Chapter 30

Inductance

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Goals for Chapter 30

- To learn how current in one coil can induce an emf in another unconnected coil
- To relate the induced emf to the rate of change of the current
- To calculate the energy in a magnetic field
- To analyze circuits containing resistors and inductors
- To describe electrical oscillations in circuits and why the oscillations decay

Introduction

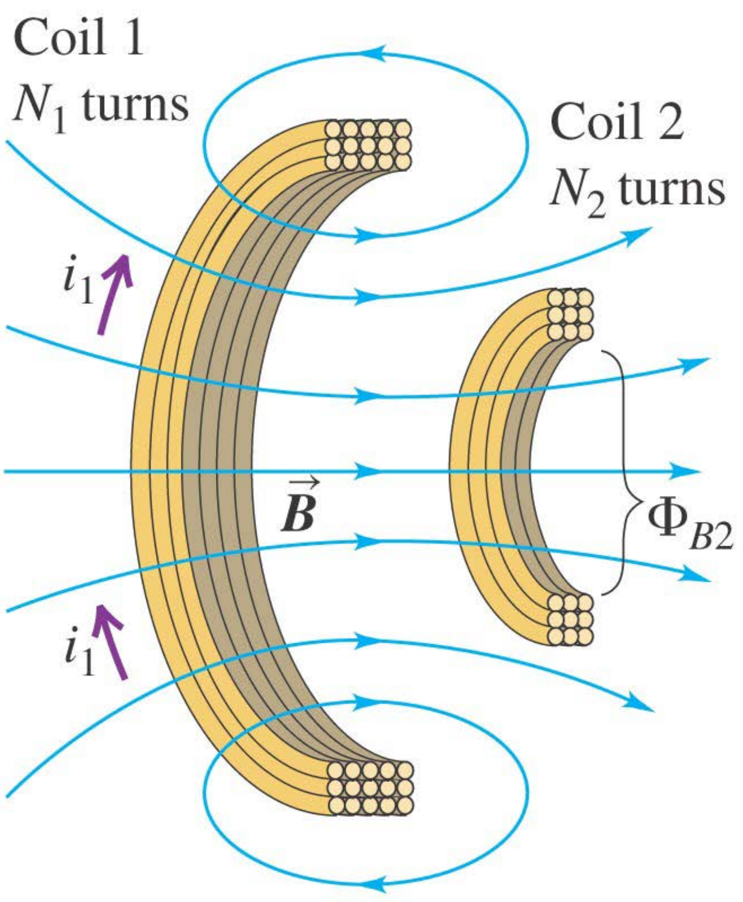
- How does a coil induce a current in a neighboring coil.
- A sensor triggers the traffic light to change when a car arrives at an intersection. How does it do this?
- Why does a coil of metal behave very differently from a straight wire of the same metal?
- We'll learn how circuits can be coupled without being connected together.

Mutual inductance

- *Mutual inductance*: A changing current in one coil induces a current in a neighboring coil. See Figure 30.1 at the right.

