Chapter 1 & 2: Basic Concepts

1. Systems of Units
2. Electric Charge
3. Current
4. Voltage
5. Power and Energy
6. Linearity Property
7. Circuit Elements
8. Ohm’s Law
9. Summary

1.1 System of Units (1)

Six basic SI units

Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

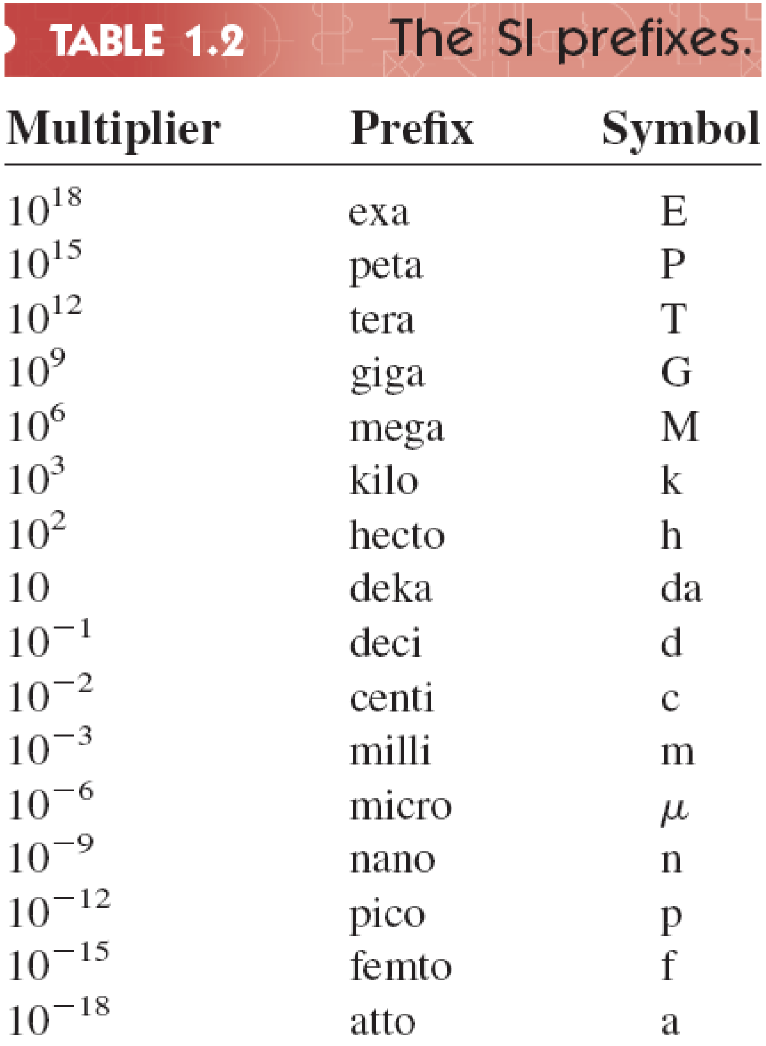


TABLE 1.2 The SI prefixes.

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

1.1 System of Units (2)

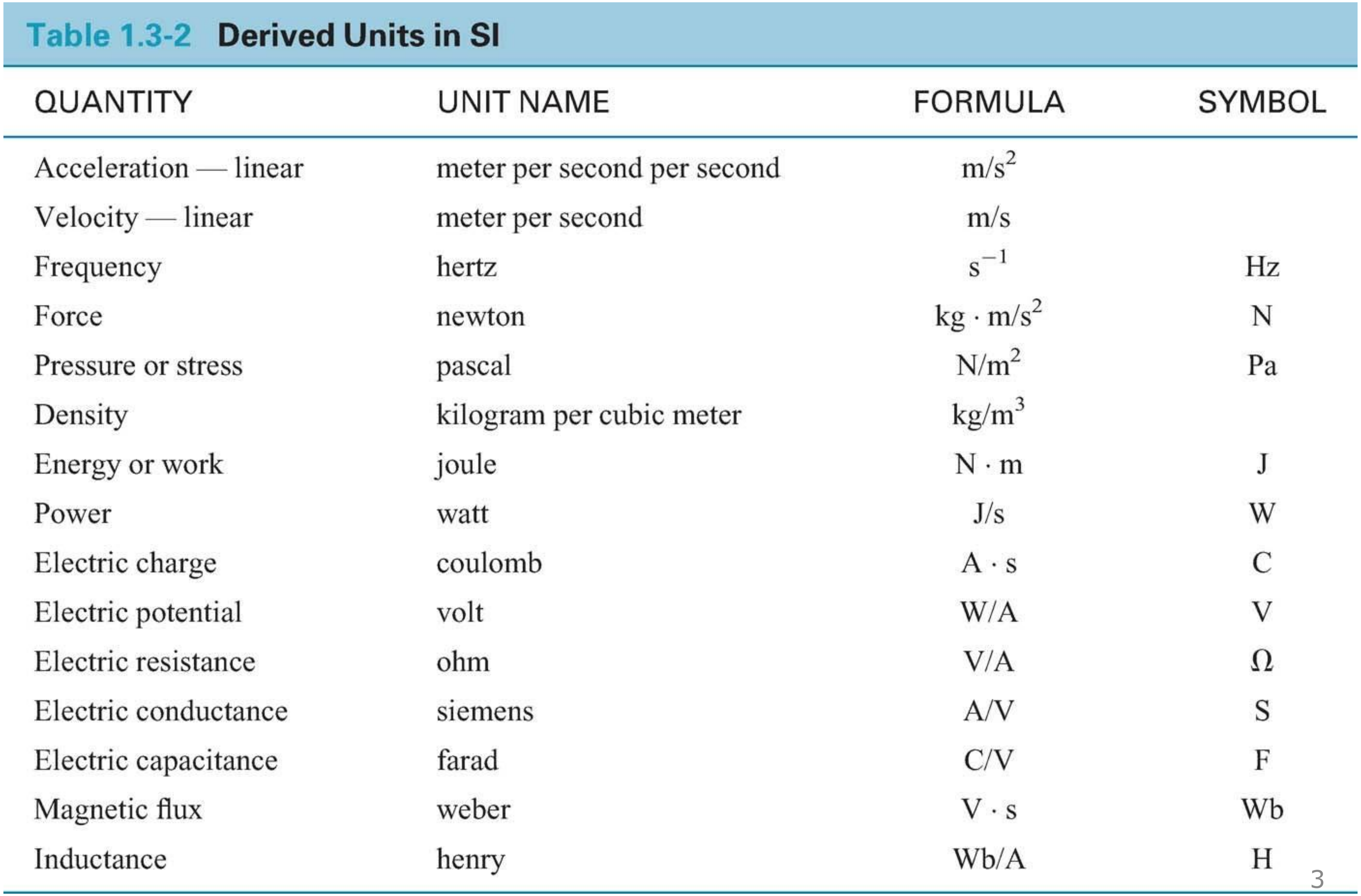
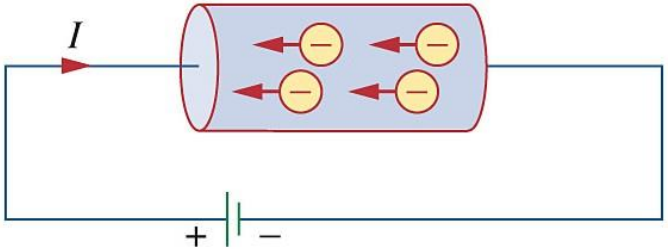


