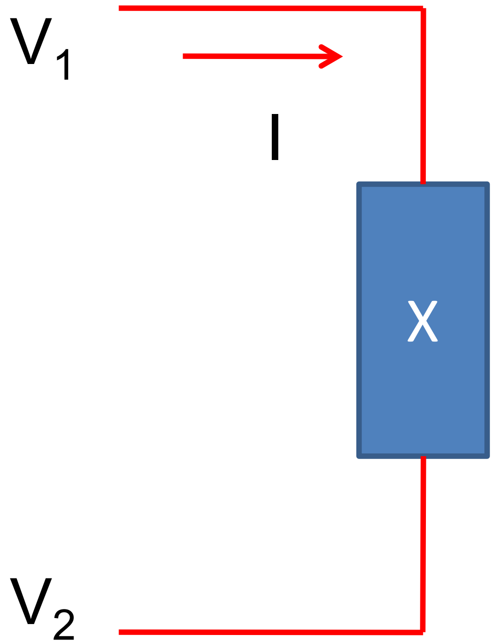
$$v = \frac{dw}{dq}$$

$$i = \frac{dq}{dt}$$

$$P(t) = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = v(t)\,i(t)$$

$$P(t) = \frac{dw}{dt} \Longrightarrow \quad w = \int_{t1}^{t2} p(t)\,dt$$

Power

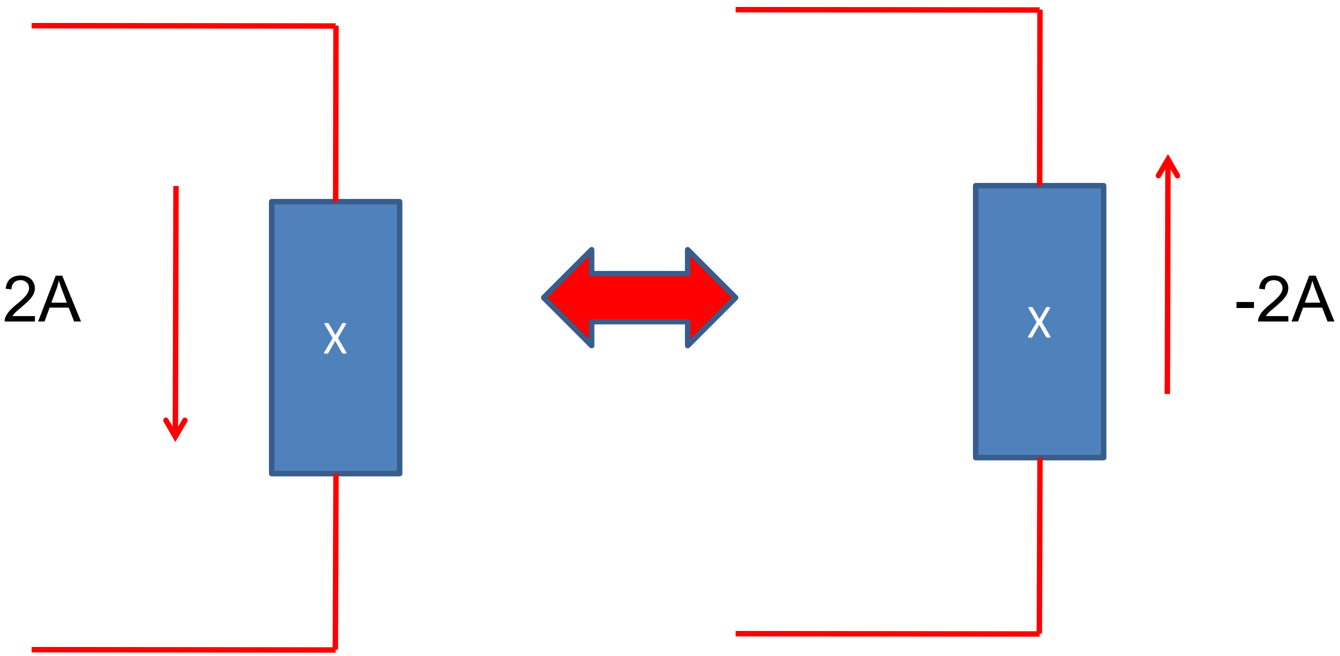


$$P = (V_1 - V_2) \times I$$

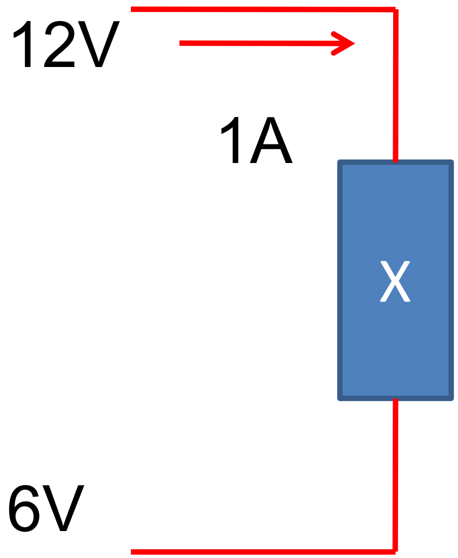
If $V_1 > V_2$ then P is positive and it means that power is being delivered to the electrical element X

If $V_1 < V_2$ then P is negative and it means that power is being extracted from the electrical element X.
X is a source of power !

Note on direction of current

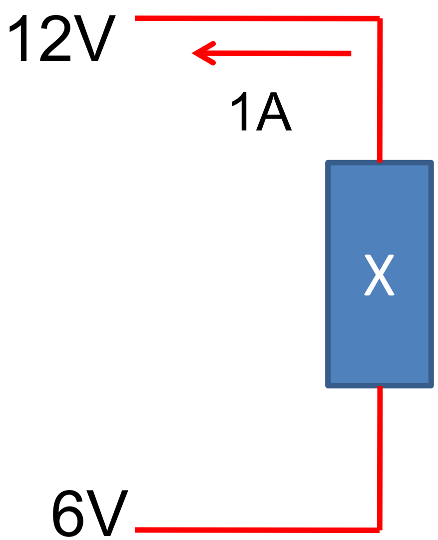


Examples



P = ?

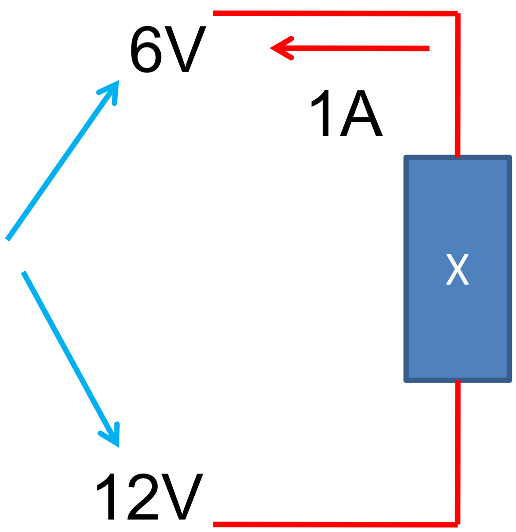
$$P = (V_1 - V_2) \times I$$
$$= (12 - 6) \times 1 = 6W$$



P = ?

$$P = (V_1 - V_2) \times I$$
$$= (12 - 6) \times -1 = -6W$$

Power is supplied by element X instead of dissipation

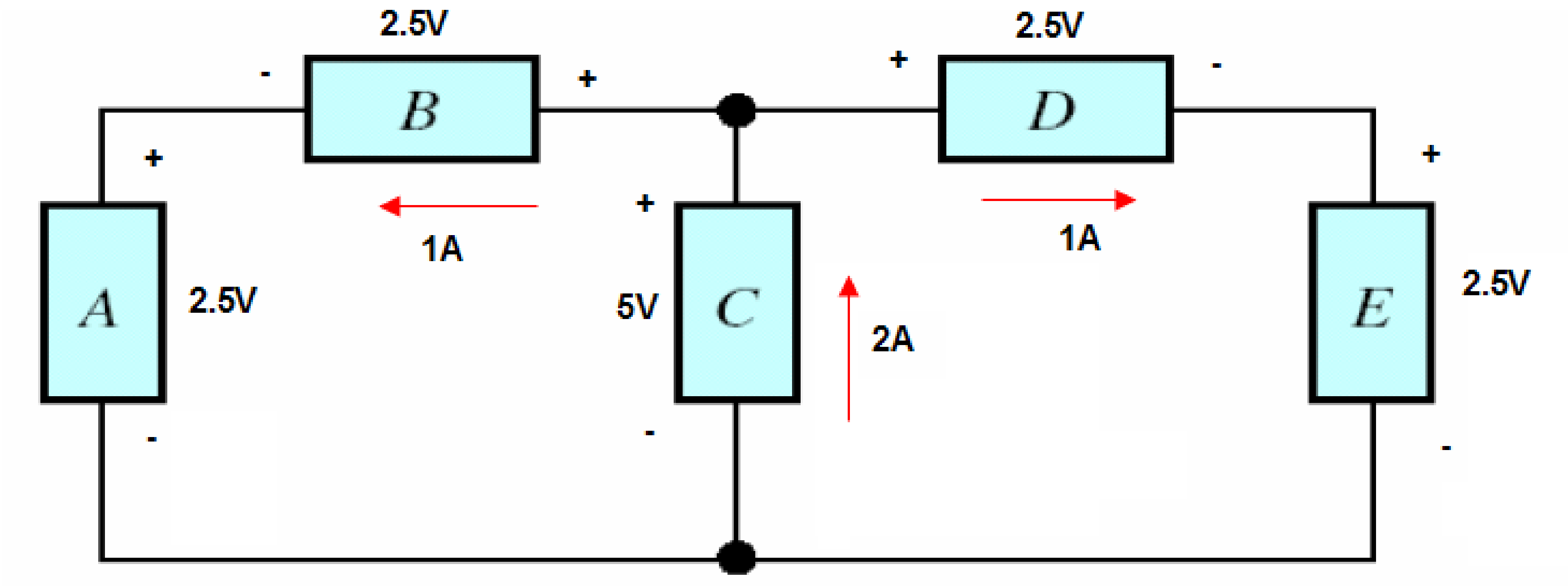


P = ?

$$P = (V_1 - V_2) \times I$$
$$= (6 - 12) \times -1 = 6W$$

power is being delivered to the electrical element X

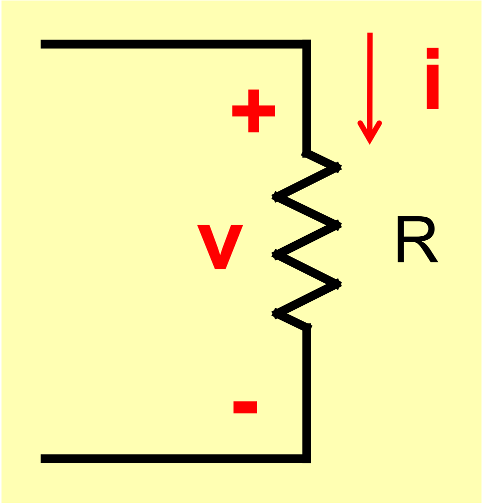
There is only one battery in the circuit. Can you find which element is a battery?