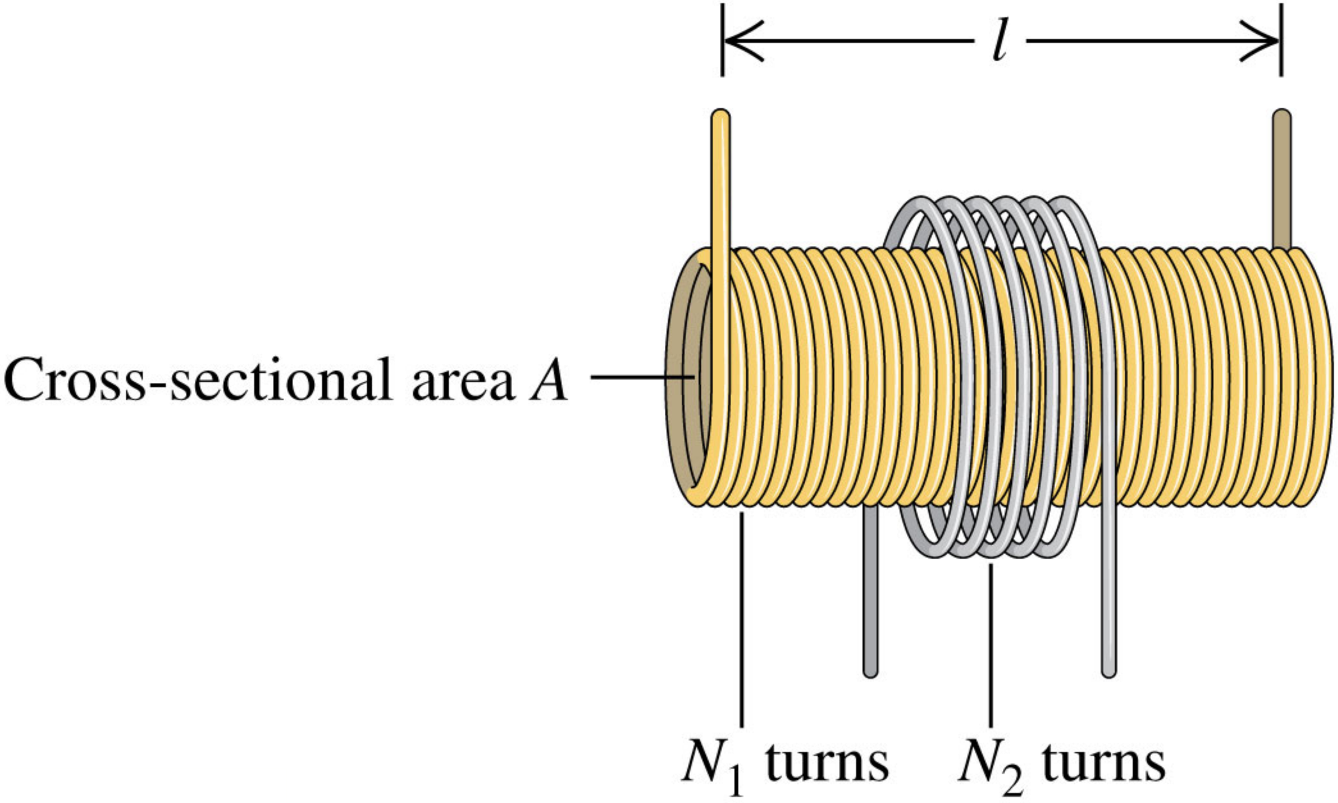
- Follow the discussion of mutual inductance in the text.

Mutual inductance: If the current in coil 1 is changing, the changing flux through coil 2 induces an emf in coil 2.



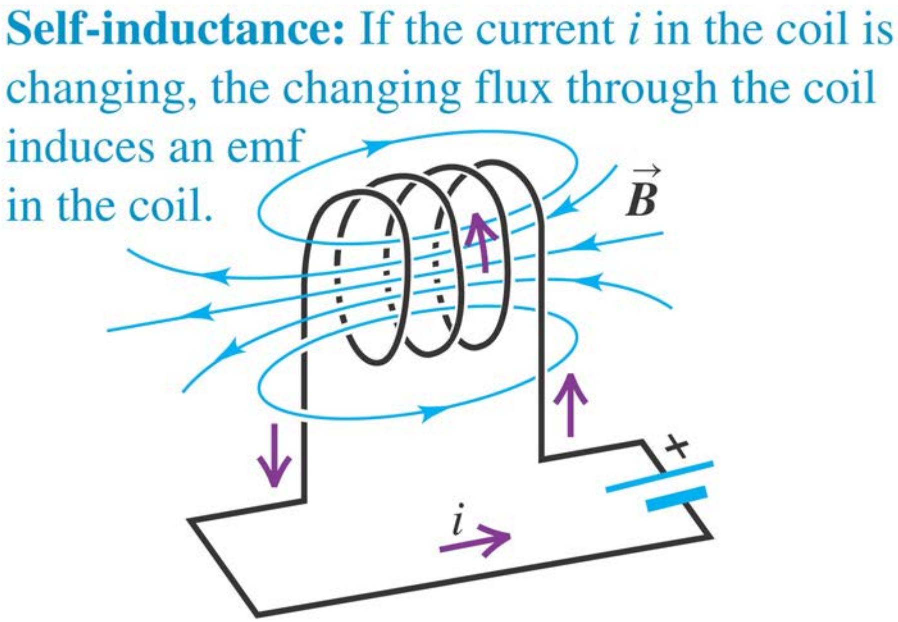
Mutual inductance examples

- Follow Example 30.1, which shows how to calculate mutual inductance. See Figure 30.3 below.
- Follow Example 30.2, which looks at the induced emf.



Self-inductance

- *Self-inductance*: A varying current in a circuit induces an emf in that same circuit. See Figure 30.4 below.
- Follow the text discussion of self-inductance and inductors.