Table 1.3-2 Derived Units in SI

QUANTITY	UNIT NAME	FORMULA	SYMBOL
Acceleration — linear	meter per second per second	m/s^2	
Velocity — linear	meter per second	m/s	
Frequency	hertz	s^{-1}	Hz
Force	newton	$kg \cdot m/s^2$	N
Pressure or stress	pascal	N/m^2	Pa
Density	kilogram per cubic meter	kg/m^3	
Energy or work	joule	$N \cdot m$	J
Power	watt	J/s	W
Electric charge	coulomb	$A \cdot s$	C
Electric potential	volt	W/A	V
Electric resistance	ohm	V/A	Ω
Electric conductance	siemens	A/V	S
Electric capacitance	farad	C/V	F
Magnetic flux	weber	$V \cdot s$	Wb
Inductance	henry	Wb/A	H

1.2 Electric Charges

- Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).
- The charge e on one electron is negative and equal in magnitude to 1.602×10^{-19} C which is called as electronic charge. In 1 C of charge, there are $1/(1.602 \times 10^{-19}\ \text{C}) = 6.24 \times 10^{18}$ electrons.
- The charges that occur in nature are integral multiples of the electronic charge.
- *Law of conservation of charge*: Charge can neither be created nor destroyed, only transferred.



Electric current due to flow of electronic charge in a conductor.

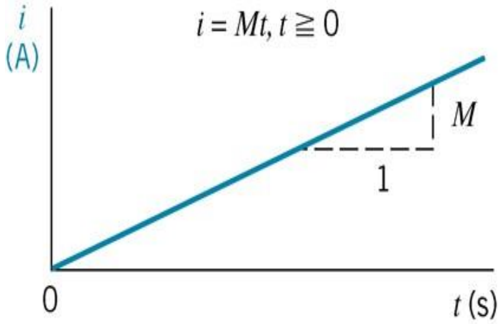
1.3 Current (1)

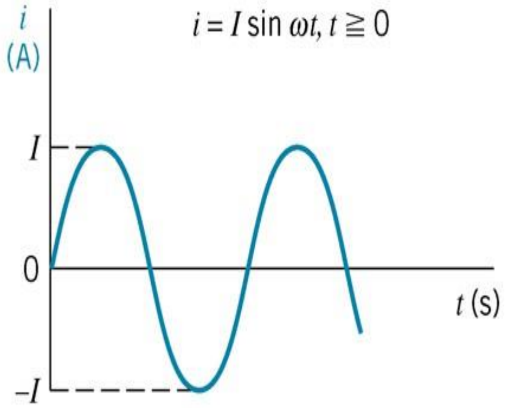
- Electric current $i = dq/dt$. The unit of ampere can be derived as $1\text{ A} = 1\text{ C/s}$.

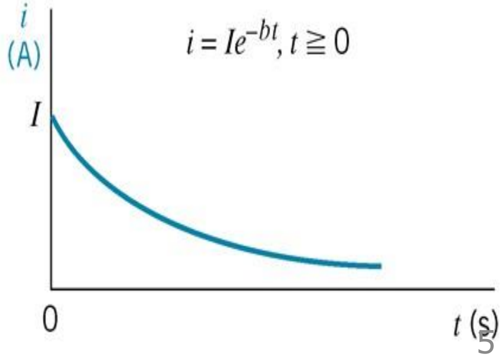
$$i \triangleq \frac{dq}{dt}$$

$$Q \triangleq \int_{t_0}^{t} i\, dt$$

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



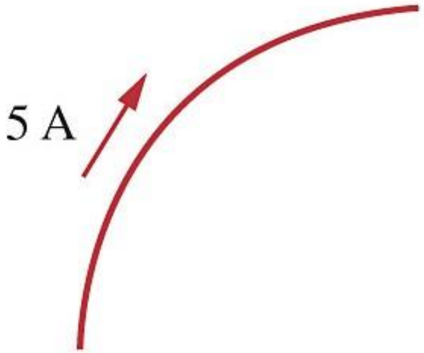




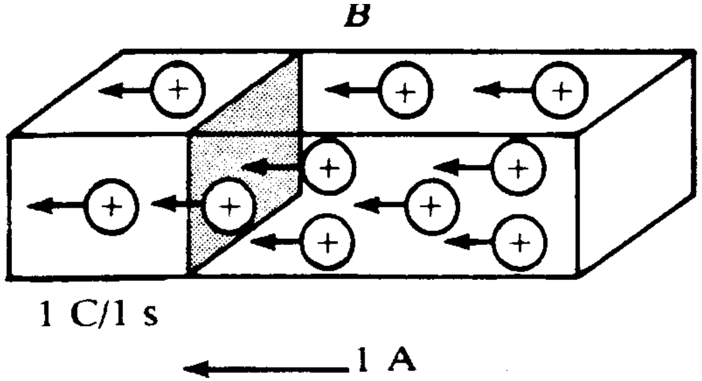
1.3 Current (2)

