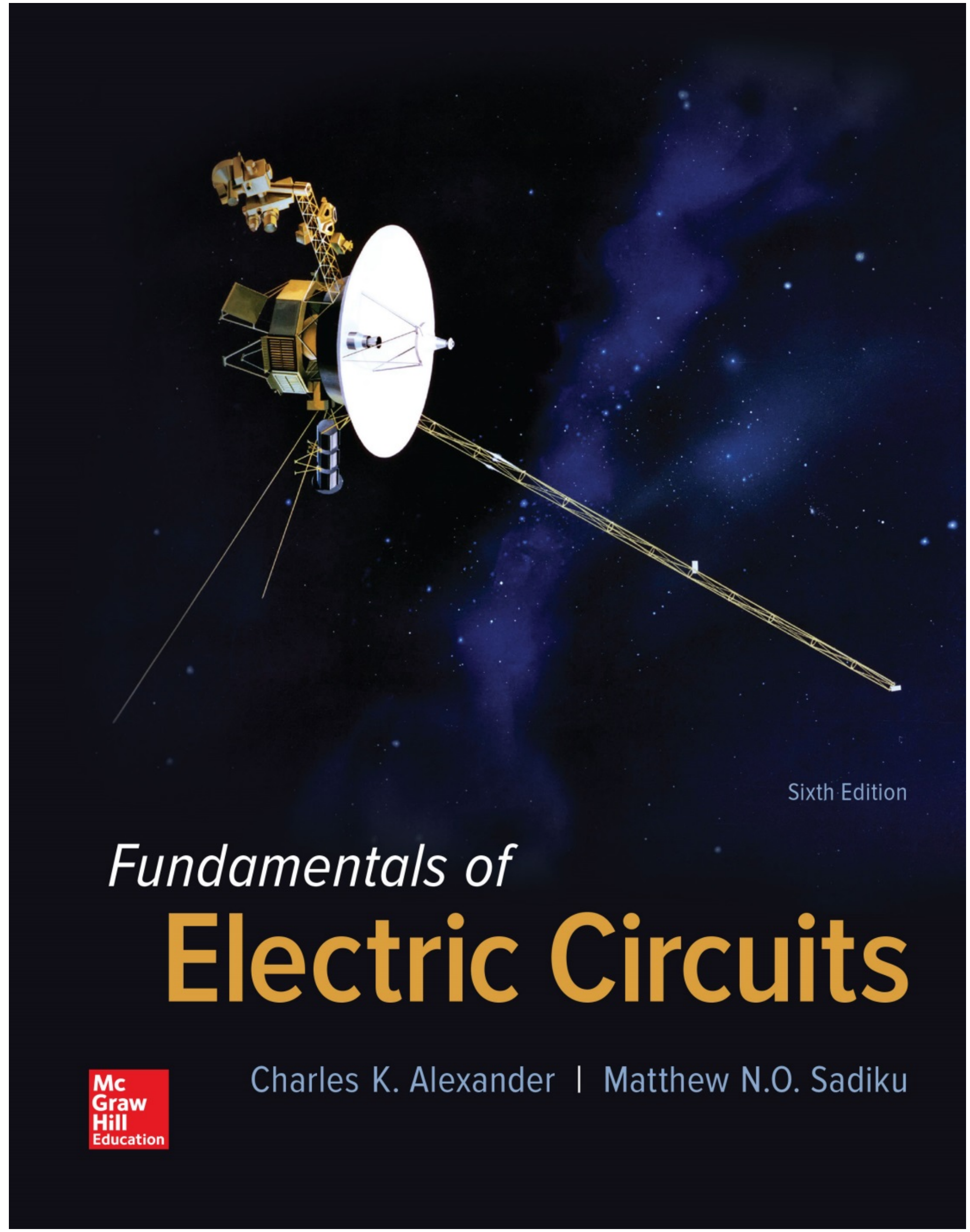
Fundamentals of Electric Circuits
Chapter 1

