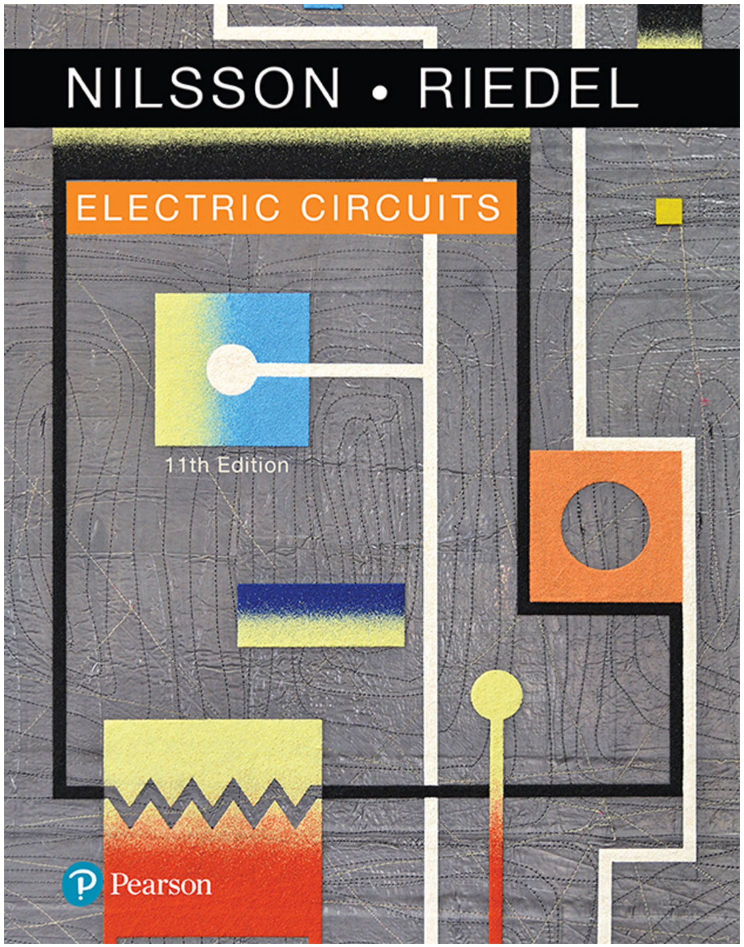
Electric Circuits

Eleventh Edition



Chapter 1

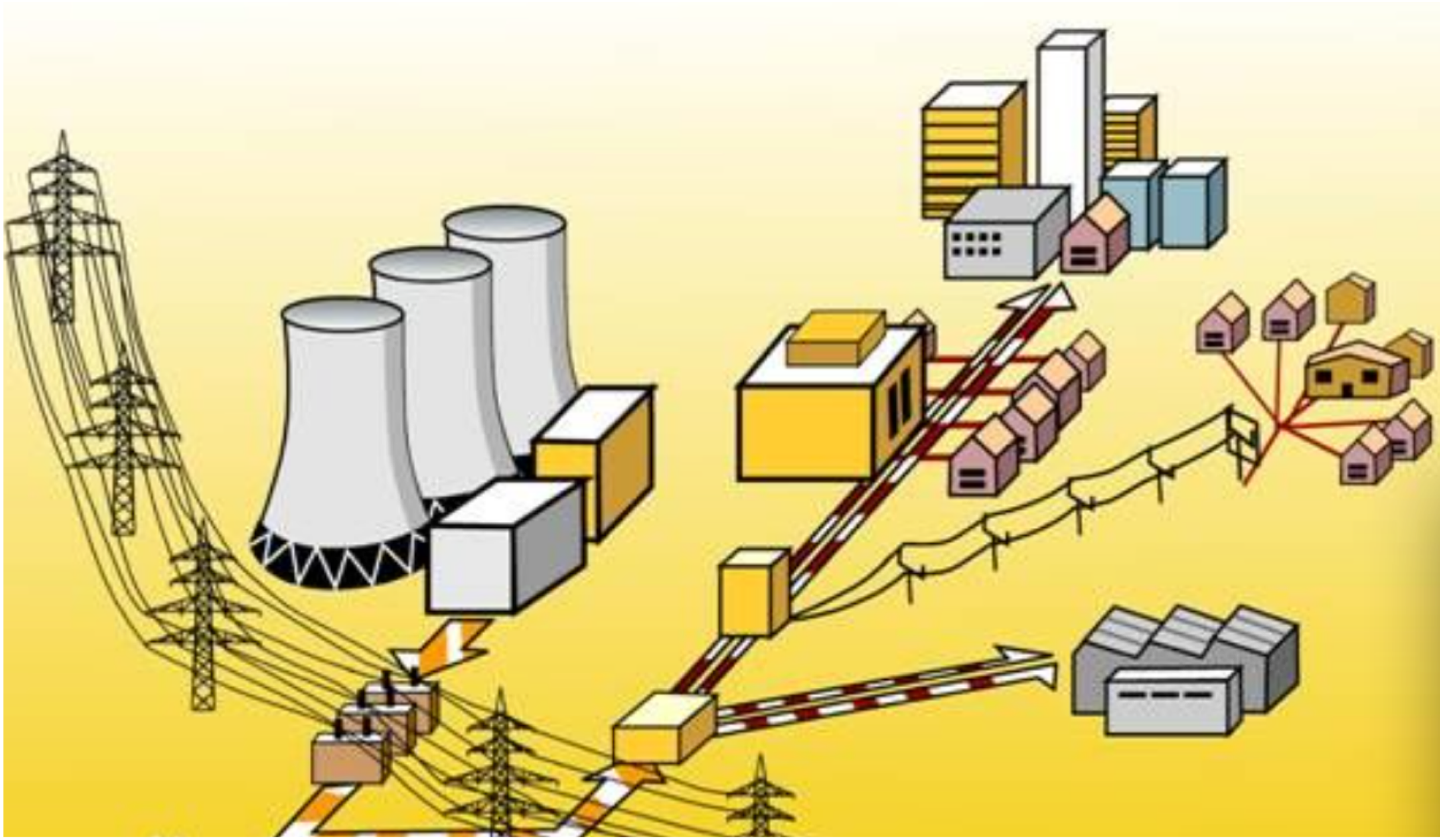
Circuit Variables

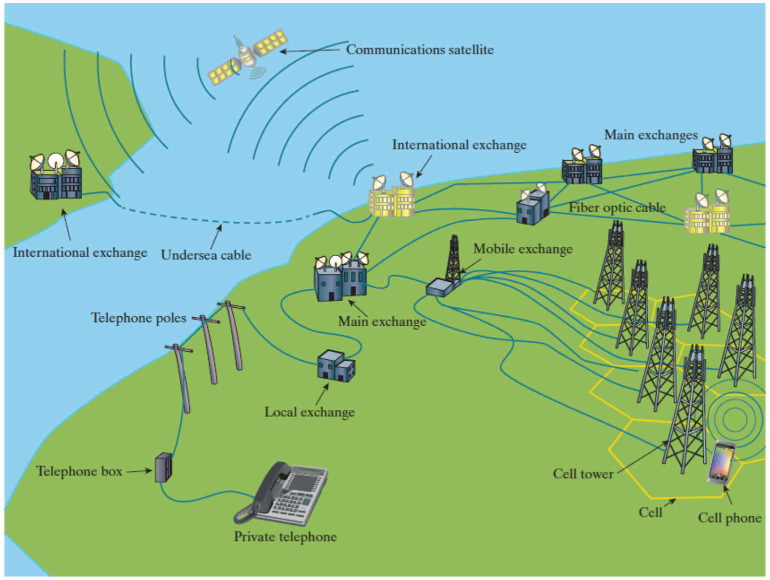
Learning Objectives

- Electrical Engineering: An Overview
- The International System of Units
- Circuit Analysis: An Overview
- Voltage and Current
- The Ideal Basic Circuit Element
- Power and Energy

