LEC 1. INTRODUCTION

ECEN203

Analogue Circuits and Systems

Introduction

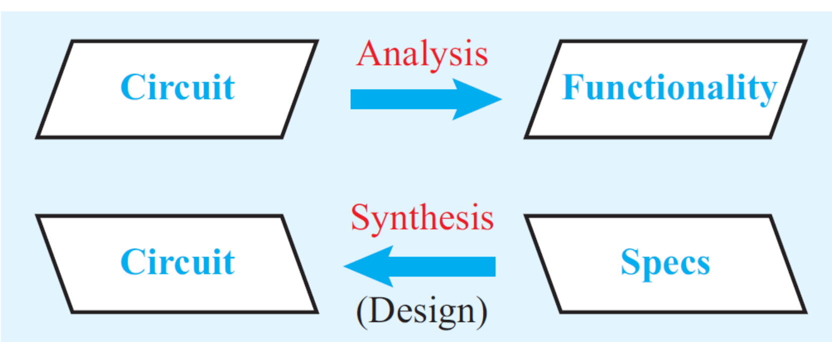
- Learn about circuit terminology;
- Differentiate between active and passive devices;
- Differentiate between a system, circuit and device;
- What is AC and DC?
- Relate electric charge to current, voltage to energy, power to current and voltage, and apply the passive sign convention.
- Describe the properties of dependent and independent sources.

Circuit Terminology

- Electronics
  - Devices – active vs. passive
  - Circuits
  - Systems

Active devices (such as transistors and ICs) require an external power source to operate; in contrast, passive devices (resistors, capacitors, and inductors) do not.

Analysis vs. Synthesis



Cell-Phone Architecture

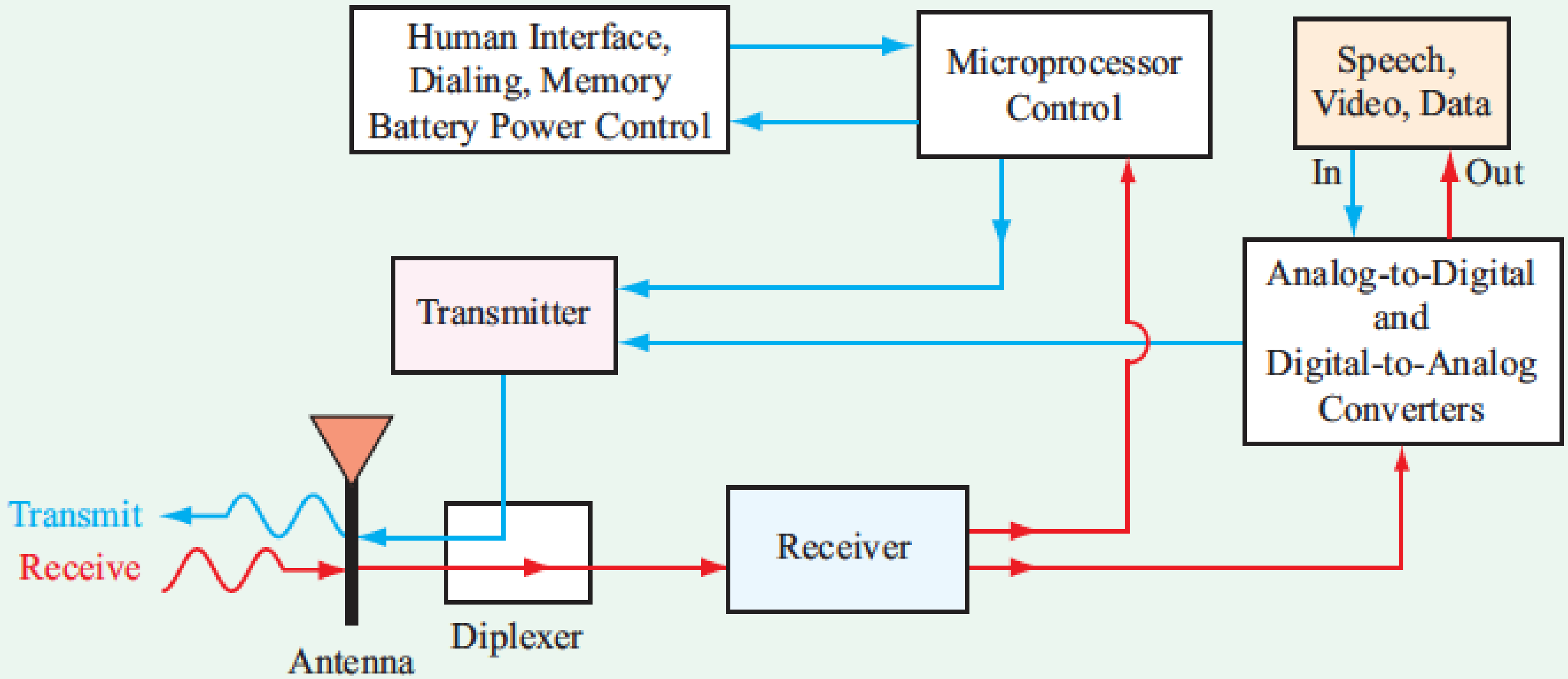


Figure 1-2: Basic cell-phone block diagram. Each block consists of multiple circuits that together provide the required functionality.

Units, Multiples, Notation

Table 1-1: Fundamental SI units.

Dimension	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol

Table 1-2: Multiple and submultiple prefixes.

Prefix	Symbol	Magnitude
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

As a general rule, we shall use:

- A lowercase letter, such as i for current, to represent the general case:

  i *may or may not be time varying*

- A lowercase letter followed with (t) to emphasize time:

  $i(t)$ *is a time-varying quantity*

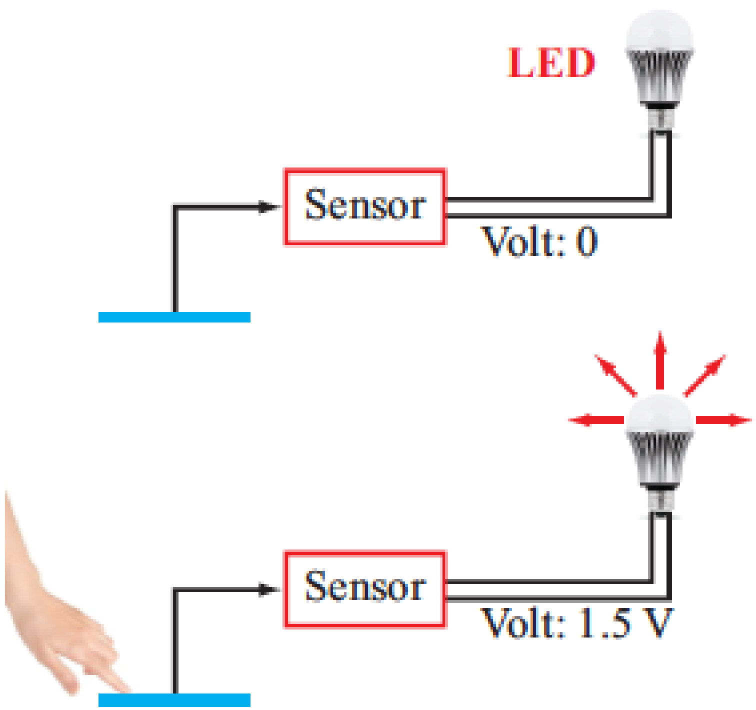
- An uppercase letter if the quantity is not time varying; thus:

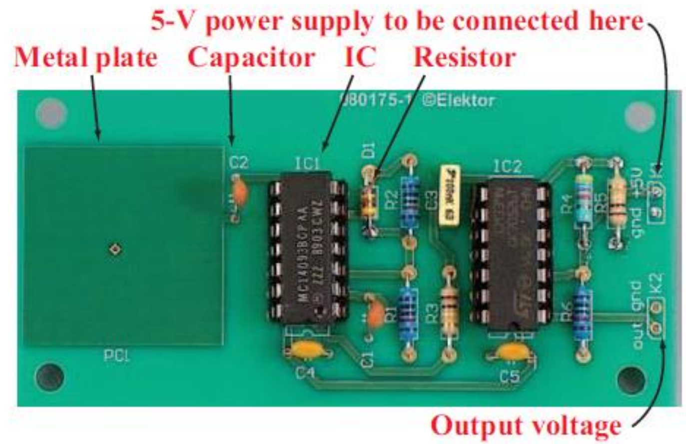
  I *is of constant value (dc quantity)*

- A letter printed in boldface to denote that:

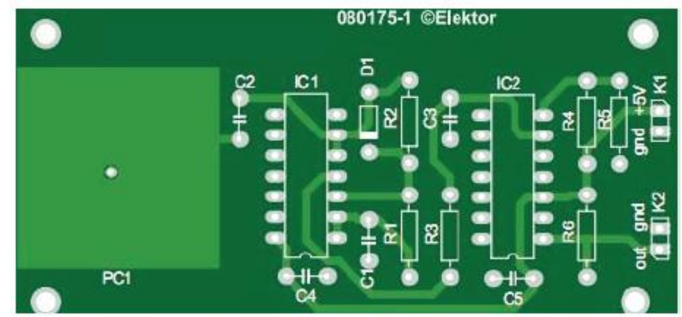
  $\mathbf{I}$ *has a specific meaning, such as a vector, a matrix, the phasor counterpart of* $i(t)$*, or the Laplace or Fourier transform of* $i(t)$