- **The direction of current flow**

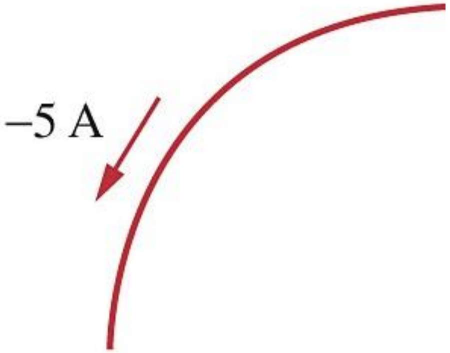
Positive current follow



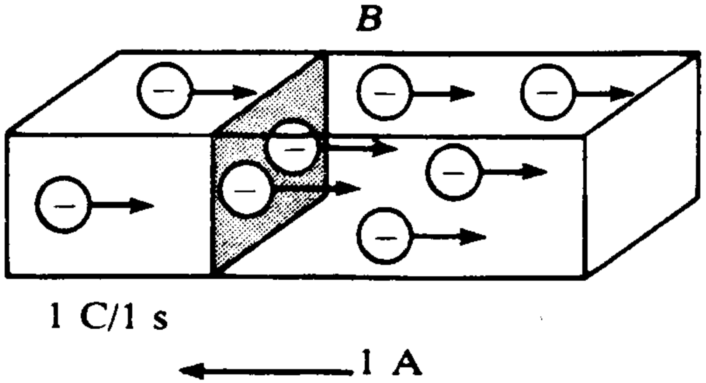
Positive ions



Negative current follow



Negative ions



1.3 Current (3)

Example

A conductor has a constant current of $5\,\mathrm{A}$.
How many electrons pass a fixed point on the conductor in one minute?

Solution

Total no. of charges pass in 1 min is given by

$5\ \mathrm{A} = (5\ \mathrm{C/s})(60\ \mathrm{s/min}) = 300\,\mathrm{C/min}$

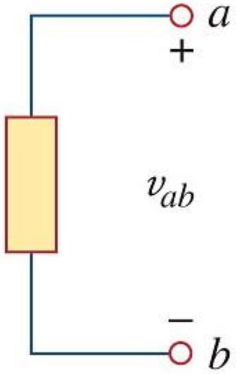
Total no. of electronics pass in 1 min is given

$$\boxed{\frac{300\ \ \mathrm{C/min}}{1.602\times 10^{-19}\,\mathrm{C/electron}} = 1.87\times 10^{21}\ \mathrm{electrons/min}}$$

1.4 Voltage

- Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).

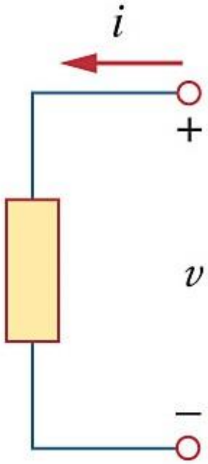
- Mathematically, $v_{ab} = dw / dq \quad \text{(volt)}$
  - w is energy in joules (J) and q is charge in coulomb (C).



- Electric voltage, v_{ab}, is always across the circuit element or between two points in a circuit.
  - $v_{ab} > 0$ means the potential of a is higher than potential of b.
  - $v_{ab} < 0$ means the potential of a is lower than potential of b.

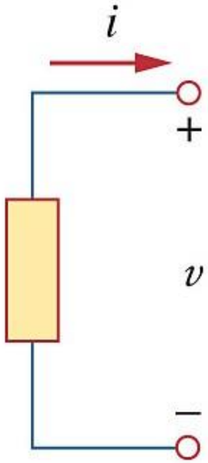
1.5 Power and Energy (1)

- Power is the time rate of expending or absorbing energy, measured in watts (W).
- Mathematical expression: $p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$



$P = +vi$

absorbing power



$p = -vi$

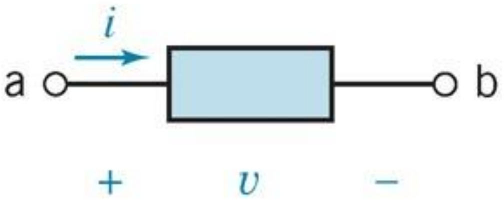
supplying power

Passive sign convention

1.5 Power and Energy (2)

power absorbed = – power supplied

POWER ABSORBED BY AN ELEMENT

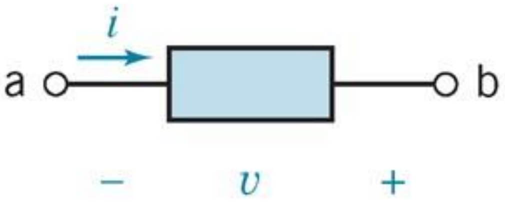


Because the reference directions of *v* and *i* adhere to the passive convention, the power

$$p = vi$$

is the power absorbed by the element.

POWER SUPPLIED BY AN ELEMENT



Because the reference directions of *v* and *i* do not adhere to the passive convention, the power

$$p = vi$$

is the power supplied by the element.

1.5 Power and Energy (3)

- *Law of conservation of energy*

$$\sum p = 0$$

- Energy is the capacity to do work, measured in joules (J).
- Mathematical expression $w = \int_{t_0}^{t} p dt = \int_{t_0}^{t} vidt$

The electric power utility companies measure energy in watt-hours (Wh), where

$$1 \text{ Wh} = 3{,}600 \text{ J}$$

2.1 Linearity Property (1)

- **Linearity** is the property of an element describing a linear relationship between cause and effect.
- **Linearity** is a combination of both the **homogeneity (scaling)** property and **additivity** property