1.1 Electrical Engineering: An Overview

Power Systems





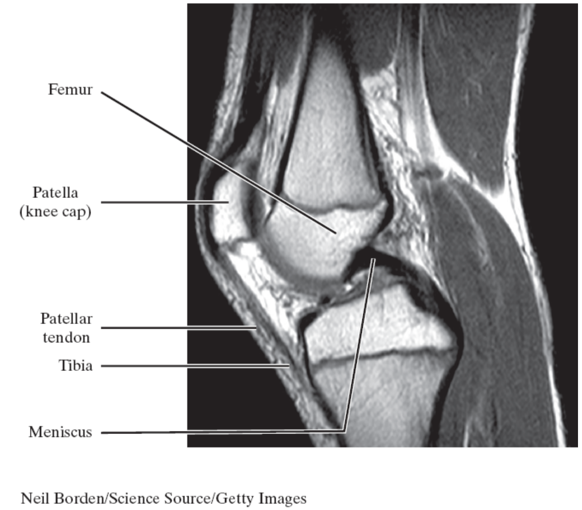


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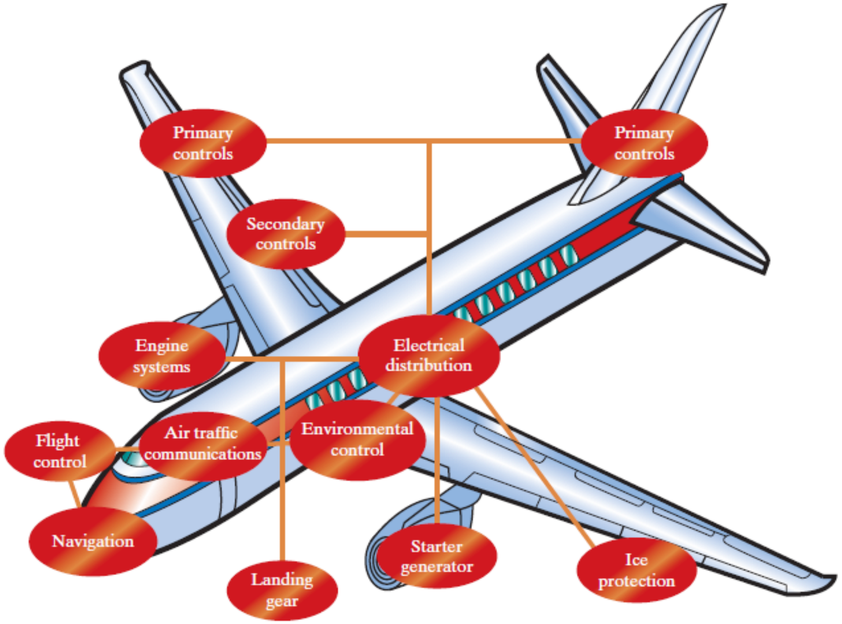
Figure 1.2: An MRI scan of an adult knee joint.

Figure 1.1: A telephone system.

Figure 1.3: Interacting systems on a commercial aircraft.



Anything in Common?

- An **electric circuit** is a *mathematical model* that approximates the behavior of an actual electrical system.

- Here, we use circuit theory, rather than electromagnetic field theory, to study a physical system represented by an electric circuit, based on the following three assumptions:
  - Electrical effects happen instantaneously throughout a system (***lumped-parameter system***)
  - The net charge on every component in the system is always zero
  - There is no magnetic coupling between the components in a system

Problem Solving

- Identify what's given and what's to be found.
- Sketch a circuit diagram or other visual model.
- Think of several solution methods and decide on a way of choosing among them.
- Calculate a solution.
- Use your creativity.
- Test your solution.

Practical Perspective – Balancing Power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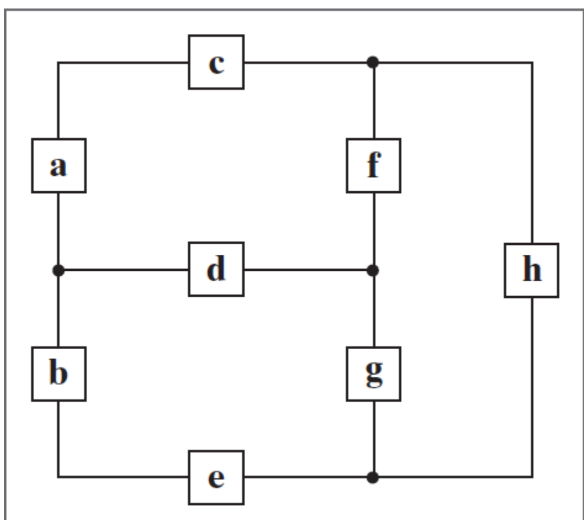


- **a** and **b**: electrical source to the home;
- **c**, **d**, and **e**: the wires that carry the electrical current from the source to the devices in the home requiring electrical power;
- **f**, **g**, and **h**: lamps, televisions, hair dryers, refrigerators, and other devices that require power.

Pearson

1.2 International System of Units

Quantity	*Basic unit*	*Symbol*
Length	meter	m
Mass	kilogram	Kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

TABLE 1.1 International System of Units (SI)

National Institute of Standards and Technology Special Publication 330, 2008 Edition, Natl. Inst. Stand. Technol. Spec. Pub. 330, 2008 Ed., 96 pages (March 2008)

Quantity	Unit Name (Symbol)	Formula
Frequency	hertz (Hz)	s^{-1}
Force	newton (N)	$kg \cdot m/s^2$
Energy or work	joule (J)	$N \cdot m$
Power	watt (W)	J/s
Electric charge	coulomb (C)	$A \cdot s$
Electric potential	volt (V)	J/C
Electric resistance	ohm (Ω)	V/A
Electric conductance	siemens (S)	A/V
Electric capacitance	farad (F)	C/V
Magnetic flux	weber (Wb)	$V \cdot s$
Inductance	henry (H)	Wb/A