Circuit Representation

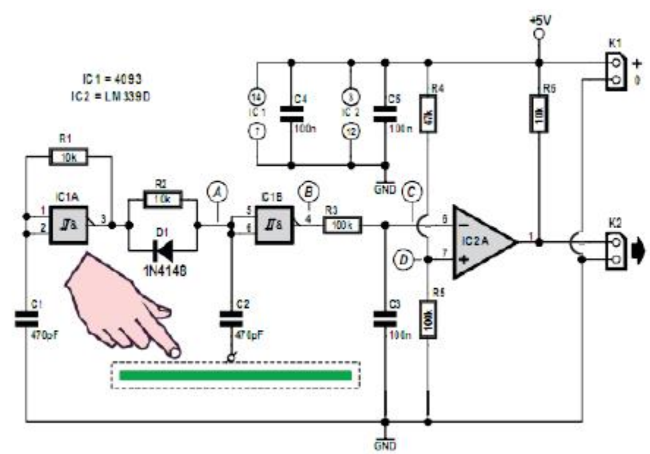




(a) Actual circuit

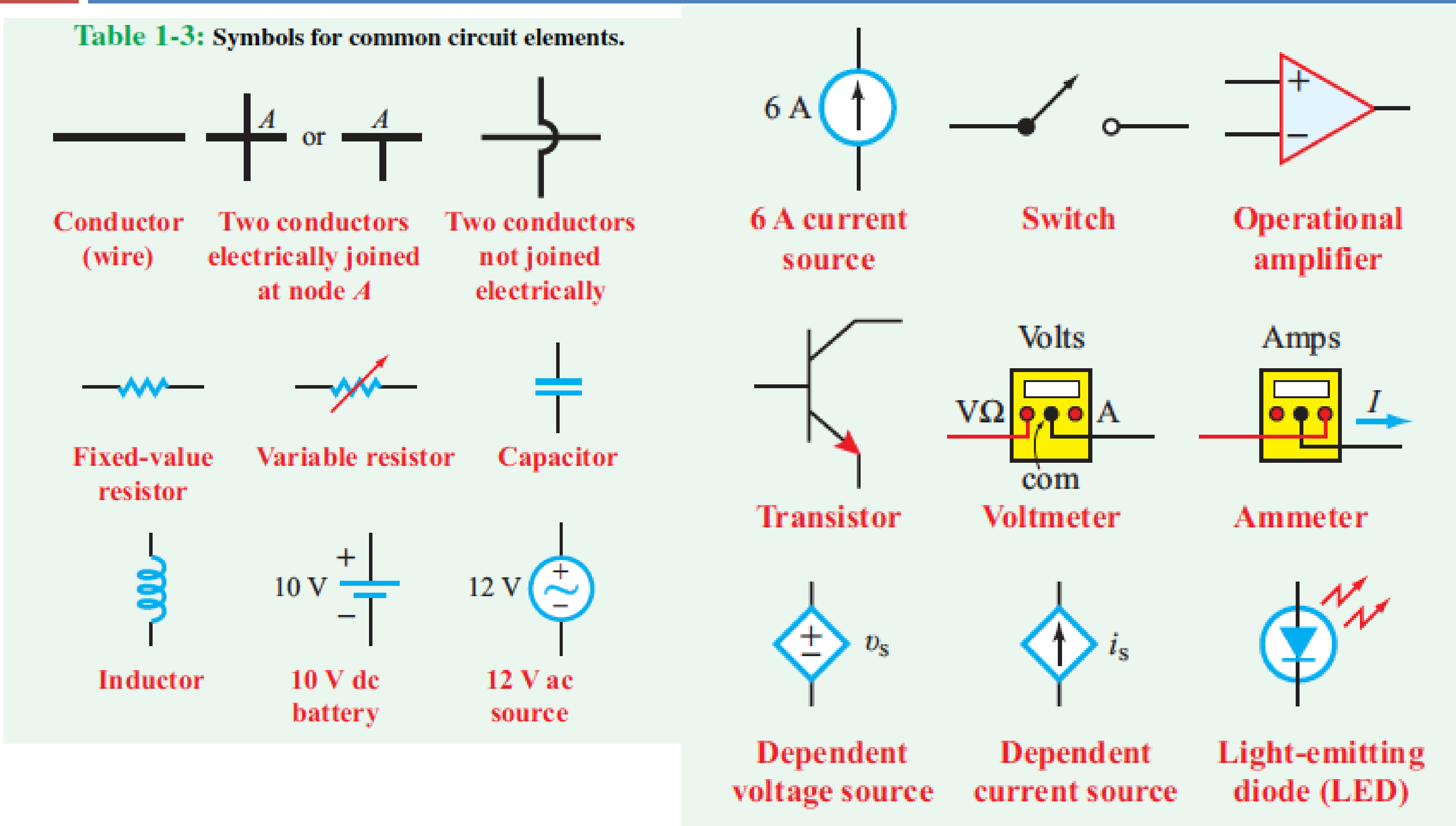


(b) PC board



(c) Circuit diagram

Common Circuit Elements

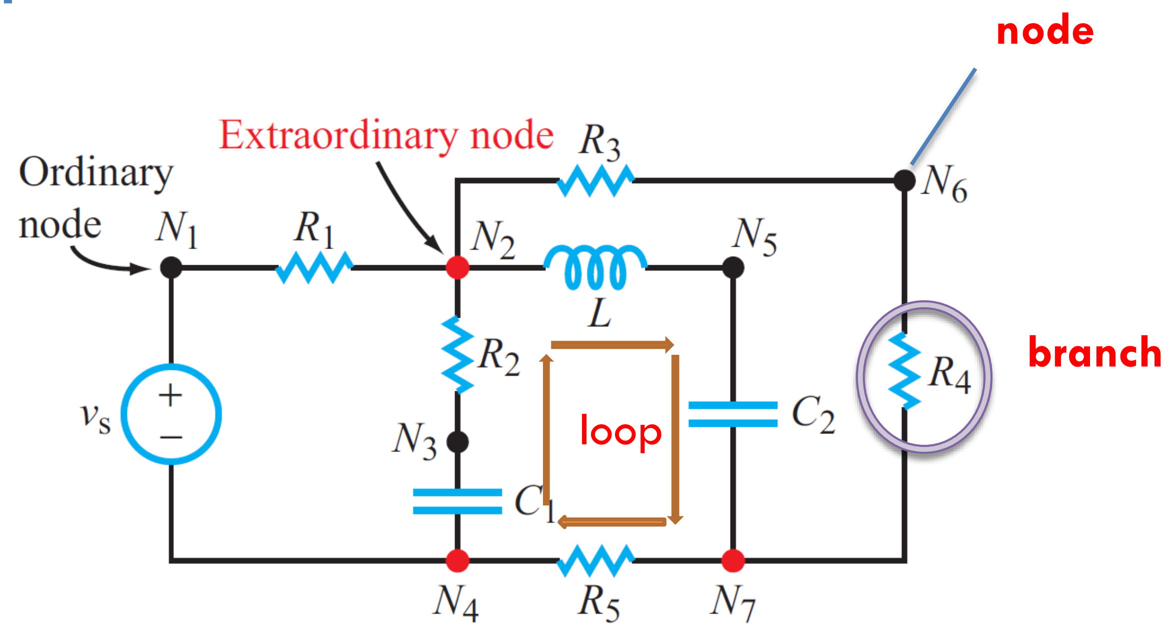


Circuit Topology

Branch: single element, such as a resistor or source

Node: connection point between two or more branches
Extraordinary Node: connection point between at least 3 branches