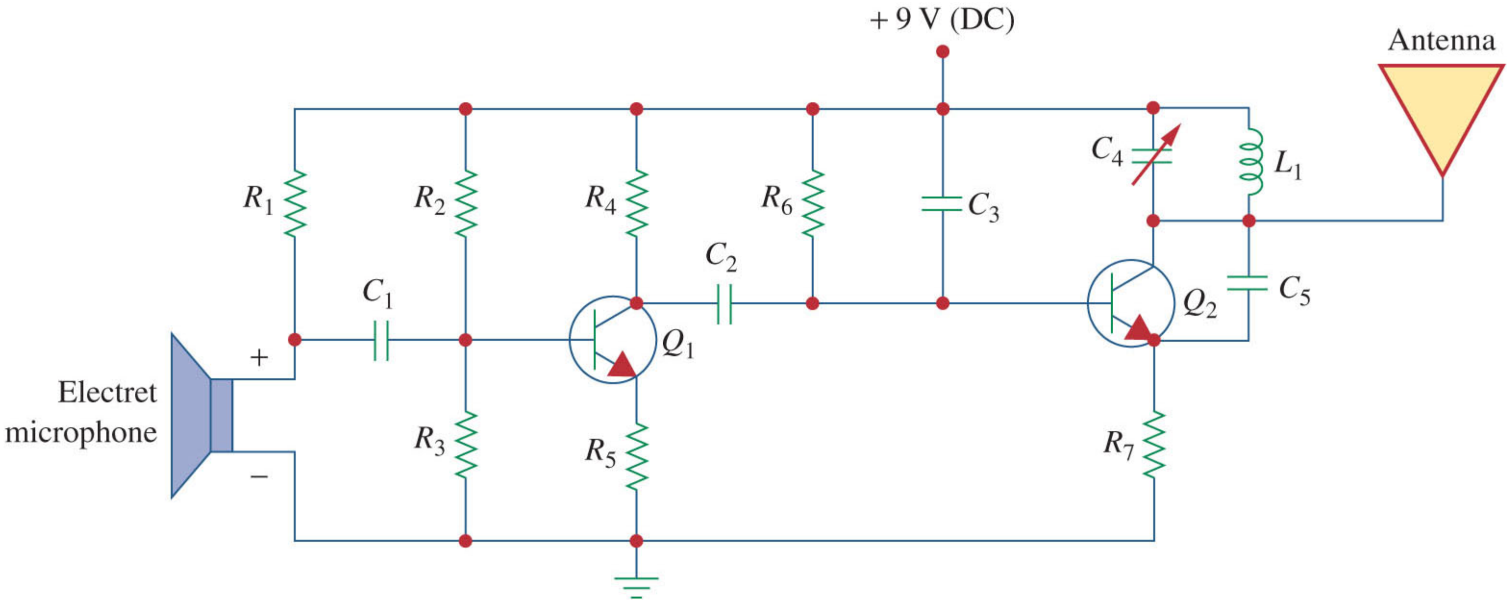


Introduction

- This chapter introduces the concept of voltage and current.
- The concept of a circuit will be introduced.
- Sources will be introduced.
- These can provide either a specified voltage or current.
- Dependent and independent sources will be discussed.
- Also a strategy for solving problems will be introduced.

What is a circuit?

- An electric circuit is an interconnection of electrical elements.
- It may consist of only two elements or many more:



Units

- When taking measurements, we must use units to quantify values
- We use the International Systems of Units (SI for short)
- Prefixes on SI units allow for easy relationships between large and small values

TABLE 1.2

The SI prefixes.

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

Charge

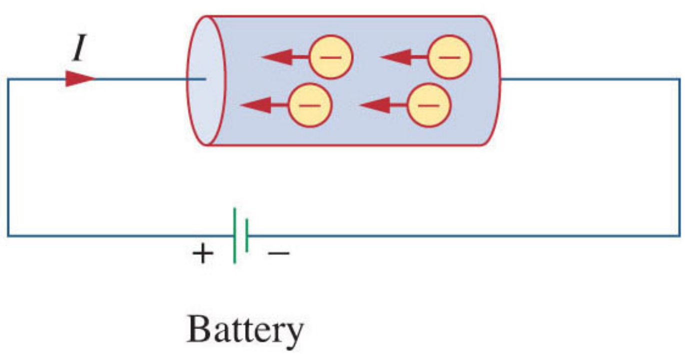
- Charge is a basic SI unit, measured in Coulombs (C)
- Counts the number of electrons (or positive charges) present.
- Charge of single electron is $1.602*10^{-19}$ C
- One Coulomb is quite large, $6.24*10^{18}$ electrons.

