INTRODUCTION TO ELECTRICAL CIRCUITS

Objectives

- Motivation
- Basic elements encountered in electric networks.
- Fundamental differences between linear and nonlinear circuits.
- Kirchhoff's voltage and current laws.
- Circuit ground.
- Voltage dividers and current dividers.
- Potentiometer and loading effects.
- Differences between ideal and practical voltage and current sources
- Independent and dependent sources
- Delivering and absorbing power.

Electrical System Objectives

- To gather, store, process, transport, and present *information*
- To distribute and convert *energy* between various forms

Electrical Engineering Subdivisions

- Communication systems
- Computer systems
- Control systems
- Electromagnetics
- Electronics
- Photonics
- Power systems
- Signal processing

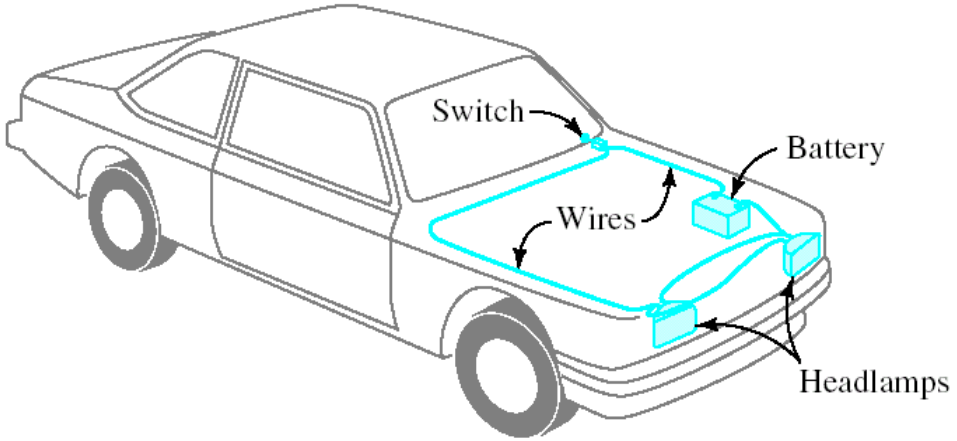
Motivation: Why Study Electrical Engineering?

- To pass the Fundamentals of Engineering (FE) Examination or PEng
- So you can lead projects in your own field
- To be able to operate and maintain electrical systems
- To communicate with electrical engineering consultants

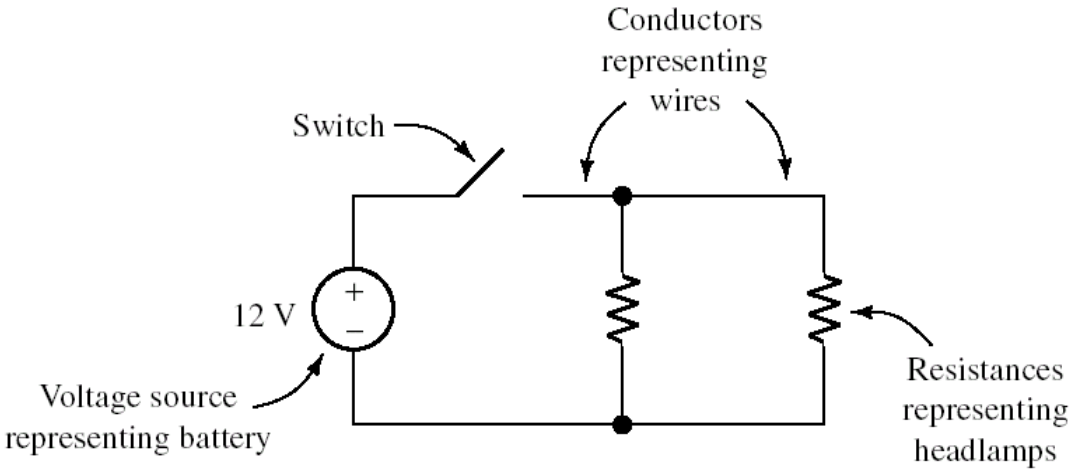
Overview of Circuit

- Example:

Headlight circuit



(a) Physical configuration



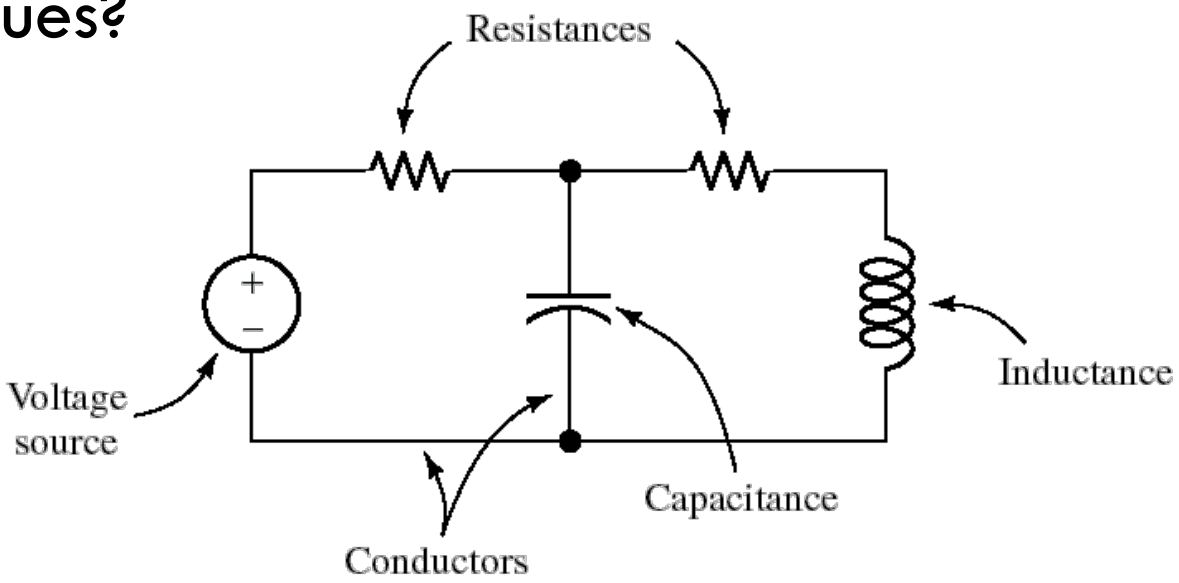
(b) Circuit diagram

Fluid Flow Analogy

- Battery => Pump
- Charge => Fluid
- Wires => Pipes
- Current => Fluid flow rate
- Voltage => Pressure difference
- Switches => Valves
- Lamps => Constriction

Electric Circuit

- Interconnection of electric elements
- Perform a desired function
- Analysis?
- Techniques?



