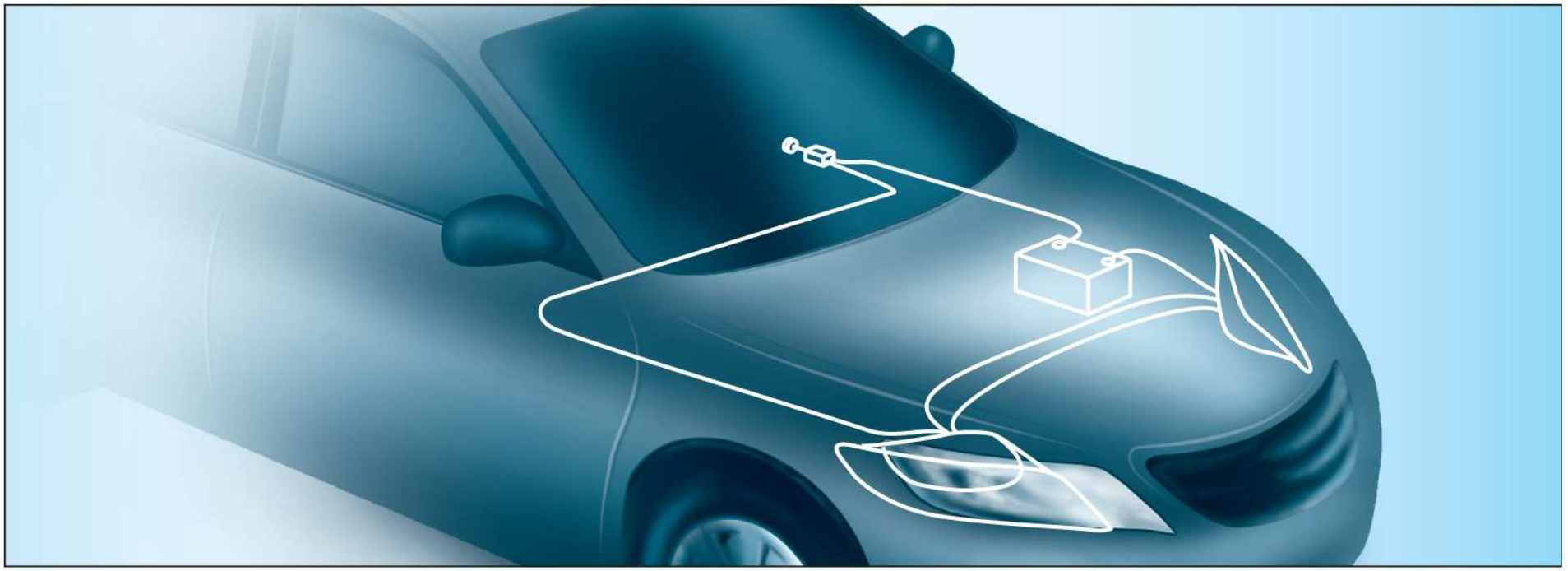
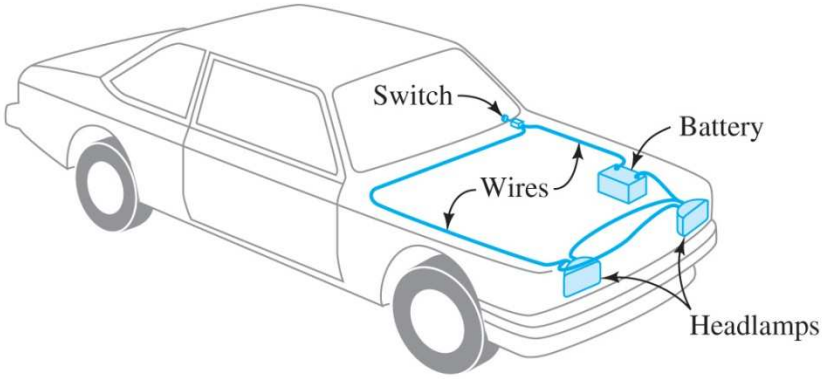


Basic Circuit Components and Theory*

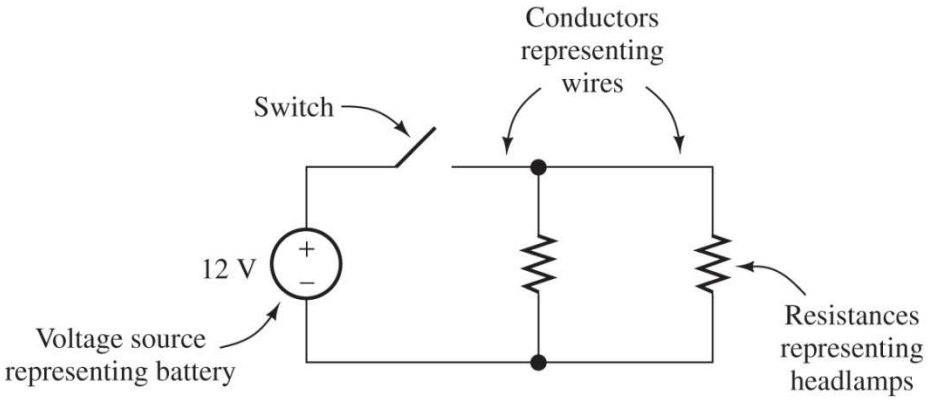
Yuttapong Jiraraksopakun

*Image courtesy: Allan R. Hambley, Electrical Engineering Principles and Applications, 4th Ed., Upper Saddle River, NJ: Pearson Education, Inc., 2008.

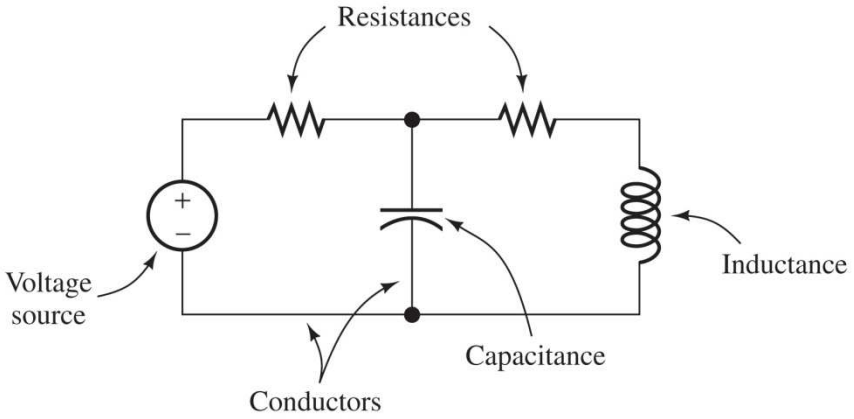
Circuits



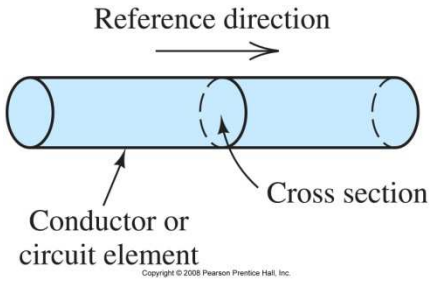
(a) Physical configuration

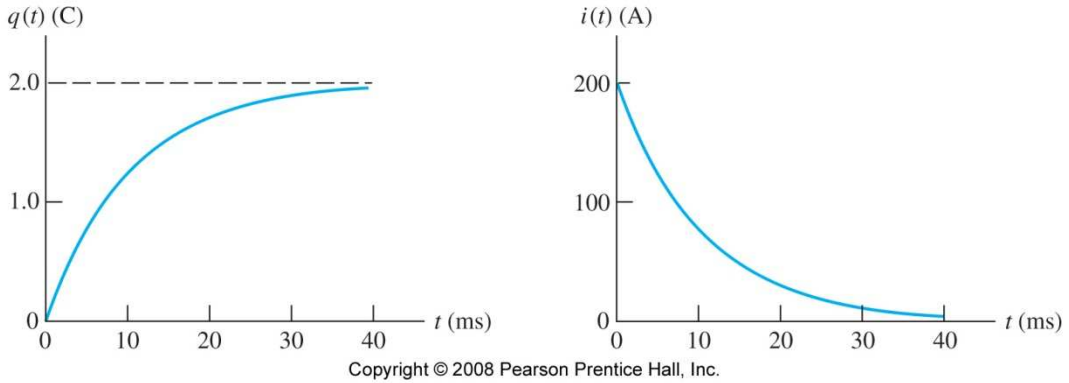


(b) Circuit diagram

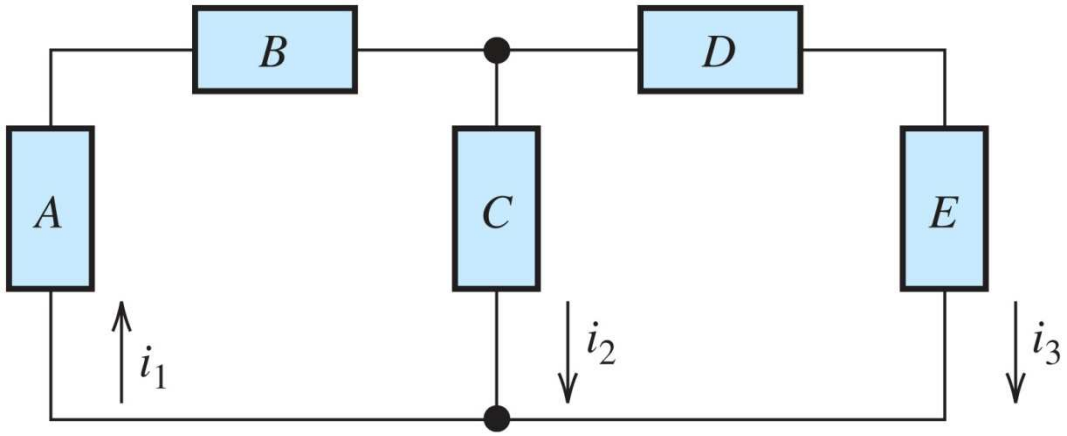


Currents

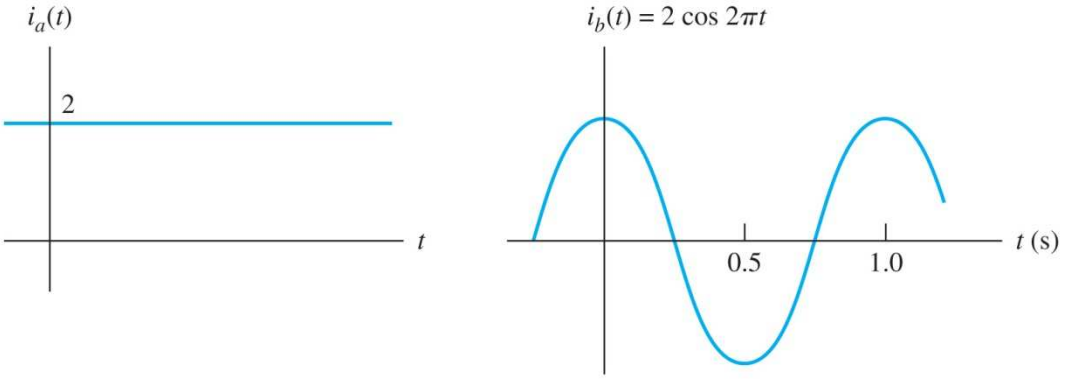




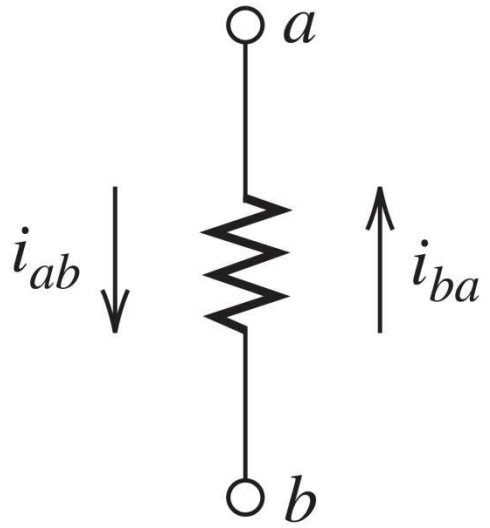
$$i(t) = \frac{dq(t)}{dt} \qquad q(t) = \int_0^t i(t)dt + q(t_0)$$