A battery is a source of power, so Power dissipated is negative

Answer is C

Power dissipated in a Resistor



$$v = i \times R$$

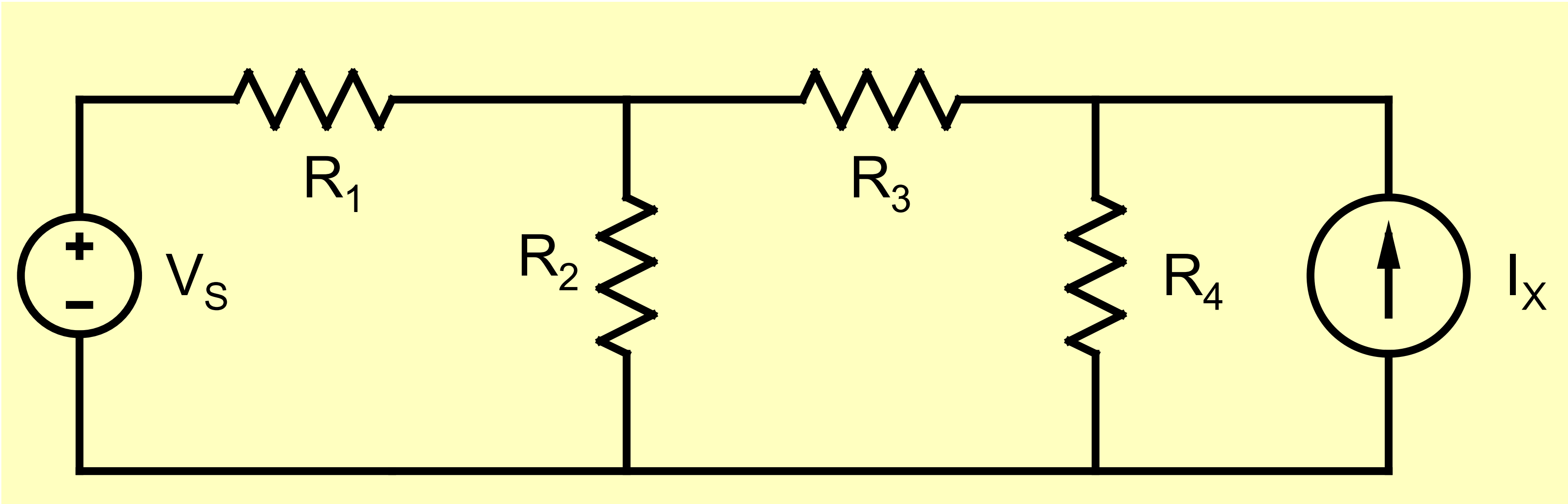
$$i = \frac{v}{R}$$

$$P = v \times i$$

$$P = i^2 \times R$$

$$P = \frac{v^2}{R}$$

Circuit Analysis

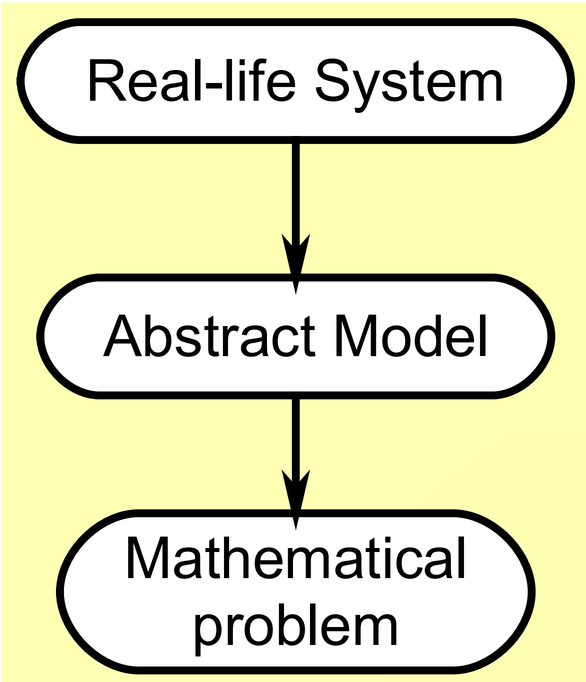


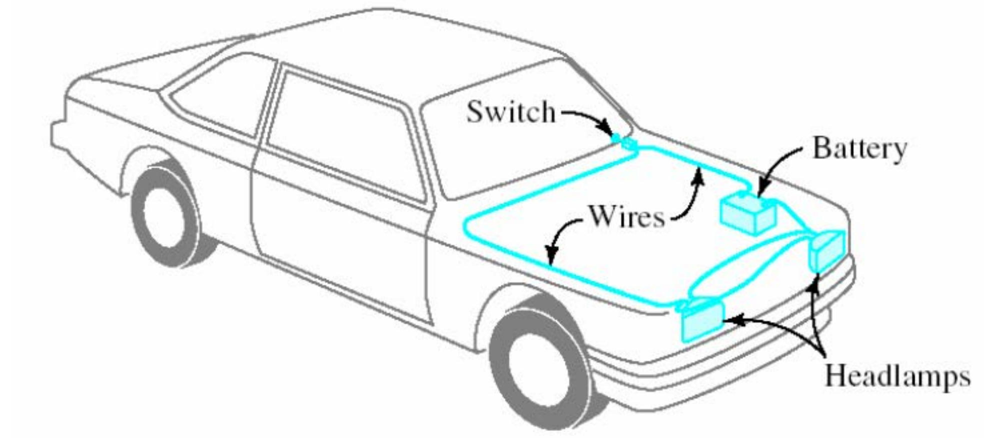
What is current in R_2 ?

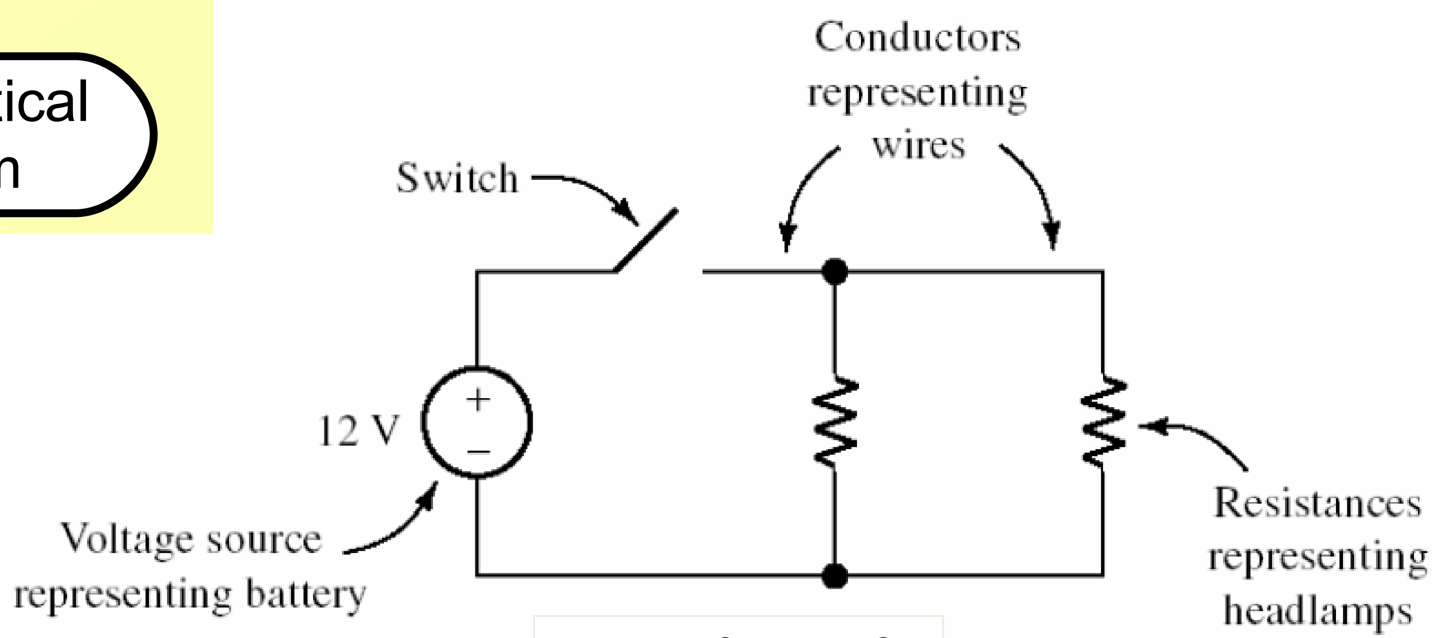
Procedure:

Use Kirchhoff's voltage law (KVL) and Kirchhoff's Current law (KCL) to transform the circuit into a set of equations whose solution gives the required voltage or current value