Circuit Elements

- 2 types based on energy
  - Passive: Receive energy and converts to heat or stores
    - Examples?
  - Active: Supply energy
    - Examples?
- 2 types based on directions
  - Bilateral: Conduction in both directions
    - Examples?
  - Unilateral: Conduction in one direction
    - Examples?

Linear and Non-linear Elements

- Linear elements: Parameters do not change with voltage or current. Satisfies
  - Homogeneity
  - Additivity

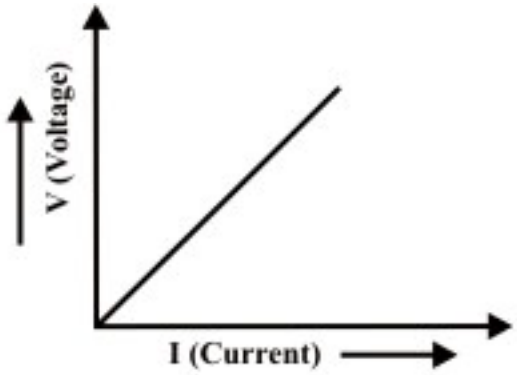


Fig. 3.2: V-I characteristics of linear element.

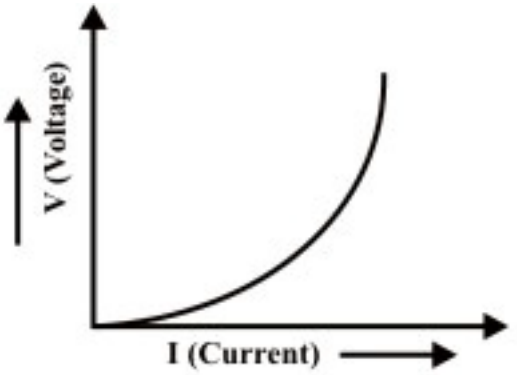
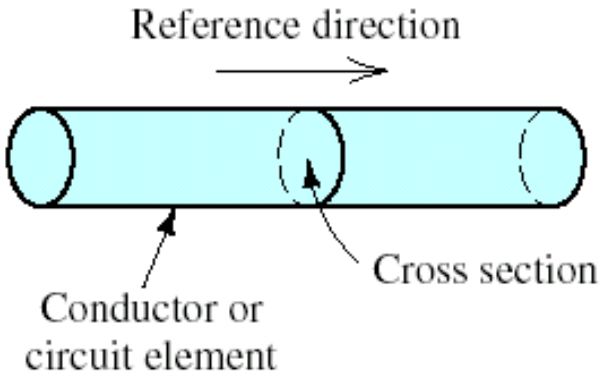


Fig. 3.3: V-I characteristics of non-linear element.

Electrical Current

Electrical current is the time rate of flow of electrical charge through a conductor or circuit element. The units are amperes (A), which are equivalent to coulombs per second (C/s).

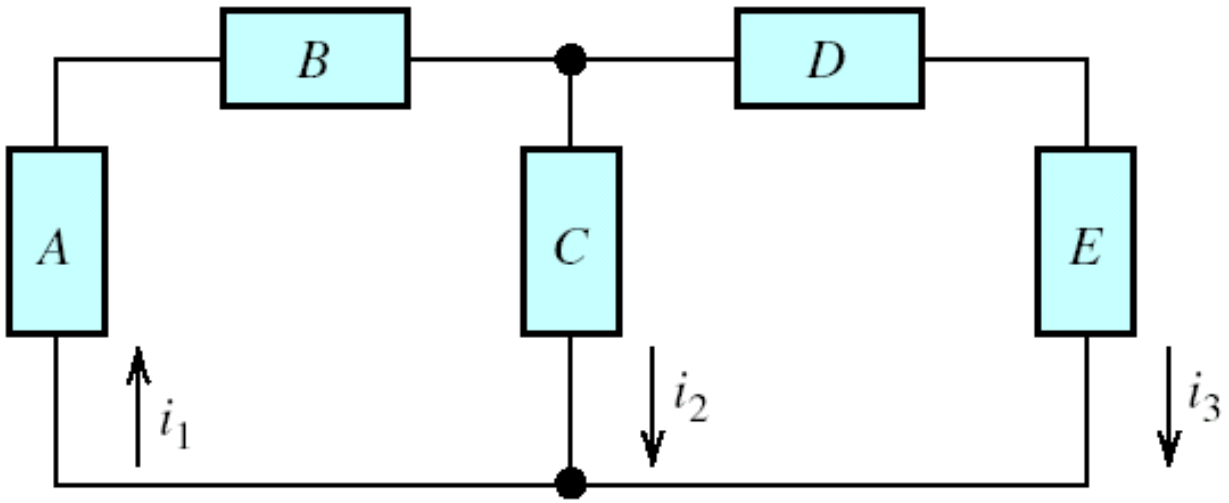


$$i(t) = \frac{dq(t)}{dt}$$

$$q(t) = \int_{t_0}^{t} i(t)dt + q(t_0)$$

Reference Direction

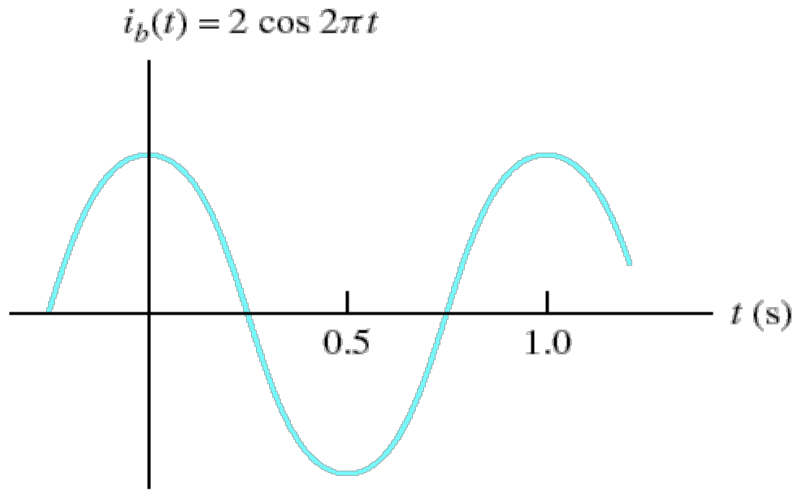
- Circuit analysis: Start by assigning current variables and reference directions
- Current with negative value?