✓ *Scaling*: $v = i\,R \rightarrow k\,v = k\,i\,R$

✓ *Additivity*: $v_1 = i_1 R \;\;\&\;\; v_2 = i_2 R$

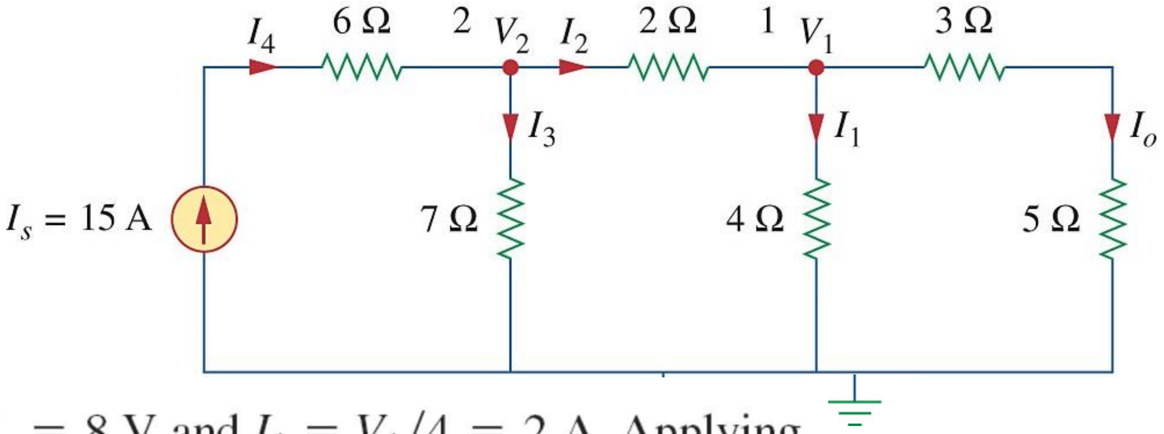
$$\rightarrow v = (i_1 + i_2)\,R = v_1 + v_2$$

A linear circuit is one whose **output** is linearly related (or directly proportional) to its **input**.

Note: A resistor is a linear element, but the relationship btw power and voltage (or current) is nonlinear.

2.1 Linearity Property (2)

Example: By assume $I_o = 1$ A, use linearity to find the actual value of I_o in the circuit.



Solution:

If $I_o = 1$ A, then $V_1 = (3 + 5)I_o = 8$ V and $I_1 = V_1/4 = 2$ A. Applying KCL at node 1 gives

$$I_2 = I_1 + I_o = 3 \text{ A}$$

$$V_2 = V_1 + 2I_2 = 8 + 6 = 14 \text{ V}, \qquad I_3 = \frac{V_2}{7} = 2 \text{ A}$$

Applying KCL at node 2 gives

$$I_4 = I_3 + I_2 = 5 \text{ A}$$

Therefore, $I_s = 5$ A. This shows that assuming $I_o = 1$ gives $I_s = 5$ A, the actual source current of 15 A will give $I_o = 3$ A as the actual value.

2.1 Linearity Property (3)

Example

Now let us consider an element: $v = i^2$

→ Determine whether this device is linear.

Solution

The response to a current i_1 is $v_1 = i_1^{2}$

The response to a current i_2 is $v_2 = i_1^{2}$

The sum of these responses is $v_1 + v_2 = i_1^{2} + i_1^{2}$

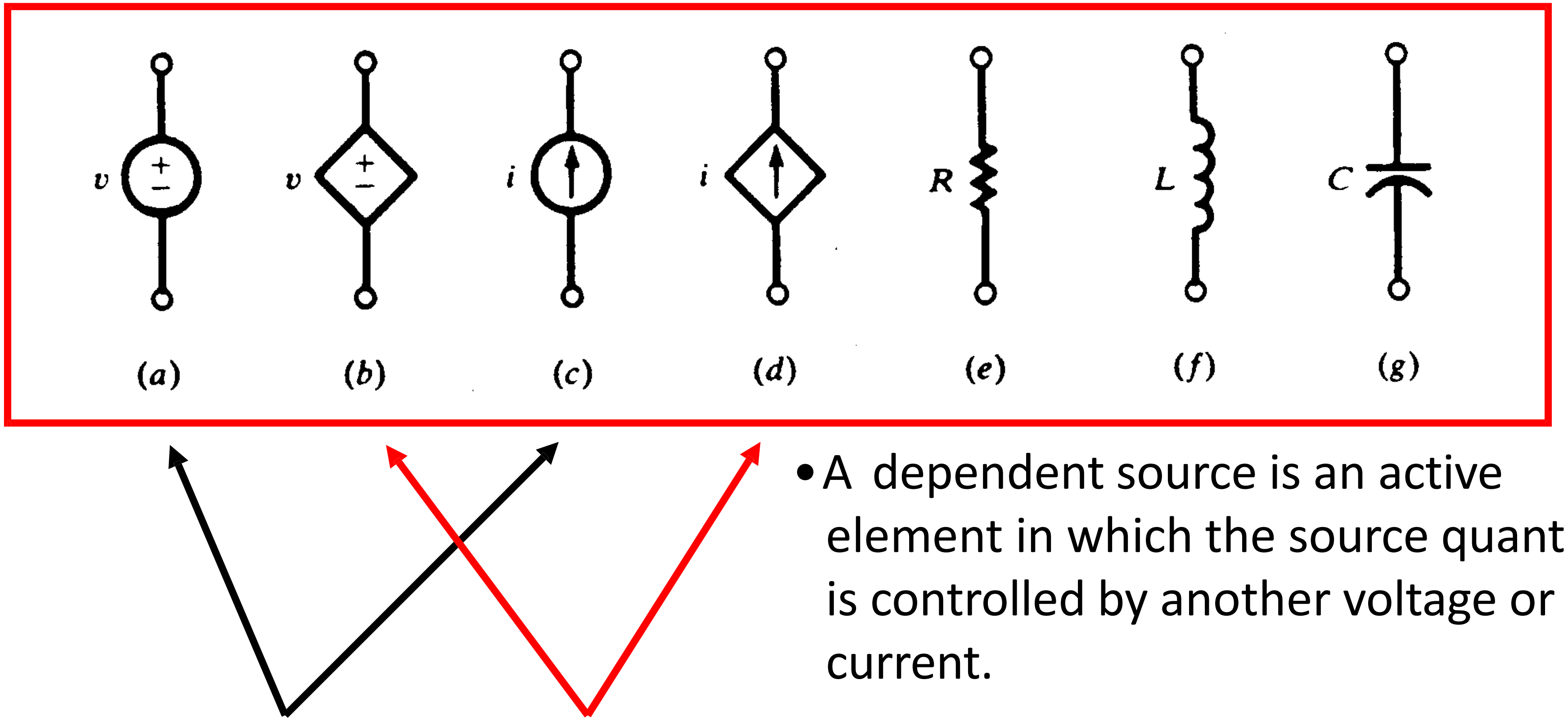
The response to $i_1 + i_2$ is

$$(i_1 + i_2)^2 = i_1^{2} + 2i_1i_2 + i_1^{2}$$

Because $i_1^2 + i_1^2 \neq (i_1 + i_2)^2$, the principle of superposition is not satisfied. Therefore, the device is nonlinear.

