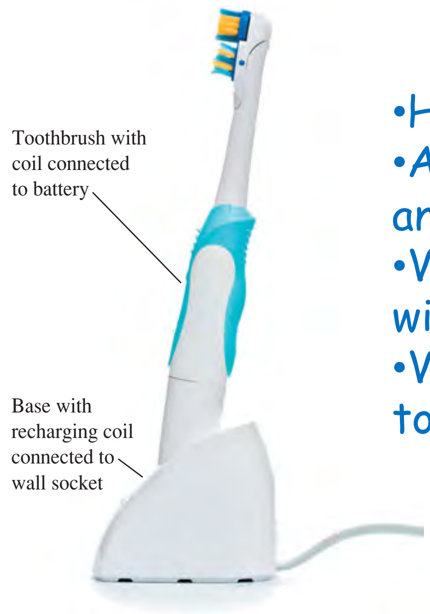
Chp 30: Inductance - (I)

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.

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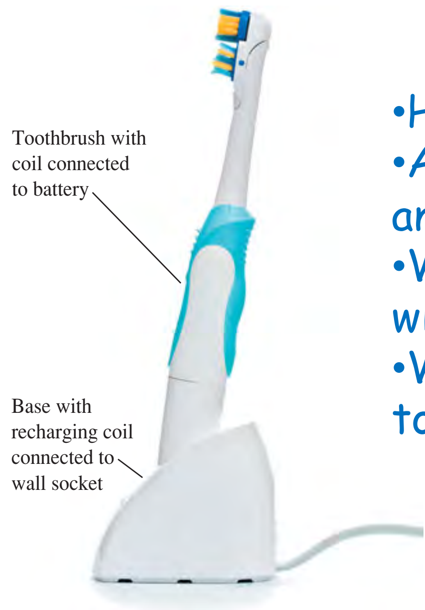

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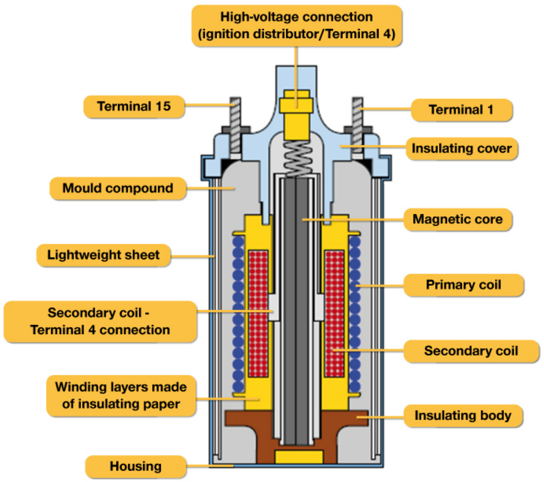
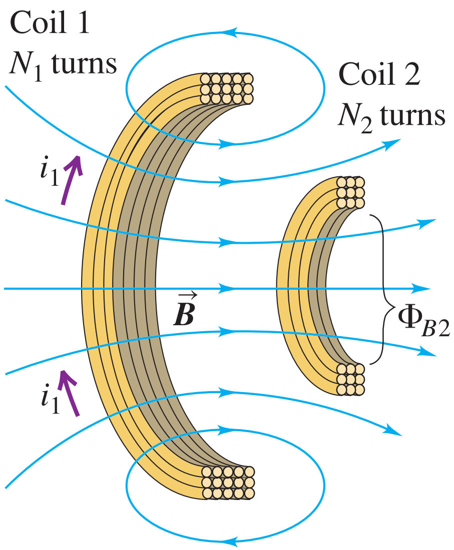


A changing current in a coil induces an emf in an adjacent coil.
The coupling between the coils is described by their *mutual inductance.*
A changing current in a coil also induces an emf in that same coil.
Such a coil is called an *inductor,* and the relationship of current to emf is described by the *inductance* (also called *self- inductance*) of the coil.