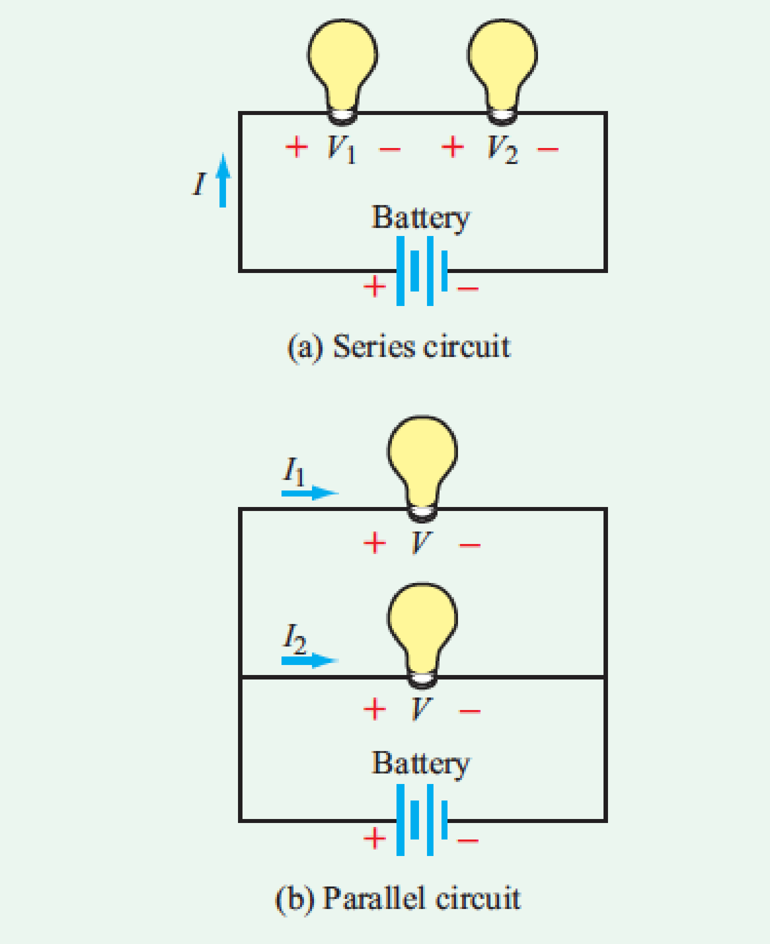
Loop: closed path in a circuit



Series and Parallel Connections

In-Series: Same current

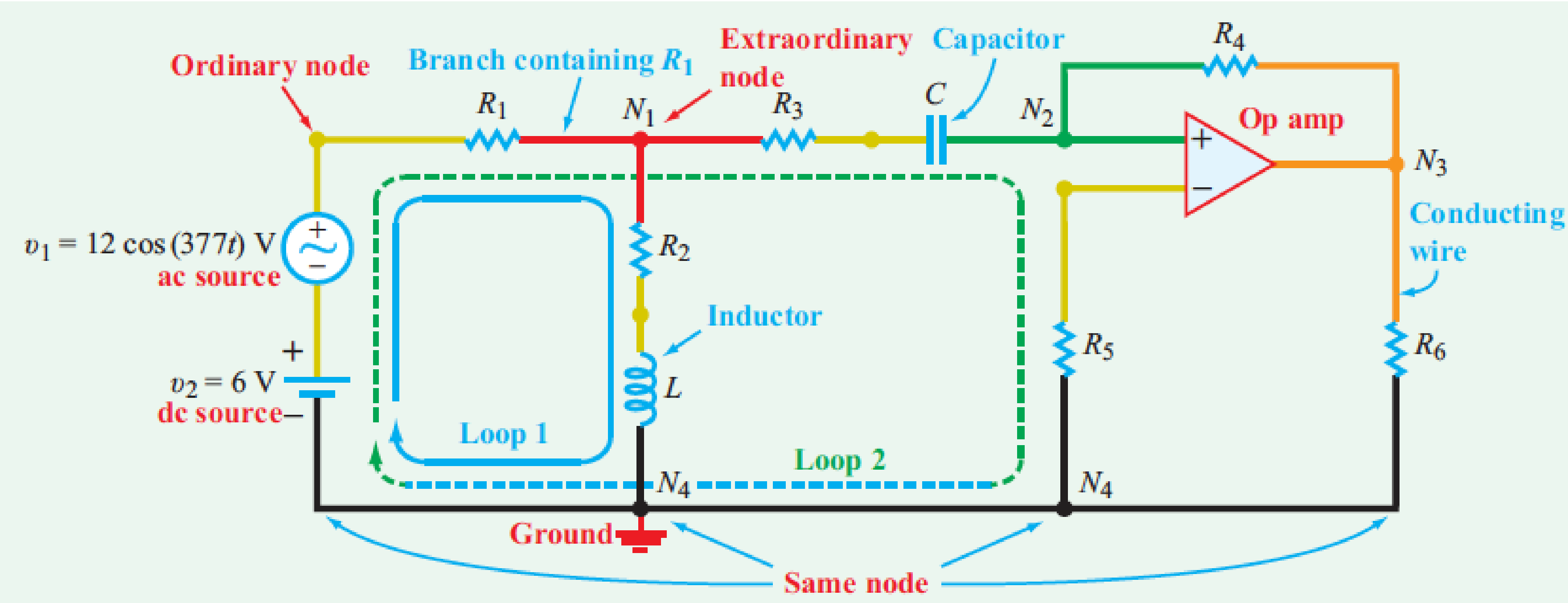
In-Parallel: Same voltage



(a) Series circuit

(b) Parallel circuit

Terminology



Ordinary node: An electrical connection point that connects to only two elements.

Extraordinary node: An electrical connection point that connects to three or more elements.

Branch: Trace between two consecutive nodes with only one element between them.

Path: Continuous sequence of branches with no node encountered more than once.

Extraordinary path: Path between two adjacent extraordinary nodes.

Loop: Closed path with the same start and end node.

Independent loop: Loop containing one or more branches not contained in any other independent loop.

Mesh: Loop that encloses no other loops.

In-series: Elements that share the same current.

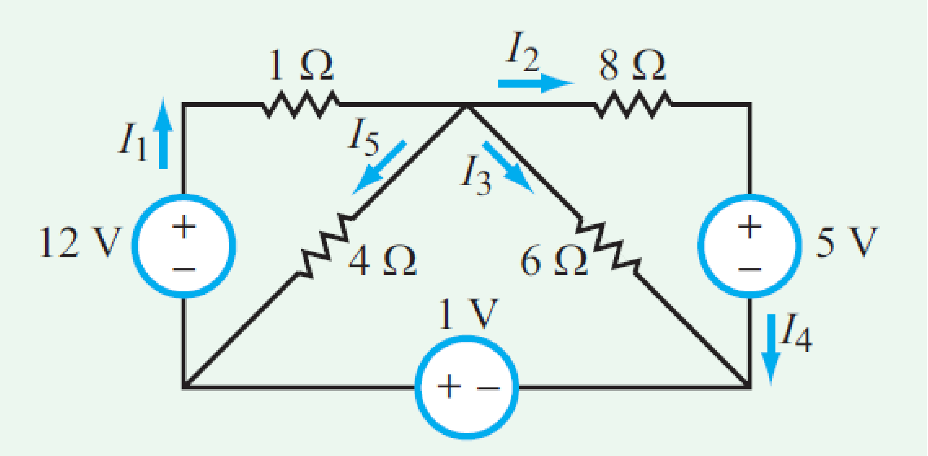
In-parallel: Elements that share the same voltage.

Example 1-1

- For this circuit,

  (1) Which current is the same as I_2?

  (2) Under what circumstance would $I_1 = I_2$?



Example 1-1 (solution)

- Two currents are the same if they flow in the same branch and in the same direction. So,

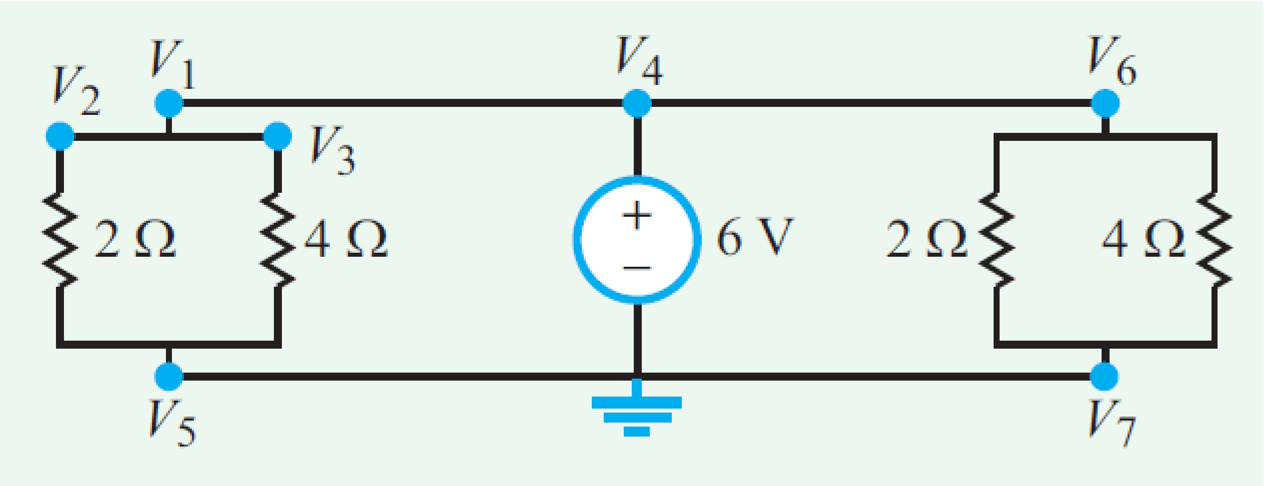
(1) $I_2 = I_4$.

(2) $I_1 = I_2$ only if $I_3 = I_5 = 0$.

Example 1-2

- For this circuit,
  (1) Which node voltages are at the same voltage as node 4?

  (2) Which node voltages are the same as the ground voltage?



Example 1-2 (solution)

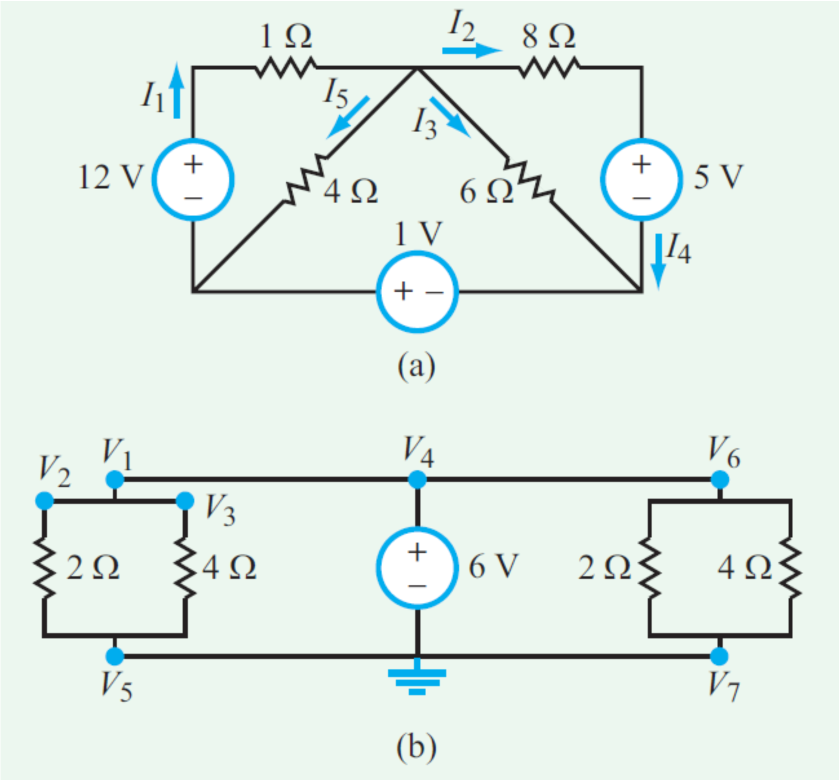
- Two nodes are electrically the same if the only connection between them is a short circuit. So,

(1) $V_1 = V_2 = V_3 = V_4 = V_6$, relative to the ground node. Hence, all five nodes are electrically the same.