Self-inductance: If the current i in the coil is changing, the changing flux through the coil induces an emf in the coil.

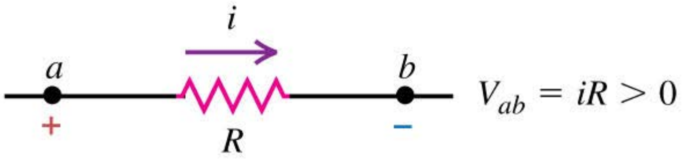
Potential across an inductor

- The potential across an inductor depends on the rate of change of the current through it.

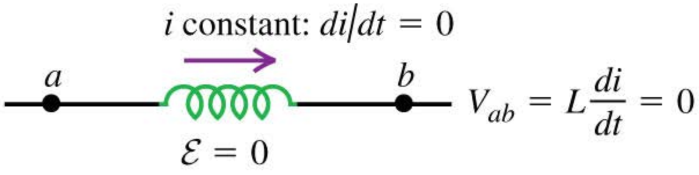
- Figure 30.6 at the right compares the behavior of the potential across a resistor and an inductor.

- The self-induced emf does *not* oppose current, but opposes a *change* in the current.

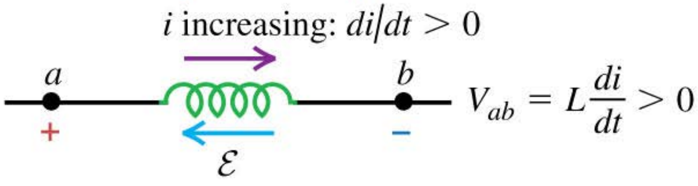
(a) Resistor with current i flowing from a to b: potential drops from a to b.



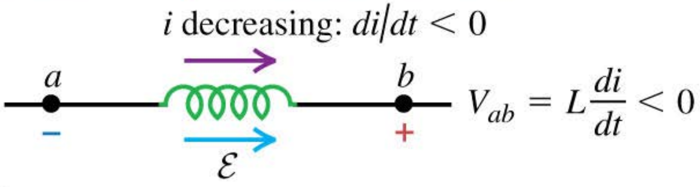
(b) Inductor with *constant* current i flowing from a to b: no potential difference.



(c) Inductor with *increasing* current i flowing from a to b: potential drops from a to b.

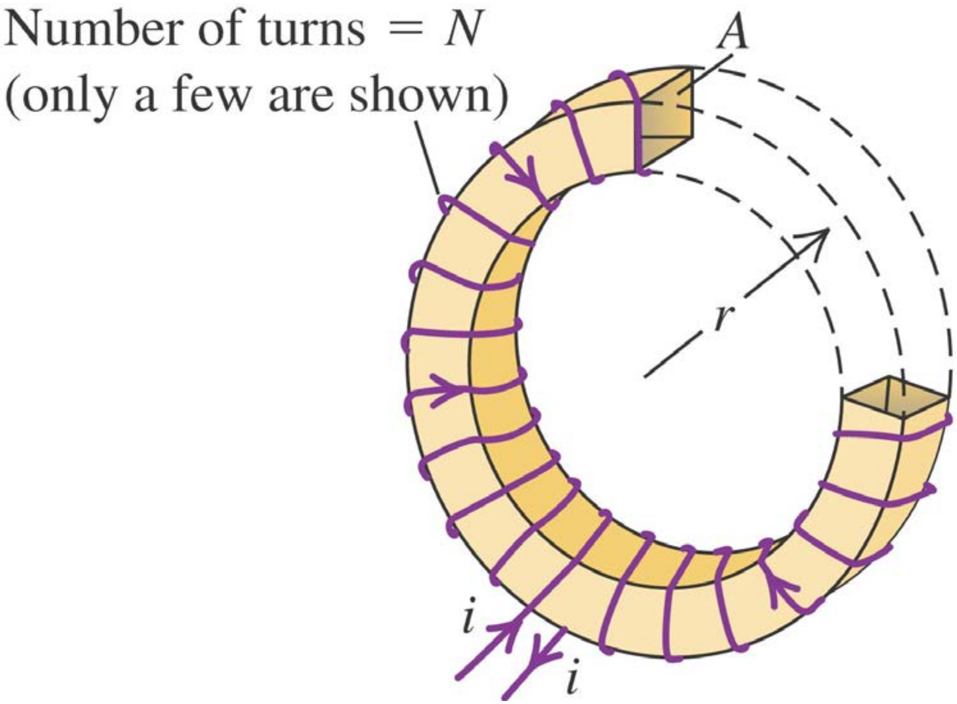


(d) Inductor with *decreasing* current i flowing from a to b: potential increases from a to b.