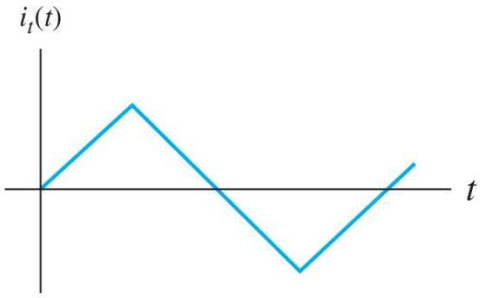


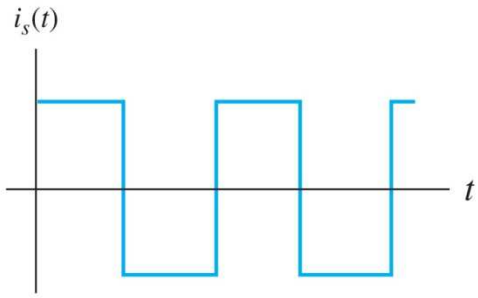
Direct and Alternating Current



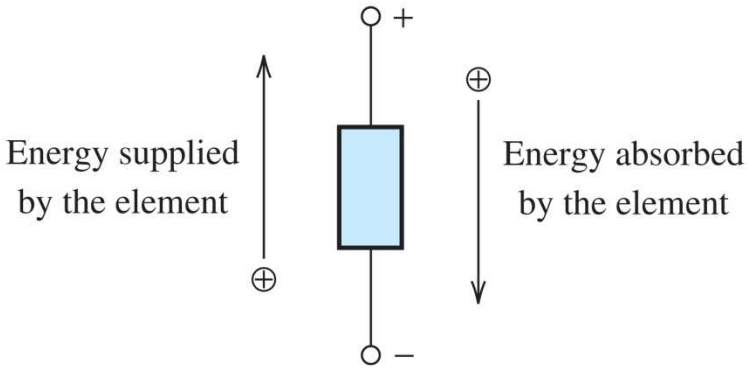
(a) Dc current (b) Ac current



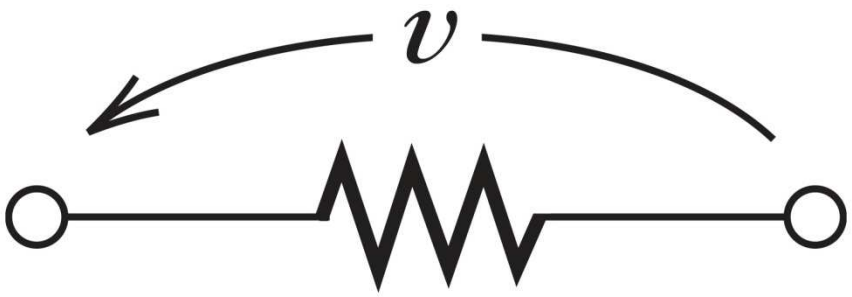


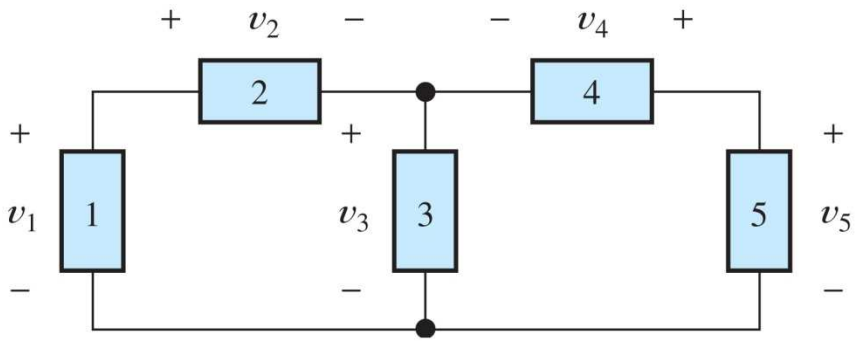


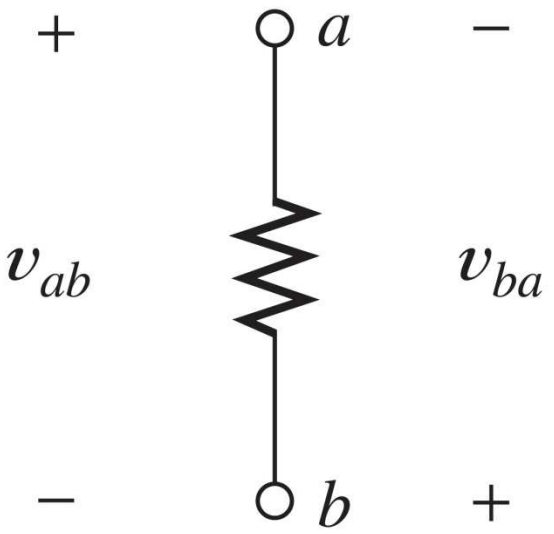
(a) Triangular waveform (b) Square waveform



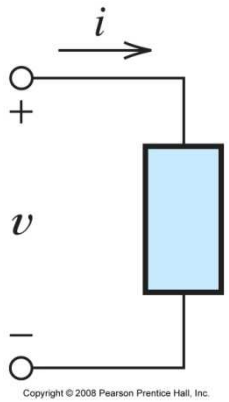
Votages





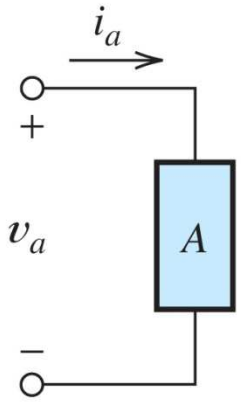


Power and Energy



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

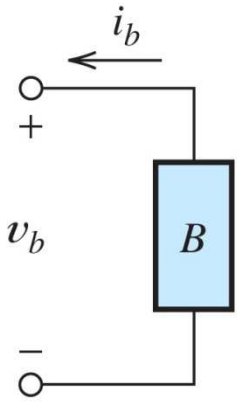
$$w(t) = \int_{t_1}^{t_2} p(t)dt$$



$v_a = 12$ V
$i_a = 2$ A

(a)

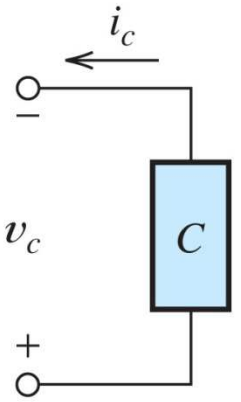
charged



$v_b = 12$ V
$i_b = 1$ A

(b)

discharged



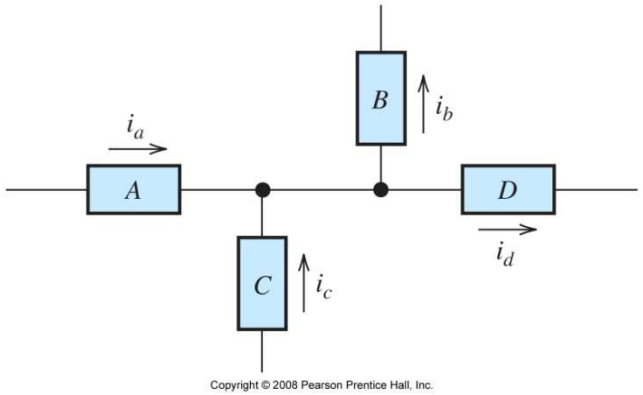
$v_c = 12$ V
$i_c = -3$ A

(c)

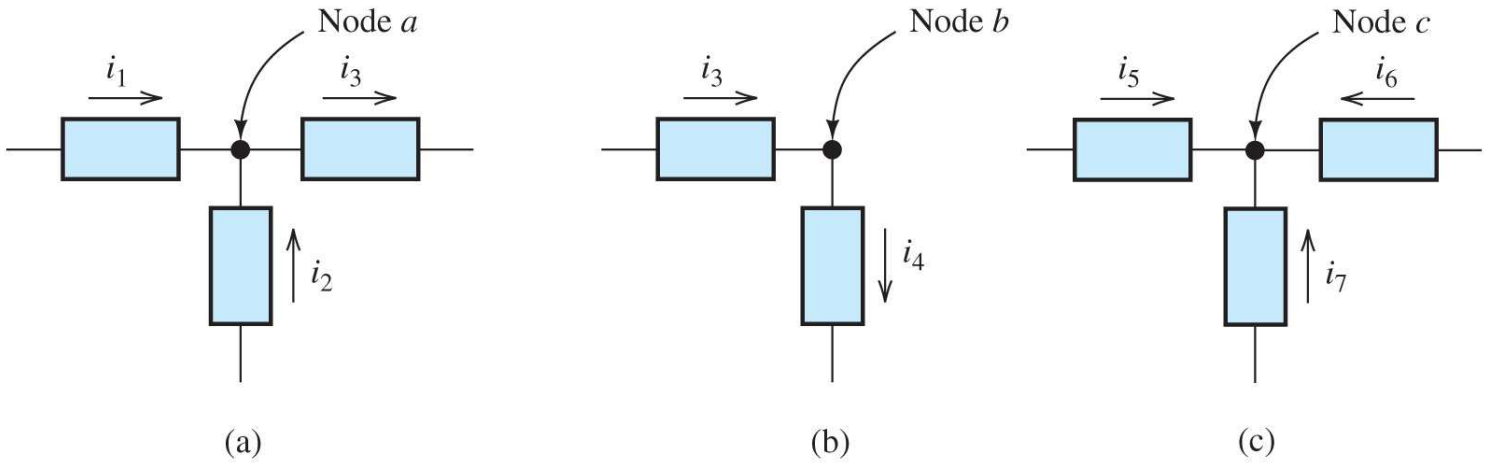
discharged

Kirchhoff's Current Law (KCL)