Mutual inductance

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



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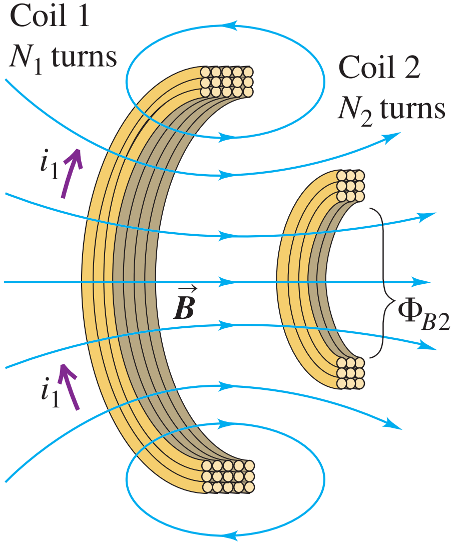

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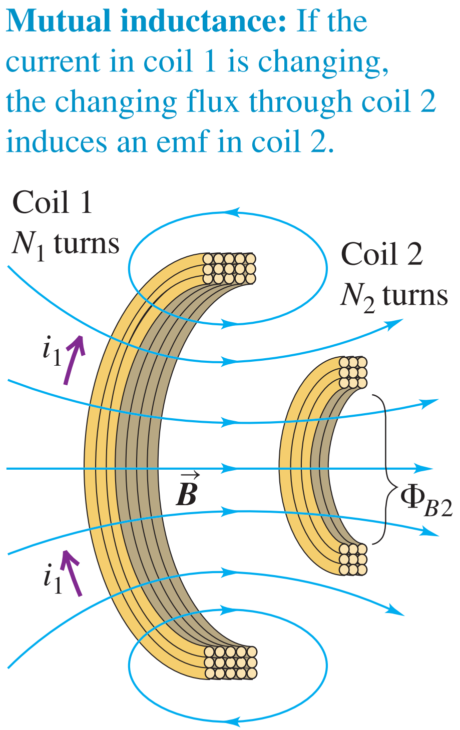

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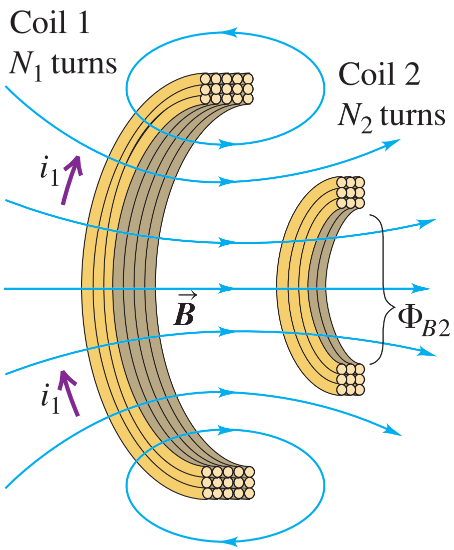

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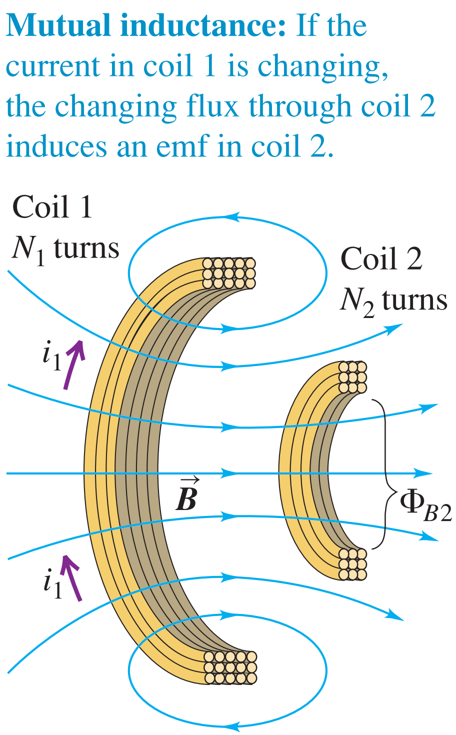

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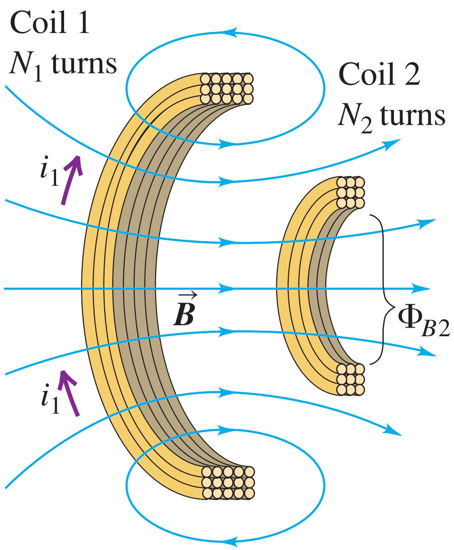