Direct Current and Alternating Current

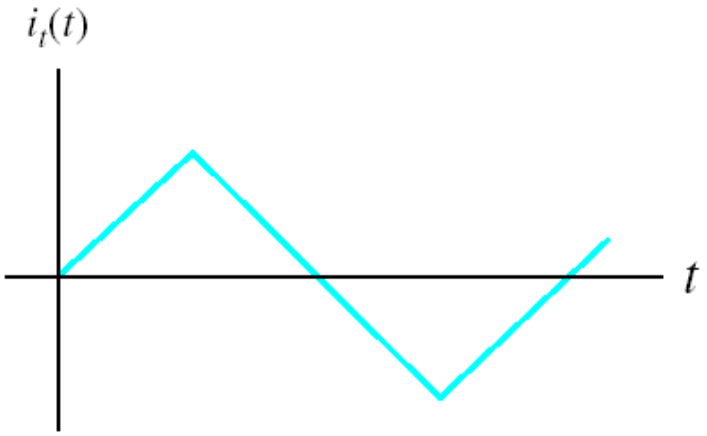
- When a current is constant with time, we say that we have **direct current**, abbreviated as dc. On the other hand, a current that varies with time, reversing direction periodically, is called **alternating current**, abbreviated as ac.

(a) Dc current

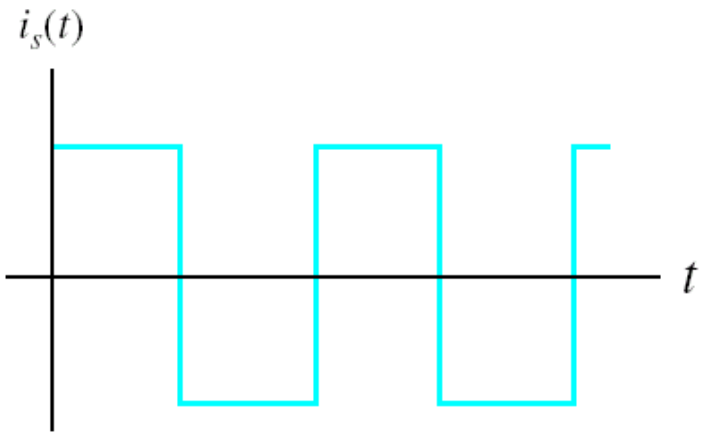


(b) Ac current

AC Current



(a) Triangular waveform

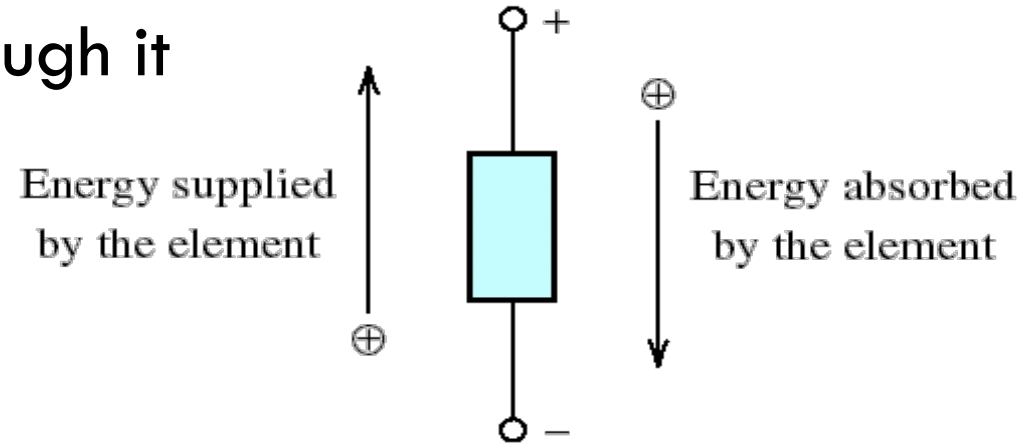


(b) Square waveform

Voltage

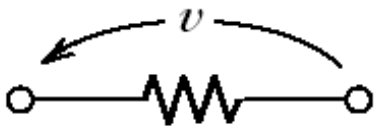
The voltage associated with a circuit element is the energy transferred per unit of charge that flows through the element. The units of voltage are volts (V), which are equivalent to joules per coulomb (J/C).

Example: Car battery of voltage 12V. 12 J are transferred to or from battery for each coulomb that flows through it



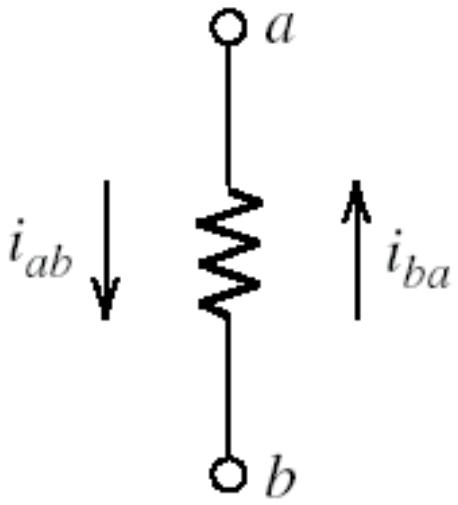
Reference Polarity

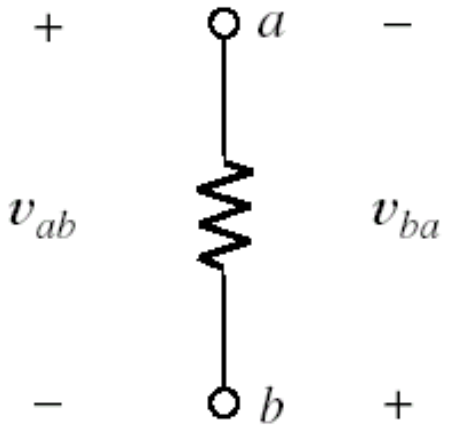
- Circuit analysis: Start by assigning voltage variables and reference polarities
- Voltage with negative value?