2.2 Circuit Elements (1)

Active Elements **Passive Elements**



Independent sources

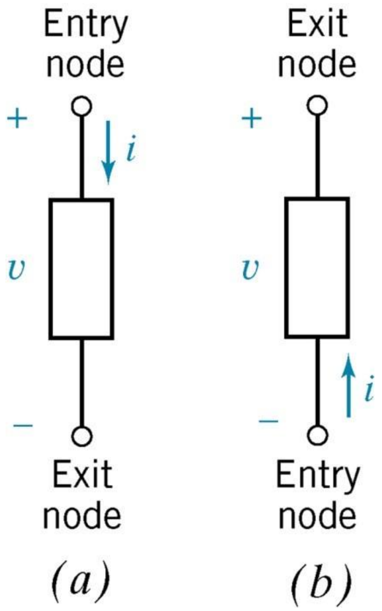
Dependent sources

- A dependent source is an active element in which the source quantity is controlled by another voltage or current.
- They have four different types: VCVS, CCVS, VCCS, CCCS. Keep in minds the signs of dependent sources.

2.2 Circuit Elements (2)

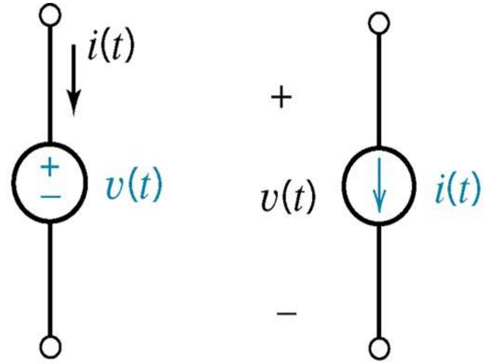
- An element is said to be passive if the total energy delivered to it from the rest of the circuit is always nonnegative (zero or positive).
- A passive element absorbs energy.
- An element is said to be *active* if it is capable of delivering energy.
- An active element is capable of supplying energy.

Fig. (a) The entry node of the current I is the positive node of the voltage v ; (b) the entry node of the current I is the negative node of the voltage v. The current flows from the entry node to the exit node.



2.2 Circuit Elements (3)

INDEPENDENT SOURCES

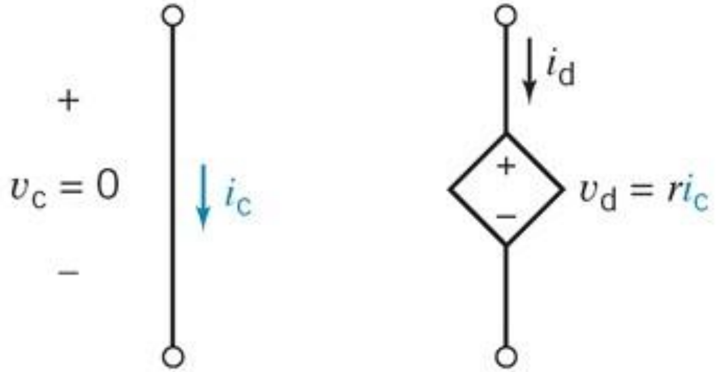


- A source is a voltage or current generator capable of supplying energy to a circuit.
- An independent source is a voltage or current generator not dependent on other circuit variables.
- The voltage of an ideal voltage source is given to be a specified function, say $v(t)$. The current is determined by the rest of the circuit.
- The current of an ideal current source is given to be a specified function, say $i(t)$. The , voltage is determined by the rest of the circuit.
- An ideal source is a voltage or a current generator independent of the current through the voltage source or the voltage across the current source.

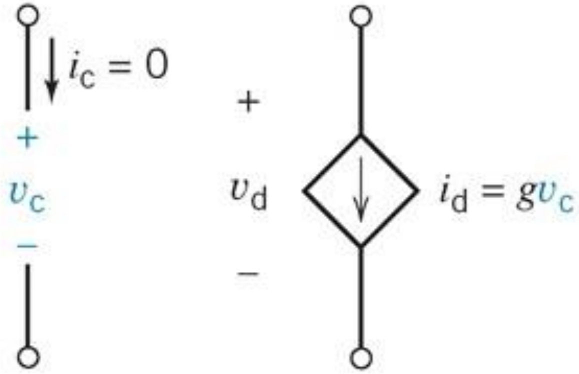
2.2 Circuit Elements (4)

DEPENDENT SOURCES

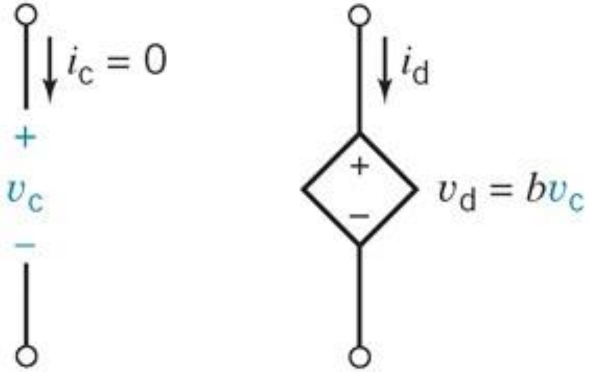
Current-Controlled Voltage Source (CCVS)
r is the gain of the CCVS.
r has units of volts/ampere.



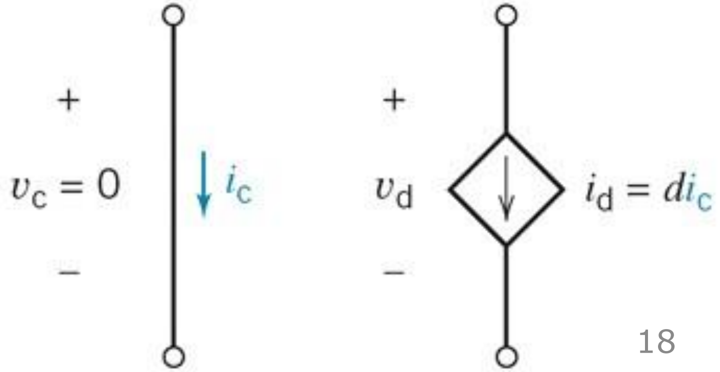
Voltage-Controlled Current Source (VCCS)
g is the gain of the VCCS.
g has units of amperes/volt.