Charge II

- In the lab, one typically sees (pC, nC, or μC)
- Charge is always multiple of electron charge
- Charge cannot be created or destroyed, only transferred.

Current

- The movement of charge is called a current
- Historically the moving charges were thought to be positive
- Thus we always note the direction of the equivalent positive charges, even if the moving charges are negative.



Current II

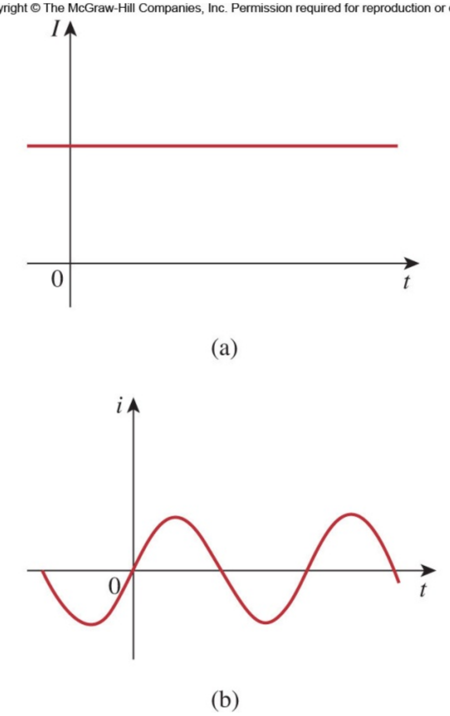
- **Current, *i*, is measured as charge moved per unit time through an element.**

$$i \equiv \frac{dq}{dt} \qquad\qquad Q \triangleq \int_{t_0}^{t} i\,dt$$

- **Unit is Ampere (A), is one Coulomb/second**

DC vs. AC

- A current that remains constant with time is called Direct Current (DC)
- Such current is represented by the capital *I*, time varying current uses the lowercase, *i*.
- A common source of DC is a battery.
- A current that varies sinusoidally with time is called Alternating Current (AC)
- Mains power is an example of AC

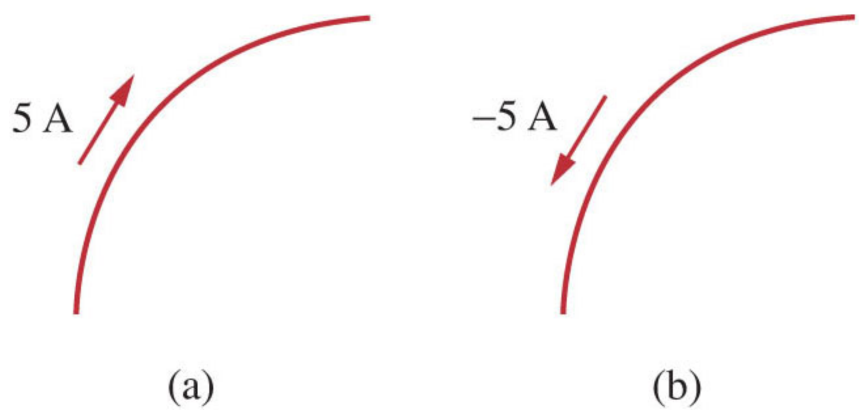


Direction of current

- The sign of the current indicates the direction in which the charge is moving with reference to the direction of interest we define.
- We need not use the direction that the charge moves in as our reference, and often have no choice in the matter.