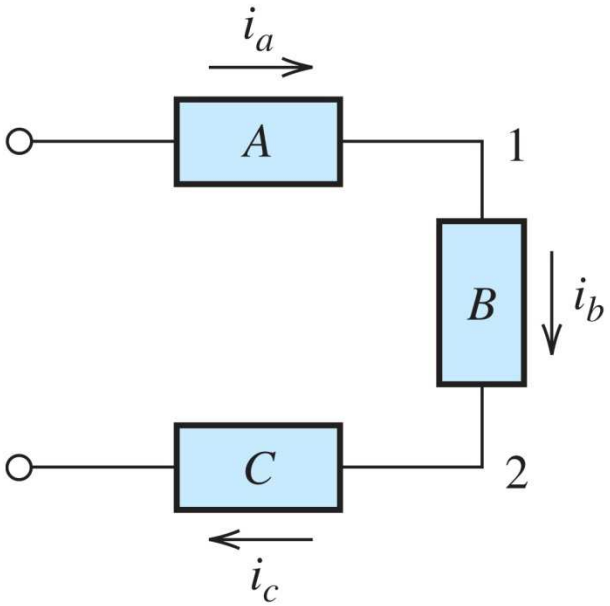
- The net current entering a node is zero



$$i_a + i_c = i_b + i_d$$

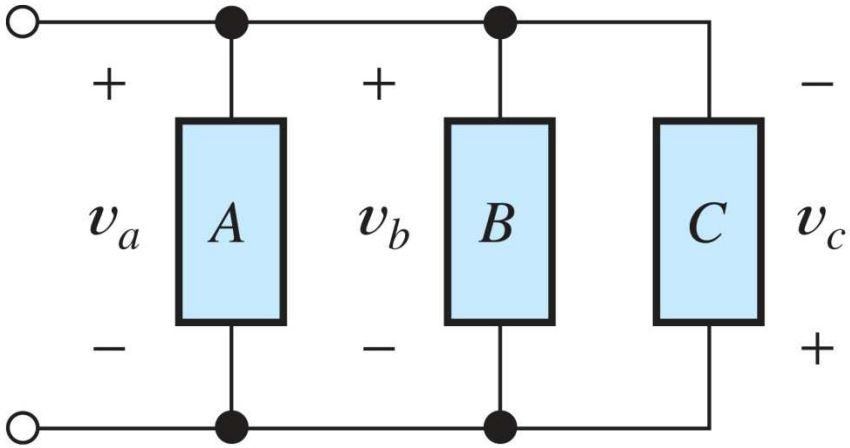


Series/ Parallel Circuits

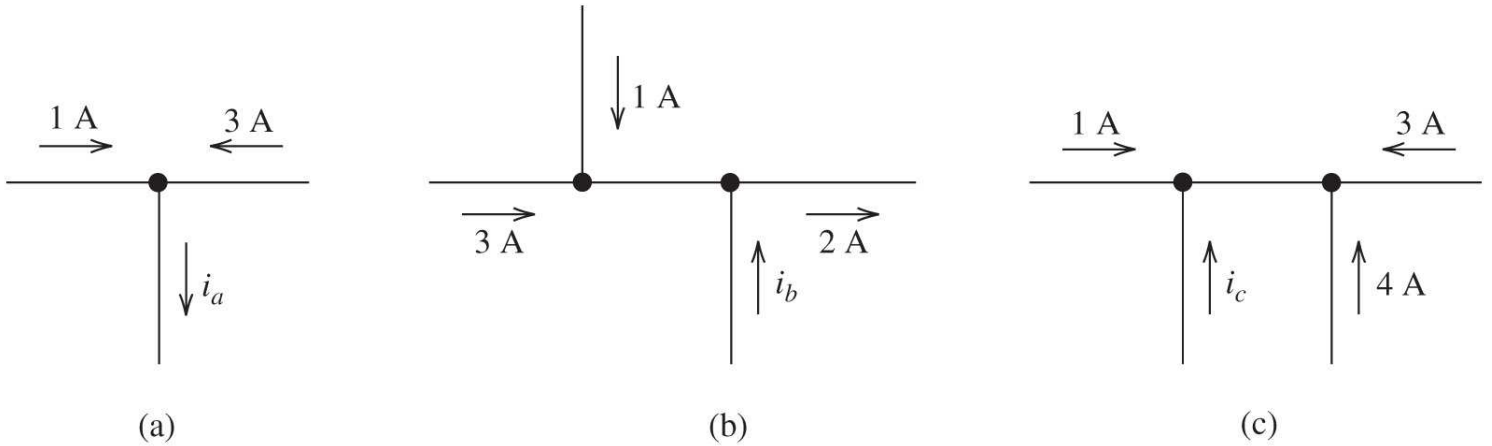


$$i_a = i_b = i_c$$

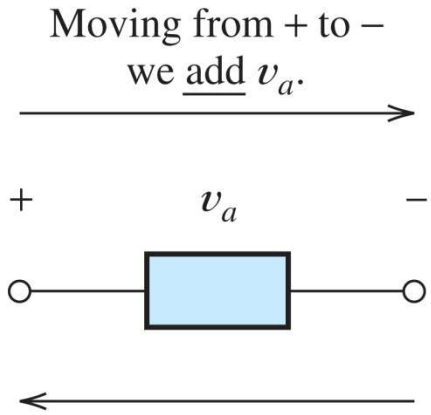
$$v_a = v_b = -v_c$$

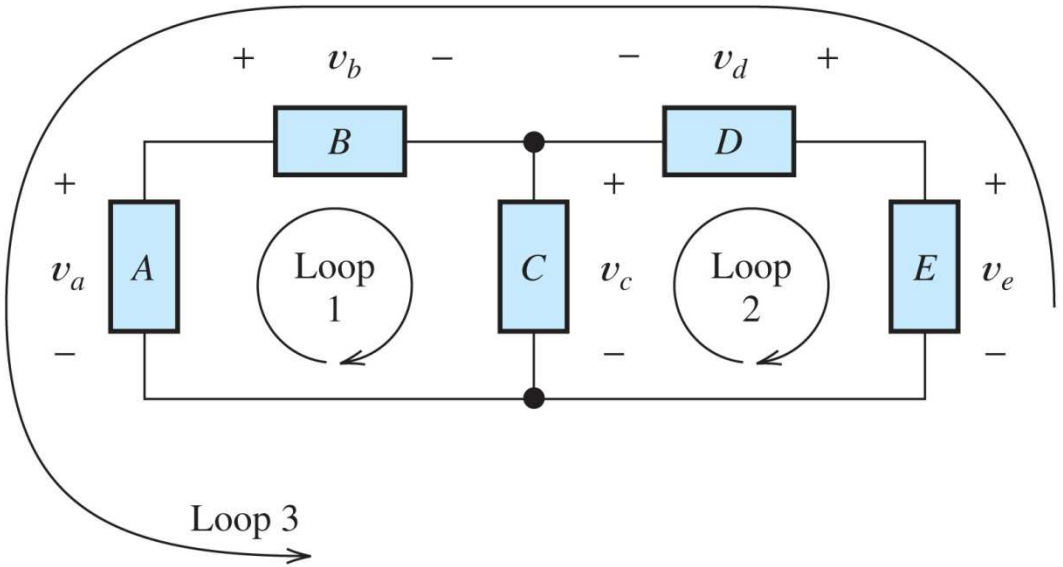


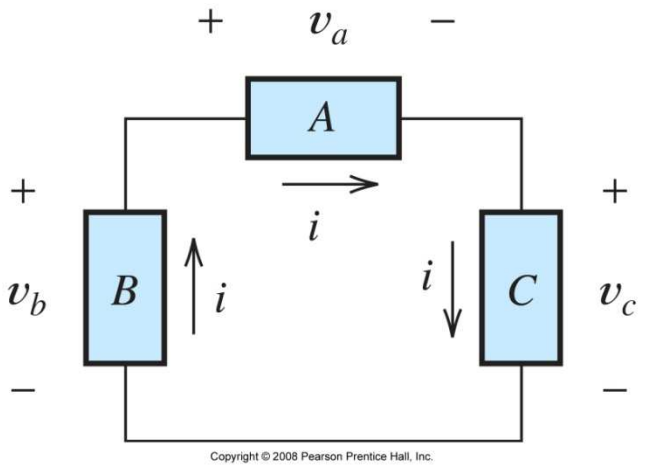
KCL Problems



Kirchhoff's Voltage Law (KVL)







KVL related to Conservation of Energy

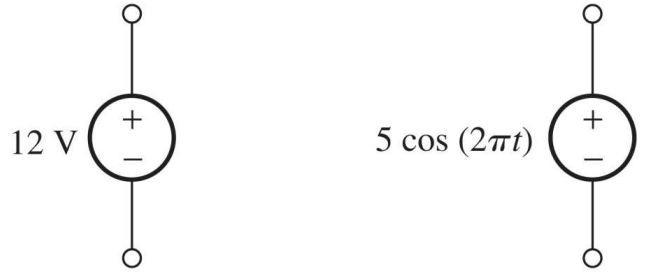
$$p_a + p_b + p_c = 0$$

$$v_a i + v_b i + v_c i = 0$$

$$v_a + v_b + v_c = 0$$

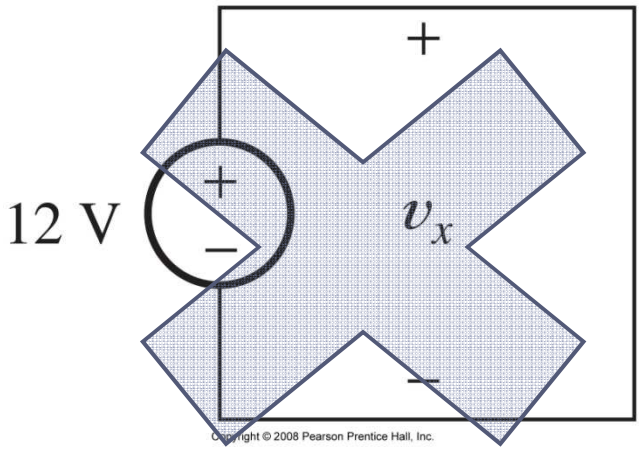
Voltage Sources

- Independent sources



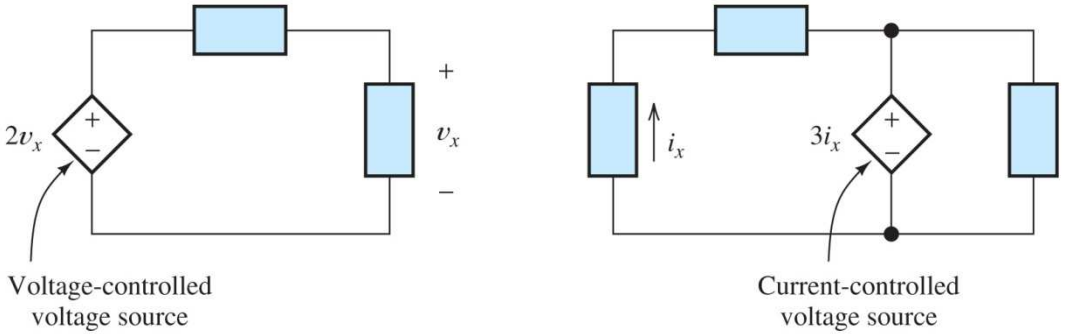
(a) Constant or dc voltage source

(b) Ac voltage source



- Dependent sources

Avoid self-contradictory circuit



Voltage-controlled voltage source

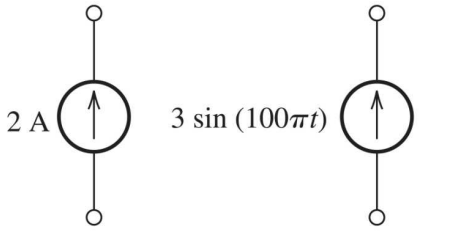
(a)