Engineering Analysis



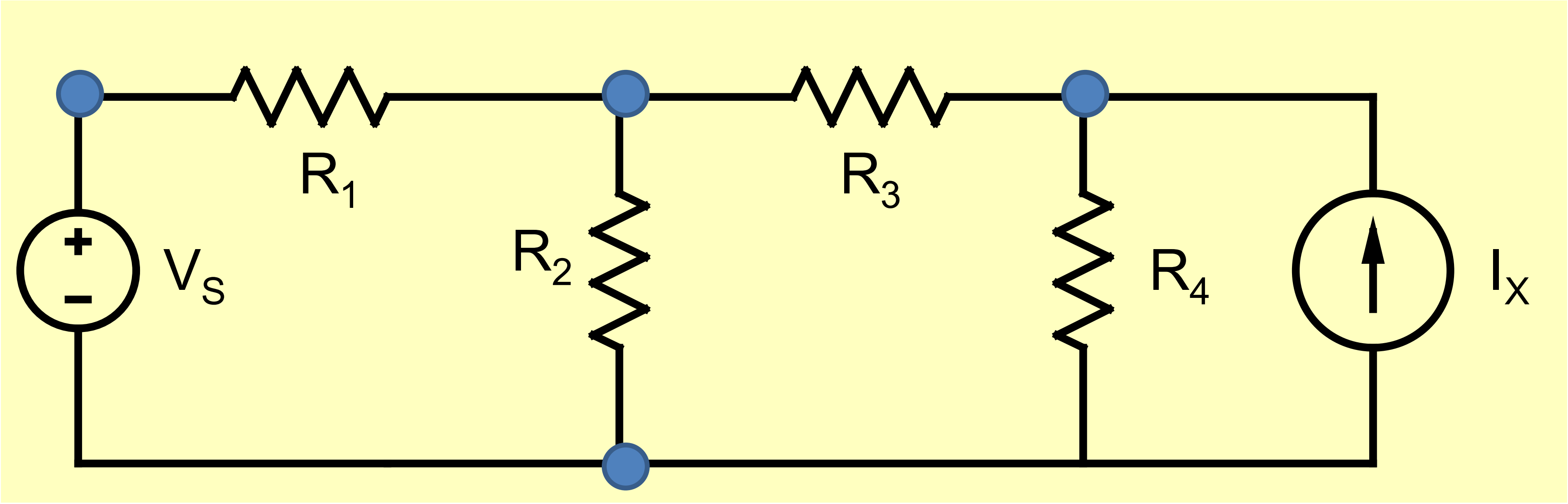




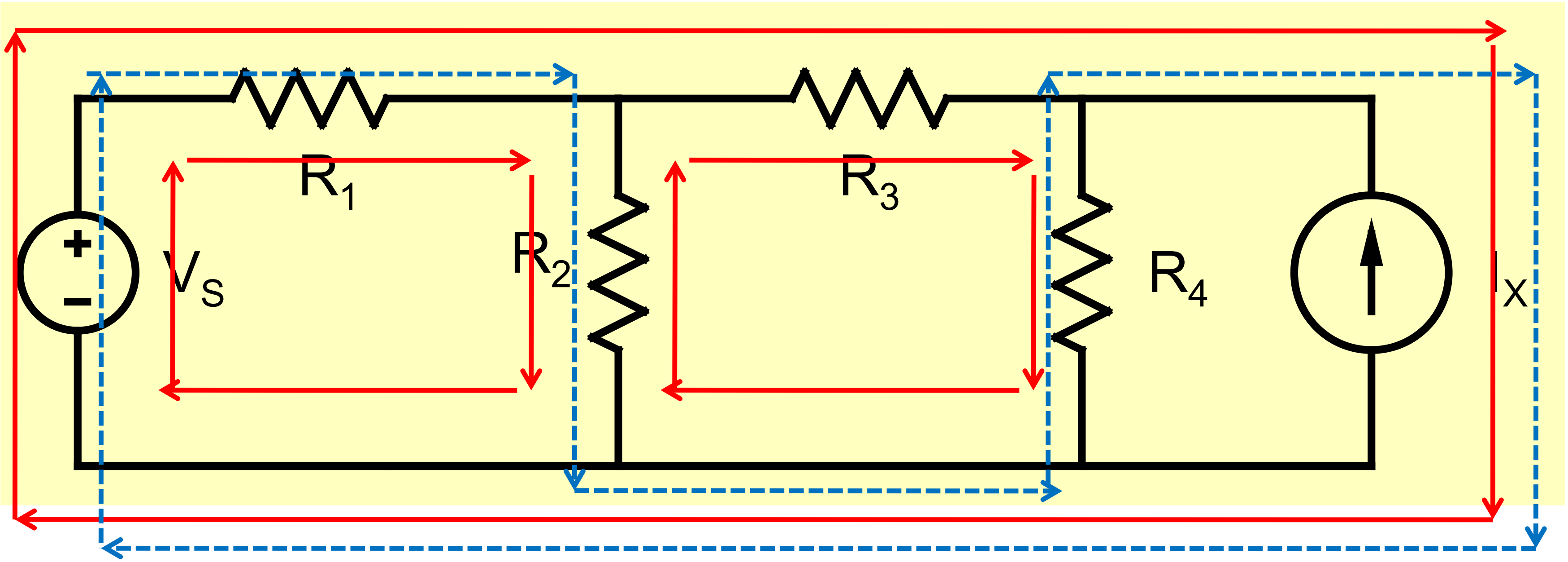
$$P = \frac{v^2}{R_1} + \frac{v^2}{R_2}$$

Nodes and loops

Node: A point where 2 or more circuit elements are connected.



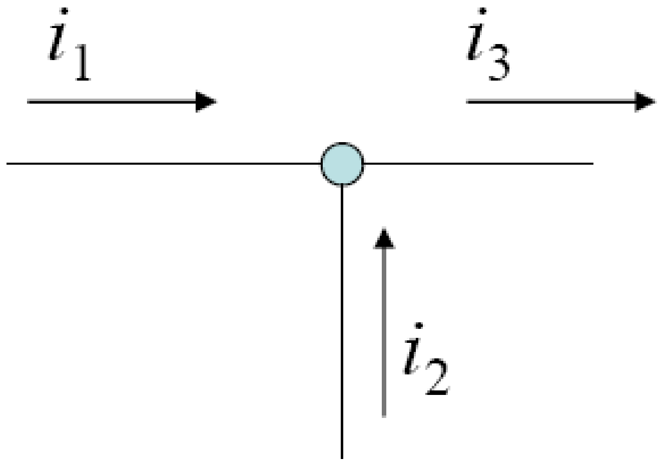
A ***loop is formed by tracing a closed path*** through circuit elements without passing through any intermediate node more than once



This is not a valid loop !

Kirchhoff's Current Law (KCL)

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



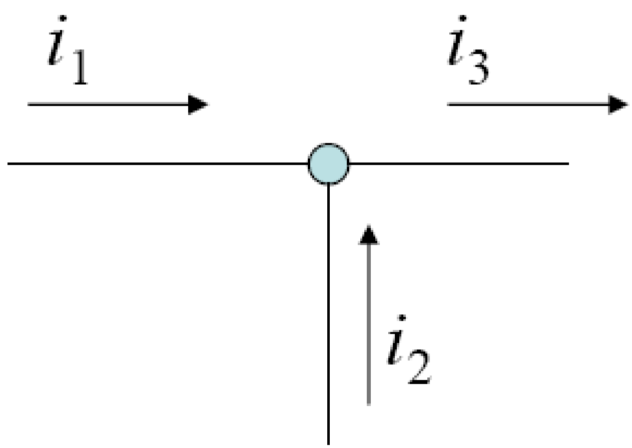
$$i_1 + i_2 = i_3$$

Kirchhoff's Current Law (KCL)

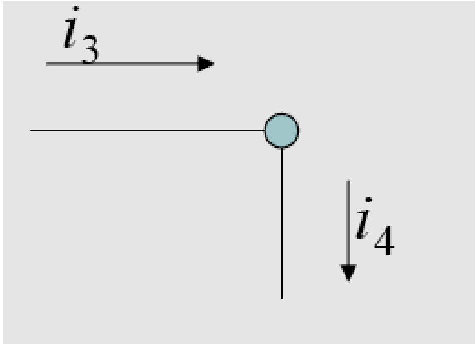
Net current entering a node is zero

$$\sum_{1}^{N} i_j = 0$$

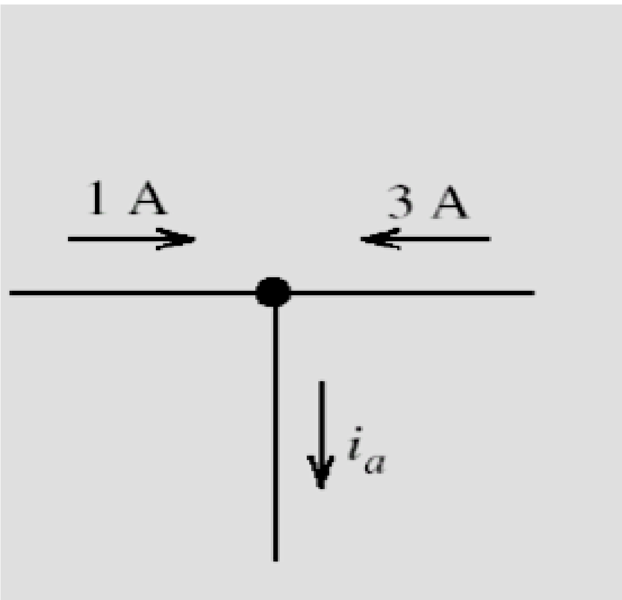
Current entering a node is considered positive and current leaving a node is considered as negative



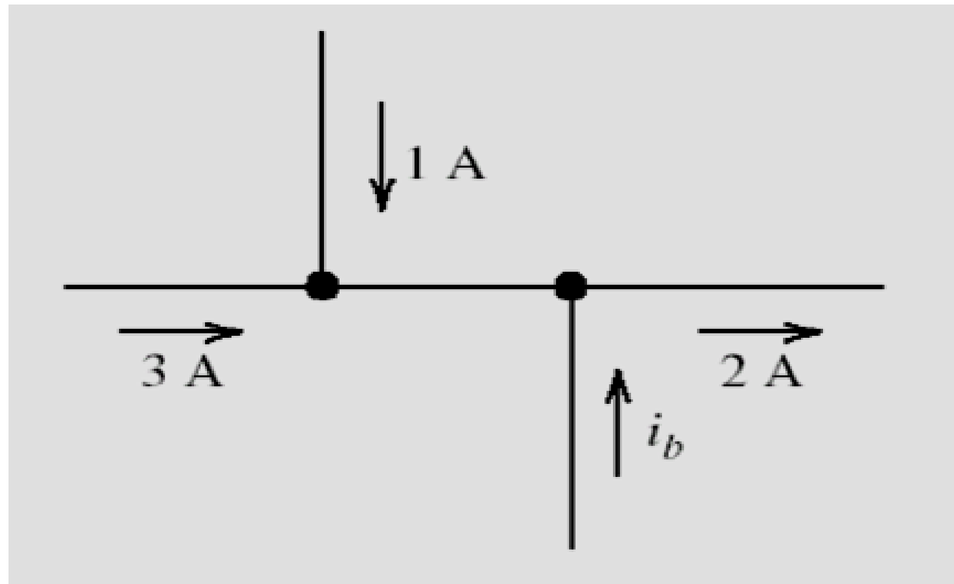
$$i_1 + i_2 - i_3 = 0$$



$$i_3 = i_4$$



(a)