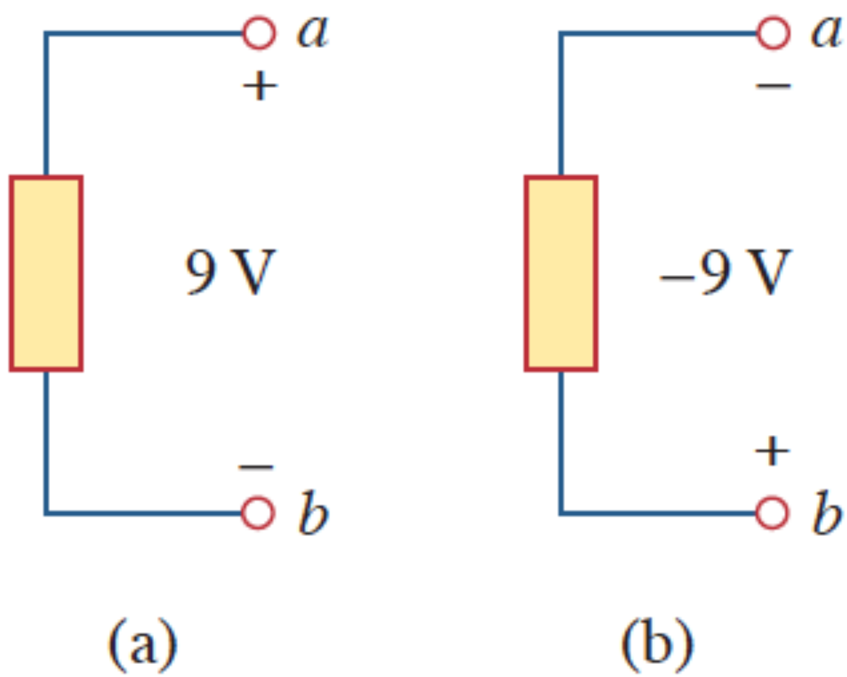
Direction of Current II

- **A positive current through a component is the same as a negative current flowing in the opposite direction.**



Voltage

- Electrons move when there is a difference in charge between two locations.
- This difference is expressed at the potential difference, or voltage (V).
- It is always expressed with reference to two locations



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

Figure 1.7
Two equivalent representations of the same voltage v_{ab}: (a) point a is 9 V above point b, (b) point b is -9 V above point a.

Voltage II

- It is equal to the energy needed to move a unit charge between the locations.
- Positive charge moving from a higher potential to a lower yields energy.
- Moving from negative to positive requires energy.

Power and Energy

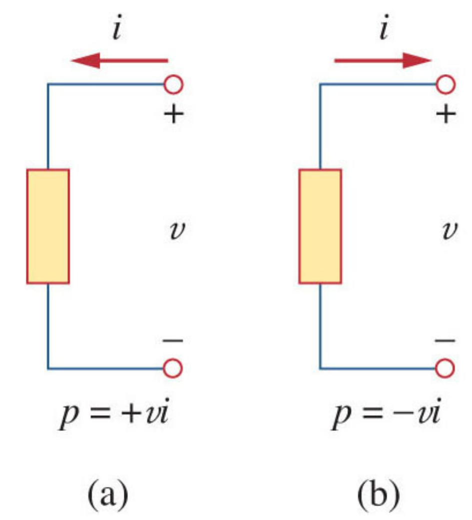
- **Voltage alone does not equal power.**
- **It requires the movement of charge, *i.e.* a current.**
- **Power is the product of voltage and current**

$$p = vi \qquad\qquad p \triangleq \frac{dw}{dt}$$

- **It is equal to the rate of energy provided or consumed per unit time.**
- **It is measured in Watts (W)**

Passive Sign Convention

- By convention, we say that an element being supplied power has positive power.
- A power source, such as a battery has negative power.
- Passive sign convention is satisfied if the direction of current is selected such that current enters through the terminal that is more positively biased.



Conservation of Energy

- In a circuit, energy cannot be created or destroyed.
- Thus power also must be conserved
- The sum of all power supplied must be absorbed by the other elements.
- Energy can be described as watts x time.
- Power companies usually measure energy in watt-hours