Voltage-Controlled Voltage Source (VCVS)
b is the gain of the VCVS.
b has units of volts/volt.



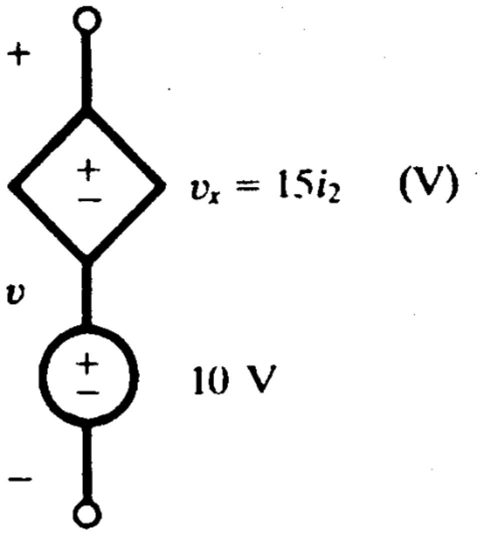
Current-Controlled Current Source (CCCS)
d is the gain of the CCCS.
d has units of amperes/ampere.



2.2 Circuit Elements (5)

Example

Obtain the voltage v in the branch for $i_2 = 1$ A



Solution

Voltage v is the sum of the current-independent 10-V source and the current-dependent voltage source v_x.

Note that the factor 15 multiplying the control current carries the units Ω.

Therefore, $v = 10 + v_x = 10 + 15(1) = 25\text{ V}$

2.2 Circuit Elements (6)

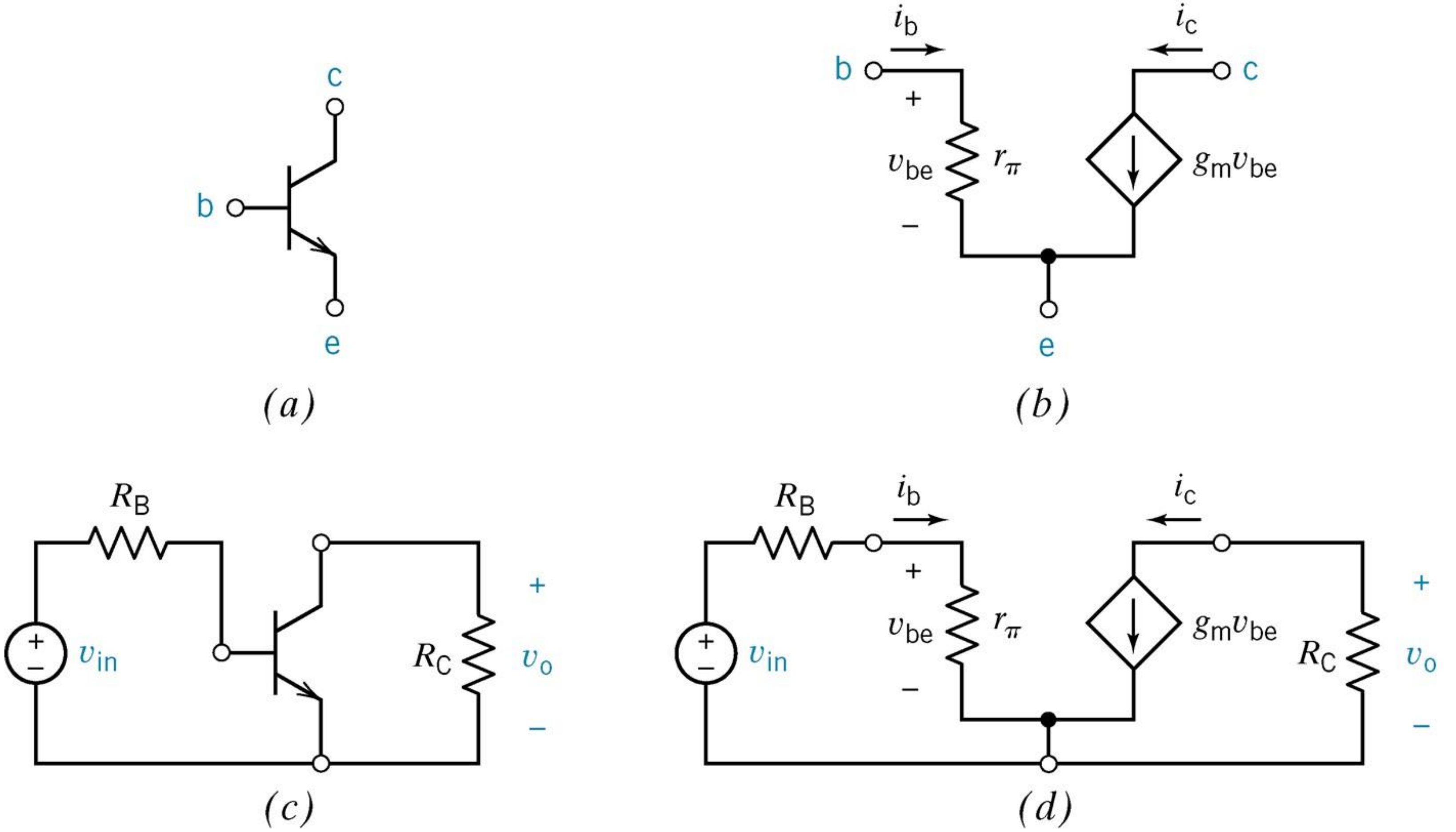
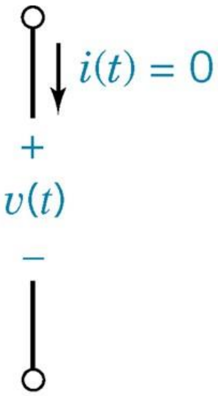


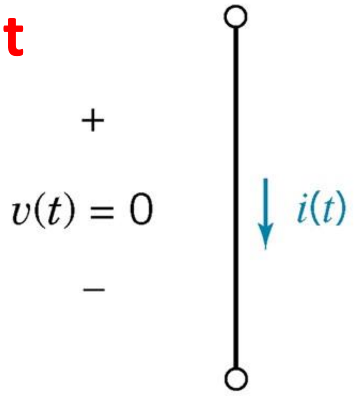
Fig. (a) A symbol for a transistor. (b) A model of the transistor.
(c) A transistor amplifier. (d) A model of the transistor amplifier.