TABLE 1.2 Derived Units in SI

National Institute of Standards and Technology Special Publication 330, 2008 Edition, Natl. Inst. Stand. Technol. Spec. Pub. 330, 2008 Ed., 96 pages(March 2008)

Prefix	Symbol	Power
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deka	da	10
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

TABLE 1.3 Standardized Prefixes to Signify Powers of 10

1.3 Circuit Analysis: An Overview

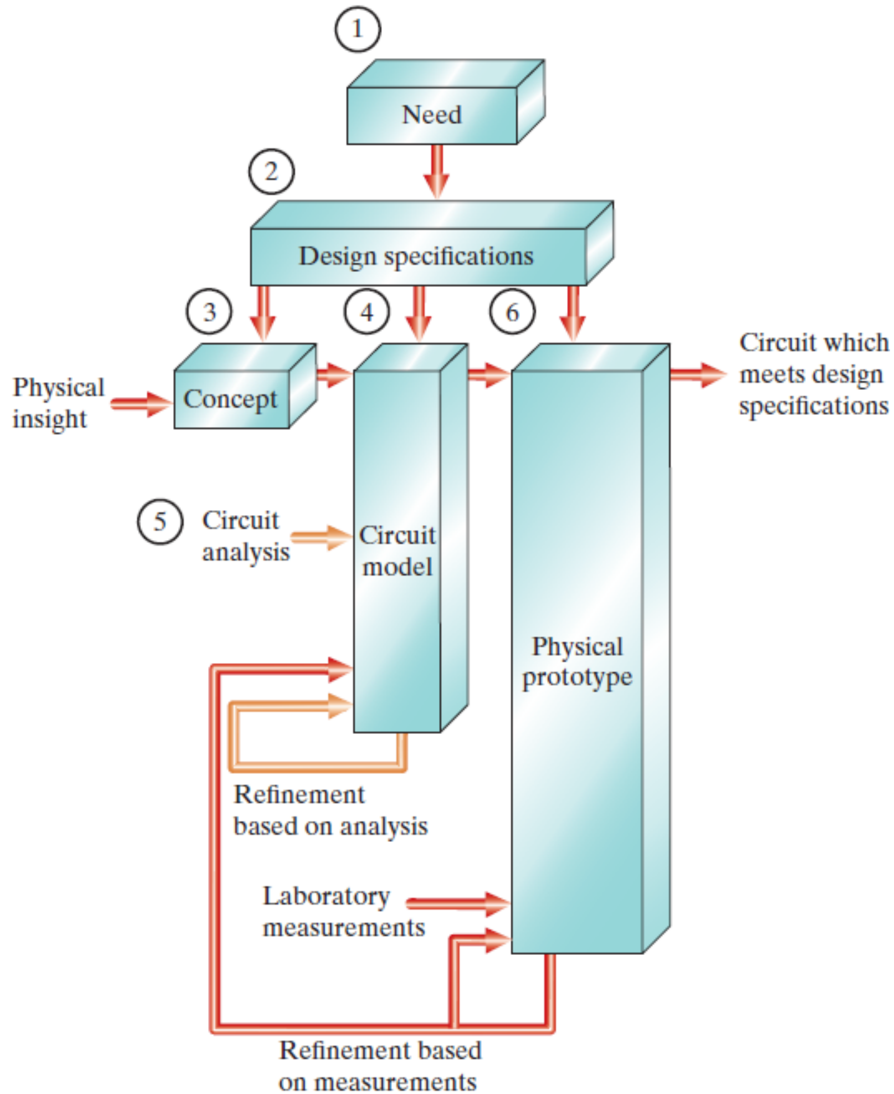


Figure 1.4: A conceptual model for electrical engineering design.

1.4 Voltage & Current

- charge is bipolar, meaning that electrical effects are described in terms of positive and negative charges.
- electric charge exists in discrete quantities, which are integral multiple of the electronic charge:
- $e = 1.6022 \times 10^{-19} C$
- Electrical effects are attributed to both the separation of charge (Voltage) and charges in motion (Current).