Current-controlled voltage source

(b)

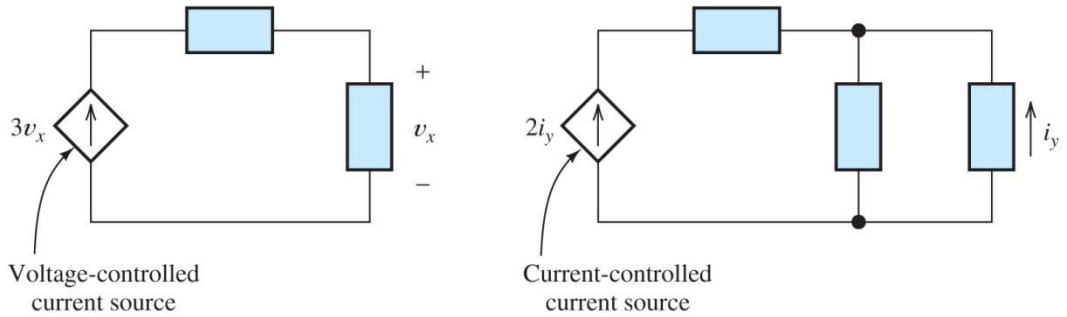
Current Sources

- Independent sources

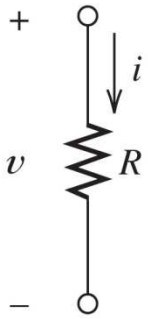


(a) Dc current source (b) Ac current source

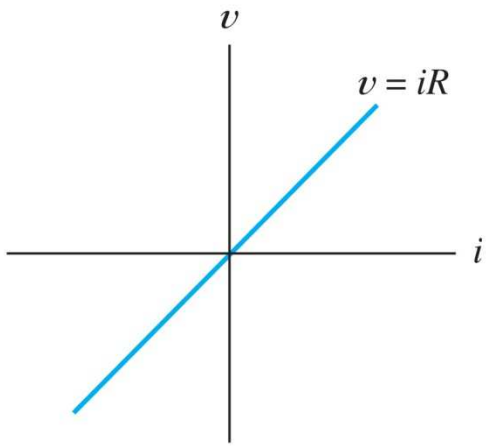
- Dependent sources



Resistance and Ohm's Law



(a) Resistance symbol

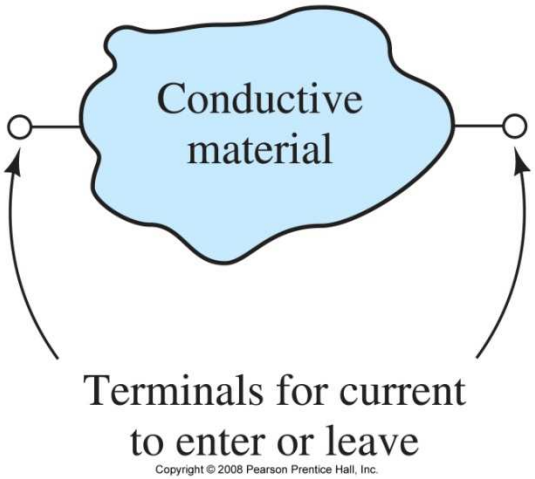


(b) Ohm's law

$$p = vi$$

$$p = Ri^2$$

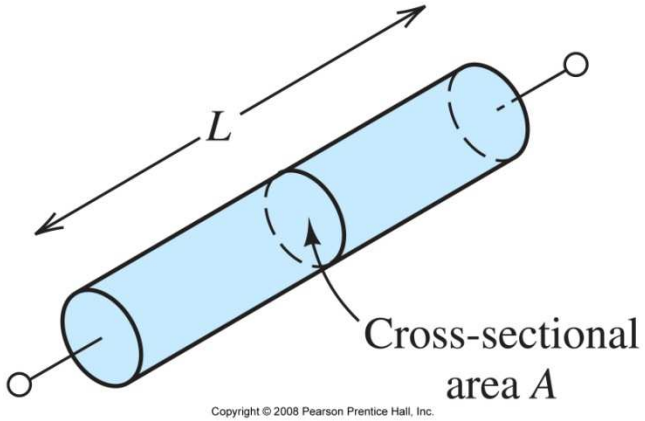
$$p = \frac{v^2}{R}$$



$$v = iR$$

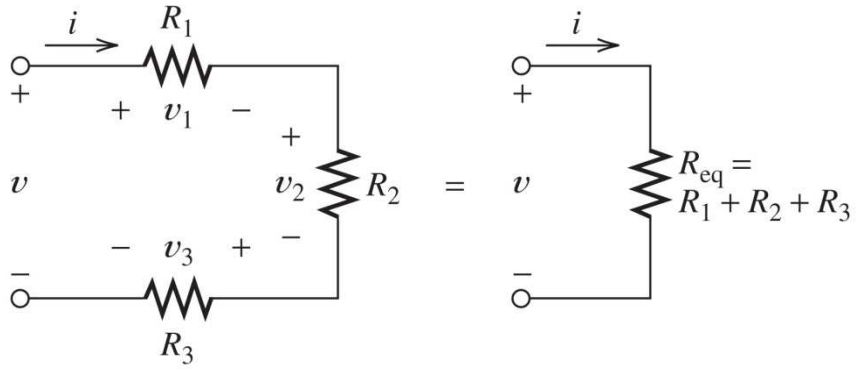
$$i = \frac{1}{R}v$$

$$i = Gv$$



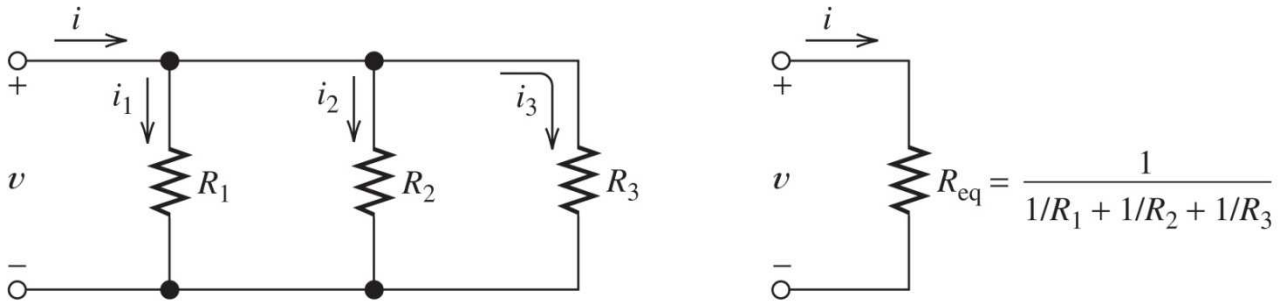
$$R = \frac{\rho L}{A}$$

Resistive Circuits



(a) Three resistances in series

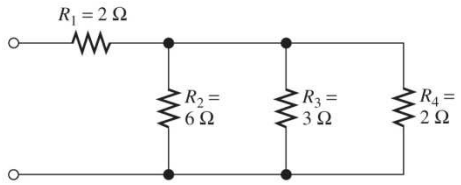
(b) Equivalent resistance



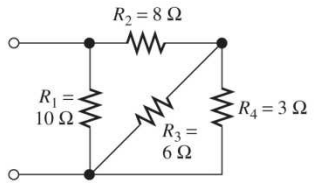
(a) Three resistances in parallel

(b) Equivalent resistance

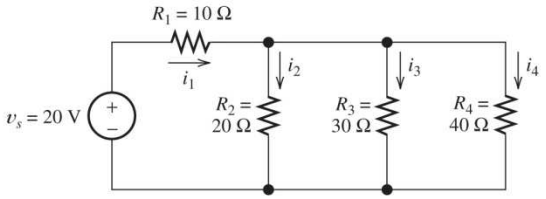
Problems



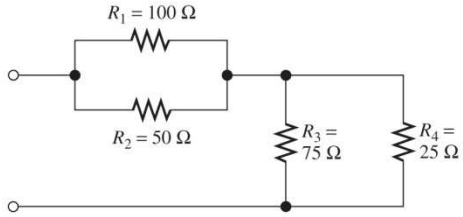
(a)



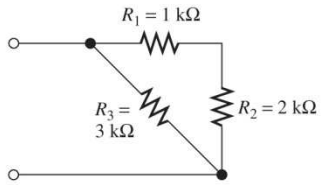
(b)



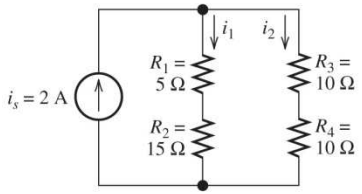
(a)



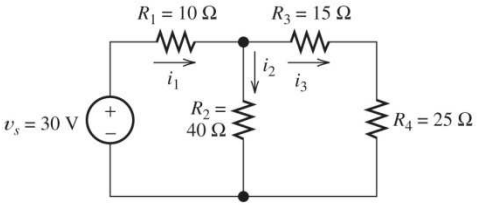
(c)



(d)