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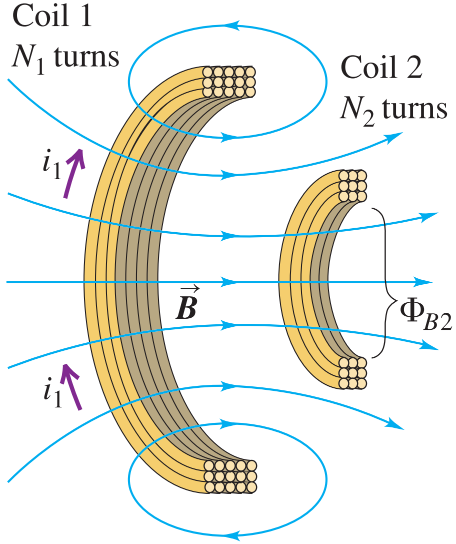

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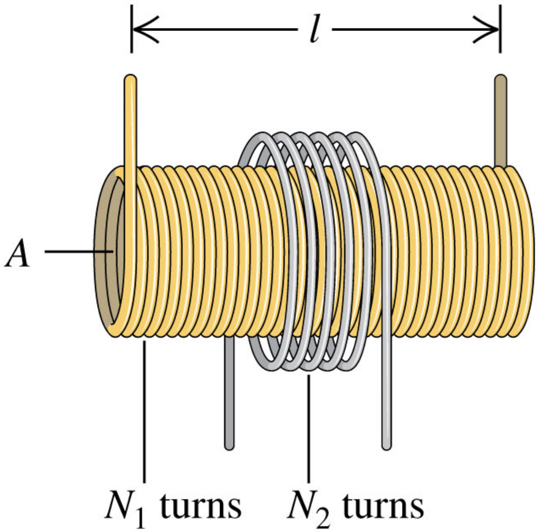
$$M = \frac{N_2 \Phi_{B2}}{i_1} = \frac{N_1 \Phi_{B1}}{i_2} \qquad \text{(mutual inductance)}$$

$$1 \text{ H} = 1 \text{ Wb/A} = 1 \text{ V} \cdot \text{s/A} = 1 \ \Omega \cdot \text{s} = 1 \text{ J/A}^2$$

Mutual inductance examples



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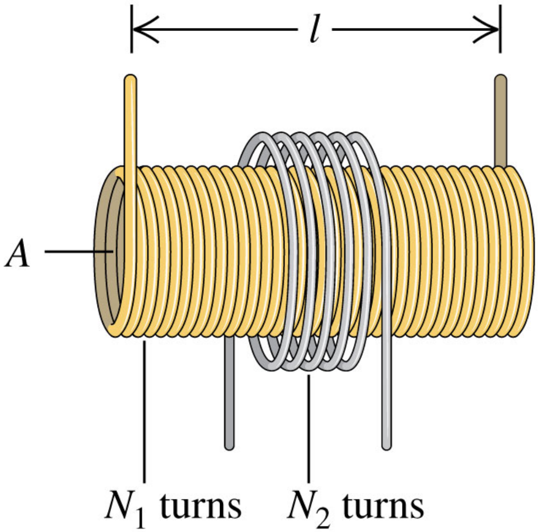

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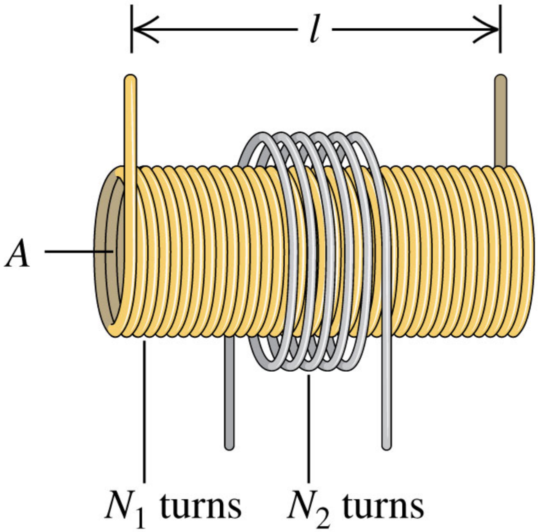