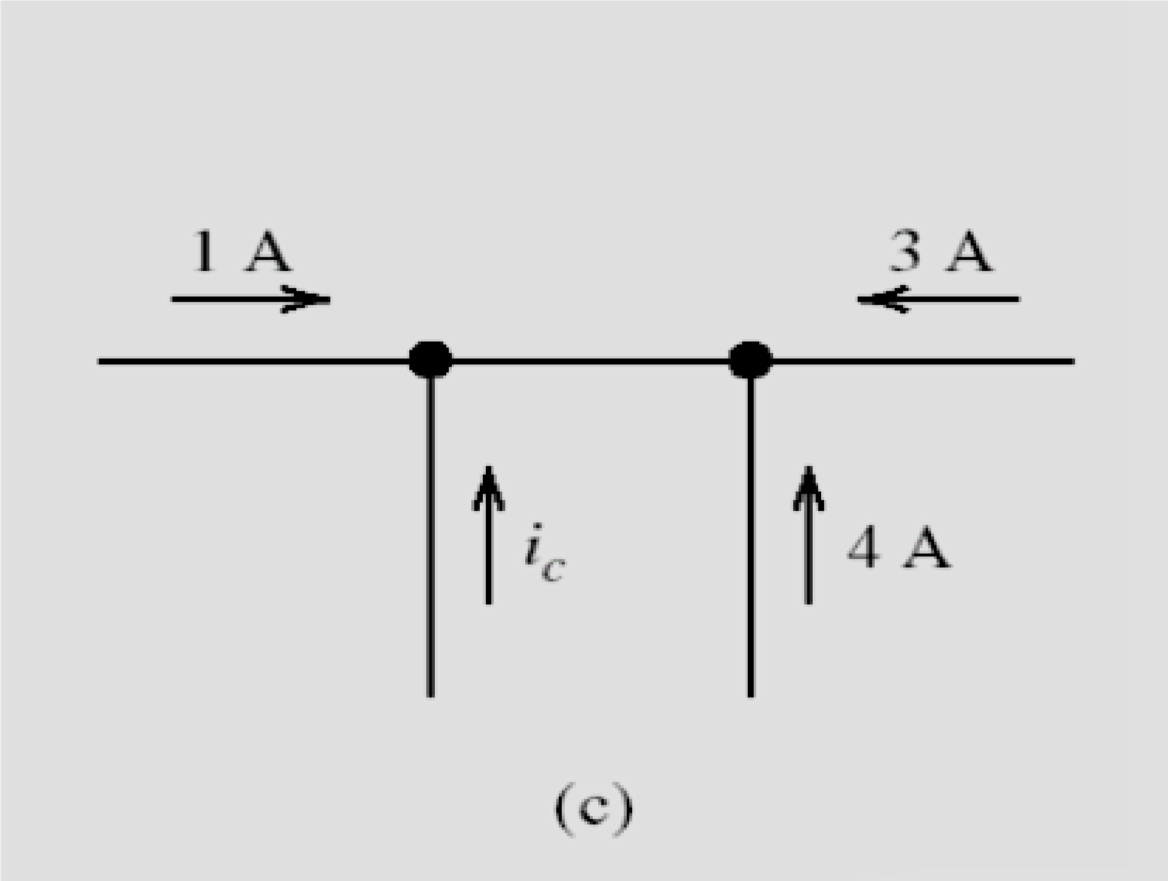
(b)

$$1 + 3 - i_a = 0$$

$$i_a = 4A$$

$$1 + 3 + i_b - 2 = 0$$

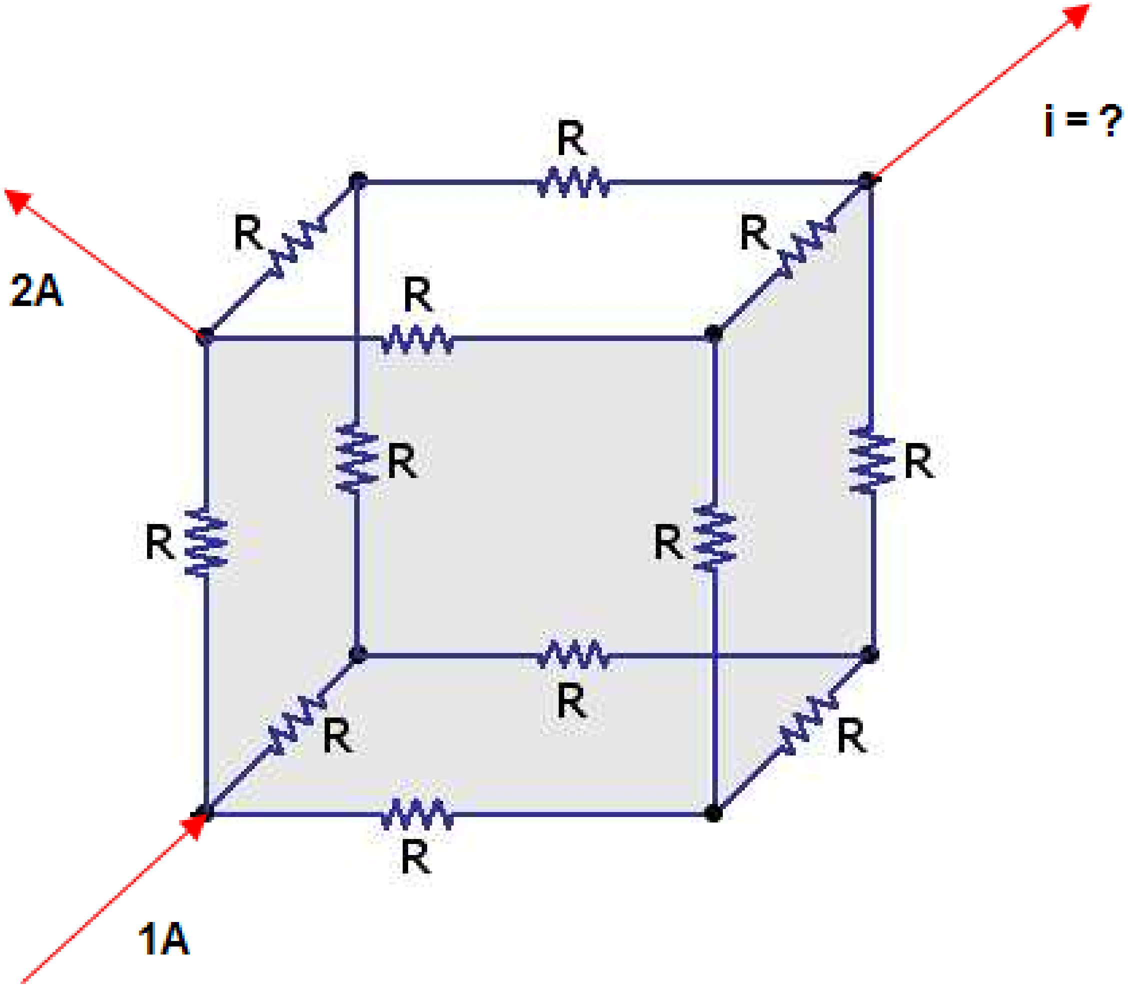
$$i_b = -2A$$



$$1+3+i_c+4=0$$

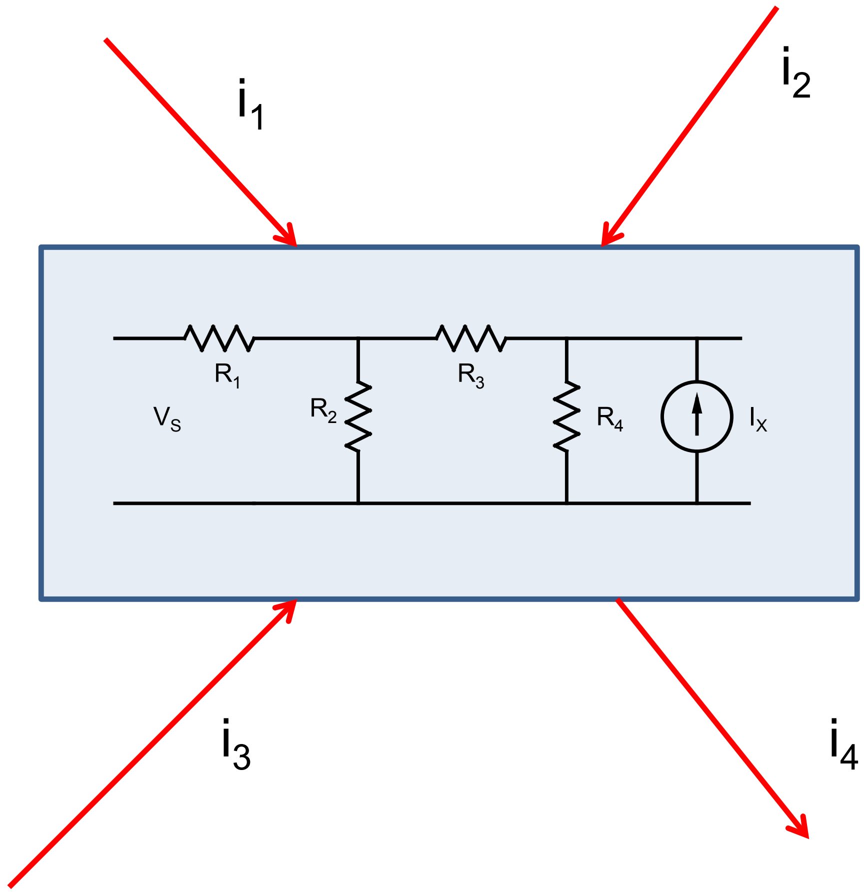
$$i_c=-8A$$

Example



KCL: More general formulation

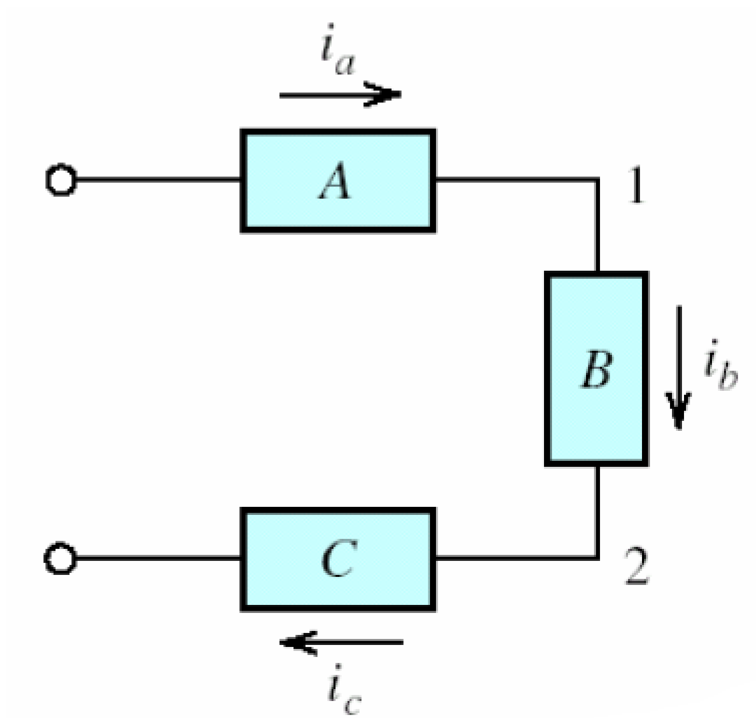
The sum of currents entering/leaving a **closed surface is zero.**