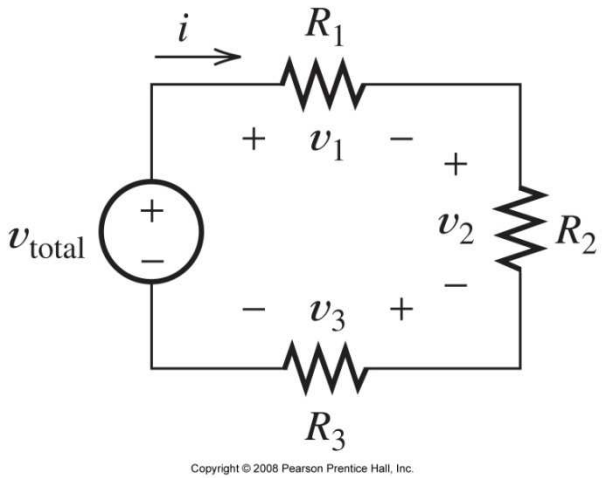


(b)

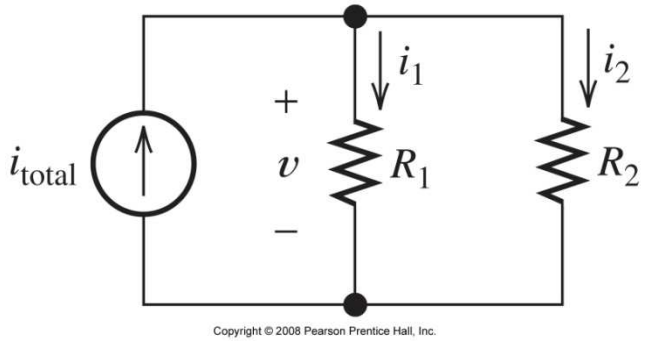


(c)

Voltage-Divider and Current-Divider Circuits

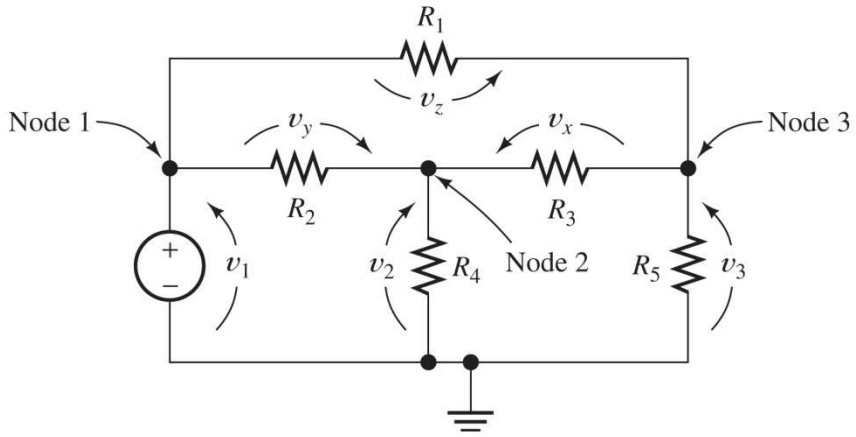


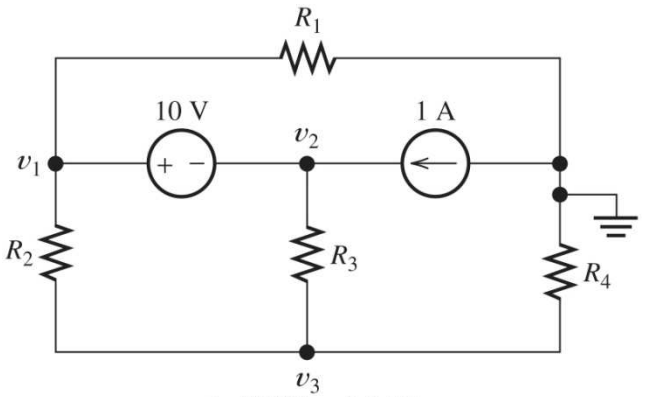
$$v_i = \frac{R_i}{R_1 + R_2 + R_3} v_{total}$$

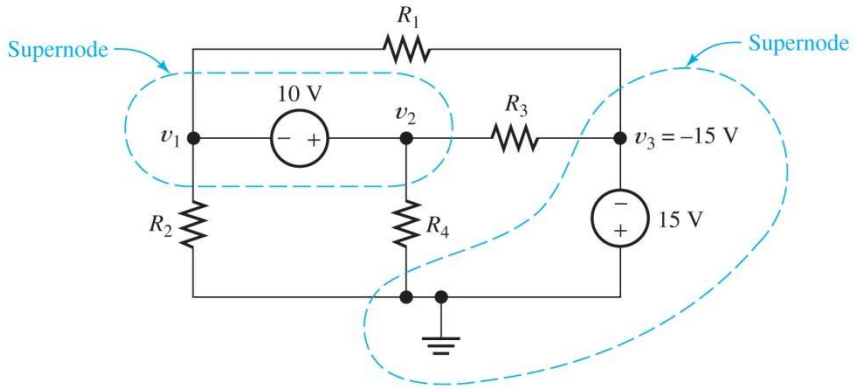


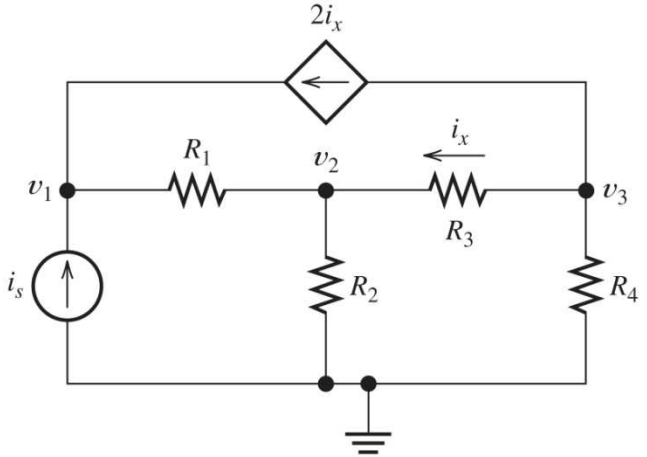
$$i_i = \frac{R_i}{R_1 + R_2} i_{total}$$

Node-Voltage Analysis

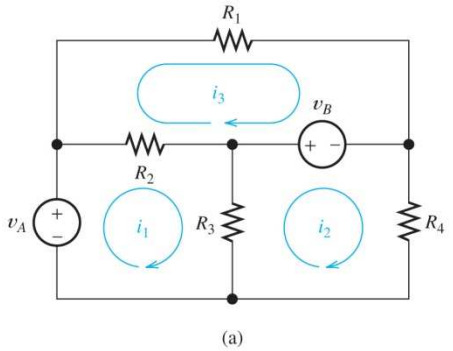




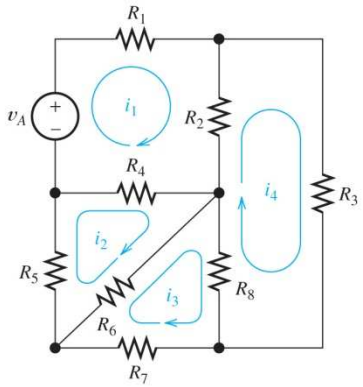




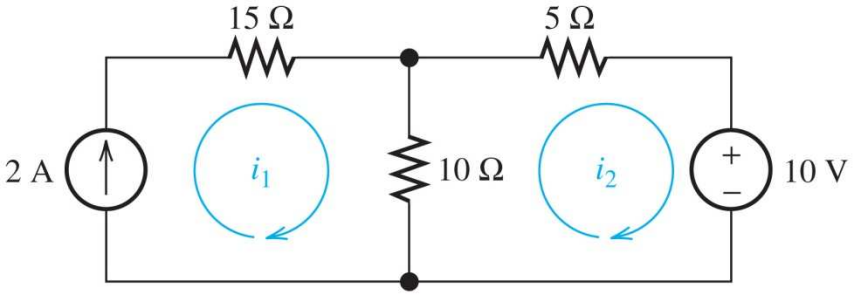
Mesh-Current Analysis

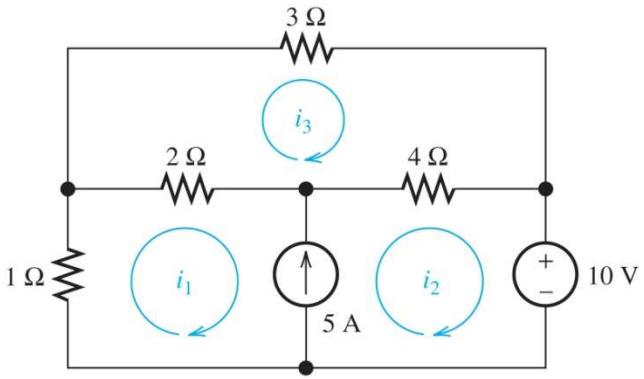


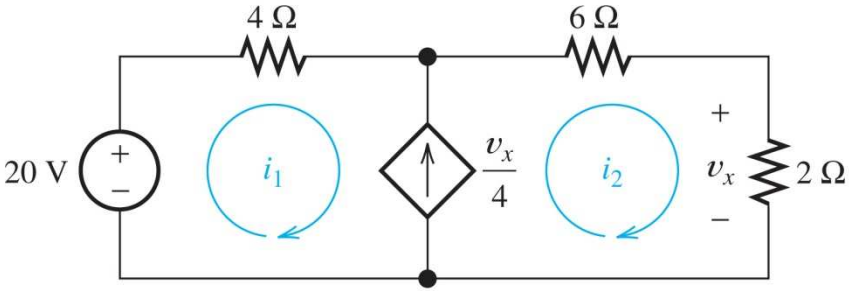
(a)



(b)