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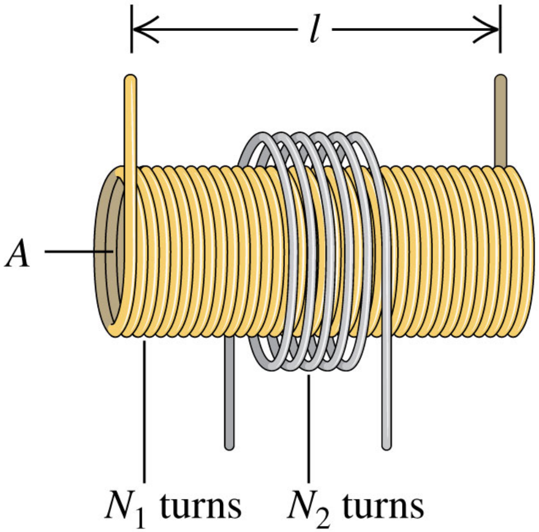

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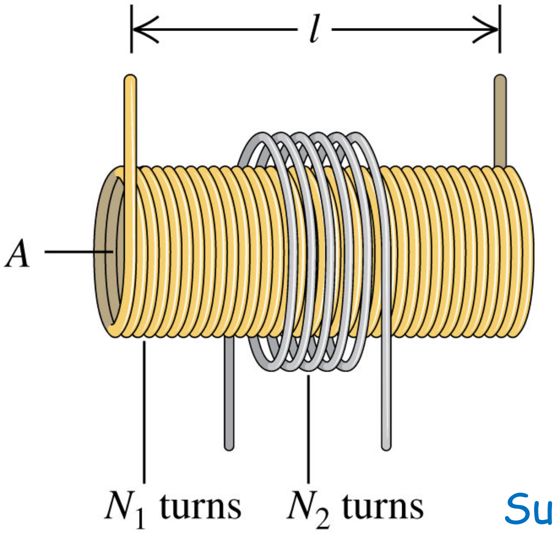

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Suppose l=0.50m, A=10cm^2=110^{-3} m^2,N_1=1000 turns, and $N2$ = 10 turns.

$$\Rightarrow \quad M = \frac{(4\pi \times 10^{-7}\ \mathrm{Wb/A\cdot m})(1.0 \times 10^{-3}\ \mathrm{m}^2)(1000)(10)}{0.50\ \mathrm{m}} = 25 \times 10^{-6}\ \mathrm{Wb/A} = 25 \times 10^{-6}\ \mathrm{H} = 25\ \mu\mathrm{H}$$

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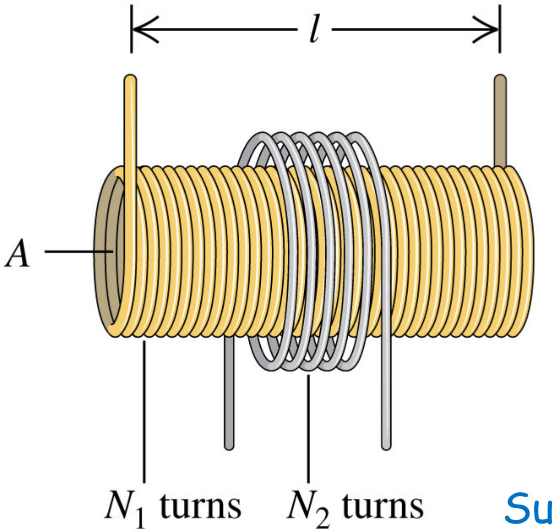

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suppose the current i_2 in the outer coil is given by i_2 = 12.0 x10^6 A/ s)t.
(a) At t = 3.0 μs, what is the average magnetic flux through each turn of the solenoid (coil 1) due to the current in the outer coil? (b) What is the induced emf in the solenoid?