Voltage

- Whenever positive and negative *charges* (q) are separated, *energy* (w) is expended.
- *Voltage* (v) is the energy per unit charge created by the separation.
  - w: the energy in joules (J)
  - q: the charge in coulombs (C)
  - v: the voltage in volts (V)
  - ✓ 1 V is the same as 1 J/C.
- Mathematically,

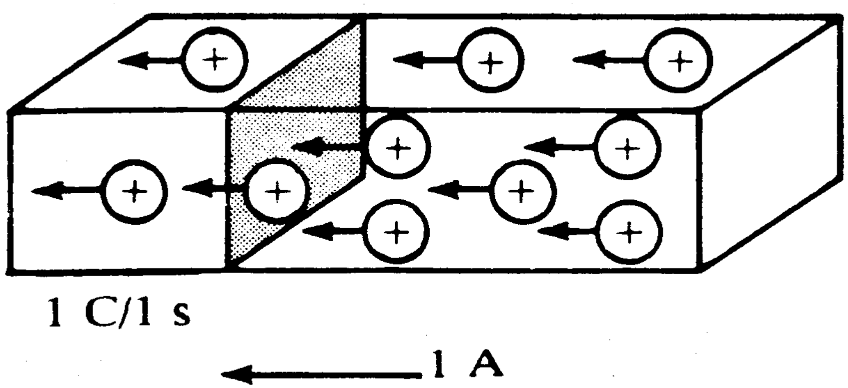
$$\boxed{v = dw/dq}$$

Current

- Motion of charges forms the electric current in a wire
- Current (i) has both a numerical value and a direction associated with it
- It is a measure of the rate at which charge (q) is moving past a given reference point in a specified direction.
  - i: the current in amperes (A)
  - q: the charge in coulombs (C)
  - t: the time in seconds (s)
  - ✓ 1 A is the same as 1 C/s.
- Mathematically,

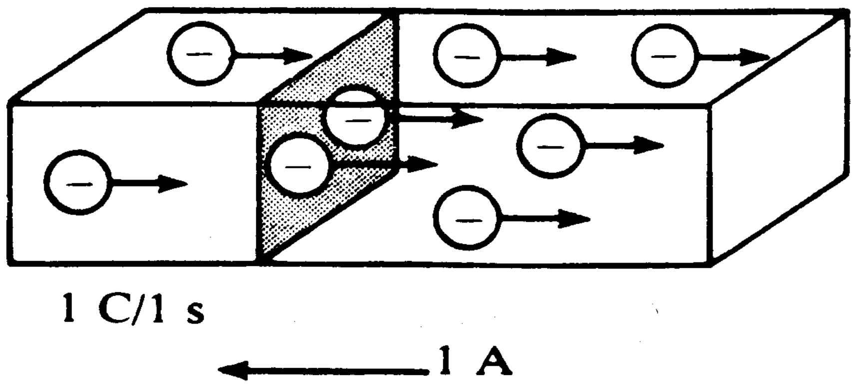
$$\boxed{i = dq/dt}$$

The Direction of Current Flow



(*a*)

Positive ions



(*b*)

Negative ions

Direction is Important!

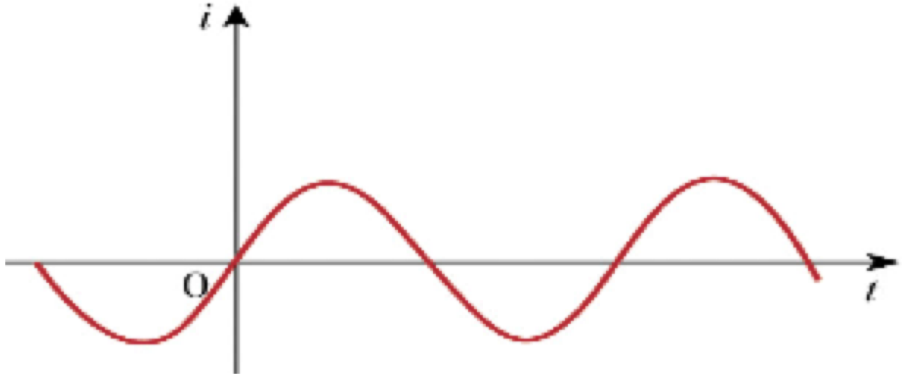
- We should pay close attention: the arrow is a fundamental part of the definition of the current!

(a) (b) (c)

DC and AC

- A direct current (dc) is a current that remains constant with time.
- An alternating current (ac) is a current that varies sinusoidally with time (and reverses direction).