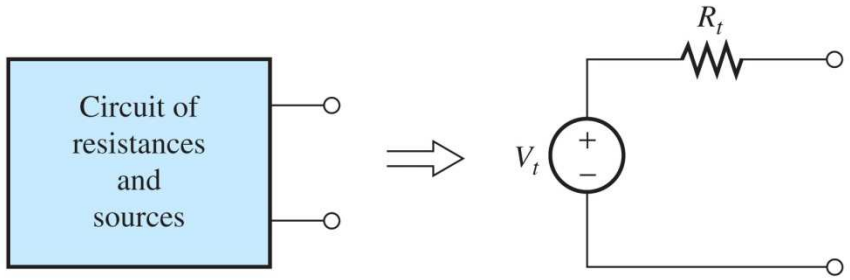




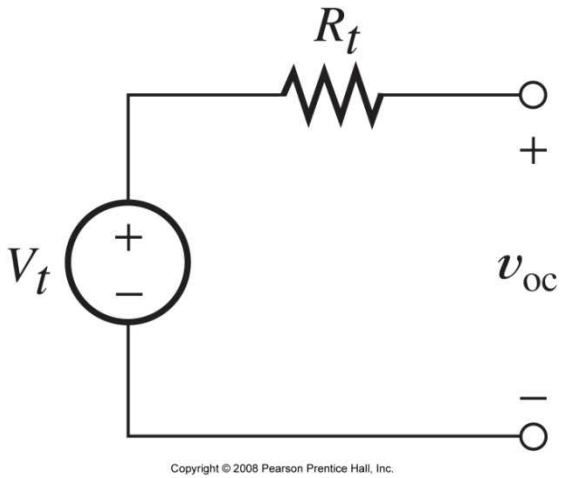


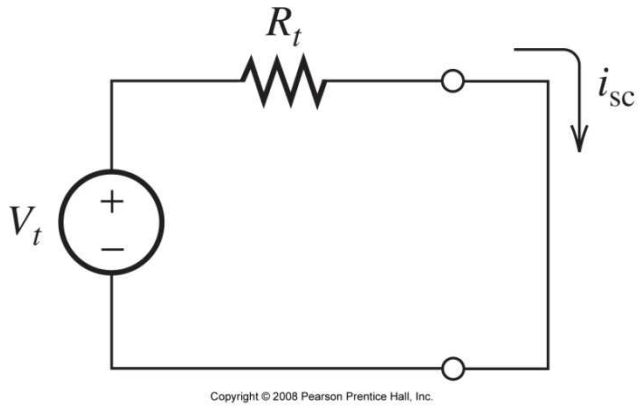
$$i_1 - i_2 = 5$$

Thévenin Equivalent Circuits



Thévenin equivalent circuit

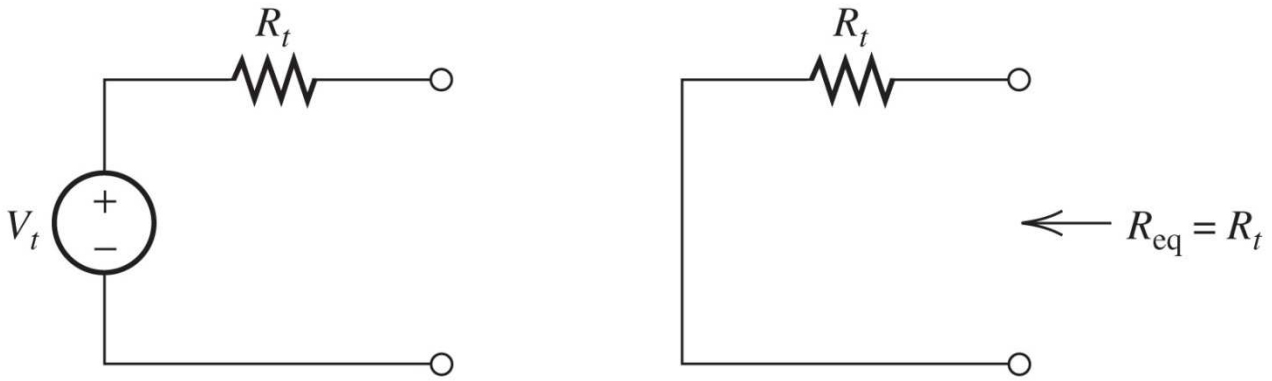




$$V_t = v_{oc} \quad \Rightarrow \quad R_t = \frac{v_{oc}}{i_{sc}} \quad \Leftarrow \quad i_{sc} = \frac{V_t}{R_t}$$

Thévenin Resistance

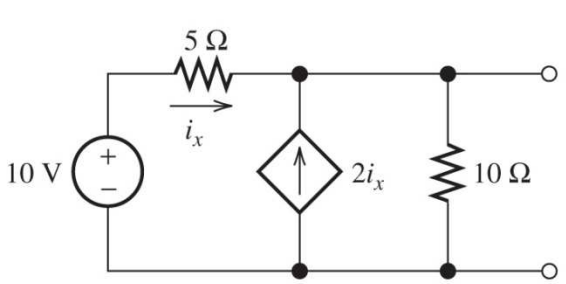
- Zeroing sources



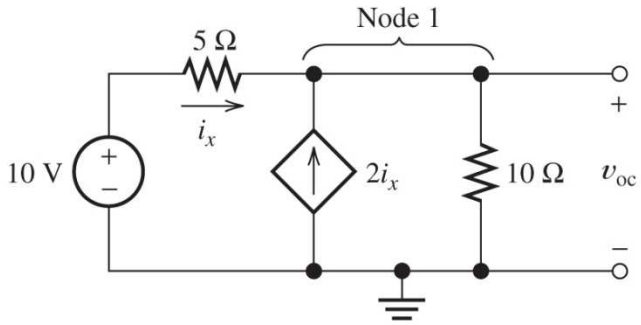
(a) Thévenin equivalent

(b) Thévenin equivalent with its source zeroed

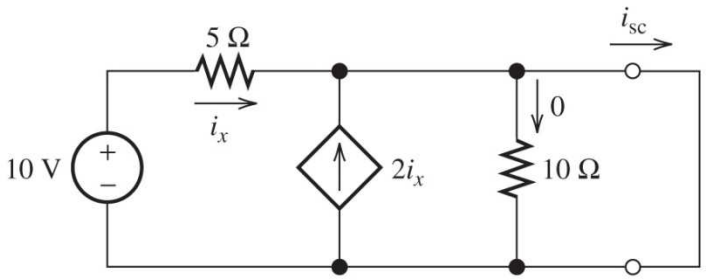
Thévenin Circuit Example



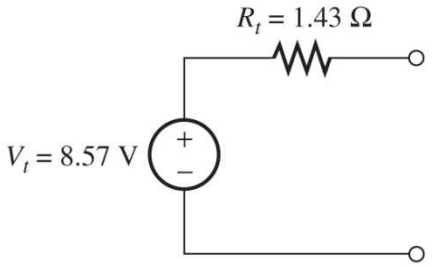
(a) Original circuit



(b) Circuit with an open circuit

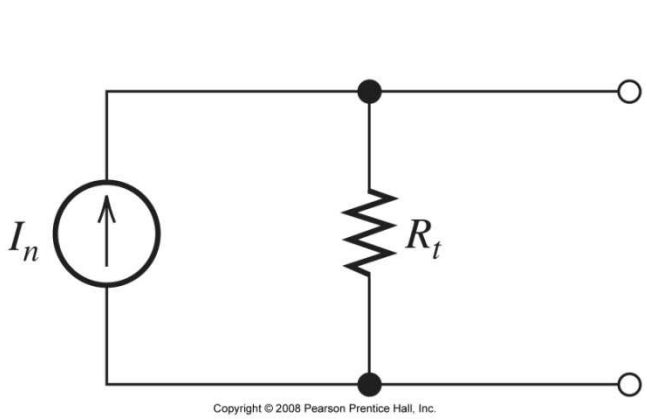


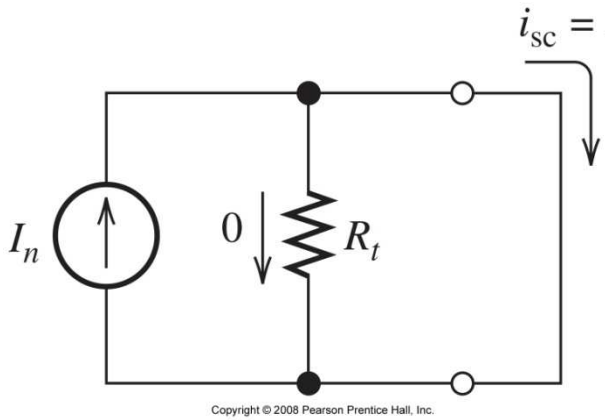
(c) Circuit with a short circuit



(d) Thévenin equivalent

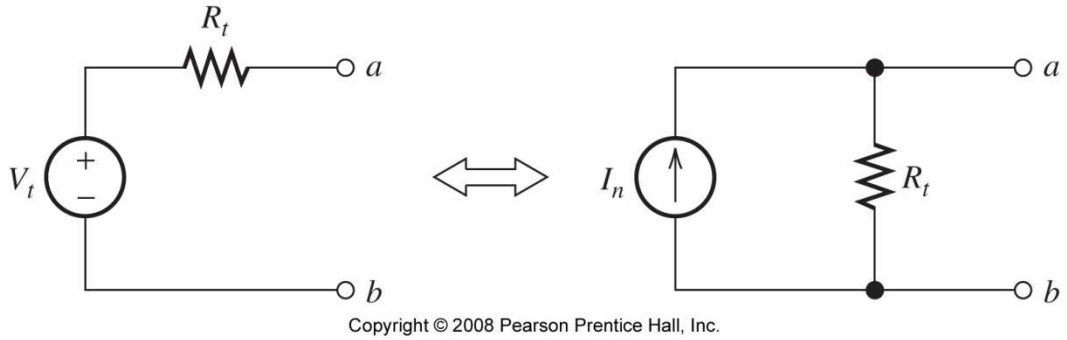
Norton Equivalent Circuits





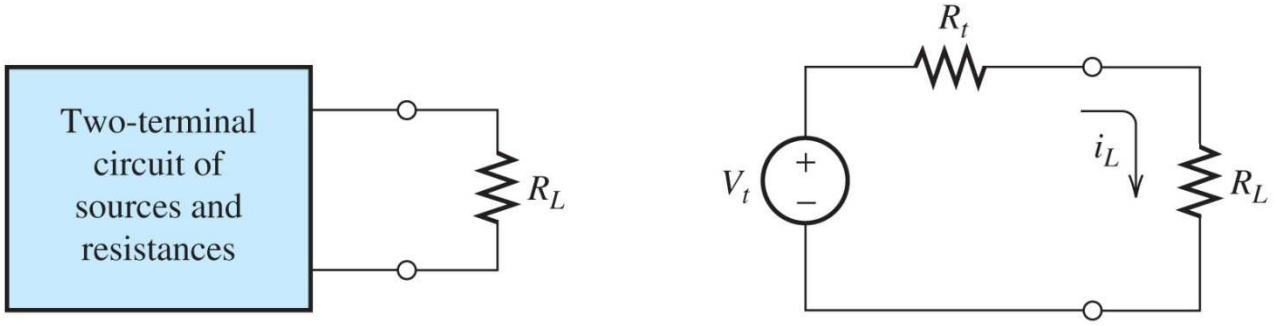
$$I_n = i_{sc}$$

- Source Transformation



$$I_n = V_t / R_t$$

Maximum Power Transfer



(a) Original circuit with load

(b) Thévenin equivalent circuit with load

$$p_L = \frac{V_t^2 R_L}{(R_t + R_L)^2}$$

$$\frac{dp_L}{dR_L} = 0 \Rightarrow R_L = R_t$$

$$P_{L\max} = \frac{V_t^2}{4R_t}$$

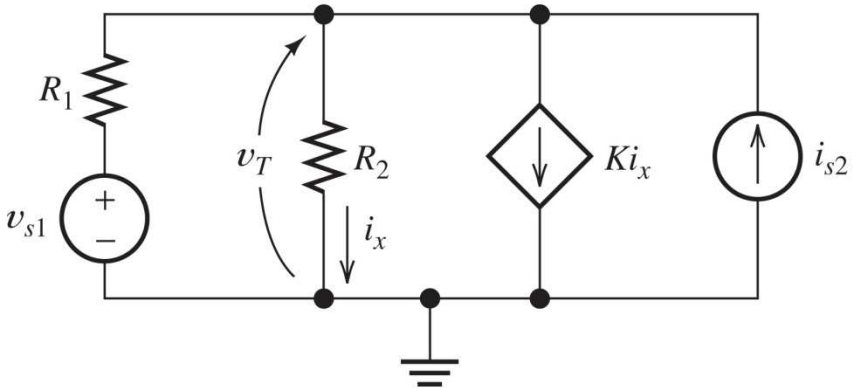
Superposition Principle

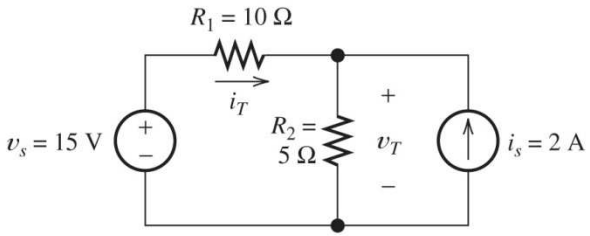
- *Total response is the sum of the responses to each of the independent sources acting individually*
- Linearity