$$i_1 + i_2 + i_3 - i_4 = 0$$

Series Circuit

Two elements are connected in series if there is no other element connected to the node joining them



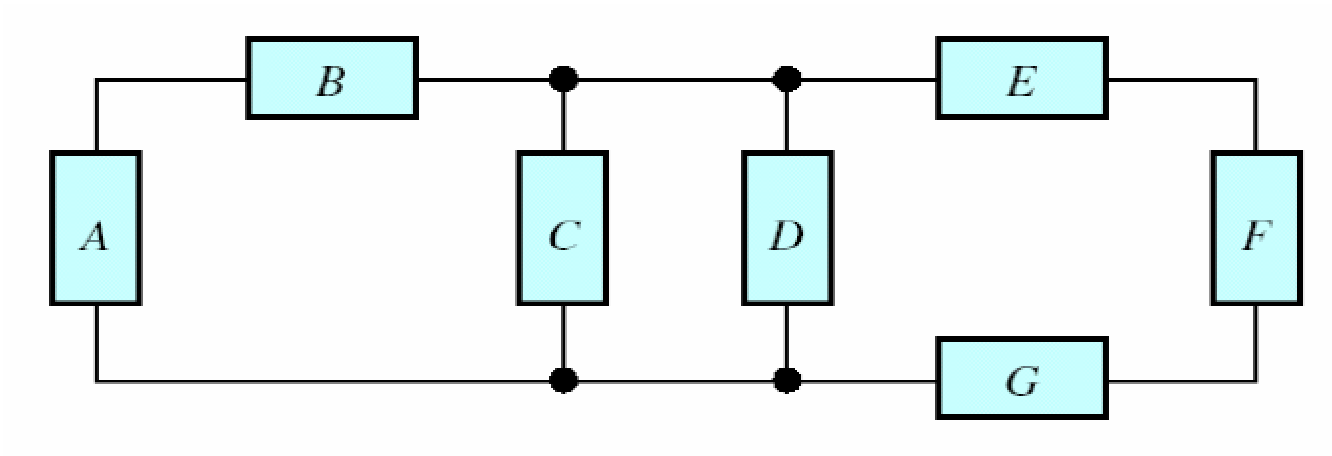
A, B and C are in series

The elements have the same current going through them

$$i_a = i_b = i_c$$

Example:

Identify the groups of elements connected in series



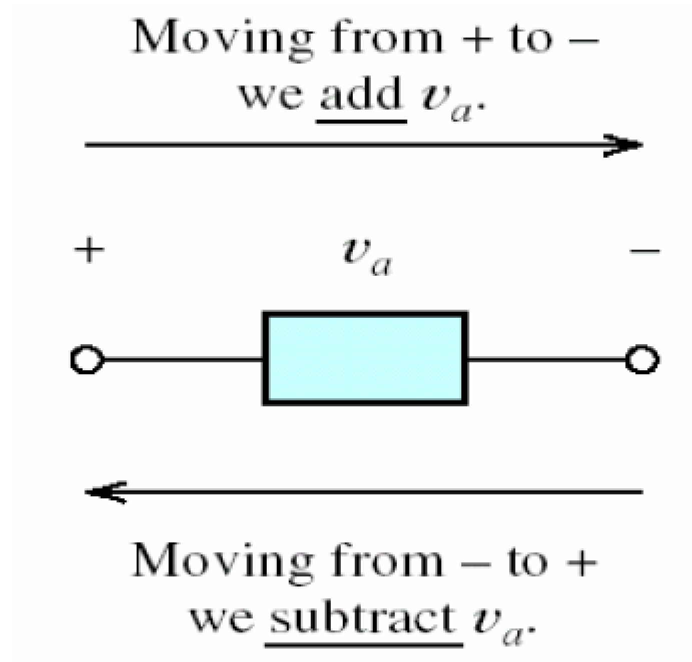
A and B are in series

E, F and G are in series

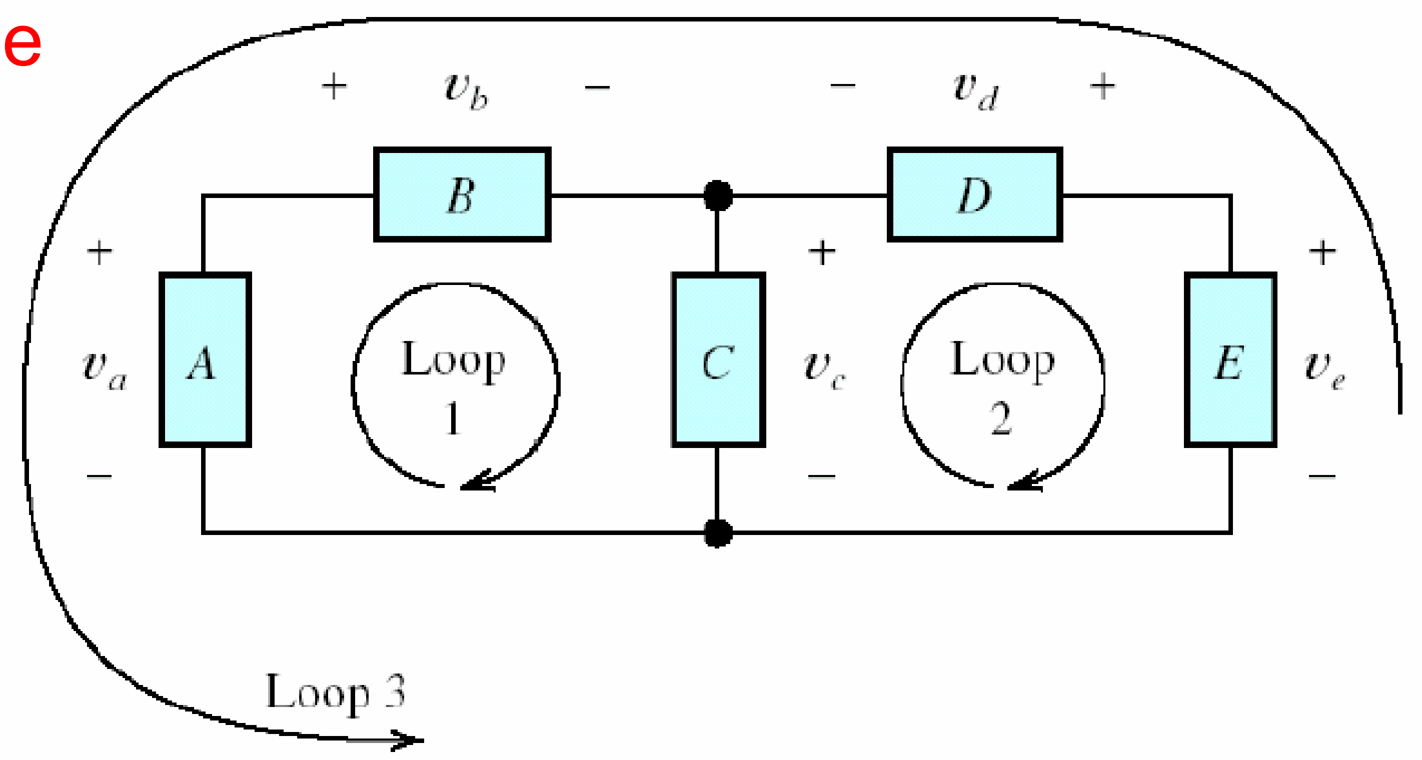
Kirchhoff's Voltage Law (KVL)

The algebraic sum of the voltages equals zero for any closed path (loop) in an electrical circuit

In applying KVL to a loop, voltages are added or subtracted depending on their reference polarities relative to the direction of travel around the loop.