Double Subscript Notation

- To denote reference direction





Power and Energy

- Current is rate of flow of charge and voltage is energy transferred per unit charge, product is rate of energy transfer.

$$p(t) = v(t)i(t)$$

$$w = \int_{t_1}^{t_2} p(t)dt$$

Reference Configuration

- Passive
  - Current enters the positive polarity of voltage
  - Positive power => energy absorbed
  - Negative power => energy supplied

Kirchhoff's Current Law

- The net current entering a node is zero.
  - Node is a point at which two or more circuit elements are joined

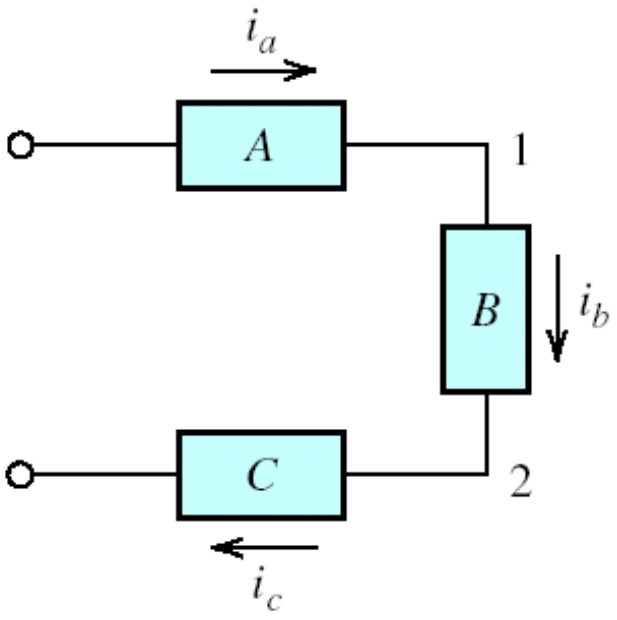
- Alternatively, the sum of the currents entering a node equals the sum of the currents leaving a node.

Physical Explanation

- If net current entering a node is non-zero (positive), positive charge would accumulate at the node each second.
- Balancing negative charge will be somewhere else.
- They will attract and merge.

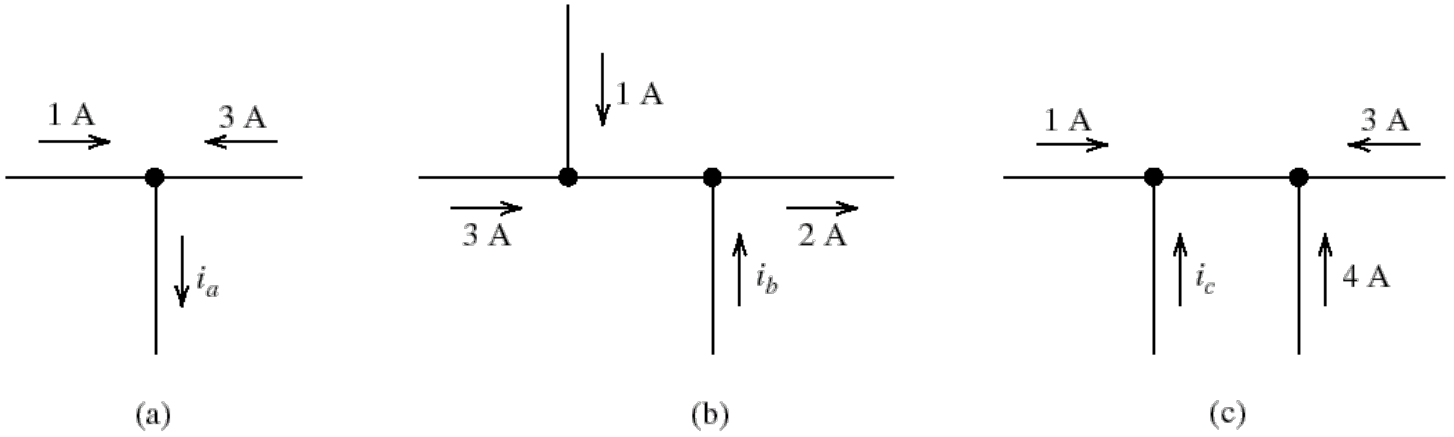
Series Circuit

- A and B are in series if no other path for current can be connected to the node joining A and B
- All elements have identical currents