$$v = 10i^2$$

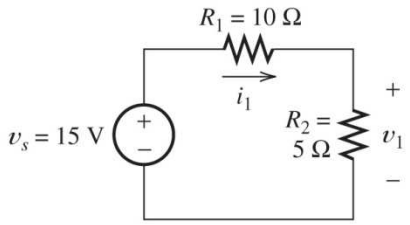
$$i_{cs} = K\cos(i_x)$$

$$i = e^v$$

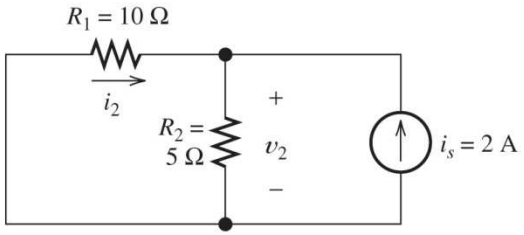




(a) Original circuit

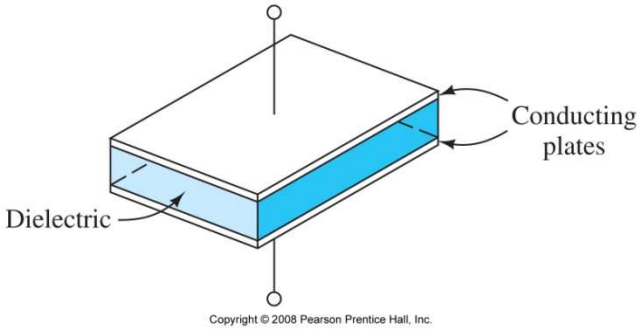


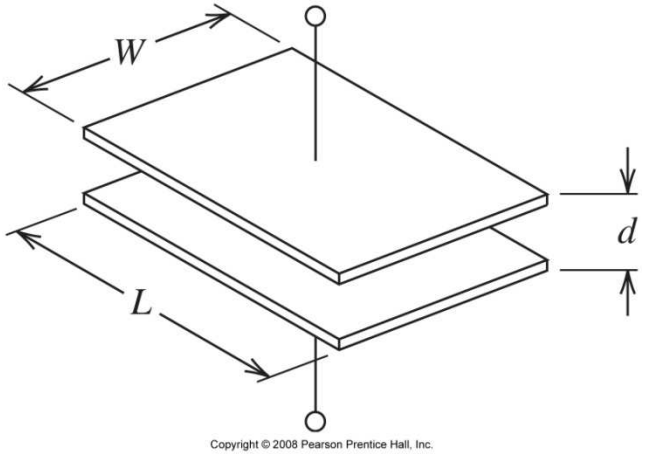
(b) Circuit with only the voltage source active



(c) Circuit with only the current source active

Capacitance



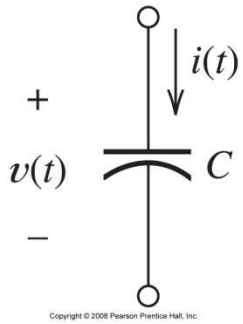


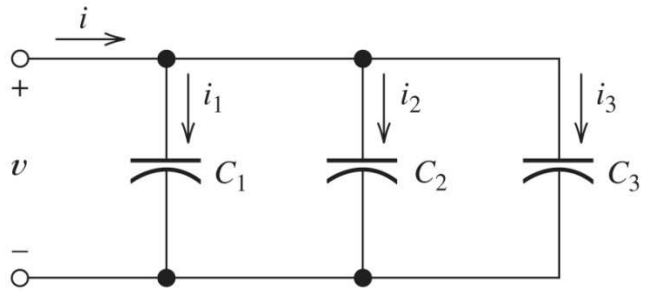
$$C = \frac{\varepsilon A}{d}$$

$$\varepsilon_0 \cong 8.85 \times 10^{-12}\ F/m$$

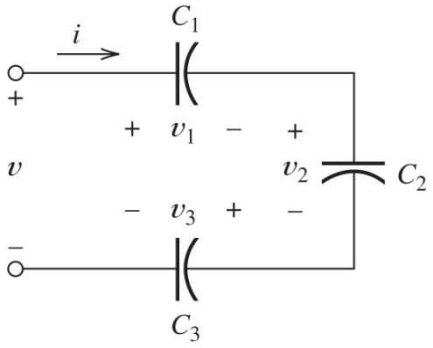
$$q = cv$$

$$i = c\frac{dv}{dt} = \frac{dq}{dt}$$





$$C_{eq} = C_1 + C_2 + C_3$$

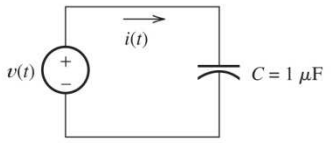


$$C_{eq} = \frac{1}{1/C_1 + 1/C_2 + 1/C_3}$$

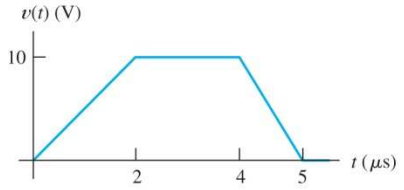
Voltage and Stored Energy

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

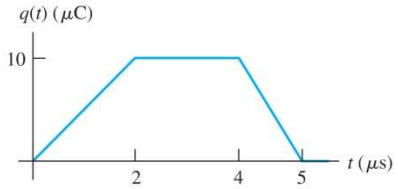
$$v(t) = \frac{1}{C}\int_{t_0}^{t} i(t)dt + v(t_0)$$



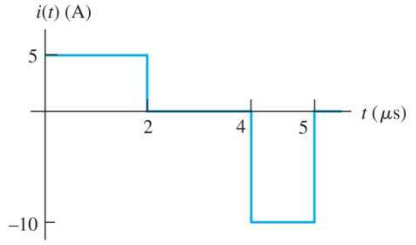
(a)



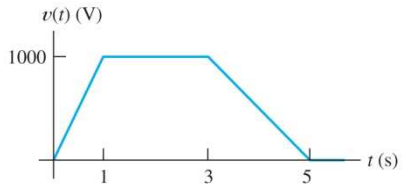
(b)



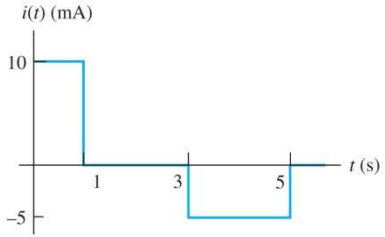
(c)



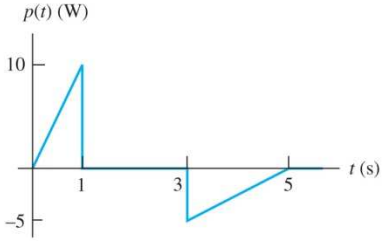
(d)



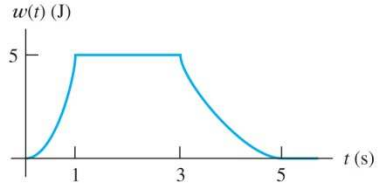
(a)



(b)



(c)



(d)

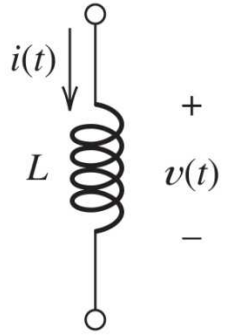
$$p(t) = v(t)i(t) = Cv\frac{dv}{dt}$$

$$w(t) = \int_{t_0}^{t} p(t)dt = \frac{1}{2}Cv^2(t)$$

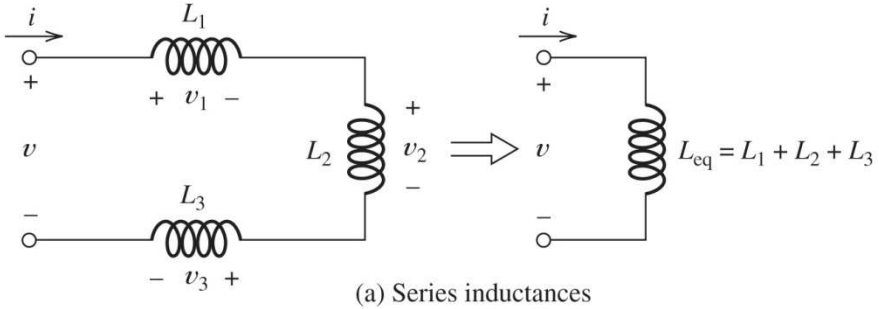
$$= \frac{1}{2}v(t)q(t)$$

$$= \frac{q^2(t)}{2C}$$

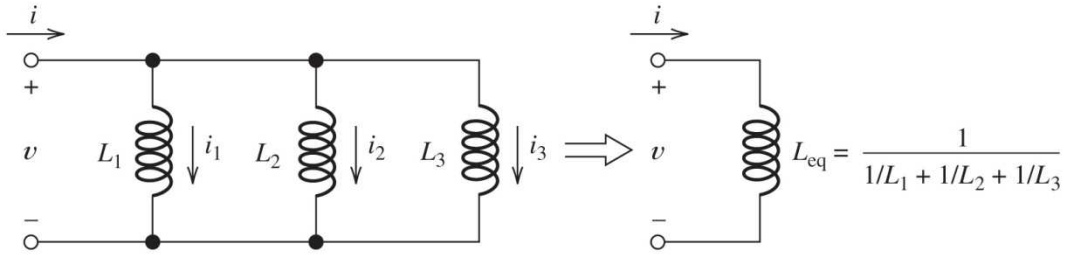
Inductance



$$v(t) = L\frac{di}{dt}$$



(a) Series inductances

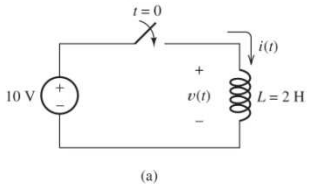


(b) Parallel inductances

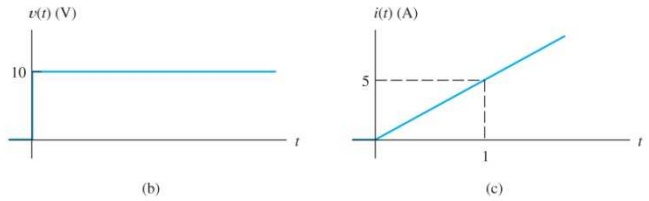
$$i(t) = \frac{1}{L}\int_{t_0}^{t} v(t)dt + i(t_0)$$