Calculating self-inductance and self-induced emf

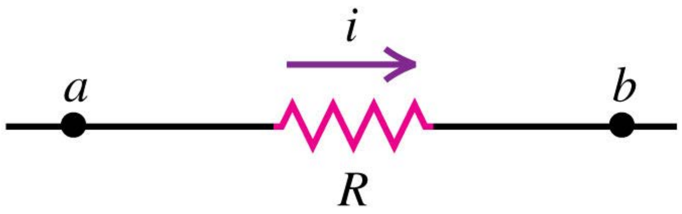
- Follow Example 30.3 using Figure 30.8 below.
- Follow Example 30.4.



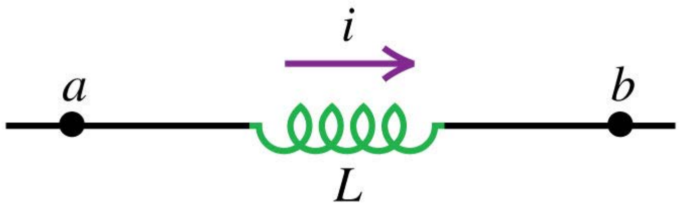
Magnetic field energy

- The energy stored in an inductor is $U = 1/2\ LI^2$. See Figure 30.9 below.
- The energy density in a magnetic field is $u = B^2/2\mu_0$ (in vacuum) and $u = B^2/2\mu$ (in a material).
- Follow Example 30.5.

Resistor with current i: energy is *dissipated.*

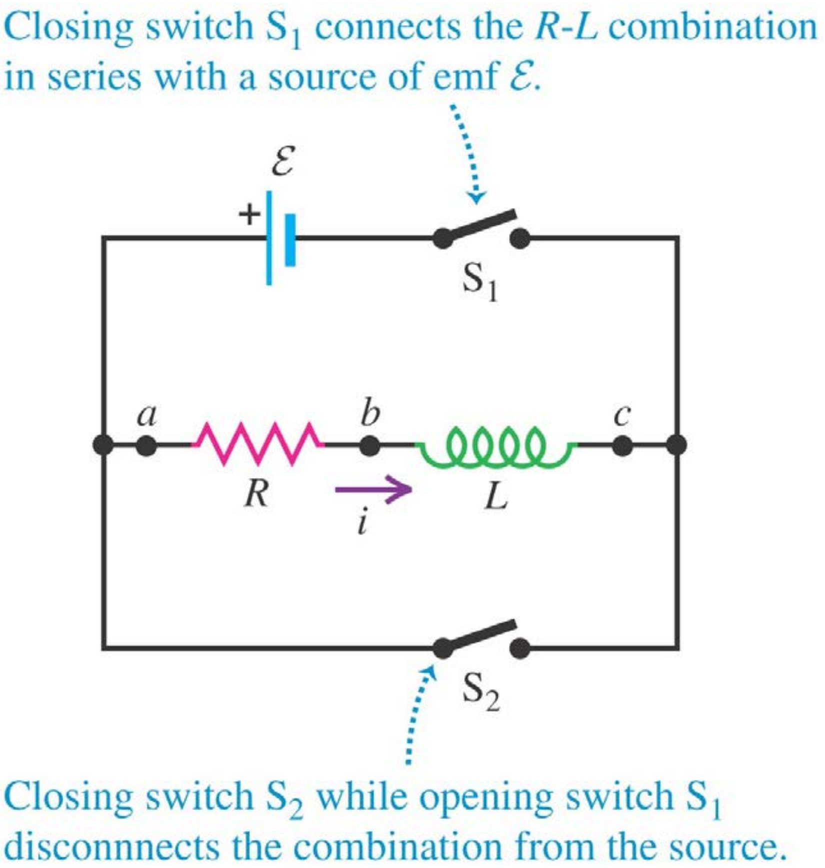


Inductor with current i: energy is *stored.*



The *R*-*L* circuit

- An *R*-*L circuit* contains a resistor and inductor and possibly an emf source.
- Figure 30.11 at the right shows a typical *R*-*L* circuit.
- Follow Problem-Solving Strategy 30.1.