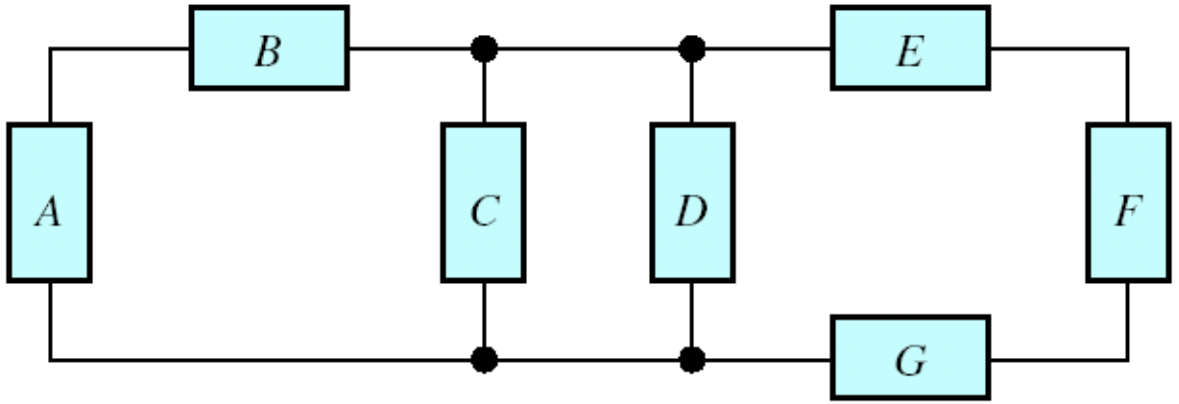


Example Exercise

- Find currents

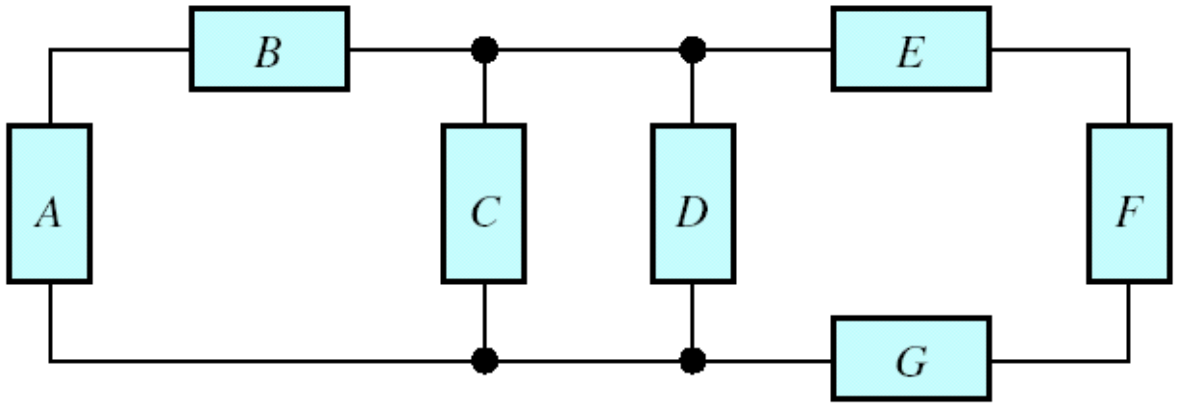


- Identify elements in series

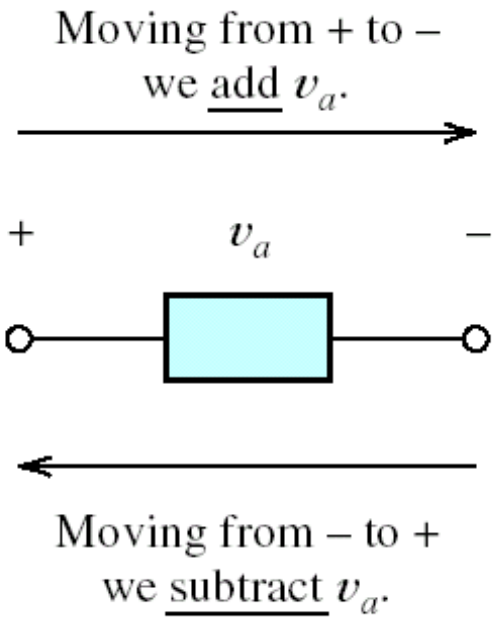


Kirchhoff's Voltage Law

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

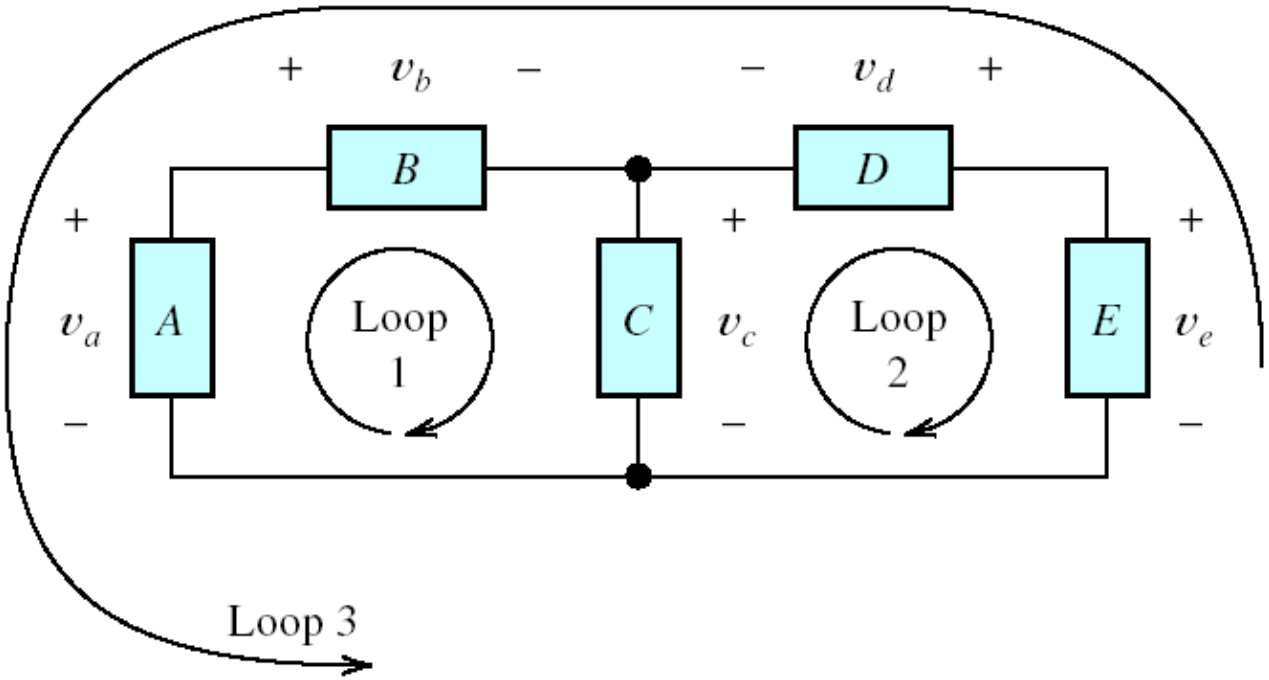


KVL Application



Example Exercise

- Write the KVL equations

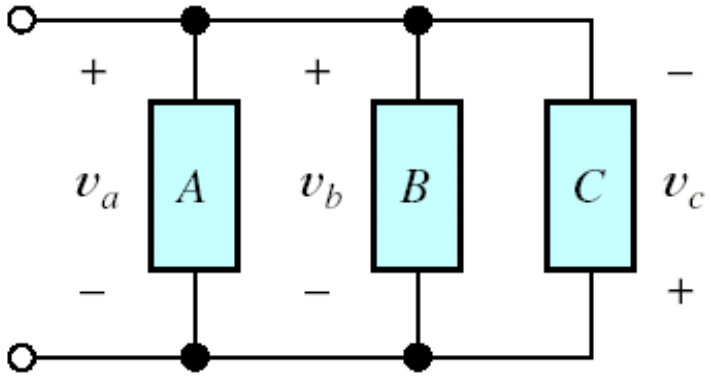


Physical Explanation

- From law of energy conservation
- Sum of powers of all the elements must be zero