2.2 Circuit Elements (7)

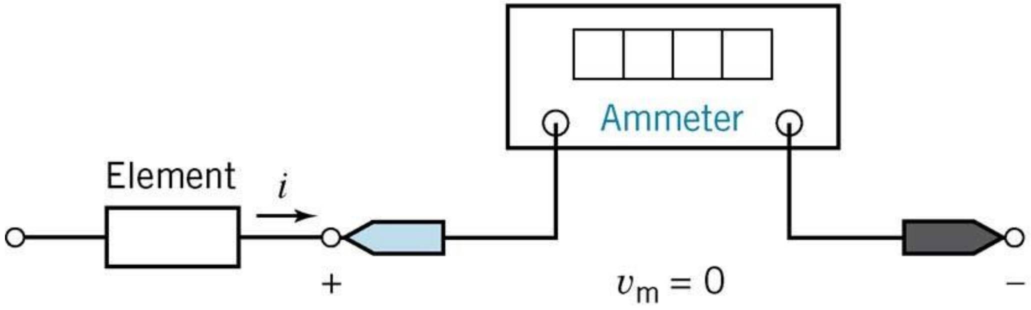
- **Open circuit**



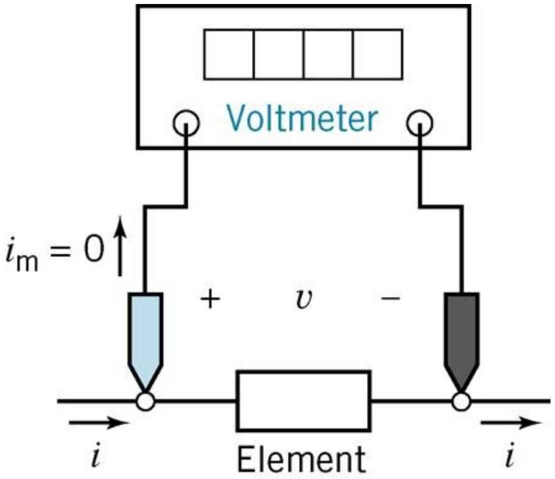
Short circuit



- **Voltmeter**



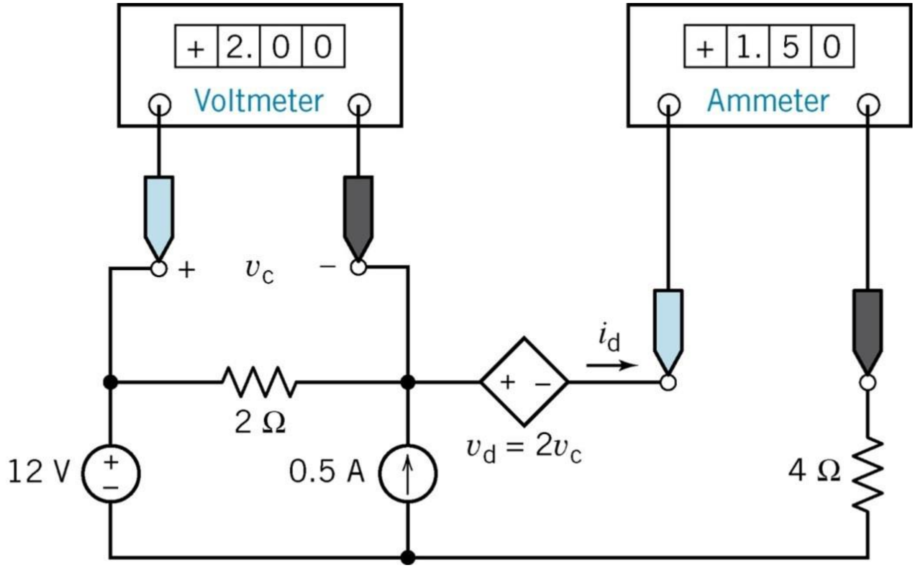
Ammeter



2.2 Circuit Elements (8)

Example: Power and Dependent Sources

Determine the power absorbed by the VCVS



Solution

The voltmeter measures v_c = 2V.

The voltage of the controlled voltage source is $v_d = 2\ v_c = 4$ V.

The ammeter measures i_d = 1.5 A.

The element current, i_d , and voltage, v_d, adhere to the passive convention.

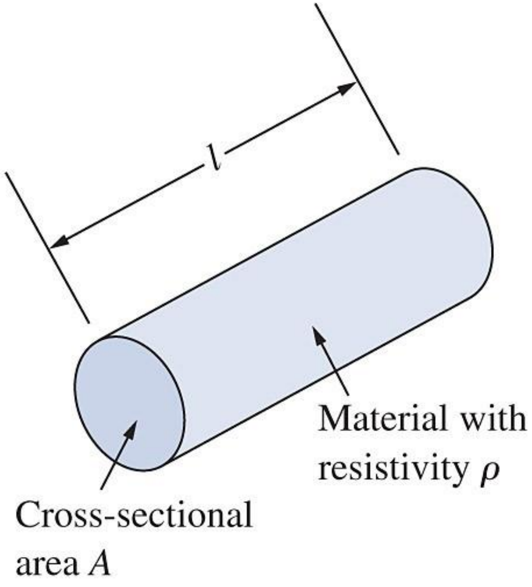
→ $p = i_d v_d = 1.5 \times 4 = 6$W is the power absorbed by the VCVS.