$$p \triangleq \frac{dw}{dt}$$

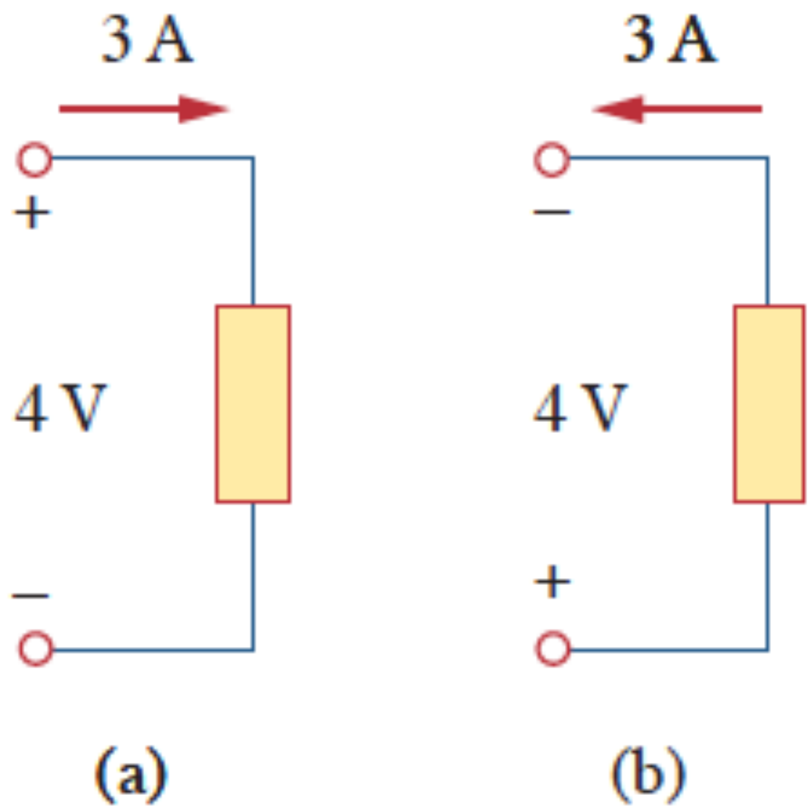
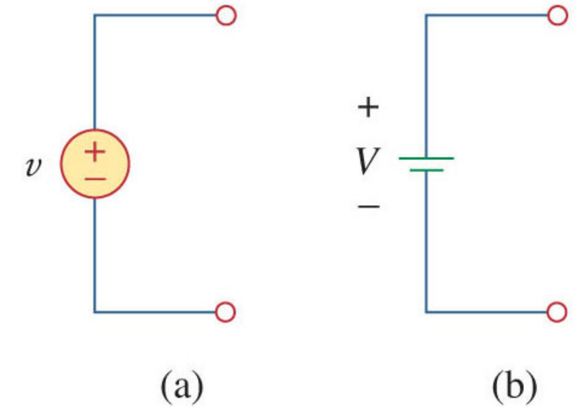


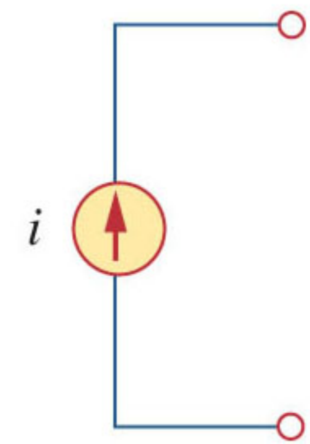
Figure 1.9
Two cases of an element with an absorbing power of 12 W: (a) $p = 4 \times 3 = 12$ W, (b) $p = 4 \times 3 = 12$ W.

Circuit Elements

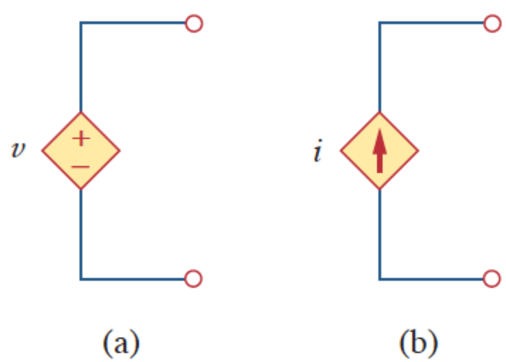
- **Two types:**
  - **Active**
  - **Passive**
- **Active elements can generate energy**
  - **Generators**
  - **Batteries**
  - **Operational Amplifiers**



Symbols for independent voltage sources:
(a) used for constant or time-varying voltage,
(b) used for constant voltage (dc).



Symbol for independent current source.