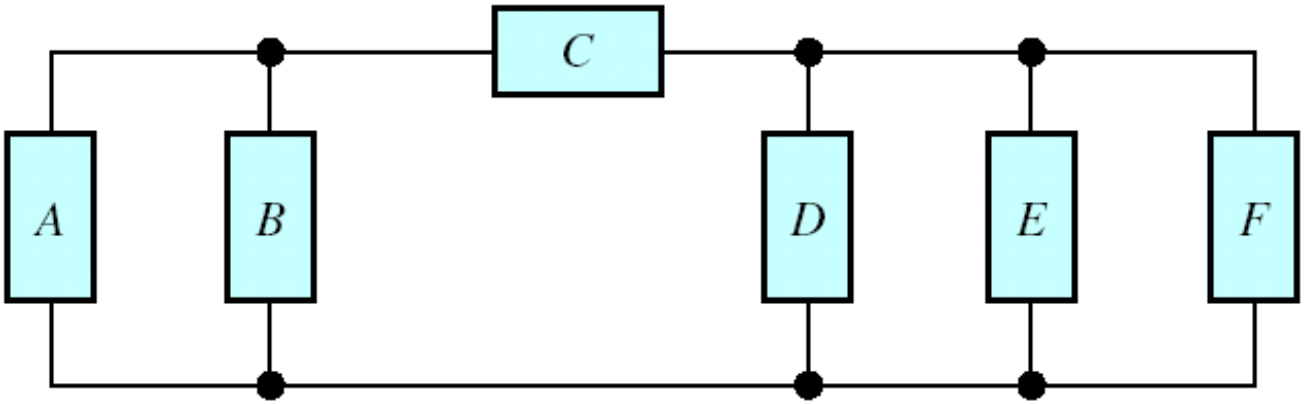
Parallel Circuits

- Voltage across parallel elements are equal in magnitude and have same polarity



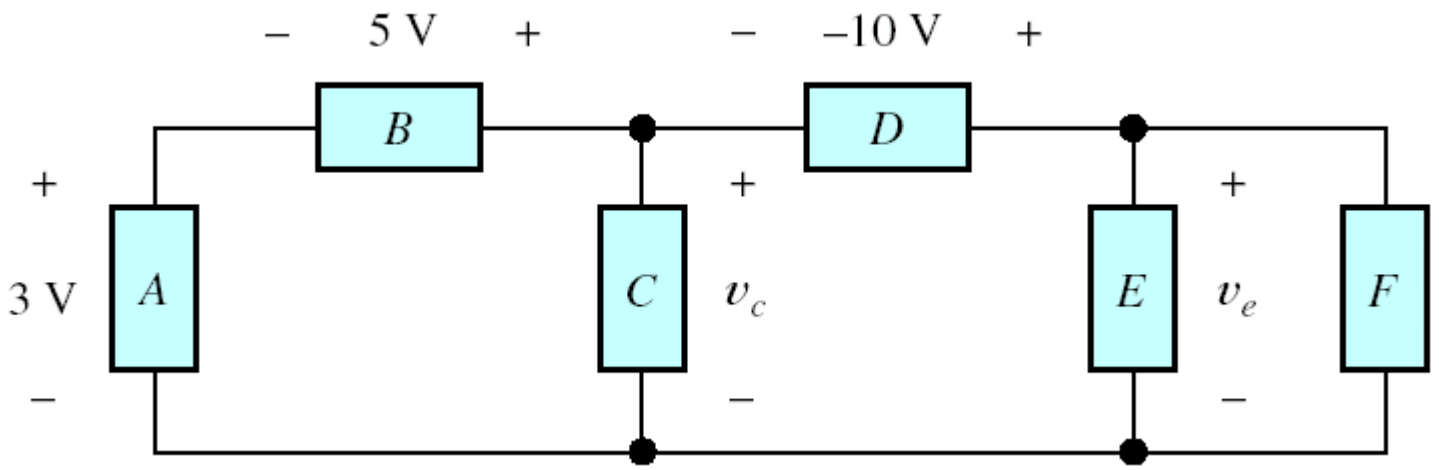
Example Exercise

- Find the elements in parallel circuits



Example Exercise

- Find elements in series and in parallel
- Find the voltage values



Circuit Elements

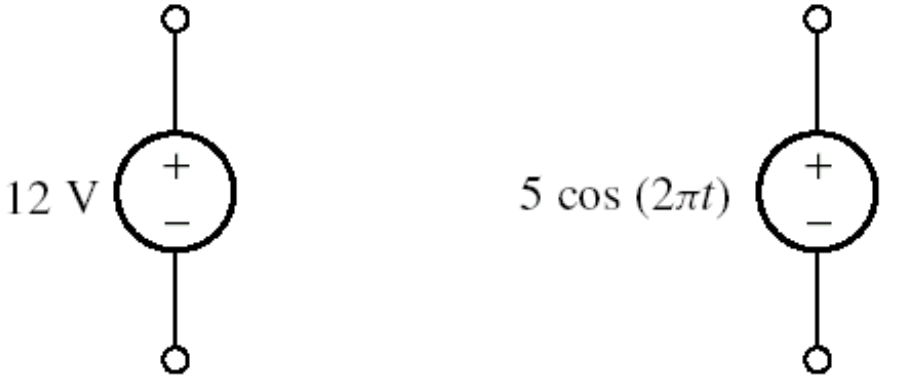
- Conductors
- Voltage sources
- Current sources
- Resistors

Conductors

- Voltage between the ends of an ideal conductor is zero regardless of the current flowing through the conductor
- Also known as short circuit

Independent Voltage Source

- Maintains a specified voltage across its terminals, independent of other elements and current through it