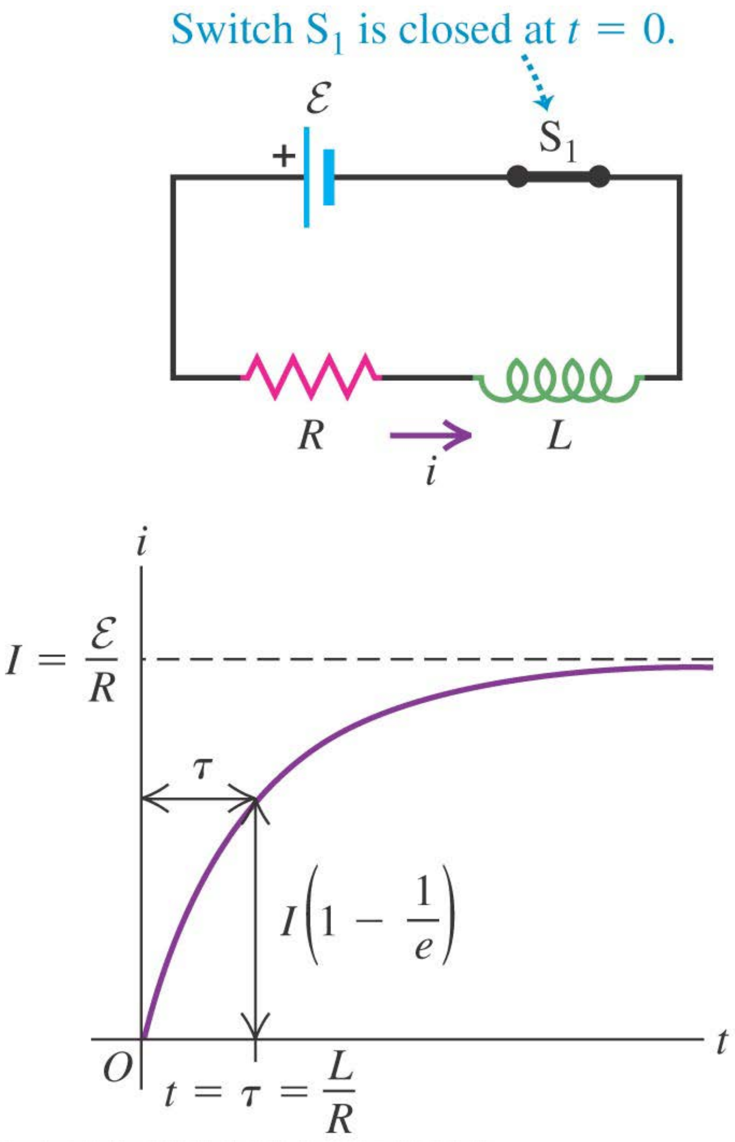


Closing switch S_1 connects the *R*-*L* combination in series with a source of emf $\mathcal{E}$.

Closing switch S_2 while opening switch S_1 disconnnects the combination from the source.