Example

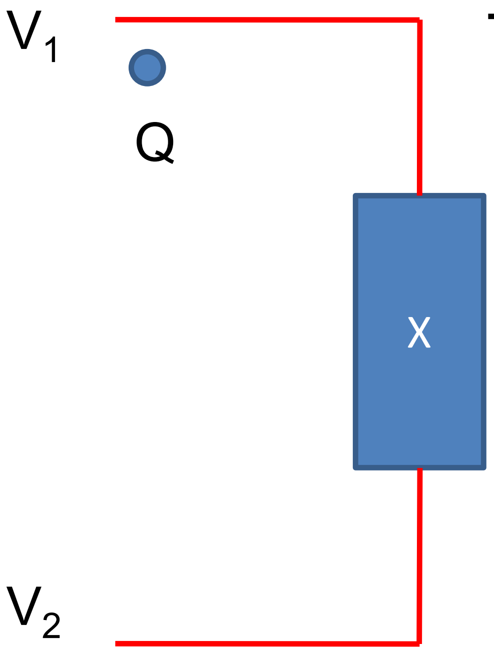


$$\text{Loop1}: -v_a + v_b + v_c = 0$$

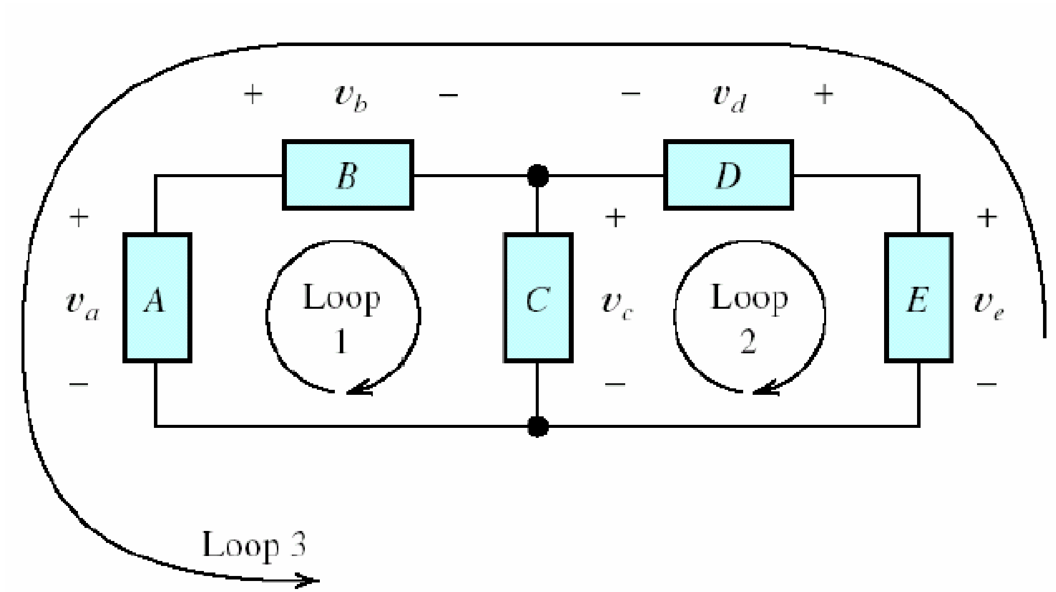
$$\text{Loop2}: -v_c - v_d + v_e = 0$$

$$\boxed{\text{Loop3}: -v_e + v_d - v_b + v_a = 0}$$

KVL and Conservation of Energy



The charge loses energy = Q x (V_1-V_2) Joules



$$\text{Loop1}: -v_a + v_b + v_c = 0$$

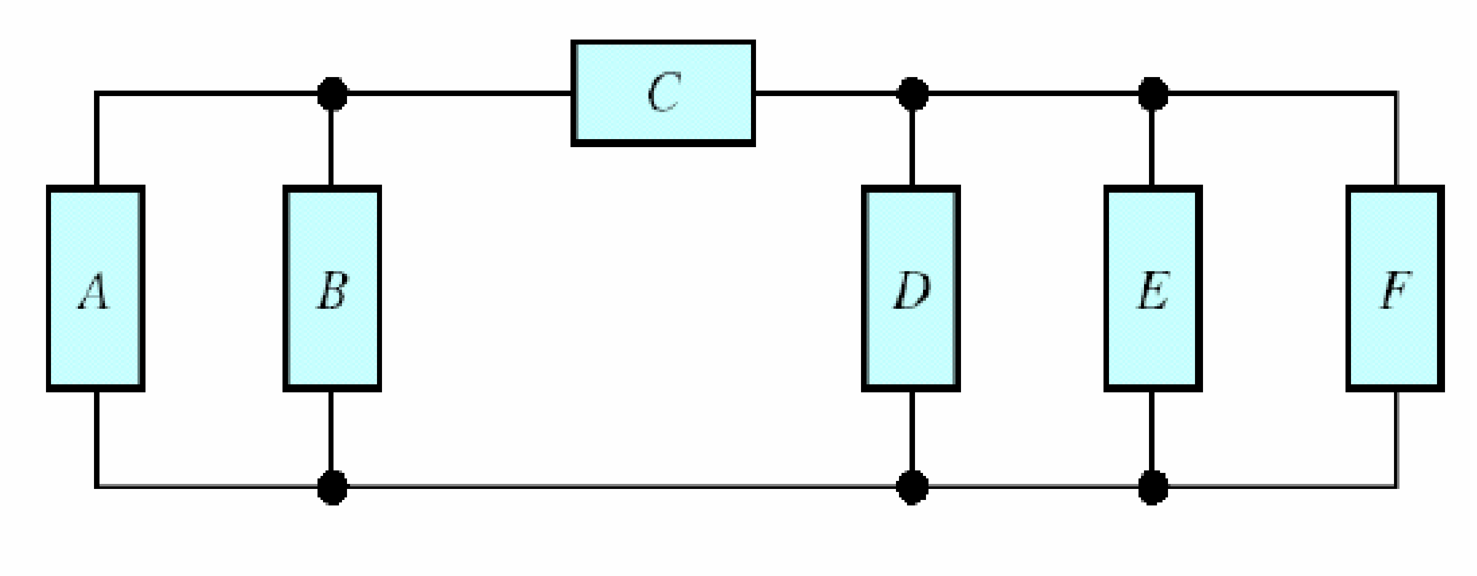
Energy gained

Energy lost

KVL: law of conservation of Energy

Parallel Circuits

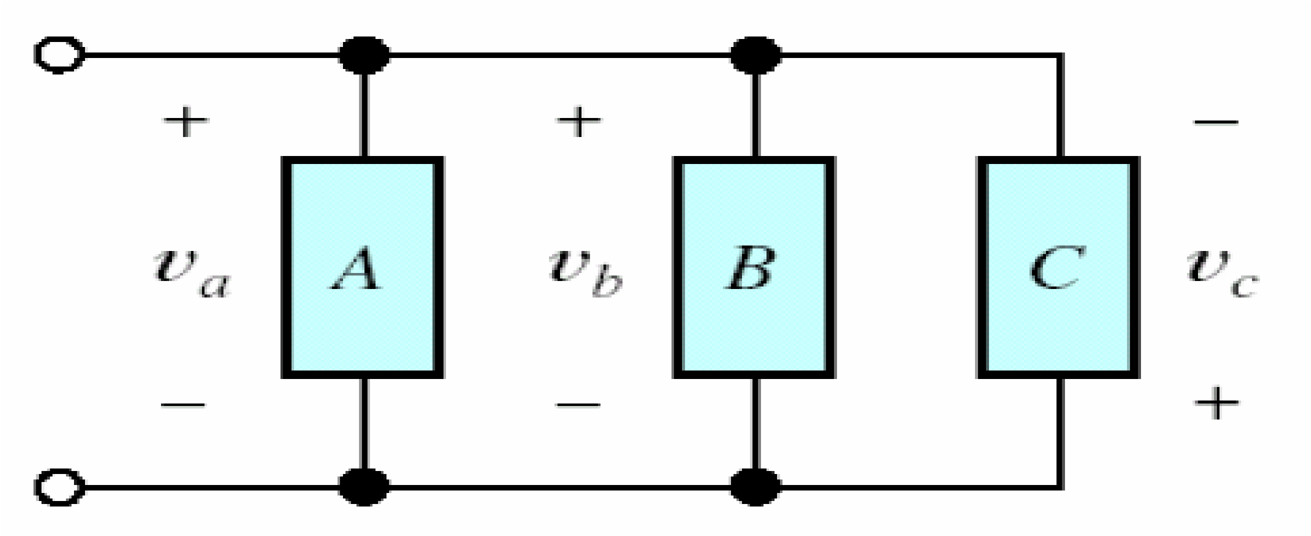
Two elements are connected in parallel if both ends of one element are connected directly to corresponding ends of the other



A and B are connected in parallel

D, E and F are connected in parallel

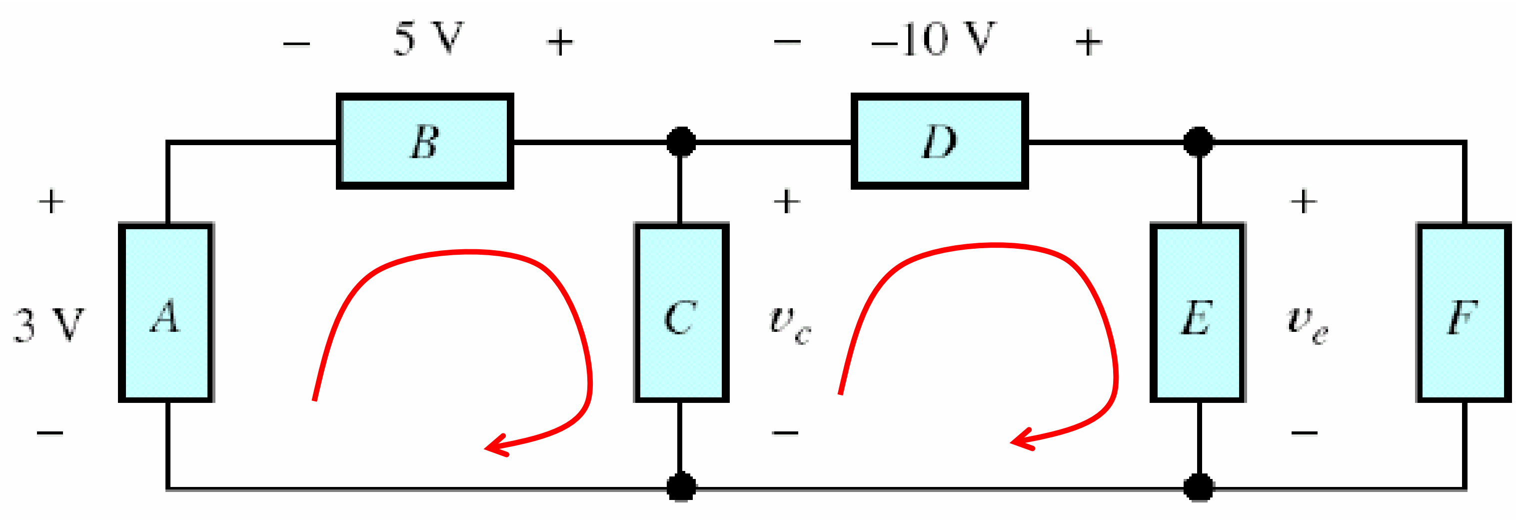
The voltage across parallel elements are equal (both magnitude and polarity)