DC



AC

1.5 Basic Circuit Element

- Only two terminals which connect to other circuit components
- Described in terms of voltage and/or current
- Cannot be reduced further

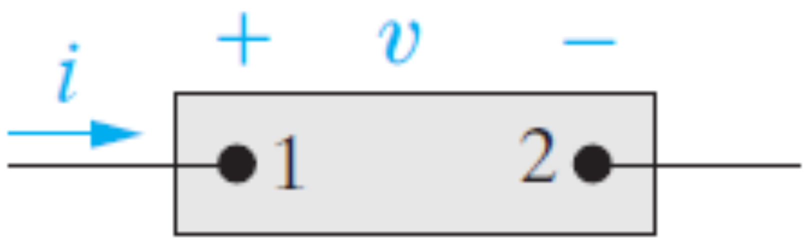


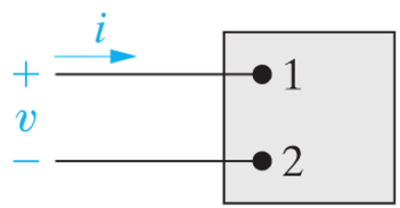
Figure 1.5: An ideal basic circuit element.

The placement of **+ sign** in terminal 1 indicates that terminal 1 is ***v*** **volts** positive with respect to terminal 2.

Note: *A voltage can exist between a pair of electrical terminals whether a current is flowing or not.*

Passive Sign Convention

Whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element, use a positive sign in any expression relating voltage to current. Otherwise use a negative sign.



	Positive Value	**Negative Value**
v	voltage drop from terminal 1 to terminal 2	voltage rise from terminal 1 to terminal 2
	or	*or*
	voltage rise from terminal 2 to terminal 1	voltage drop from terminal 2 to terminal 1
i	positive charge flowing from terminal 1 to terminal 2	positive charge flowing from terminal 2 to terminal 1
	or	*or*
	negative charge flowing from terminal 2 to terminal 1	negative charge flowing from terminal 1 to terminal 2

TABLE 1.4 Interpretation of Reference Directions in Fig. 1.5

Notes

- The plus-minus pair of algebraic signs does not indicate the actual polarity of the voltage but is simply part of a convention that enables us to talk unambiguously about the voltage across the terminal pair.

- *The definition of any voltage **must** include plus-minus sign pair!*

1.6 Power & Energy

- Power (p) is the time rate of expending or absorbing energy (w)

  - p: the power in watts (W)
  - w: the energy in joules (J)
  - t: the time in seconds (s)
  - q: the charge in coulombs (C)
  - v: the voltage in volts (V)
  - i: the current in amperes (A)

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

•If power is positive (p>0), power is delivered to circuit.

•If power is negative (p<0), power is extracted from circuit element.