(2) Nodes V_5 and V_7 are the same as the ground node.

Example 1-3

- Which elements, or combinations of elements, in the circuits are connected in series and which are connected in parallel?



Example 1-3 (solution)

- For circuit (a),

In series: 8 Ω resistor and 5 V voltage source (call it combination 1).

In series: 1 Ω resistor and 12 V voltage source (call it combination 2).

In parallel: 6 Ω resistor and combination 1. (Call this combination 3.)

In parallel: 4 Ω resistor and combination 2. (Call this combination 4.)

Also, combination 3, combination 4, and the 1 V source are all in series.

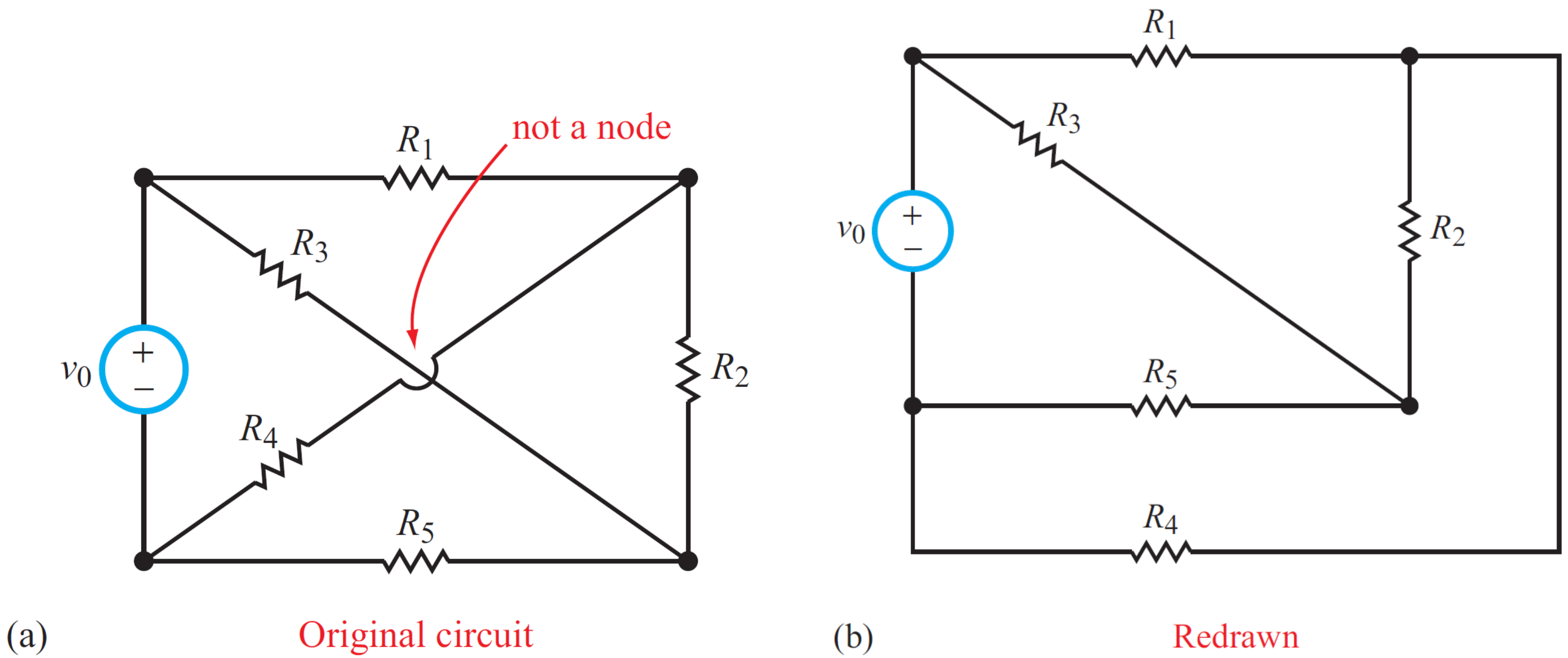
- For circuit (b),

In series: none.

In parallel: all five elements.

Planar Circuits

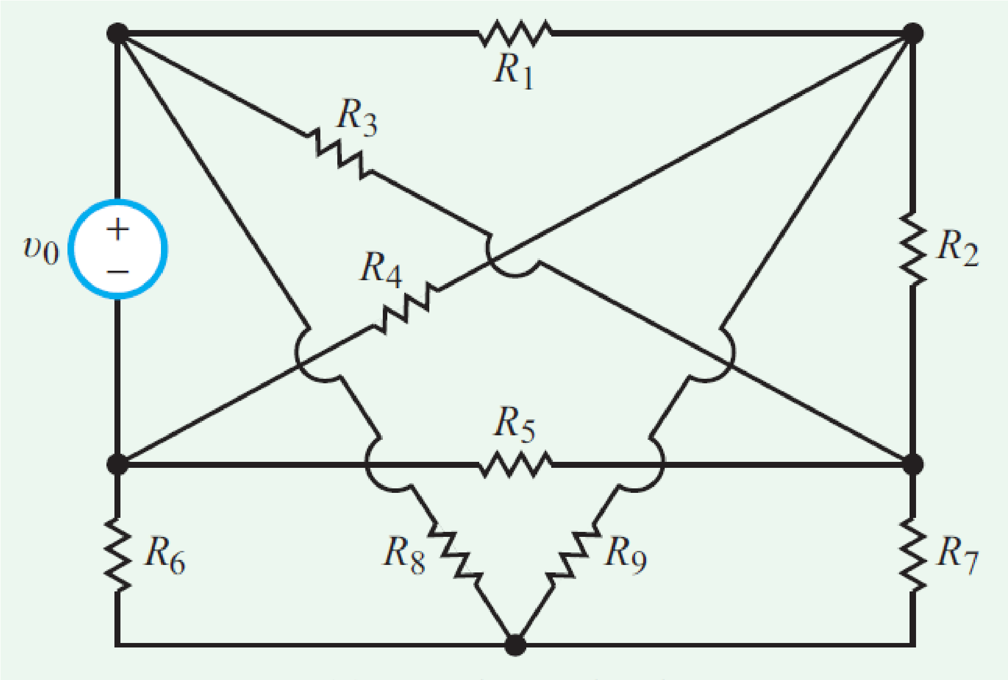
- **Planar circuits**: can be drawn in 2-D without branches crossing each other
- Whenever possible, re-draw circuit to simplify!



Non-planar circuits

- This circuit is non-planar because no matter how to redraw, it will always include at least one crossover of branches.

(try it yourself!)



Charge

- Unit of charge = coulomb (C)
- Symbol used to represent charge is q
- Proton is e, electron is – e.
- Charge implies "net charge" = sum of all protons – sum of all electrons
- Charge is always an integral multiple of e.

$$e = 1.6 \times 10^{-19} \qquad \text{(C)}$$

1. Charge can be either positive or negative.
2. The fundamental (smallest) quantity of charge is that of a single electron or proton. Its magnitude usually is denoted by the letter e.
3. According to the law of conservation of charge, the (net) charge in a closed region can neither be created nor destroyed.
4. Two like charges repel one another, whereas two charges of opposite polarity attract.

Current

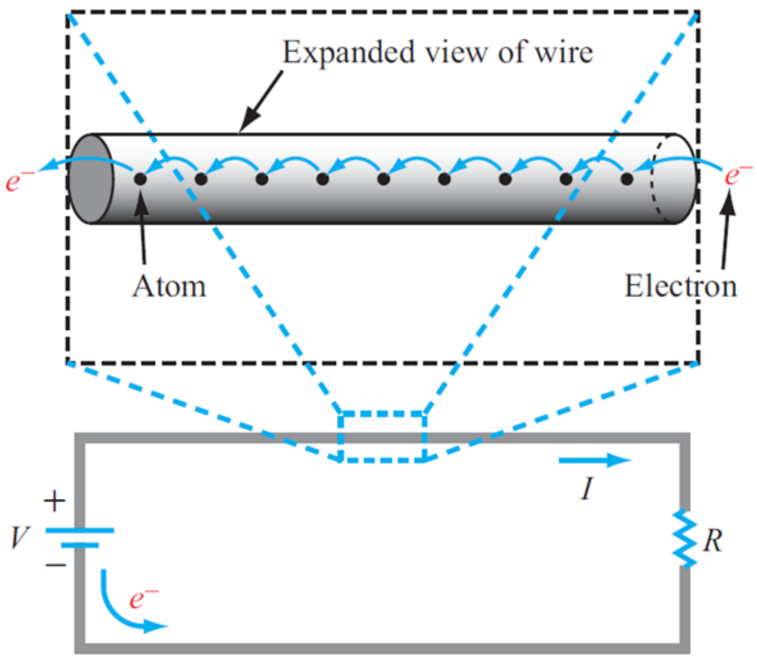
- Movement of charge, creates electric current.
- Governed by Ohm's law.