Symbols for: (a) dependent voltage source, (b) dependent current source

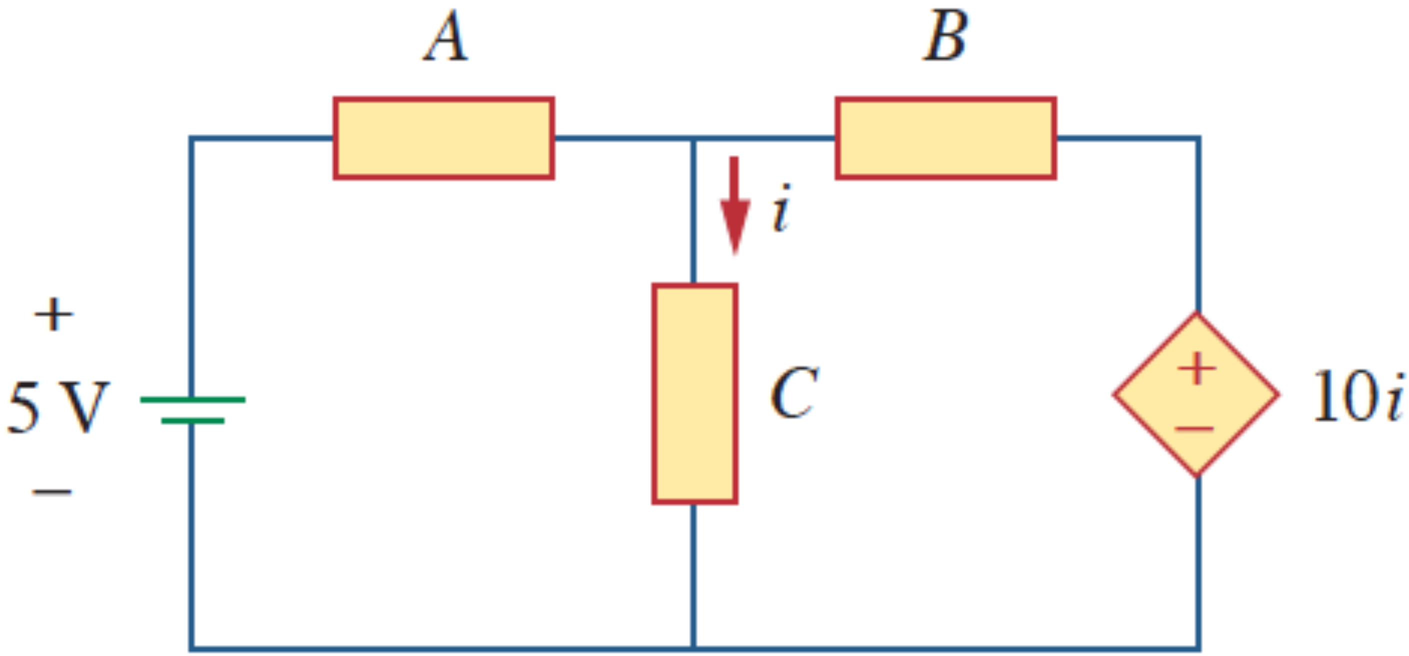


Figure 1.14

The source on the right-hand side is a current-controlled voltage source.

Circuit Elements II

- **Passives** absorb energy
  - Resistors
  - Capacitors
  - Inductors
- But it should be noted that only the resistor dissipates energy ideally.
- The inductor and capacitor do not.

Example 1.5

Find the power delivered to an element at $t = 3$ ms if the current entering its positive terminal is

$$i = 5 \cos 60\pi t \text{ A}$$

and the voltage is: (a) $v = 3i$, (b) $v = 3\, di/dt$.

Solution:

(a) The voltage is $v = 3i = 15 \cos 60\pi t$; hence, the power is

$$p = vi = 75 \cos^2 60\pi t \text{ W}$$

At $t = 3$ ms,

$$p = 75 \cos^2 (60\pi \times 3 \times 10^{-3}) = 75 \cos^2 0.18\pi = 53.48 \text{ W}$$

(b) We find the voltage and the power as

$$v = 3\frac{di}{dt} = 3(-60\pi)5 \sin 60\pi t = -900\pi \sin 60\pi t \text{ V}$$

$$p = vi = -4500\pi \sin 60\pi t \cos 60\pi t \text{ W}$$

At $t = 3$ ms,

$$\begin{aligned} p &= -4500\pi \sin 0.18\pi \cos 0.18\pi \text{ W} \\ &= -14137.167 \sin 32.4^\circ \cos 32.4^\circ = -6.396 \text{ kW} \end{aligned}$$

Example 1.7

Calculate the power supplied or absorbed by each element in Fig. 1.15.