(a

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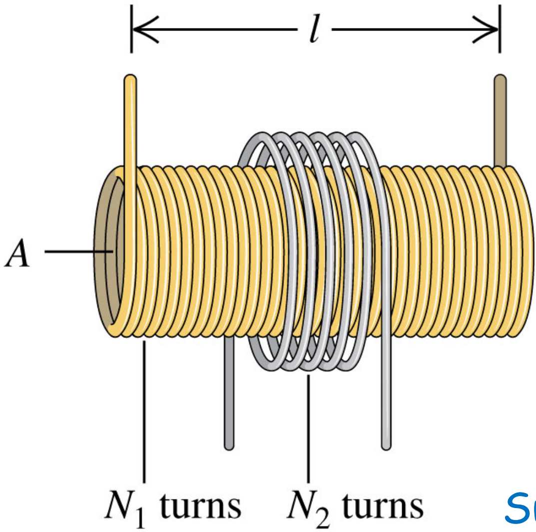

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(a) At t = 3.0 μs, what is the average magnetic flux through each turn of the solenoid (coil 1) due to the current in the outer coil? (b) What is the induced emf in the solenoid?

(a) $i_2 = (2.0 \times 10^6\ \mathrm{A/s})(3.0 \times 10^{-6}\ \mathrm{s})$

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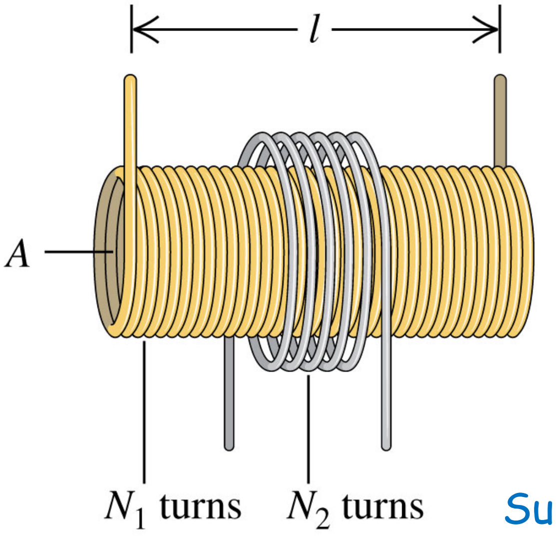

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(a) $i_2 = (2.0 \times 10^6\ \mathrm{A/s})(3.0 \times 10^{-6}\ \mathrm{s})$

$$\Phi_{B1} = \frac{M i_2}{N_1} = \frac{(25 \times 10^{-6}\ \mathrm{H})(6.0\ \mathrm{A})}{1000} = 1.5 \times 10^{-7}\ \mathrm{Wb}$$

(b) di_2/dt = 2 x10^6 A/s)

$$\mathcal{E}_1 = -M\frac{di_2}{dt} = -(25 \times 10^{-6}\ \mathrm{H})(2.0 \times 10^6\ \mathrm{A/s}) = -50\ \mathrm{V}$$

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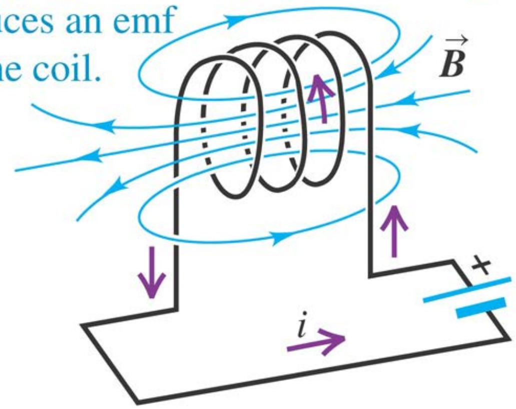

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When a current is present in a circuit, it sets up a **magnetic field** that causes a **magnetic flux** through the *same* circuit;
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➔Thus any circuit that carries a varying current has an emf induced in it by the variation in *its own* magnetic field.