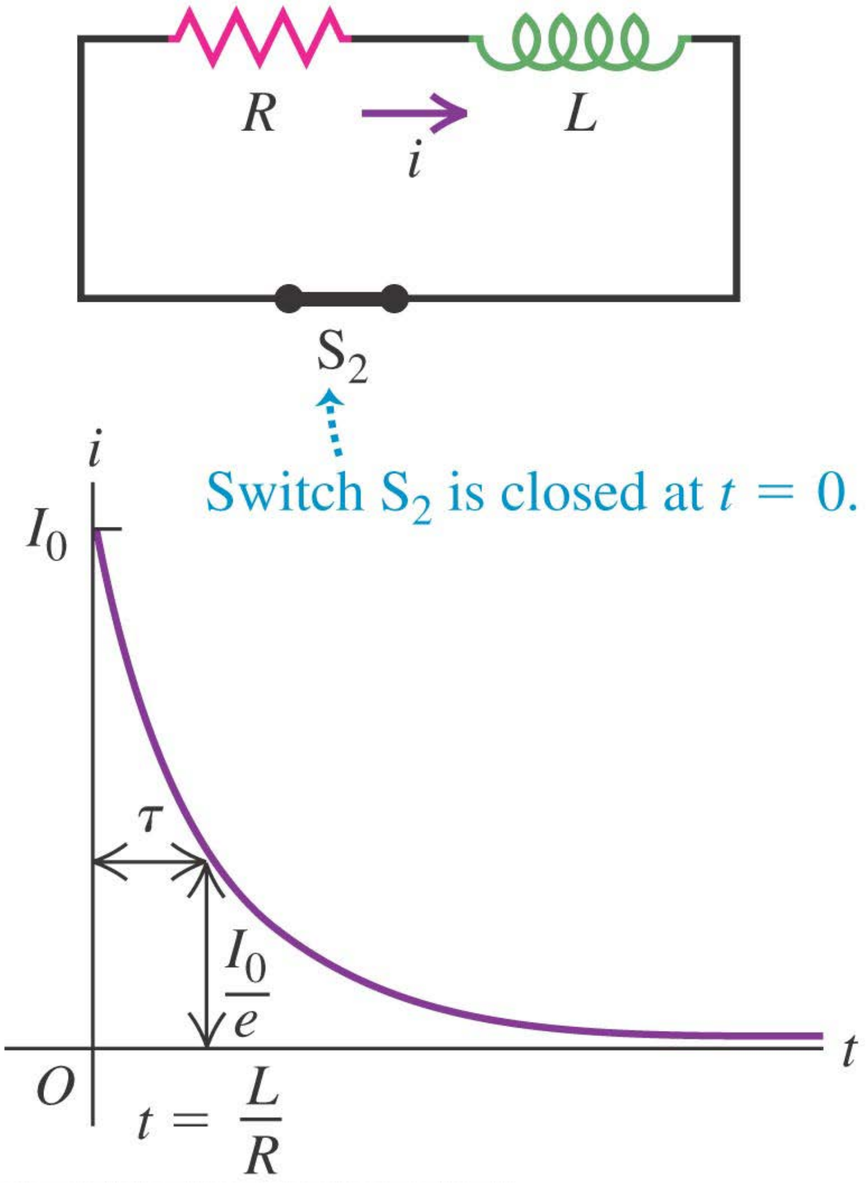
Current growth in an *R*-*L* circuit

- Follow the text analysis of current growth in an *R*-*L* circuit.
- The *time constant* for an *R*-*L* circuit is $\tau = L/R$.
- Figure 30.12 at the right shows a graph of the current as a function of time in an *R*-*L* circuit containing an emf source.
- Follow Example 30.6.