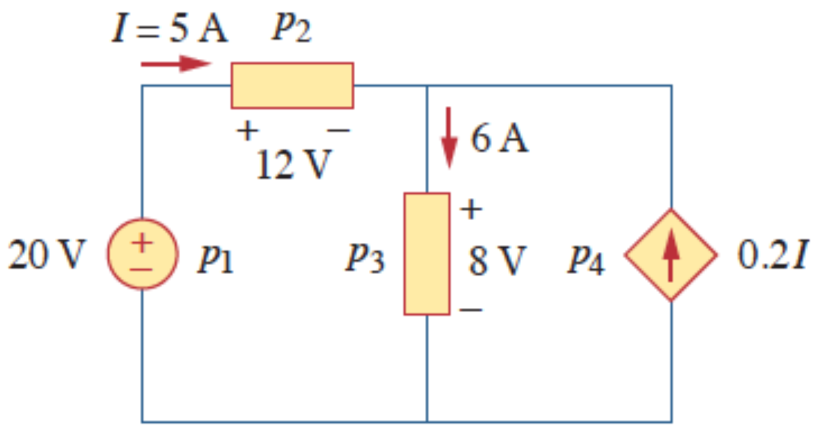


Figure 1.15
For Example 1.7.

$$p_1 = 20(-5) = -100 \text{ W} \qquad \text{Supplied power}$$

$$p_2 = 12(5) = 60 \text{ W} \qquad \text{Absorbed power}$$

$$p_3 = 8(6) = 48 \text{ W} \qquad \text{Absorbed power}$$

$$p_4 = 8(-0.2I) = 8(-0.2 \times 5) = -8 \text{ W} \qquad \text{Supplied power}$$

$$p_1 + p_2 + p_3 + p_4 = -100 + 60 + 48 - 8 = 0$$

Ideal Voltage Source

- **An ideal voltage source has no internal resistance.**
- **It also is capable of producing any amount of current needed to establish the desired voltage at its terminals.**
- **Thus we can know the voltage at its terminals, but we don't know in advance the current.**

Ideal Current Source

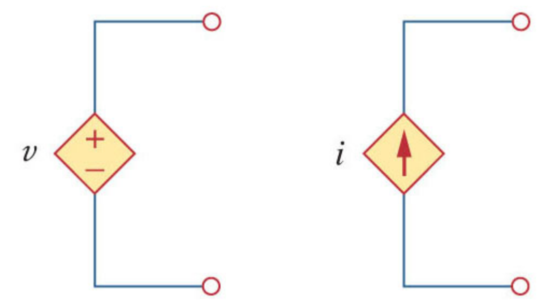
- **An Ideal Current sources are the opposite of the voltage source:**
- **They have infinite resistance**
- **They will generate any voltage to establish the desired current through them.**
- **We can know the current through them in advance, but not the voltage.**

Ideal sources

- Both the voltage and current source ideally can generate infinite power.
- They are also capable of absorbing power from the circuit.
- It is important to remember that these sources do have limits in reality:
- Voltage sources have an upper current limit.
- Current sources have an upper voltage limit.

Dependent Sources

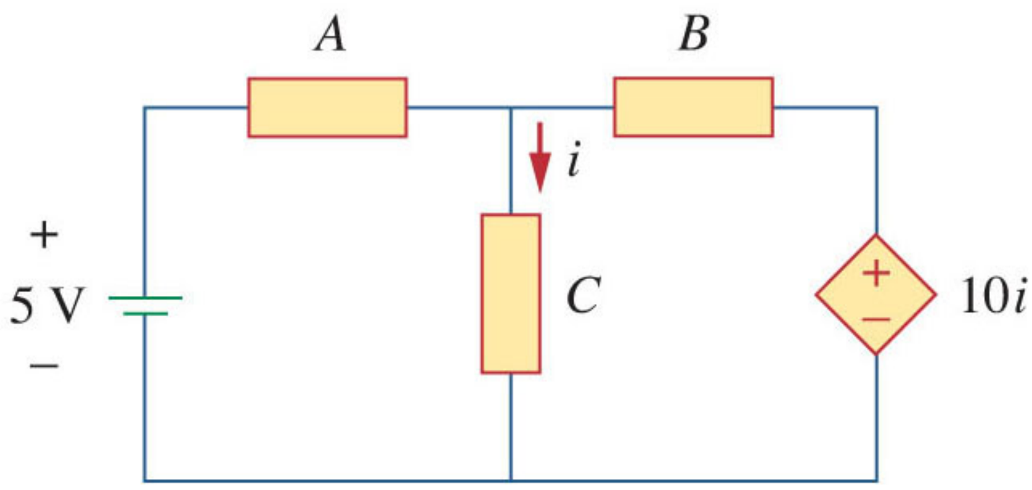
- A dependent source has its output controlled by an input value.
- Symbolically represented as a diamond
- Four types:
  - A voltage-controlled voltage source (VCVS).
  - A current-controlled voltage source (CCVS).
  - A voltage-controlled current source (VCCS).
  - A current-controlled current source (CCCS).