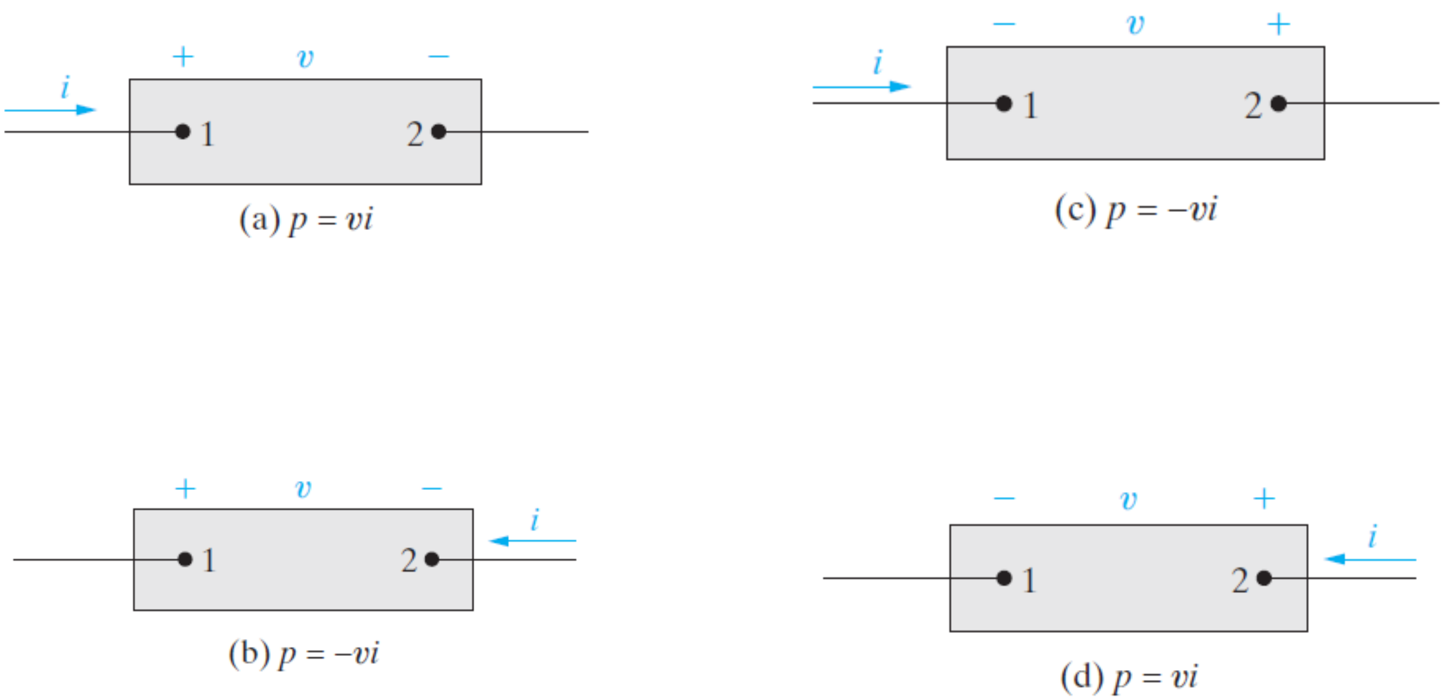
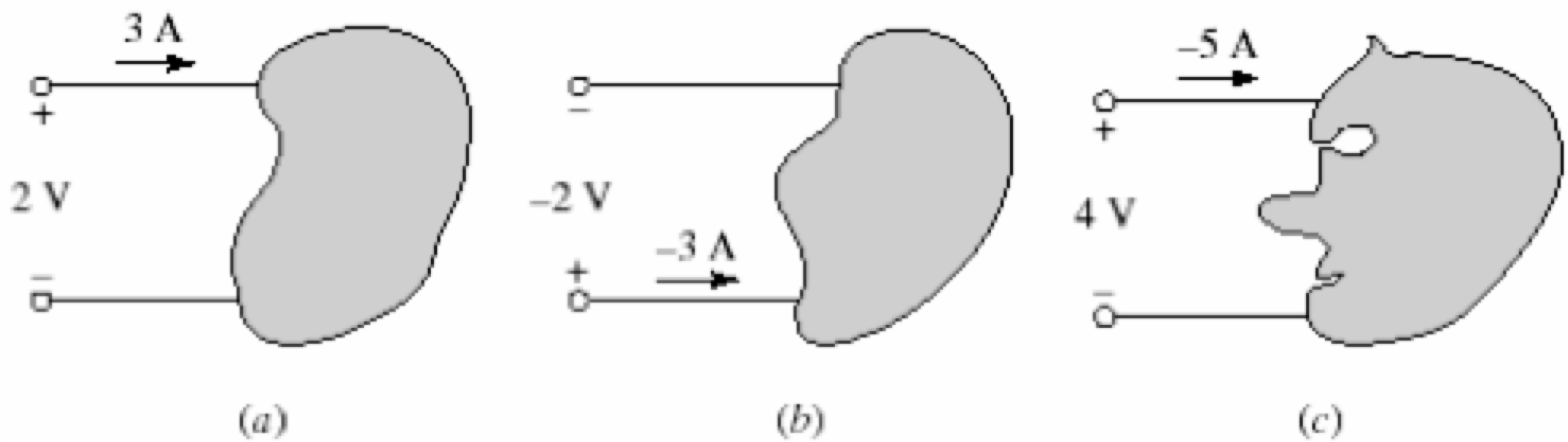


Figure 1.6: Polarity references and the expression for power.

The algebraic sign of power is based on charge movement through voltage drops and rises. *As positive charges move through a drop in voltage, they lose energy, and as they move through a rise in voltage, they gain energy.*

Example

- If the power is positive (that is, if $p > 0$), power is being delivered to the circuit inside the box. If the power is negative (that is, if $p < 0$), power is being extracted from the circuit inside the box (absorbed by circuit element).
- Compute the power absorbed by each part in the following:



(*a*, *b*, *c*) Three examples of two-terminal elements.