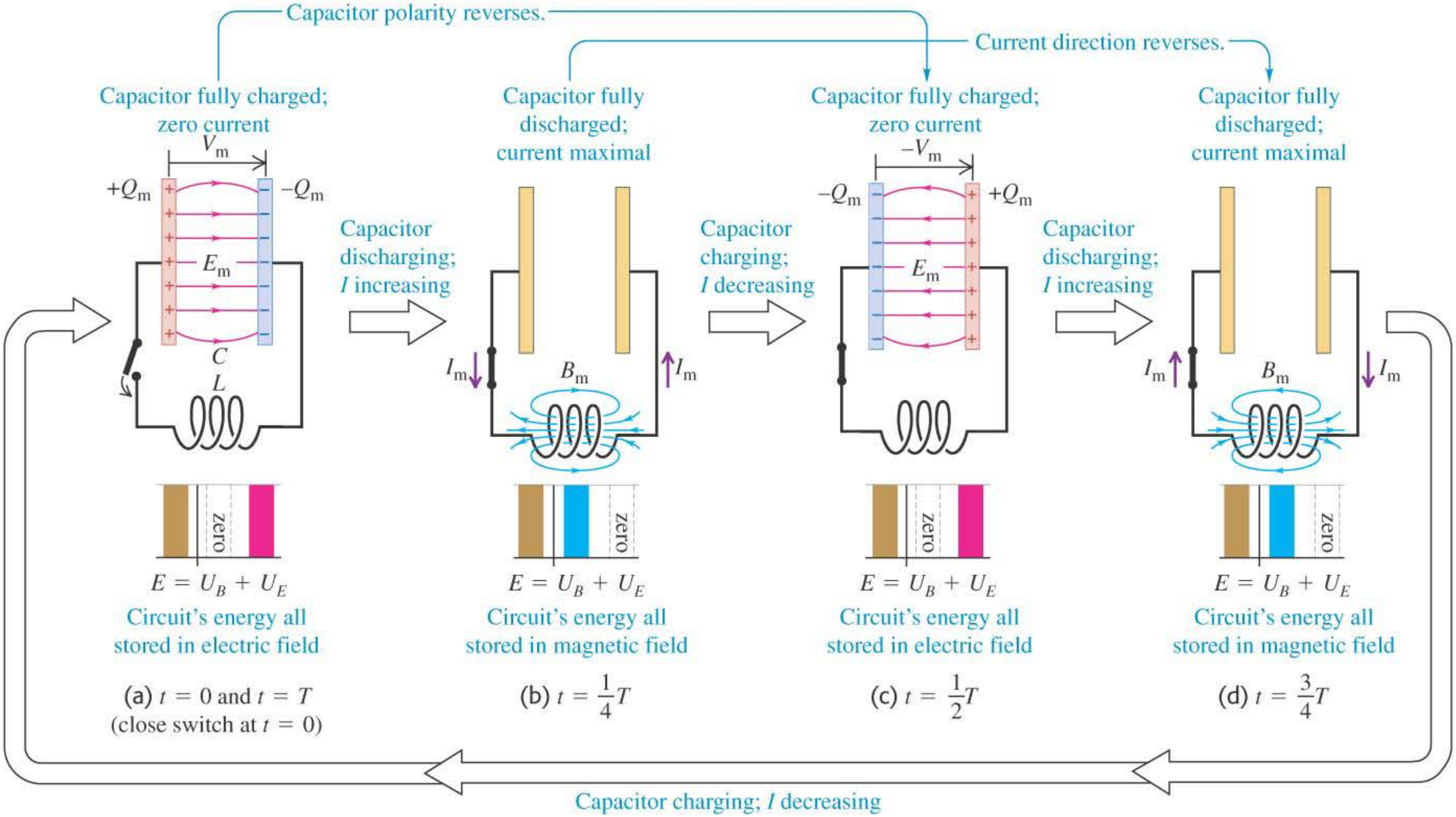
Current decay in an *R*-*L* circuit

- Read the text discussion of current decay in an *R*-*L* circuit.
- Figure 30.13 at the right shows a graph of the current versus time.
- Follow Example 30.7.



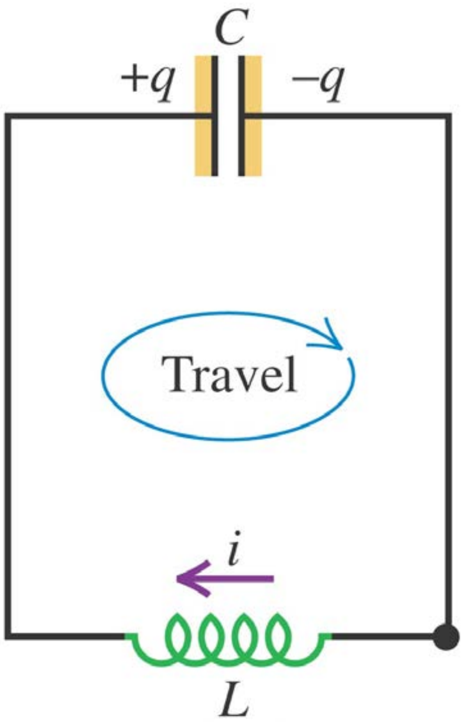
The *L*-*C* circuit

- An *L*-*C circuit* contains an inductor and a capacitor and is an *oscillating* circuit. See Figure 30.14 below.



Electrical oscillations in an *L*-*C* circuit

- Follow the text analysis of electrical oscillations and energy in an *L*-*C* circuit using Figure 30.15 at the right.



Electrical and mechanical oscillations

- Table 30.1 summarizes the analogies between SHM and *L*-*C* circuit oscillations.
- Follow Example 30.8.
- Follow Example 30.9.