$$v_a = v_b = -v_c$$

Example

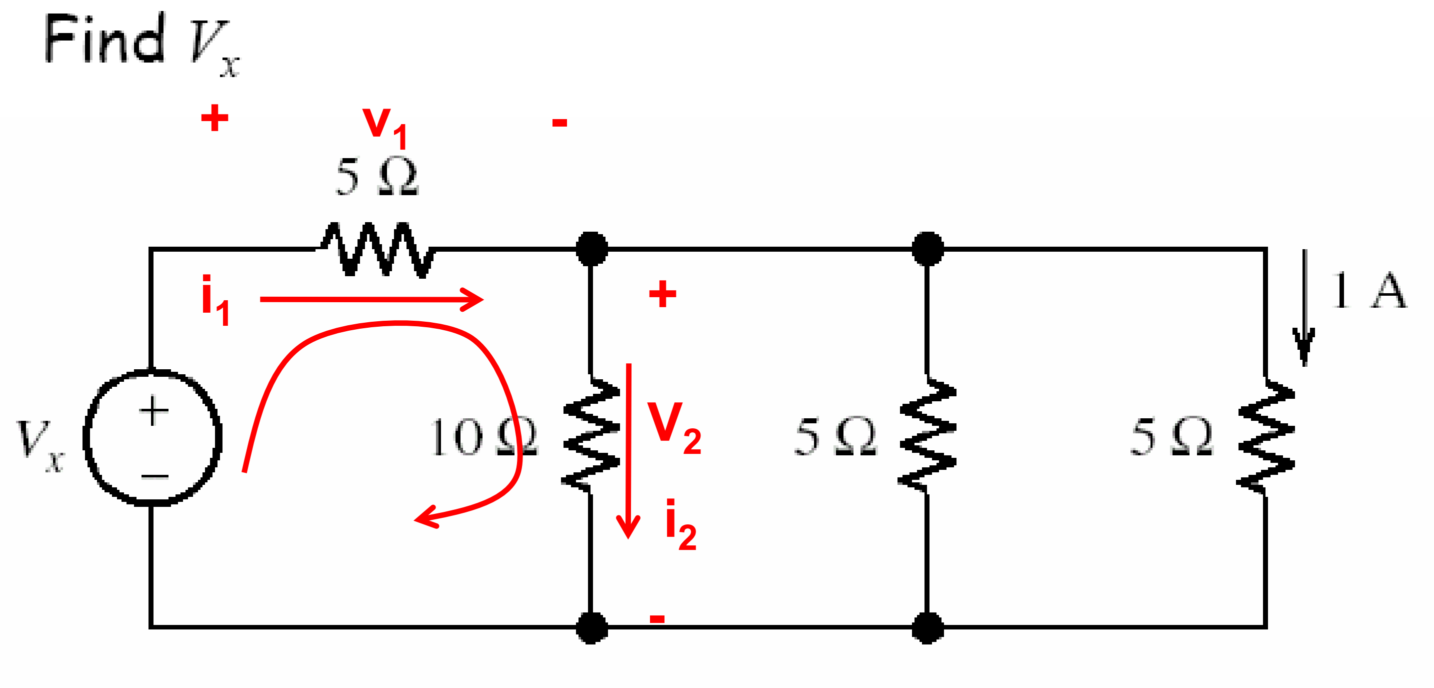
Use KVL to find v_c and v_e



$$-3-5+v_c=0 \Rightarrow v_c=8V$$

$$-v_c-(-10)+v_e=0 \Rightarrow v_e=-2V$$

Use KVL , KCL and Ohm's law to solve the given problem

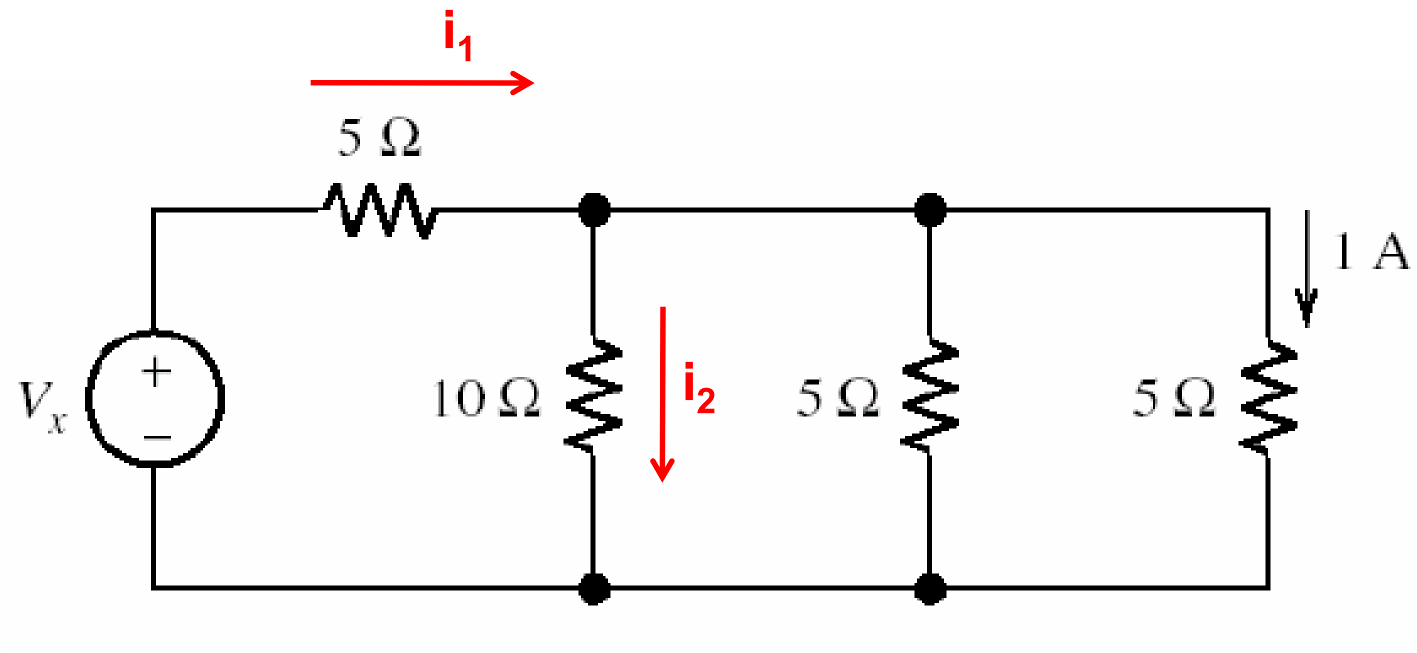


$$-v_x + v_1 + v_2 = 0 \Rightarrow v_x = v_1 + v_2$$

$$v_1 = i_1 \times 5$$

$$v_2 = i_2 \times 10$$

Next Problem: Find currents i_1 and i_2



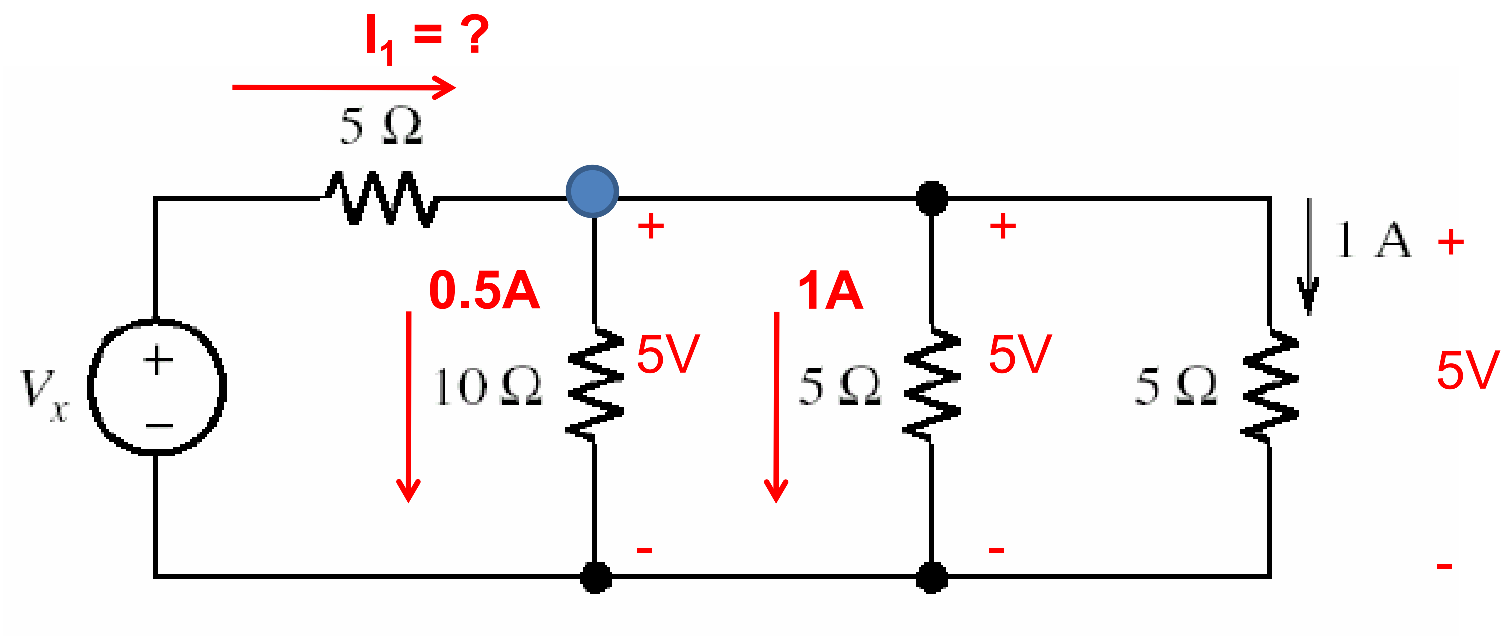
$$v_x = v_1 + v_2$$

$$v_1 = i_1 \times 5$$

$$v_2 = i_2 \times 10$$

$$v_x = (i_1 + 2\, i_2) \times 5$$

Use ohm's law : v = I x R



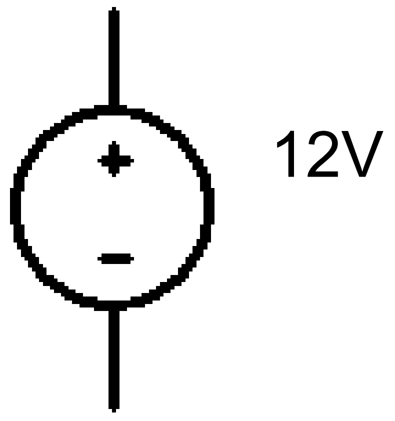
Apply KCL at the indicated node

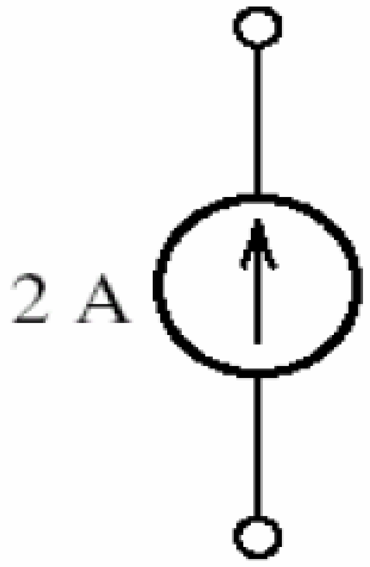
$$i_1 - 0.5 - 1 - 1 = 0 \Rightarrow i_1 = 2.5\,A$$