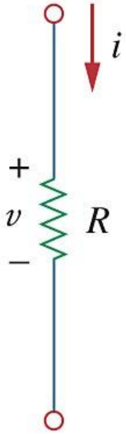
2.3 Ohms Law (1)

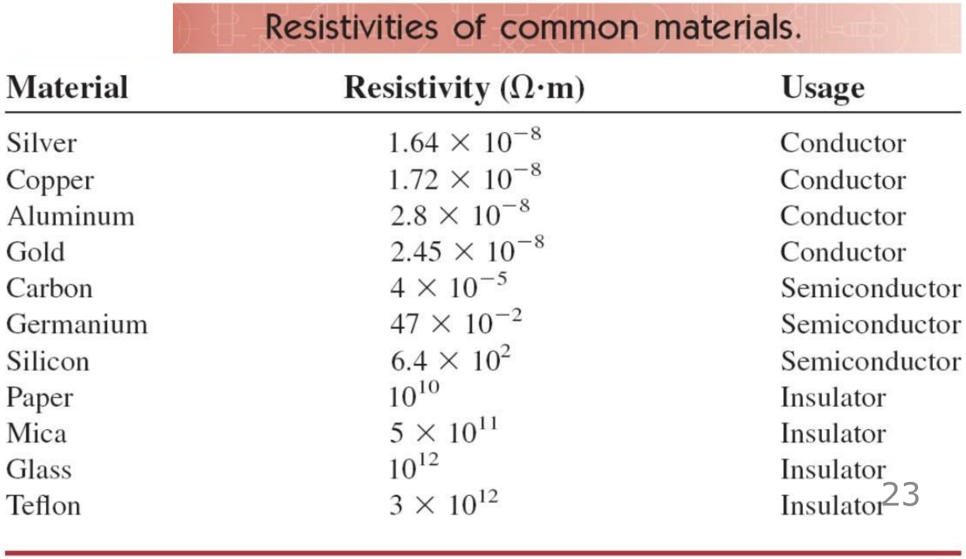
- Materials in general have a characteristic behavior of resisting the flow of electric charge. This ability to resist current is known as ***resistance*** and is represented by the symbol R. The resistance of any material with a uniform cross-sectional area A depends on A and its length ℓ,

$$\boxed{R = \rho\frac{\ell}{A}} \qquad i = \frac{Av}{\rho l}$$

where ρ is known as the ***resistivity*** of the material in ohm-meters.





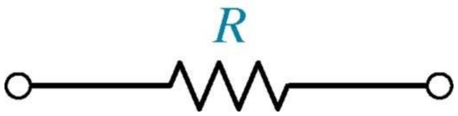

Resistivities of common materials.

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

2.3 Ohms Law (2)

- **Ohm's law** states that the voltage across a resistor is directly proportional to the current i flowing through the resistor R.
- Mathematically,

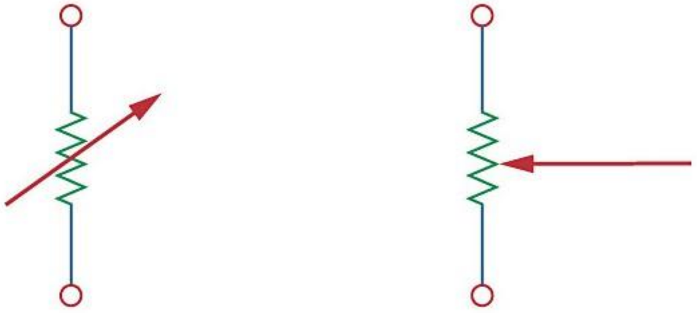
$$\boxed{v = iR}$$



- Two extreme possible values of R: 0 and ∞ are related with two basic circuit concepts: short circuit and open circuit.

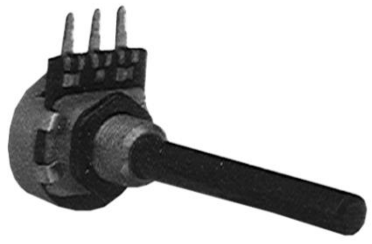
(a)

(b)



(a) (b)

Circuit symbol for: (a) a variable resistor in general, (b) a potentiometer.



2.3 Ohms Law (3)

- ***Conductance*** is the ability of an element to conduct electric current; it is the reciprocal of resistance R and is measured in mhos or siemens.

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

- *The power dissipated by a resistor:*

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

- Notes:

1. The power dissipated in a resistor is a nonlinear function of either current or voltage.
2. Since R and G are positive quantities, the power dissipated in a resistor is always positive. Thus, a resistor always absorbs power from the circuit. This confirms the idea that a resistor is a passive element, incapable of generating energy.

2.4 Summary (1)

- The engineer uses models, called circuit elements, to represent the devices that make up a circuit. In this book, we consider only linear elements or linear models of devices. A device is linear if it satisfies the properties of both superposition and homogeneity.
- The relationship between the reference directions of the current and voltage of a circuit element is important. The voltage polarity marks one terminal + and the other -. The element voltage and current adhere to the passive convention if the current is directed from the terminal marked + to the terminal marked -.
- Resistors arc widely used as circuit elements. When the resistor voltage and current adhere to the passive convention, resistors obey Ohm's law; the voltage across the terminals of the resistor is related to the current into the positive terminal as $v = Ri$. The power delivered to a resistance is $p = i^2R = v^2/R$ watts.

2.4 Summary (2)

- An independent source provides a current or a voltage independent of other circuit variables. The voltage of an independent voltage source is specified, but the current is not. Conversely, the current of an independent current source is specified whereas the voltage is not.
- A dependent source provides a current (or a voltage) that is dependent on another variable elsewhere in the circuit.
- The short circuit and open circuit are special cases of independent sources. A short circuit is an ideal voltage source having $v(t) = 0$.
- An open circuit is an ideal current source having $i(t) = 0$. Open circuits and short circuits can also be described as special cases of resistors. A resistor with resistance $R = 0$ ($G = \infty$) is a short circuit. A resistor with conductance $G = 0$ ($R = \infty$) is an open circuit.

2.4 Summary (3)

- An ideal ammeter measures the current following though its terminals and has zero voltage across its terminals. An ideal voltmeter measures the voltage across its terminals and has terminal current equal to zero. Ideal voltmeters act like open circuits, and ideal ammeters act like short circuits.
- Transducers are devices that convert physical quantities, such as rotational position, to an electrical quantity such as voltage. In this chapter, we describe two transducers: potentiometers and temperature sensors.
- Switches are widely used in circuits to connect and disconnect elements and circuits. They can also be used to create discontinuous voltages or currents