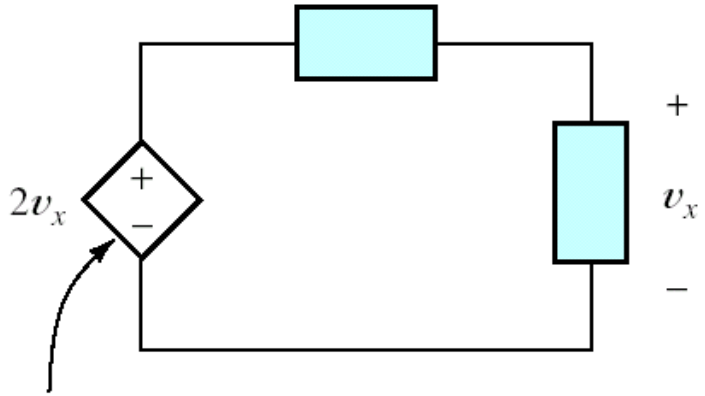


(a) Constant or dc voltage source

(b) Ac voltage source

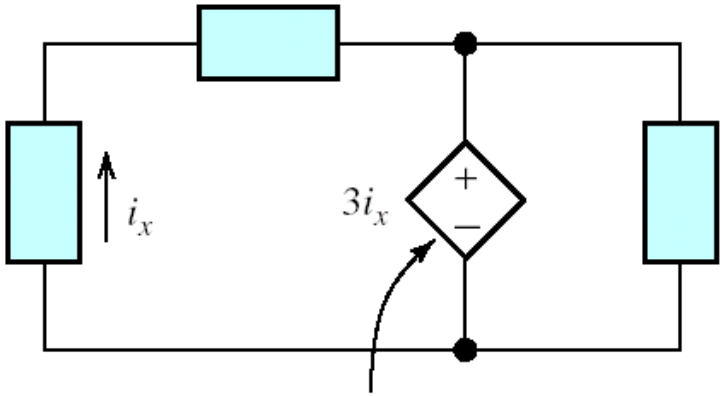
Dependent Voltage Source

- Voltage is a function of other voltages or currents in the circuit



Voltage-controlled voltage source

(a)

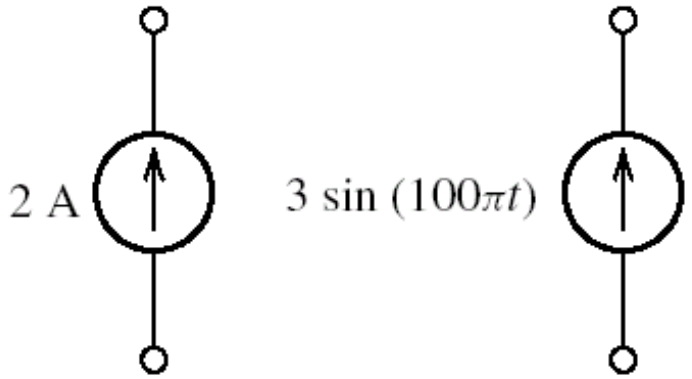


Current-controlled voltage source

(b)

Independent Current Source

- Maintains a specified current through itself, independent of other elements and voltage across it

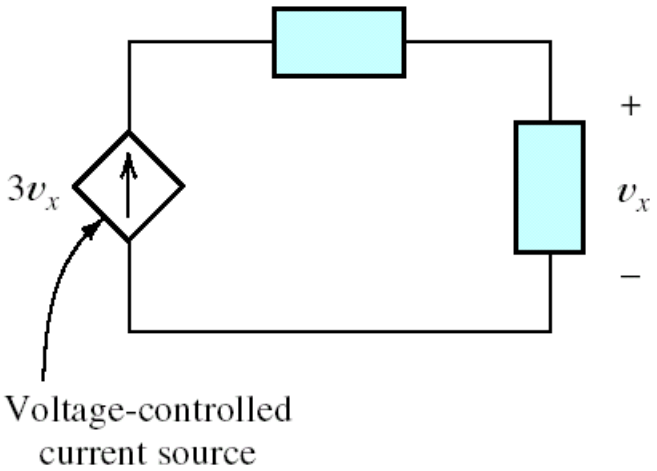


(a) Dc current source

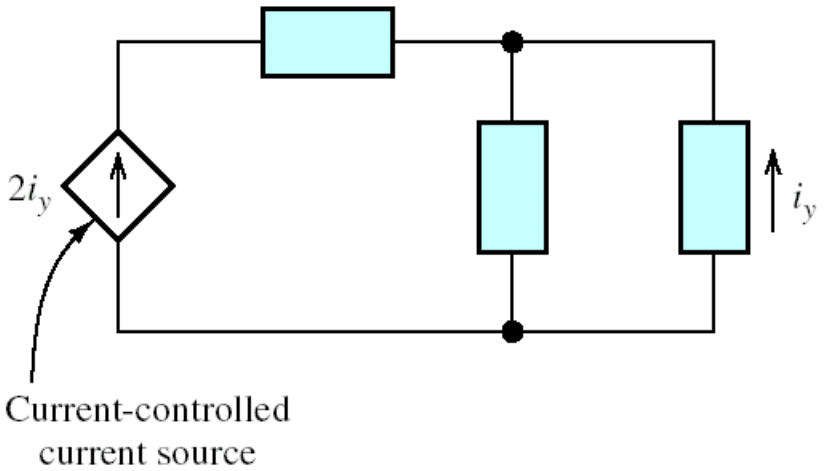
(b) Ac current source

Dependent Current Source

- Current is a function of other voltages or currents in the circuit



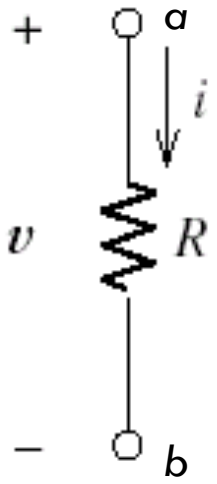
(a)



(b)