▶ ***Electric current*** is defined as the time rate of transfer of electric charge across a specified cross section. ◀

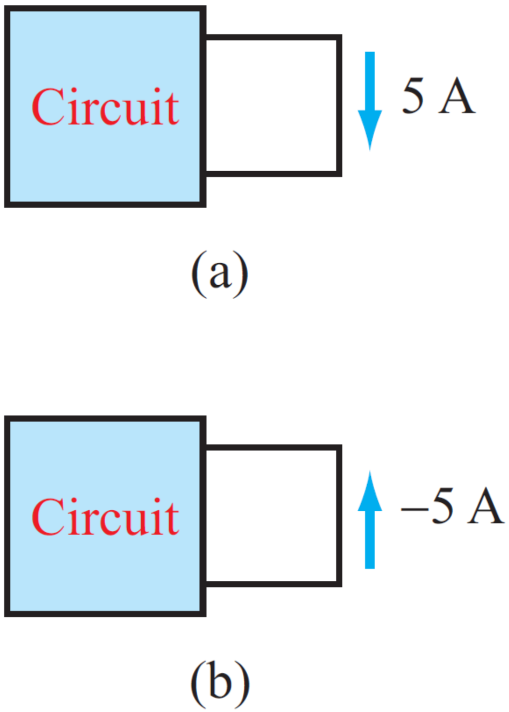
$$i = \frac{dq}{dt} \qquad \text{(A)},$$

▶ The direction of electric current I is defined to be the same as the direction of flow that positive charges would follow, which is opposite to the direction of flow of electrons e^-. ◀

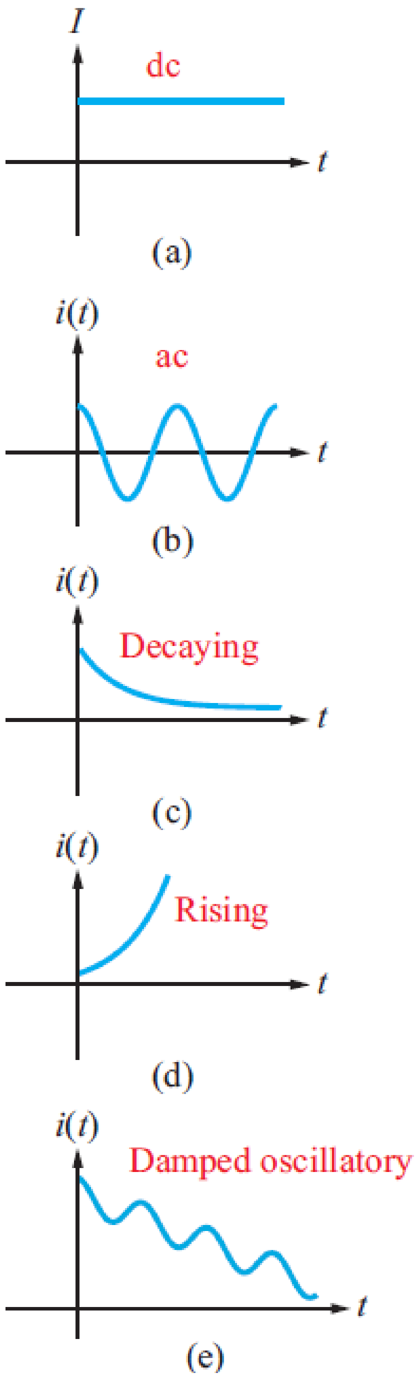
▶ The current flows from the positive (+) terminal of the battery to its negative (−) terminal, along the path ***external*** to the battery. ◀



Current



Circuit
5 A
(a)
Circuit
–5 A
(b)

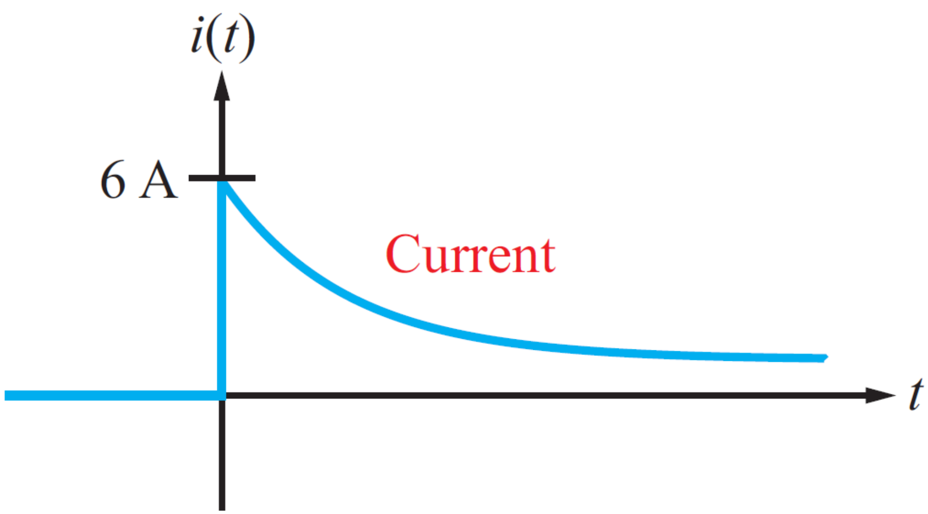


I
dc
t
(a)
i(t)
ac
t
(b)
i(t)
Decaying
t
(c)
i(t)
Rising
t
(d)
i(t)
Damped oscillatory
t
(e)

Example 1-4: Charge Transfer

- **Given:**

$$i(t) = \begin{cases} 0 & \text{for } t < 0, \\ 6e^{-0.2t} \text{ A} & \text{for } t \geq 0. \end{cases}$$



Determine: (a) $q(t)$

(b) $\Delta Q(1, 2)$

Solution:

$$dq = i \, dt$$

$$\int_{-\infty}^{t} dq = \int_{-\infty}^{t} i \, dt$$

$$q(t) - q(-\infty) = \int_{-\infty}^{t} i \, dt$$

$$q(t) = \int_{-\infty}^{t} i \, dt \qquad \text{(C)}.$$

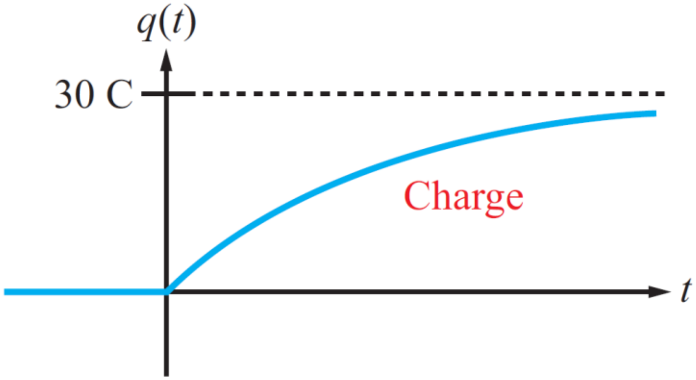
Example 1-4: Charge Transfer (cont.)

$$q(t) = \int_0^t 6e^{-0.2t}\,dt = \frac{-6}{0.2}\,e^{-0.2t}\Big|_0^t = 30[1 - e^{-0.2t}]\ \text{C}.$$

(b)

$$\Delta Q(t_1, t_2) = q(t_2) - q(t_1)$$

$$= \int_{-\infty}^{t_2} i\,dt - \int_{-\infty}^{t_1} i\,dt = \int_{t_1}^{t_2} i\,dt.$$



For $t_1 = 1$ s, $t_2 = 2$ s, and $i(t)$ as given by Eq. (1.4),

$$\Delta Q(1,2) = \int_1^2 6e^{-0.2t}\,dt = \frac{6e^{-0.2t}}{-0.2}\Big|_1^2$$

$$= -30(e^{-0.4} - e^{-0.2}) = 4.45\ \text{C}.$$

Example 1-5

The charge flowing past a certain location in a wire is given by

$$q(t) = \begin{cases} 0 & \text{for } t < 0, \\ 5te^{-0.1t} \ \text{C} & \text{for } t \geq 0. \end{cases}$$

Determine (a) the current at $t = 0$ and (b) the instant at which $q(t)$ is a maximum and the corresponding value of q.

Example 1-5 (solution)

(a)

$$i = \frac{dq}{dt} = \frac{d}{dt}(5te^{-0.1t}) = 5e^{-0.1t} - 0.5te^{-0.1t}$$
$$= (5 - 0.5t)e^{-0.1t} \text{ A.}$$

Setting $t = 0$ in the expression gives $i(0) = 5$ A.
Note that $i \neq 0$, even though $q(t) = 0$ at $t = 0$.

(b)

$$\frac{dq}{dt} = (5 - 0.5t)e^{-0.1t} = 0,$$

which is satisfied when

$$5 - 0.5t = 0 \qquad \text{or} \qquad t = 10 \text{ s},$$

as well as when

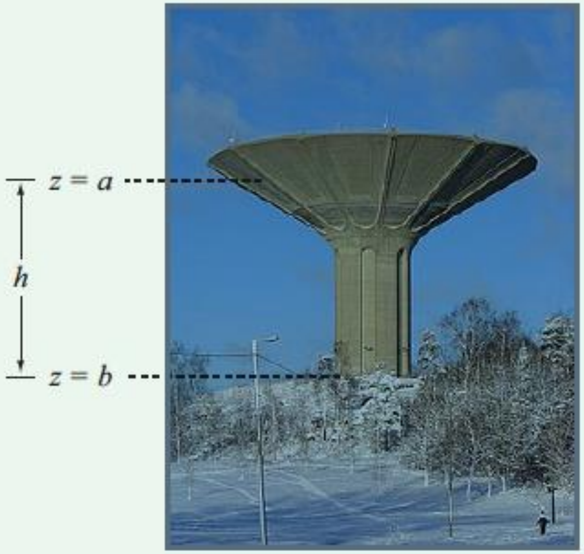
$$e^{-0.1t} = 0 \qquad \text{or} \qquad t = \infty.$$

The first value ($t = 10$ s) corresponds to a maximum and the second value ($t = \infty$) corresponds to a minimum (which can be verified either by graphing $q(t)$ or by taking the second derivative of $q(t)$ and evaluating it at $t = 10$ s and at $t = \infty$).