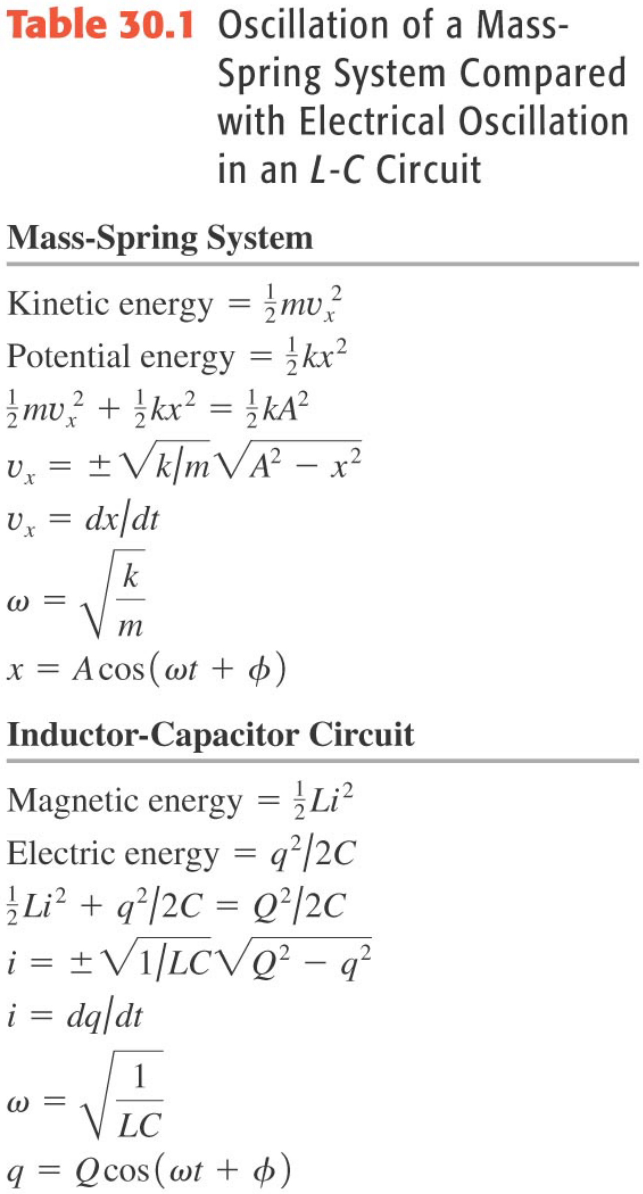


Table 30.1 Oscillation of a Mass-Spring System Compared with Electrical Oscillation in an *L*-*C* Circuit

Mass-Spring System

Kinetic energy $= \frac{1}{2}mv_x^2$
Potential energy $= \frac{1}{2}kx^2$
$\frac{1}{2}mv_x^2 + \frac{1}{2}kx^2 = \frac{1}{2}kA^2$
$v_x = \pm\sqrt{k/m}\sqrt{A^2 - x^2}$
$v_x = dx/dt$
$\omega = \sqrt{\frac{k}{m}}$
$x = A\cos(\omega t + \phi)$

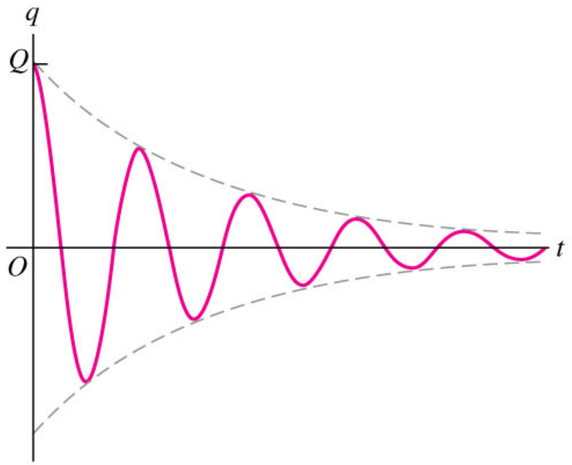
Inductor-Capacitor Circuit

Magnetic energy $= \frac{1}{2}Li^2$
Electric energy $= q^2/2C$
$\frac{1}{2}Li^2 + q^2/2C = Q^2/2C$
$i = \pm\sqrt{1/LC}\sqrt{Q^2 - q^2}$
$i = dq/dt$
$\omega = \sqrt{\frac{1}{LC}}$
$q = Q\cos(\omega t + \phi)$

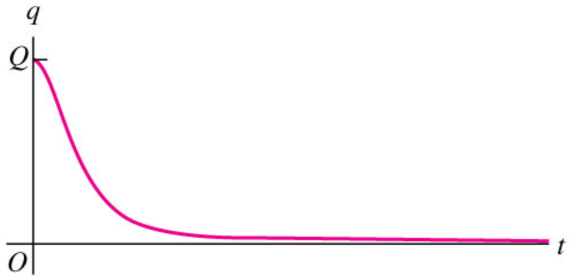
The *L-R-C* series circuit

- Follow the text analysis of an *L-R-C* circuit.
- An *L-R-C* circuit exhibits *damped harmonic motion* if the resistance is not too large. (See graphs in Figure 30.16 at the right.)
- Follow Example 30.10.

(a) Underdamped circuit (small resistance *R*)



(b) Critically damped circuit (larger resistance *R*)



(c) Overdamped circuit (very large resistance *R*)