Balancing Power

- The law of conservation of energy

$$\sum p = 0$$

- Energy is the capacity to do work, measured in joules (J).
- Mathematically,

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

Practical Perspective – Balancing Power

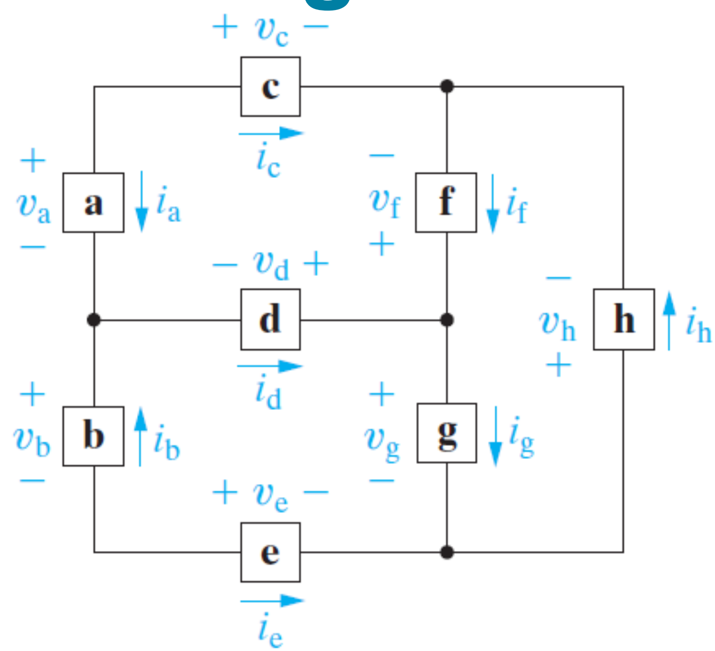


Figure 1.7: Circuit model for power distribution in a home, with voltages and currents defined.

Component	v(V)	i(A)
a	120	−10
b	120	9
c	10	10
d	10	1
e	−10	−9
f	−100	5
g	120	4
h	−220	−5

$p_a = v_a i_a = (120)(-10) = -1200$ W

$p_b = -v_b i_b = -(120)(9) = -1080$ W

$p_c = v_c i_c = (10)(10) = 100$ W

$p_d = -v_d i_d = -(10)(1) = -10$ W

$p_e = v_e i_e = (-10)(-9) = 90$ W

$p_f = -v_f i_f = -(-100)(5) = 500$ W

$p_g = v_g i_g = (120)(4) = 480$ W

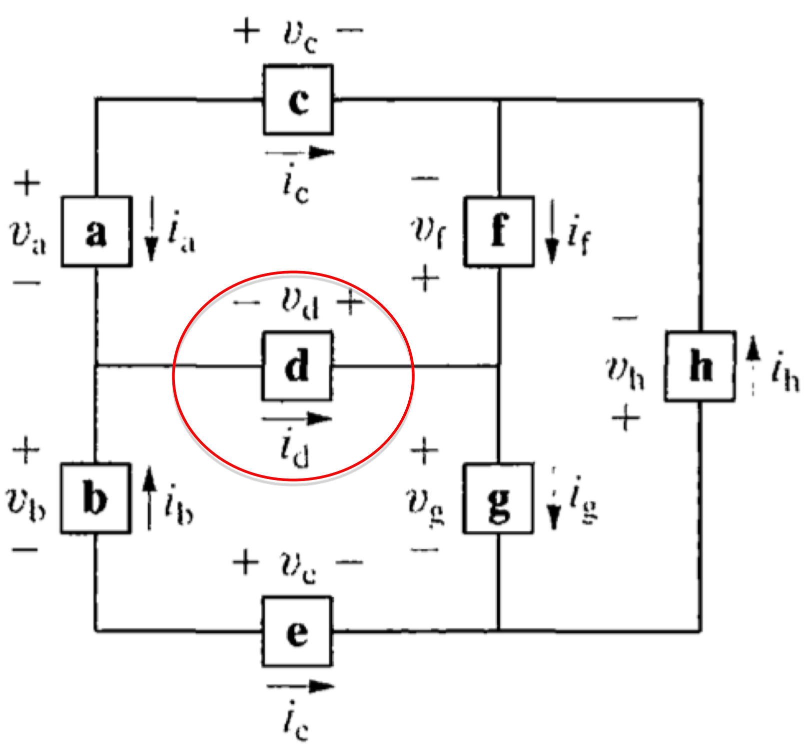
$p_h = v_h i_h = (-220)(-5) = 1100$ W

$$p_{\text{supplied}} = p_a + p_b + p_d = -1200 - 1080 - 10 = -2290 \text{ W}$$

$$p_{\text{absorbed}} = p_c + p_e + p_f + p_g + p_h$$
$$= 100 + 90 + 500 + 480 + 1100 = 2270 \text{ W}$$

$$p_{\text{supplied}} + p_{\text{absorbed}} = -2290 + 2270 = -20 \text{ W}$$

Something is wrong—if the values for voltage and current in this circuit are correct, the total power should be zero!



Component	v(V)	i(A)
a	120	−10
b	120	9
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d	10	1
e	−10	−9
f	−100	5
g	120	4
h	−220	−5