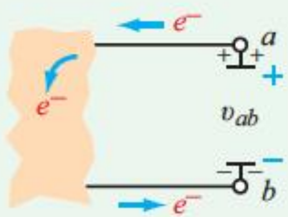
At $t = 10$ s,

$$q(10) = 5 \times 10e^{-0.1 \times 10} = 50e^{-1} = 18.4 \text{ C.}$$

Voltage & Power



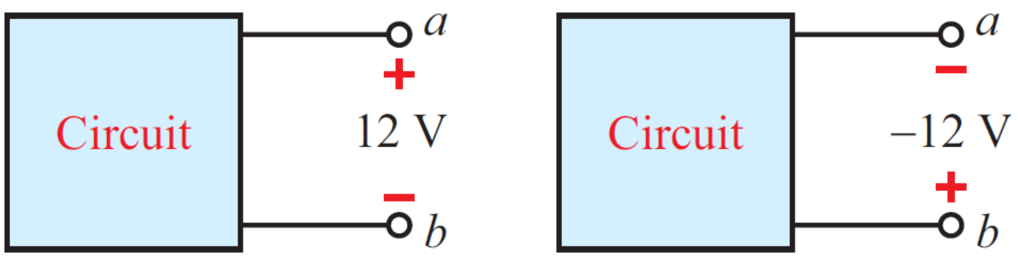
(a) Raising water from ground level at *b* to height *a*



(b) Moving charge from *a* to *b*

Figure 1-15: Moving charge *dq* through the material in (b) is analogous to raising mass *dm* in (a).

$$v_{ab} = \frac{dw}{dq}$$



$$V_{ab} = -V_{ba}$$

The voltage between location ***a*** and location ***b*** is the ratio of ***dw*** to ***dq***, where ***dw*** is the energy in joules (J) required to move (positive) charge ***dq*** from ***b*** to ***a*** (or negative charge from *a* to *b*).

Reference/Ground

- Choose reference point for potential
- Assign potential at reference = 0, called ground
- Now all potentials are relative to ground terminal

Example 1-6

- In (a), node 4 was selected as the ground node.
- Supposed node 1 is now selected as the ground node, as shown in (b), use information in (a) to determine node voltages V2to V4 when defined relative to V1 at node 1.

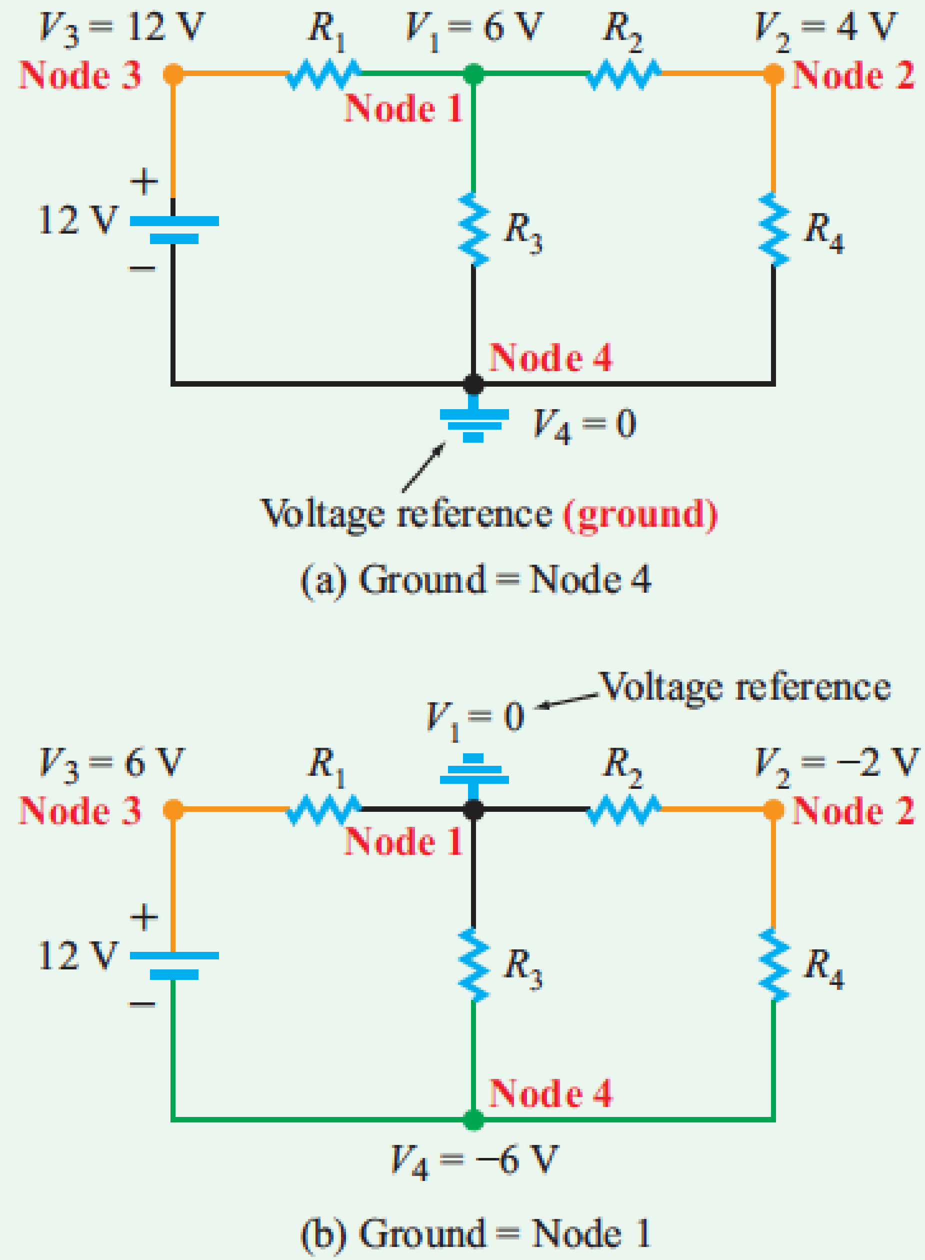


Figure 1-17: Ground is any point in the circuit selected to serve as a reference point for all points in the circuit.

Example 1-6 (solution)

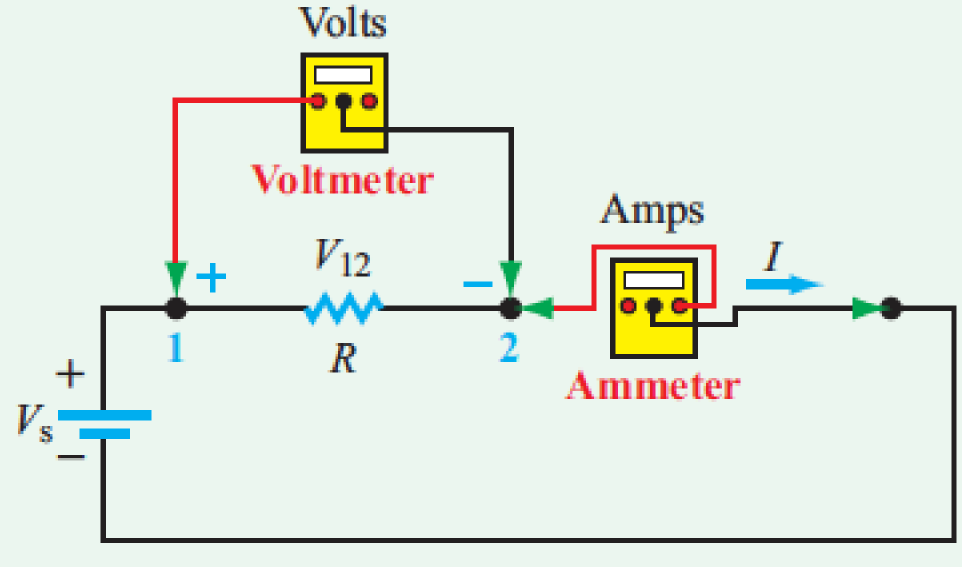
Solution: In the circuit of **Fig. 1-17(a)**, V_2 is 2 V lower in level than V_1 (4 V compared to 6 V). Hence, in the new configuration in **Fig. 1-17(b)**, V_2 will still be 2 V lower than V_1, and since $V_1 = 0$, it follows that $V_2 = -2$ V. Similarly, $V_3 = 6$ V and $V_4 = -6$ V.