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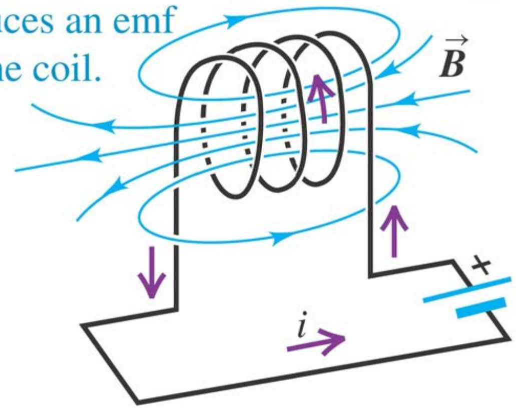

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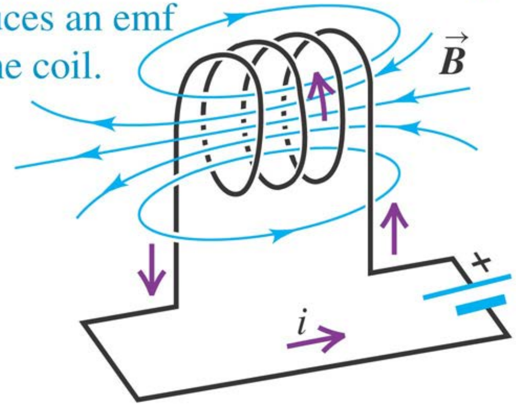

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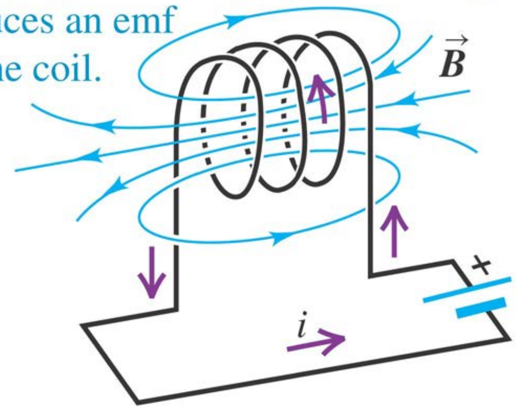

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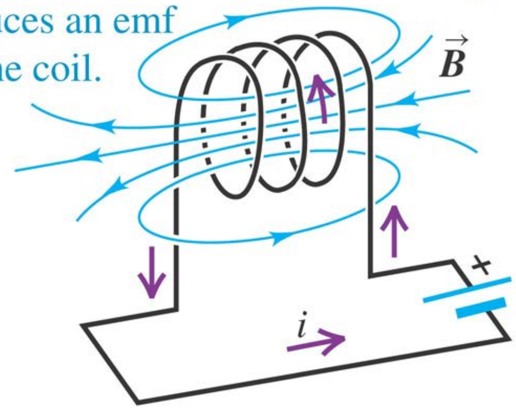

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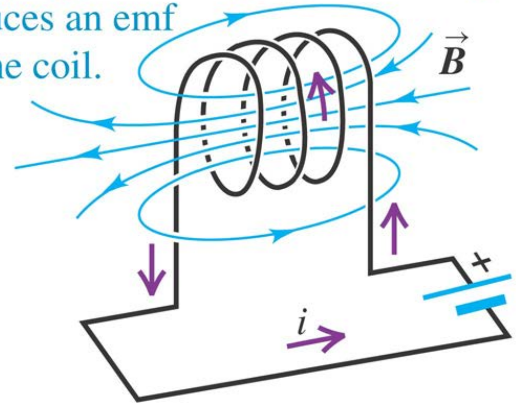