Resistors and Ohm's Law

- Voltage across a resistor is proportional to current through it
- Passive Reference Configuration
- Unit Ohms (Ω)



$$v = iR$$

$$v_{ab} = i_{ab}R$$

Conductance

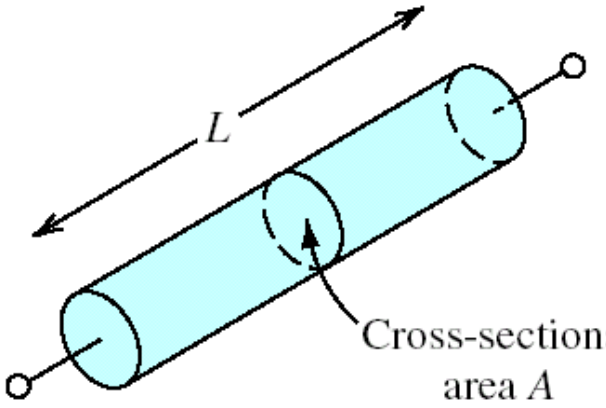
- Inverse of resistance
- Unit Siemens (S)

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

$$i = Gv$$

Physical Parameters

- Resistance Calculation
  - ρ is the resistivity of the material



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

Power Calculations

- $p=vi$
- $p=i^2R$
- $p=v^2/R$
- Always positive => power is absorbed by resistance

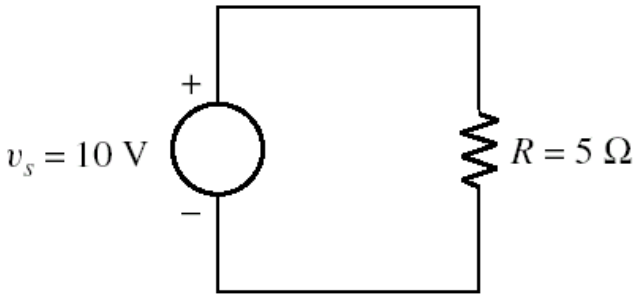
- Resistors vs. resistance

Circuit Analysis

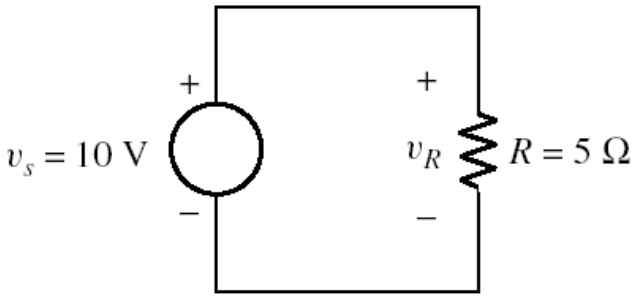
- Find current, voltage, power
- Steps:
  1. Select reference polarities and directions
  2. Apply KCL, KVL and Ohm's Law
  3. Obtain the desired parameters and correct polarities and directions

Toy Example Exercise

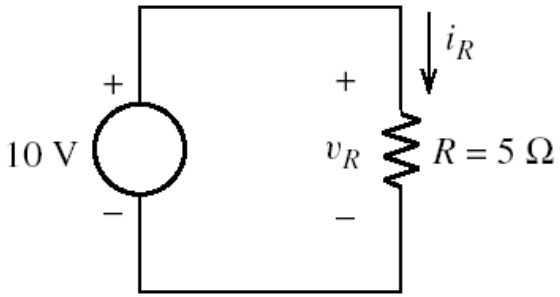
- Analyze the circuit



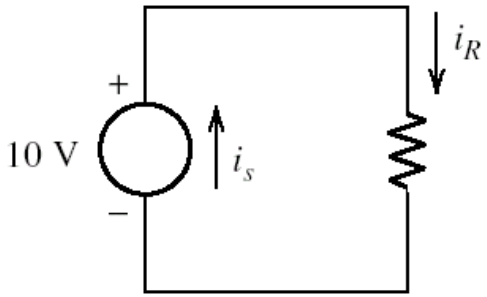
(a) Circuit diagram



(b) KVL requires that $v_R = 10$ V



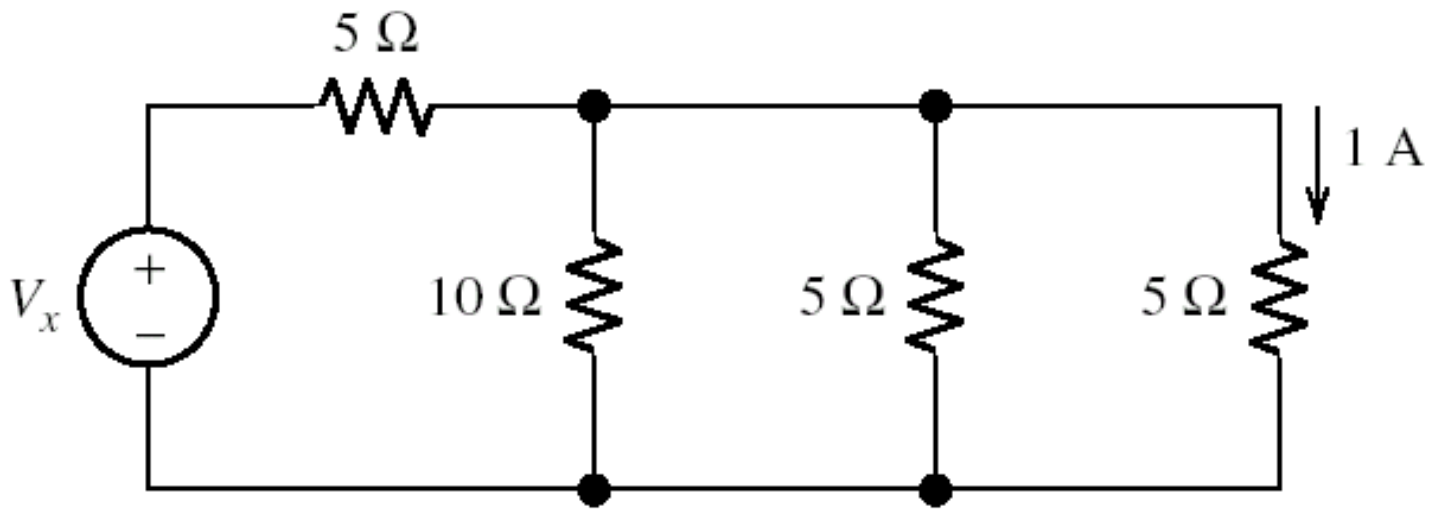
(c) Ohm's law yields $i_R = v_R/R = 2$ A



(d) KCL requires that $i_s = i_R$

Example Exercise

- Analyze the circuit



Example Exercise

- Analyze the circuit