To summarize:

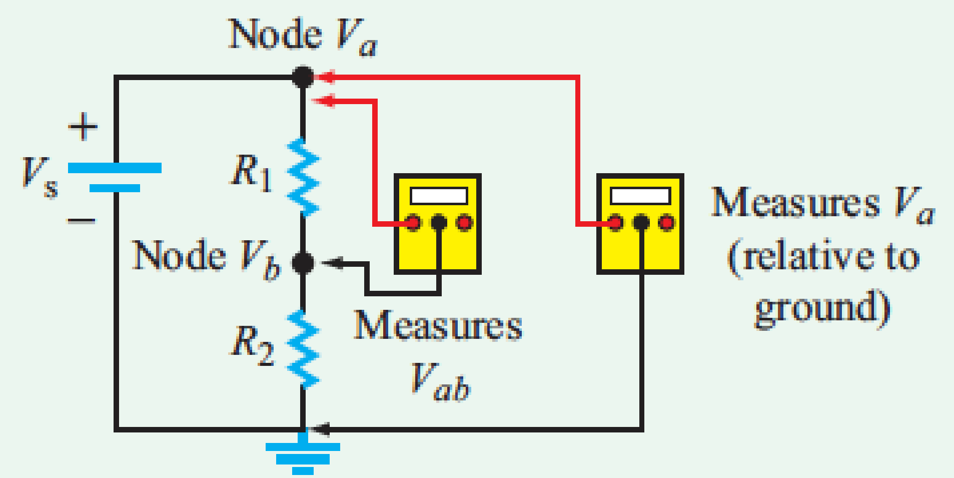
	node 4 = ground	node 1 = ground
$V_1 =$	6 V	0
$V_2 =$	4 V	−2 V
$V_3 =$	12 V	6 V
$V_4 =$	0 V	−6 V

Measuring Voltage & Current

- Voltmeter: measures voltage
- without drawing current
- Ammeter: measures current
- without dropping voltage



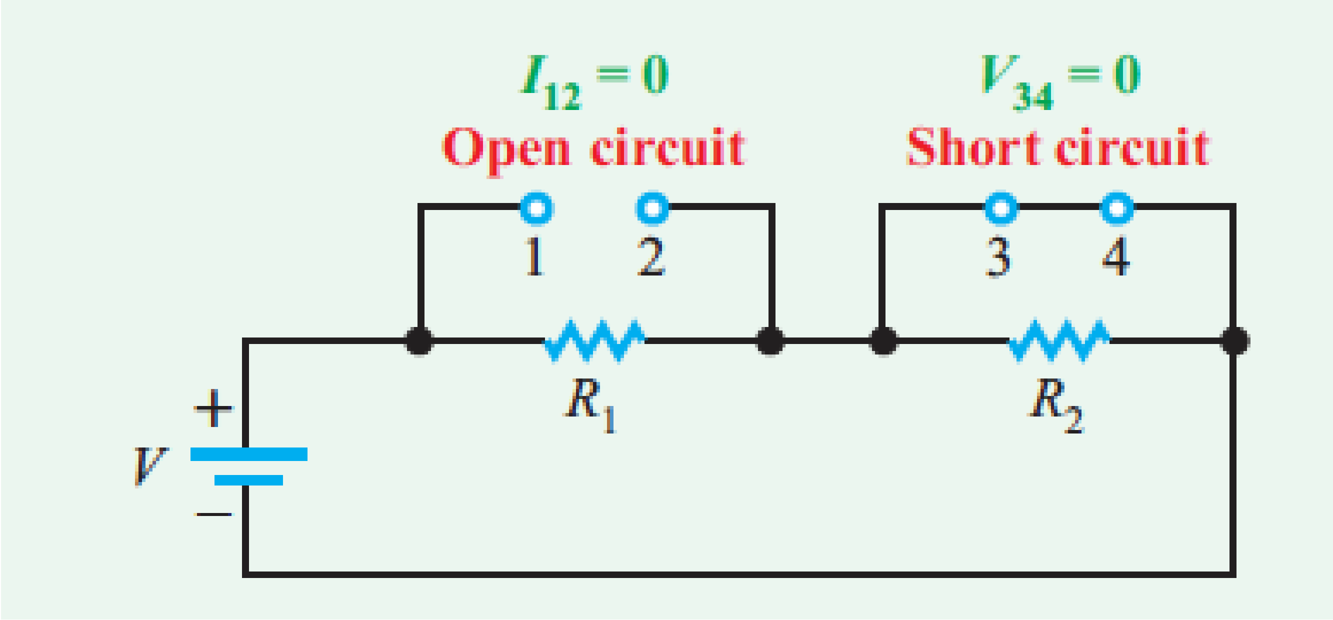
(a) Voltmeter and ammeter connections



(b) Voltmeters connected to measure voltage difference V_{ab} and node voltage V_a (relative to ground)

Open Circuit & Short Circuit

- Open circuit: no path for current flow ($R = \infty$)
- Short circuit: no voltage drop ($R = 0$)



Power

Rate of expending or absorbing energy

$$P = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = vi$$

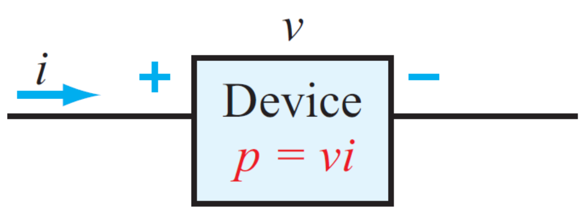
$$\sum P = 0$$ Energy conservation

Units: watts

One watt = power rate of one joule of work per second. 1 W = 1 A x 1 V

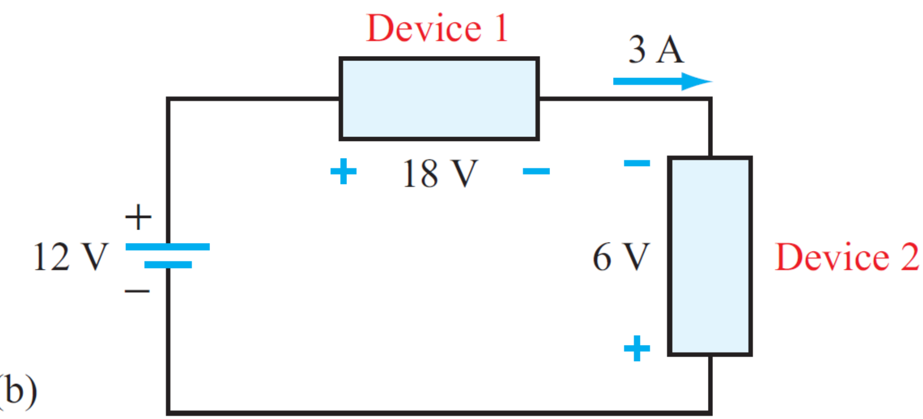
Passive Sign Convention

Passive Sign Convention



$p > 0$ power delivered to device
$p < 0$ power supplied by device

*Note that i direction is defined as entering (+) side of v.



(b)

Device 1: $P_1 = V_1 I_1 = 18 \times 3 = 54$ W,

Device 2: $P_2 = V_2 I_2 = (-6) \times 3 = -18$ W

Battery:

$P_{\text{bat}} = 12(-3) = -36$ W,

Example 1-7: Energy Consumption

- **Given:** Resistor consuming 20 W before switch turned off at $t = 0$.

  Also $$v(t) = 100e^{-2t} \text{ V} \qquad \text{for } t \geq 0$$

- **Determine:** Total energy consumed by resistor after $t = 0$.

- **Solution:** $$I = P/V = 20/100 = 0.2 \text{ A} \qquad \text{(before } t = 0\text{)}$$

$$i(t) = 0.2e^{-2t} \text{ A} \qquad \text{for } t \geq 0.$$

The instantaneous power is

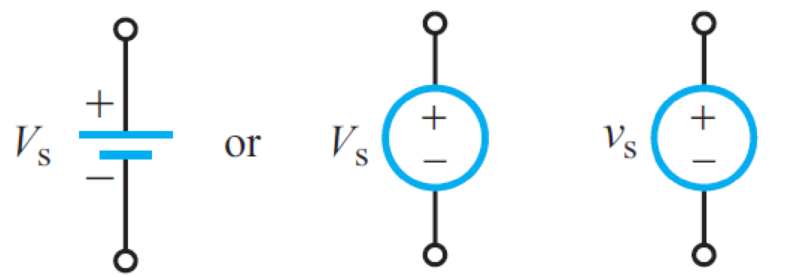
$$p(t) = v(t) \cdot i(t) = (100e^{-2t})(0.2e^{-2t}) = 20e^{-4t} \text{ W}.$$

$$W = \int_0^\infty p(t)\, dt = \int_0^\infty 20e^{-4t}\, dt = -\frac{20}{4} e^{-4t} \Big|_0^\infty = 5 \text{ J}.$$