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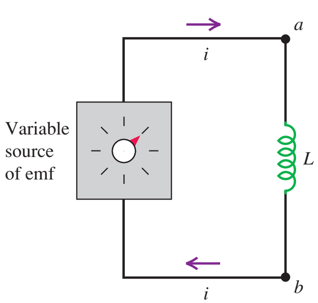
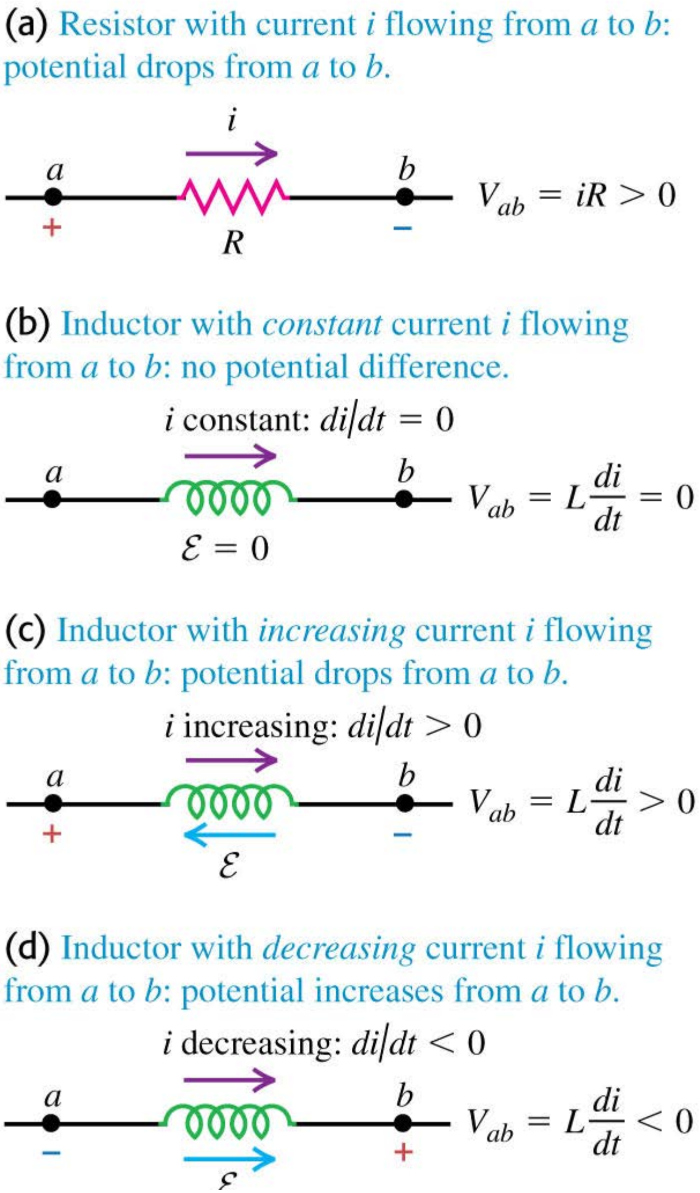
Inductors As Circuit Elements



A circuit device that is designed to have a particular inductance is called an **inductor**, or a *choke*. The usual circuit symbol for an inductor is

Potential across an inductor



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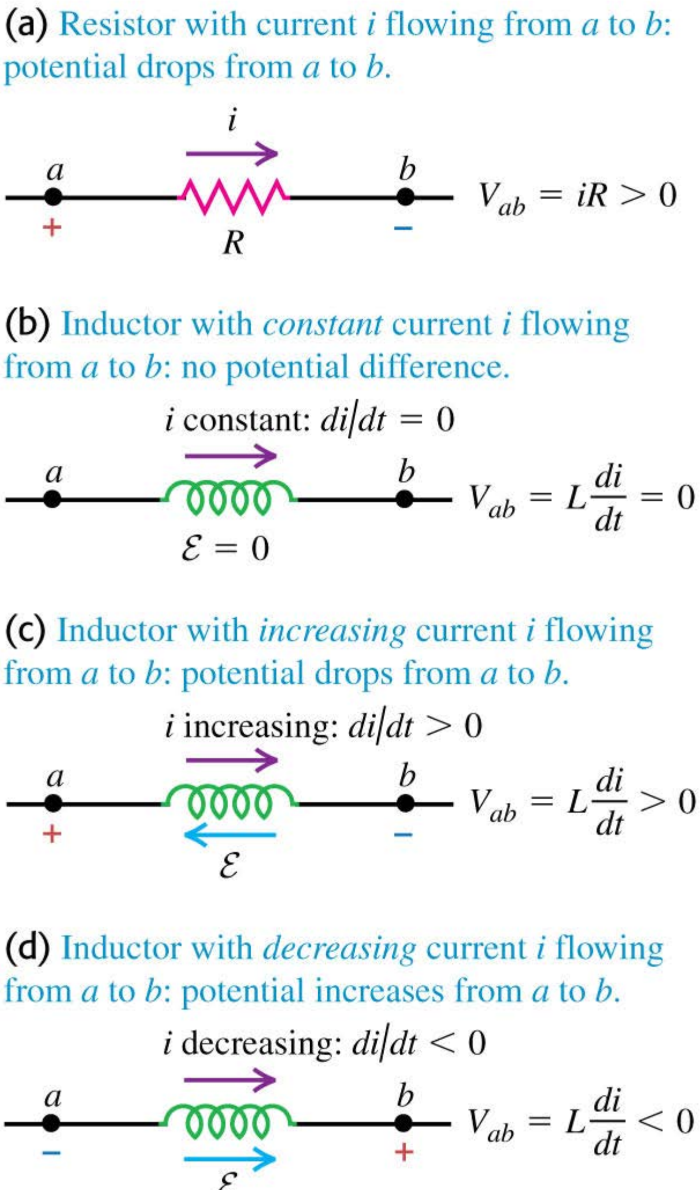