(a) (b)

Dependent Source example

- **The circuit shown below is an example of using a dependent source.**
- **The source on the right is controlled by the current passing through element C.**

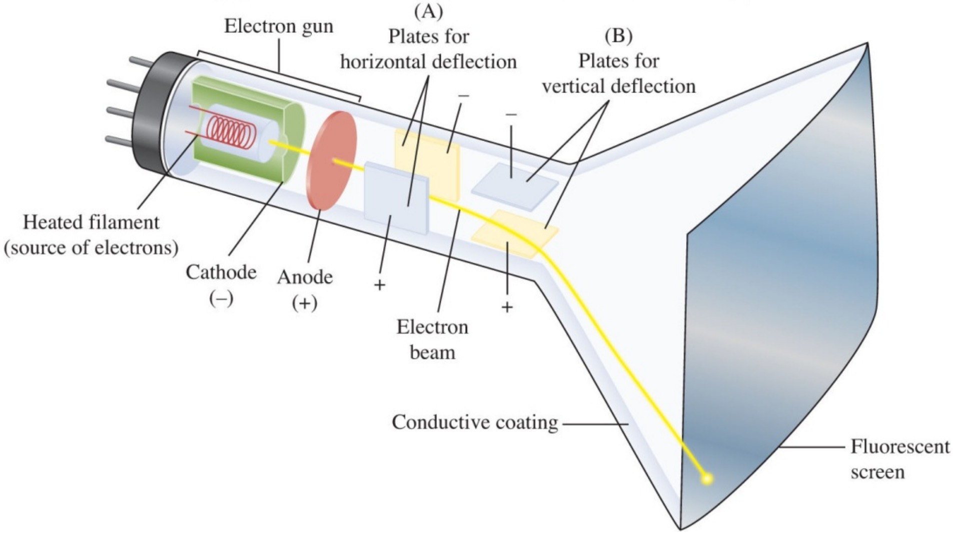


Circuit Applications of Dependent Sources

- Dependent sources are good models for some common circuit elements:
  - **Transistors**: In certain modes of operation, transistors take either a voltage or current input to one terminal and cause a current that is somehow proportional to the input to appear at two other terminals.
  - **Operational Amplifiers**: Not covered yet, but the basic concept is they take an input voltage and generate an output voltage that is proportional to that.

TV Picture Tube

- Old style cathode Ray Tubes (CRT) are a good example of the flow of electrons
- A hot filament is the source of electrons
- Charged plates accelerate and steer a thin stream (beam) of electrons
- The beam strikes a phosphor coated screen causing light emission.



Problem Solving I

- **Successfully solving an engineering problem requires a process.**
- **Shown here is an effective method for determining the solution any problem.**
  1. **Carefully define the problem.**
  2. **Present everything you know about the problem.**
  3. **Establish a set of alternative solutions and determine the one that promises the greatest likelihood of success.**

Problem Solving II

4. Attempt a problem solution.
5. Evaluate the solution and check for accuracy.
6. Has the problem been solved satisfactorily? If so, present the solution; if not, then return to step 3 and continue through the process again.

Problem Solving III

- **Carefully define the problem**
  - This is the most important step
  - What needs to be solved?
  - What questions need to be addressed before solving? Find the sources to answer them.
- **Present everything you know about the problem**
  - What do you know?
  - What don't you?

Problem Solving IV

- Establish a set of alternative solutions and determine the one that promises the greatest likelihood of success.
  - Most problems have more than one way to be solved
  - But not all solutions are as simple
  - Are the required tools available?

Problem Solving V

- Attempt to solve the problem
  - Documenting this process is very important
- Evaluate the solution and check for accuracy
  - Does it makes sense?
  - Is it consistent with any assumptions made?
- Is the solution satisfactory? If not, try an alternate solution.