Circuit Elements: Independent Sources

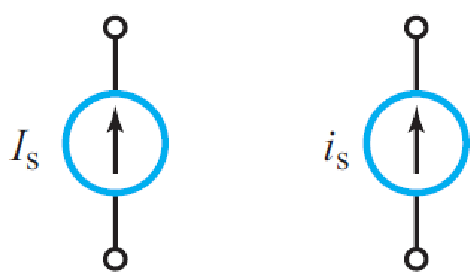
Independent Sources

Ideal Voltage Source



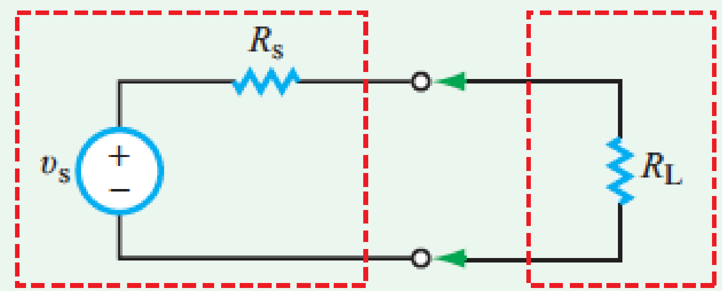
Battery | dc source | Any source*

Ideal Current Source



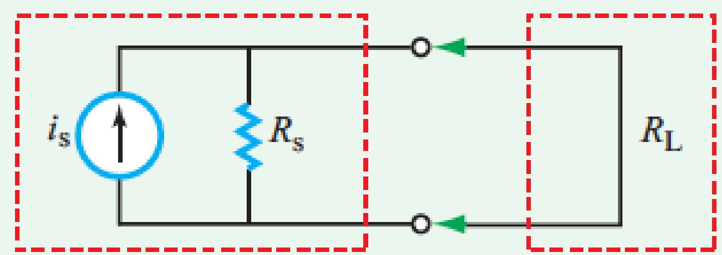
dc source | Any source

Realistic Voltage Source



Realistic voltage source | Load

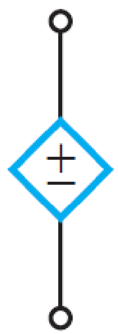
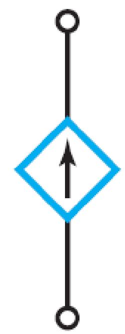
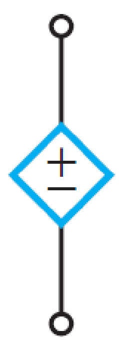
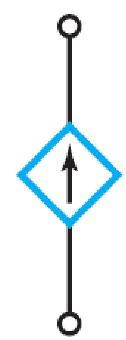
(a) Realistic voltage source connected to load R_L



Realistic current source | Load

(b) Realistic current source connected to load R_L

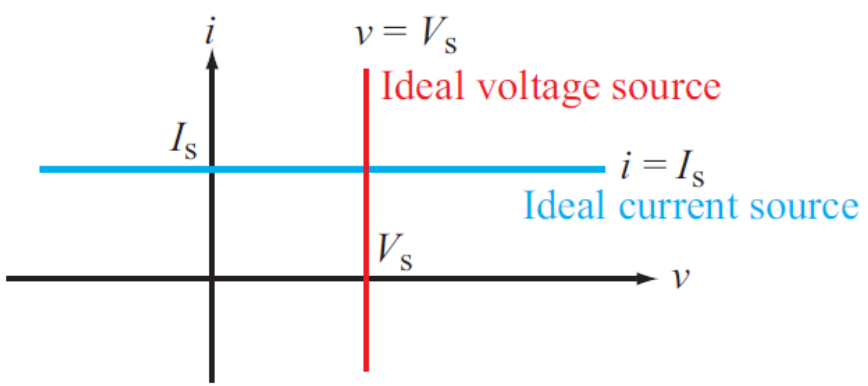
Circuit Elements: Dependent Sources

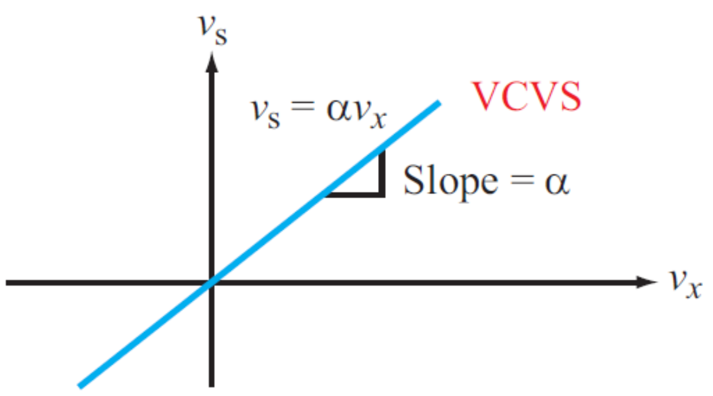
Dependent Sources	
Voltage-Controlled Voltage Source (VCVS)  $v_s = \alpha v_x$	**Voltage-Controlled Current Source (VCCS)**  $i_s = g v_x$
Current-Controlled Voltage Source (CCVS)  $v_s = r i_x$	**Current-Controlled Current Source (CCCS)**  $i_s = \beta i_x$

Note: α, g, r, and β are constants; v_x and i_x are a specific voltage and a specific current elsewhere in the circuit. *Lowercase v and i represent voltage and current sources that may or may not be time varying, whereas uppercase V and I denote dc sources.

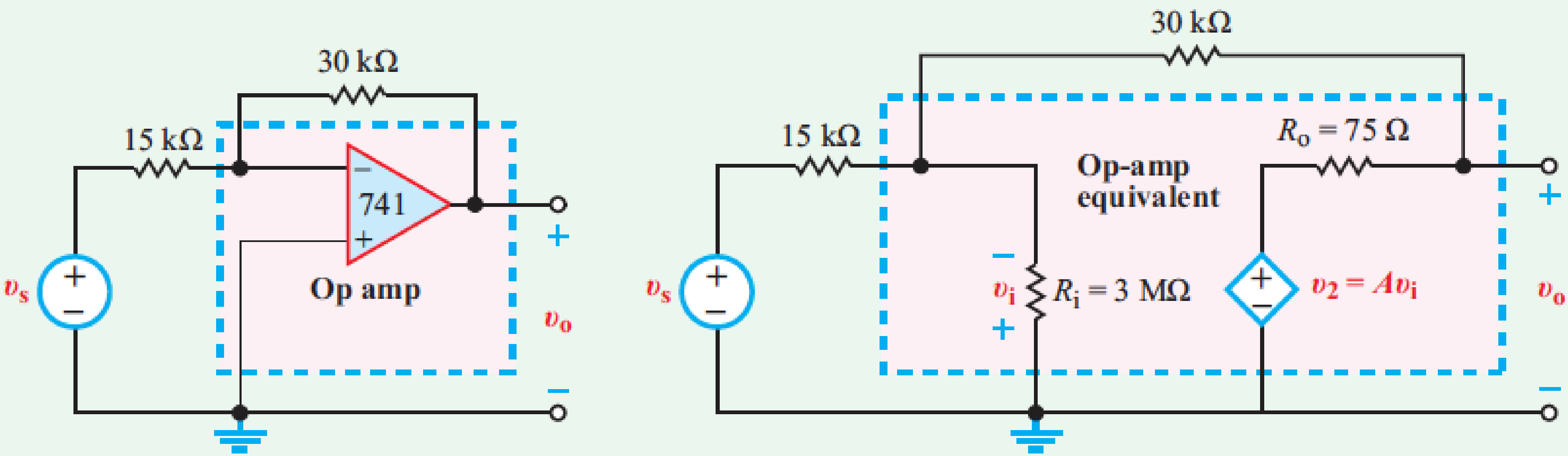
I-V for Sources

- Current/voltage fixed for independent sources
  - What does a non-ideal source look like?
- Dependent sources vary with reference voltage/current
  - What are units for slope?





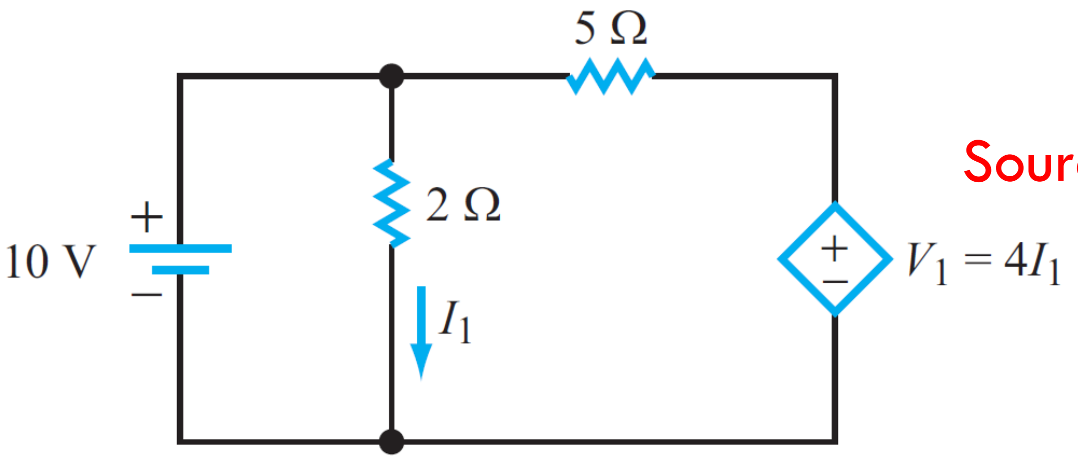
Equivalent Circuit Using Dependent Source



(a) Op-amp circuit (b) Equivalent circuit with dependent voltage source

Example 1-8: Dependent Source

- Given:



Source is CCVS

Determine: V_1

Solution:

$$I_1 = \frac{10}{2} = 5 \text{ A}.$$

Consequently,

$$V_1 = 4I_1 = 4 \times 5 = 20 \text{ V}.$$

Summary

Mathematical and Physical Models

Ohm's law $\quad i = v/R$

Current $\quad i = dq/dt$

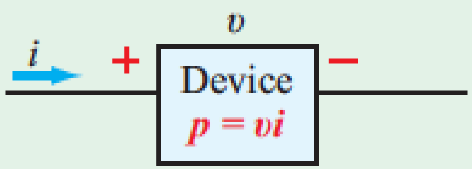
Direction of i = direction of flow of (+) charge

Charge transfer $\quad q(t) = \int_{-\infty}^{t} i \, dt$

$$\Delta Q = q(t_2) - q(t_1) = \int_{t_1}^{t_2} i \, dt$$

Voltage = potential energy difference per unit charge

Passive sign convention



$p > 0$	power delivered to device
$p < 0$	power supplied by device

Note that i direction is defined as entering (+) side of v.

Energy $\quad w = \int_{0}^{\infty} p(t) \, dt$