$$p(t) = Li(t)\frac{di}{dt}$$

$$w(t) = \frac{1}{2}Li^2(t)$$

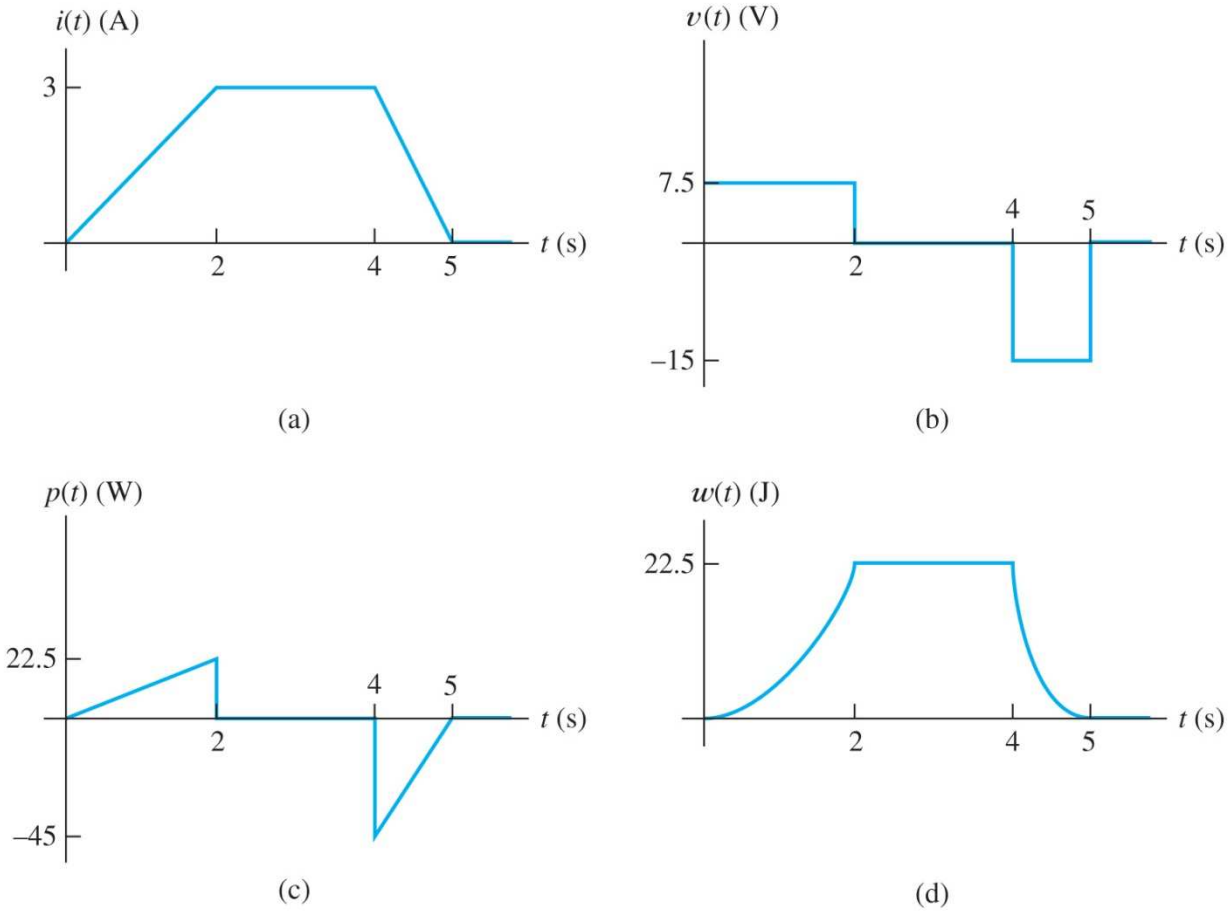


(a)

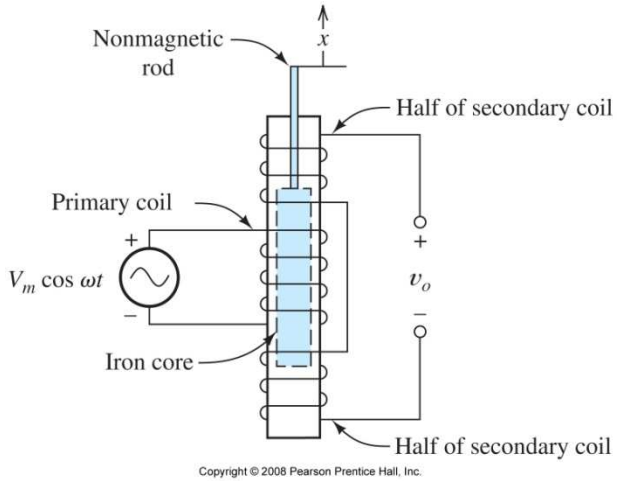


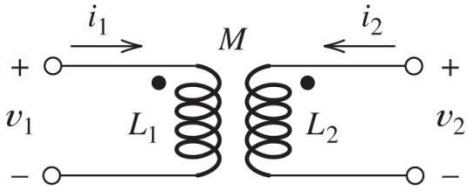
(b) (c)

Voltage, Power, and Energy for Inductance



Mutual Inductance

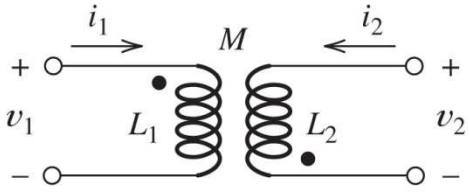




$$v_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$v_2 = M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$

(a)

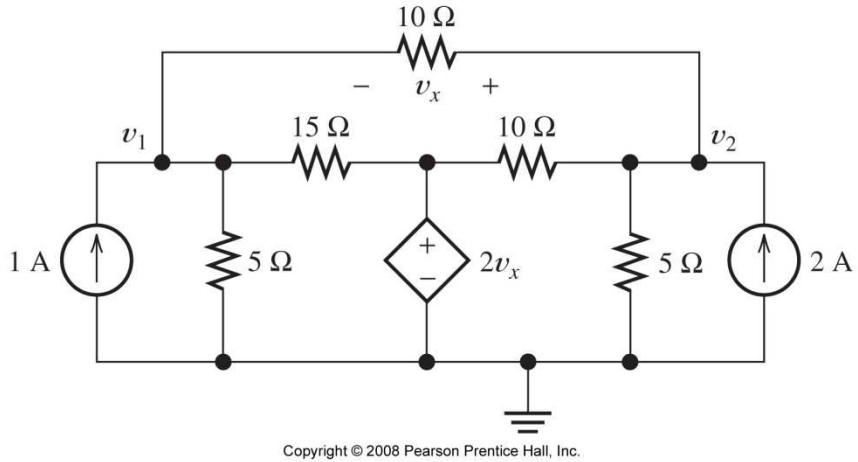


$$v_1 = L_1 \frac{di_1}{dt} - M \frac{di_2}{dt}$$

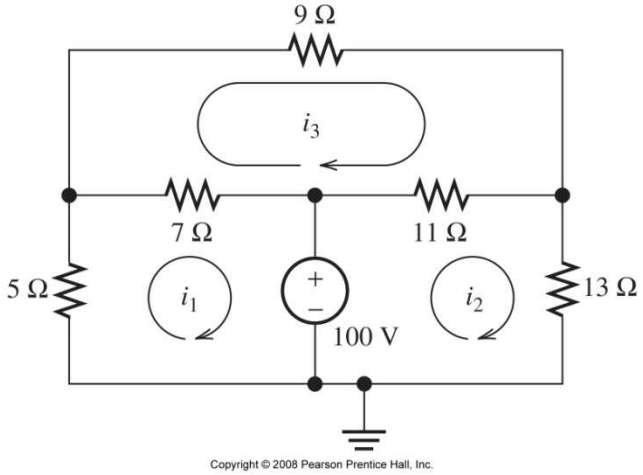
$$v_2 = -M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$

(b)

Problems

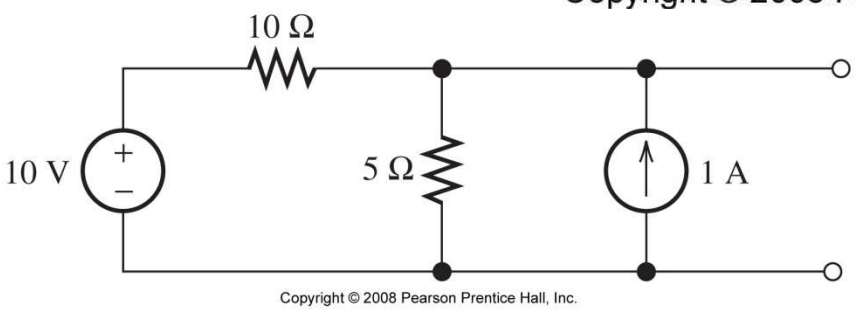


solve for node voltage

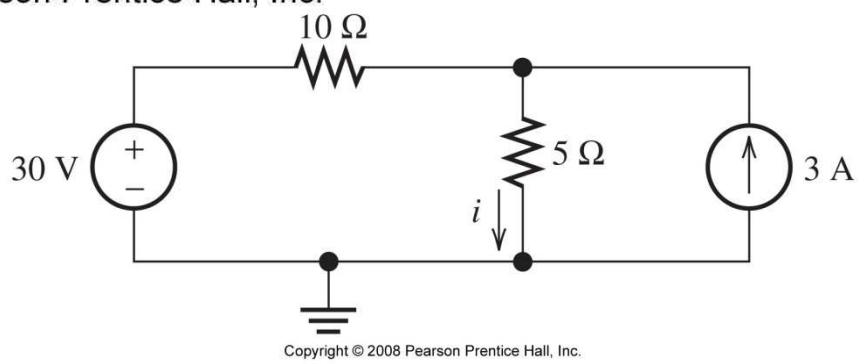


solve for power delivered by the voltage source

Problems



find Thévenin and Norton equivalent circuits



find *i* using superposition principle