$$v_1 = i_1 \times 5 = 12.5V$$

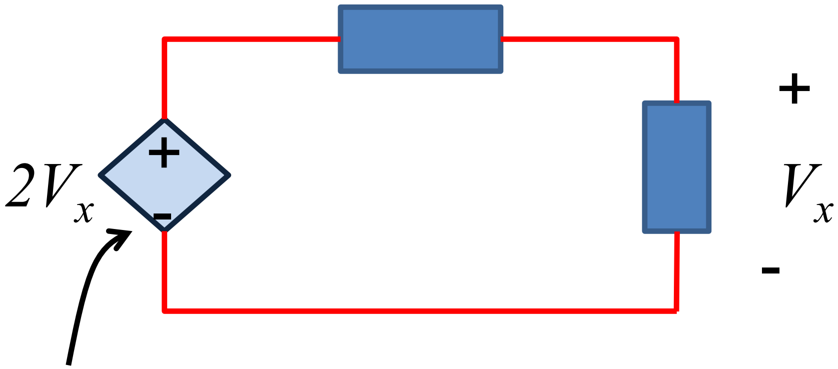
$$v_x = v_1 + v_2 = 12.5 + 5 = 17.5V$$

Independent Sources

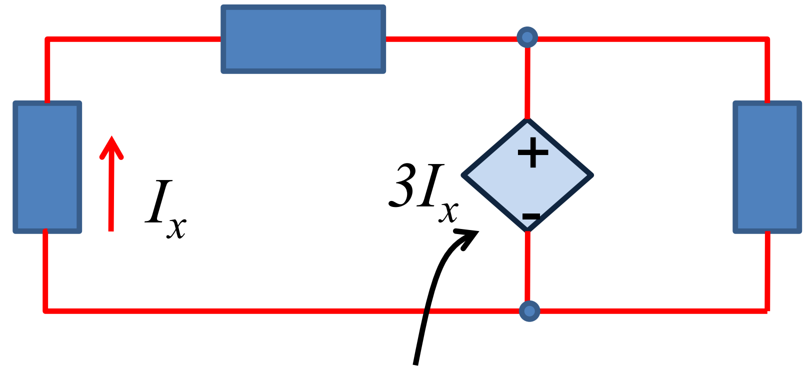




Dependent (Controlled) Voltage Sources



Voltage-controlled
Voltage source



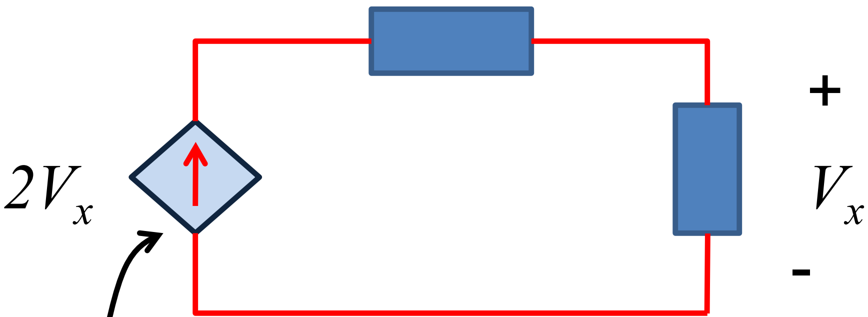
Current-controlled
Voltage source

- Very useful in constructing circuit models for real-world devices such as transistors and amplifiers

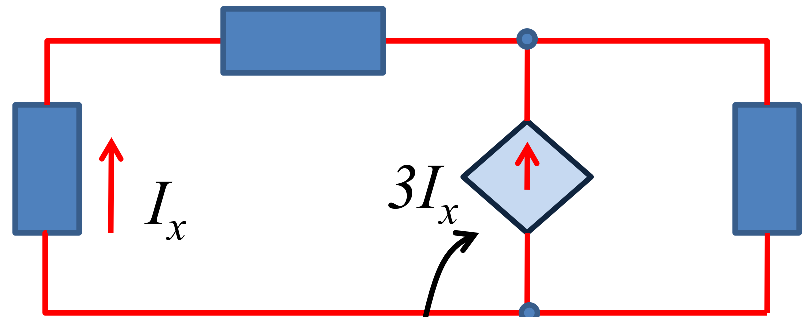
- For a voltage controlled source: $V = K_1 V_x$,
  K_1 is a gain parameter with no units

- For a current controlled source: $V = K_2 I_x$,
  K_2 is a gain parameter with units [V/A]

Dependent (Controlled) Current Sources



Voltage-controlled current source



Current-controlled current source

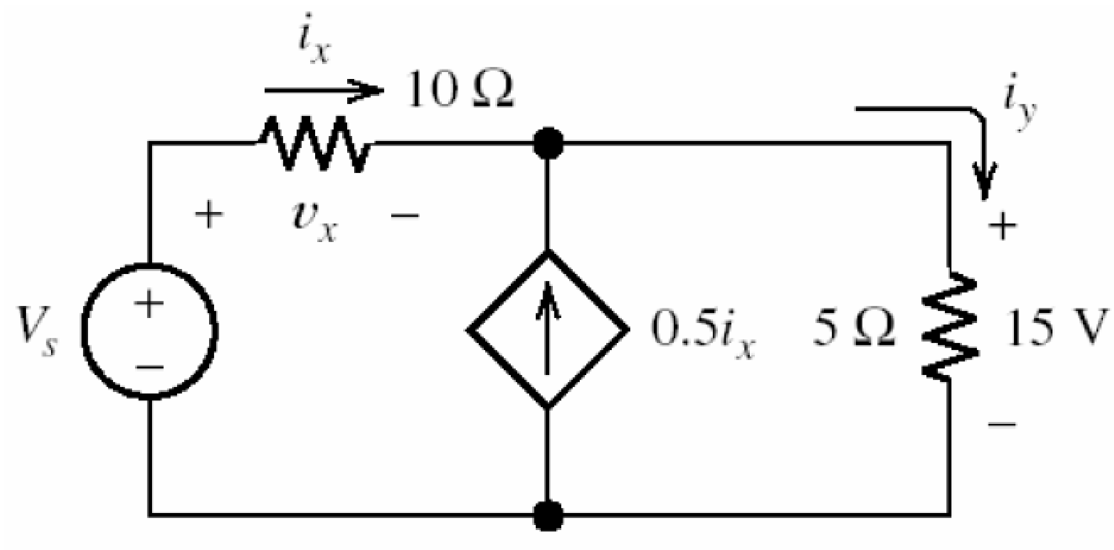
- Very useful in constructing circuit models for real-world devices such as transistors and amplifiers

- For a voltage controlled source: $I = K_3 V_x$,
  K_3 *is a gain parameter with units* [A/V]

- For a current controlled source: $I = K_4 I_x$,
  K_4 *is a gain parameter with no units*

Example:

Find the source voltage in the following circuit



$$i_y = \frac{15\ \text{V}}{5\ \Omega} = 3\ \text{A}$$

$$i_x + 0.5 i_x = i_y$$

$$i_x = 2\ \text{A}$$

$$v_x = 10 i_x = 20\ \text{V}$$

$$V_s = v_x + 15$$

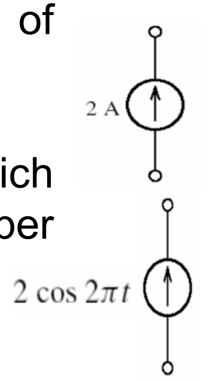
$$V_s = 35\ \text{V}$$

Summary

Current: The time rate of flow of electrical charge $i(t) = \dfrac{dq(t)}{dt}$

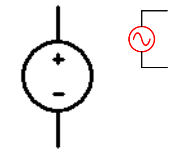
– The units are amperes (A), which are equivalent to coulombs per second (*C/s*)

Direction of current flow is opposite to direction of electron flow

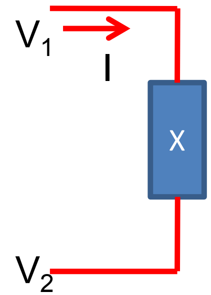


Voltage difference is the Source of current flow

Units of Voltage: Volts (V)



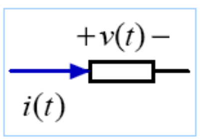
Power



$$P = (V_1 - V_2) \times I$$

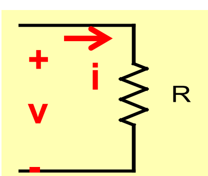
$$P(t) = \frac{dw}{dt} \Rightarrow \quad w = \int_{t1}^{t2} p(t)\,dt$$

Ohm's law



$$v(t) = R \times i(t)$$

$$i(t) = \frac{v(t)}{R} = G \times v(t)$$



$$P = i^2 \times R$$

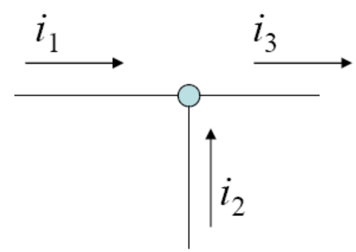
$$P = \frac{v^2}{R}$$

Two elements are connected in series if there is no other element connected to the node joining them. Same current flows

Two elements are connected in parallel if both ends of one element are connected directly to corresponding ends of the other. **Same voltage**

Kirchhoff's Current Law (KCL)

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



$$i_1 + i_2 = i_3$$

Kirchhoff's Voltage Law (KVL)

The algebraic sum of the voltages equals zero for any closed path (loop) in an electrical circuit