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going around a conducting loop, measuring potential differences across circuit elements, the algebraic sum of these differences around any closed loop must be zero because the electric field produced by charges distributed around the circuit is *conservative* $E_c = 0$

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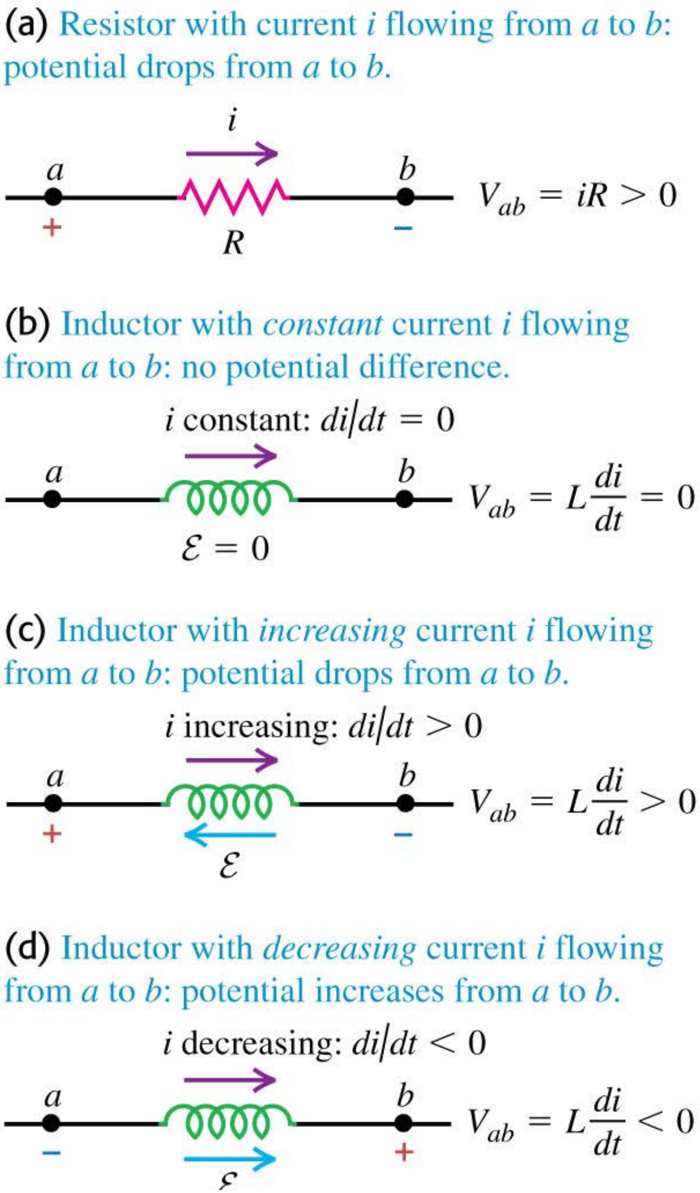

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The self-induced emf does *not* oppose current, but opposes a *change* in the current.

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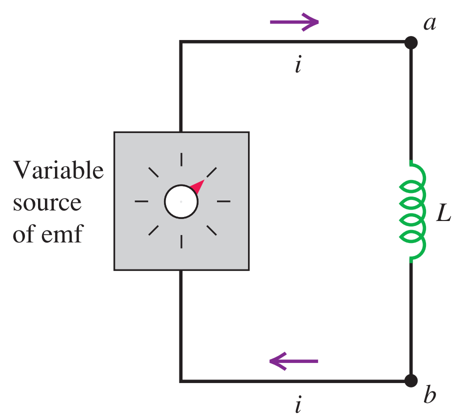

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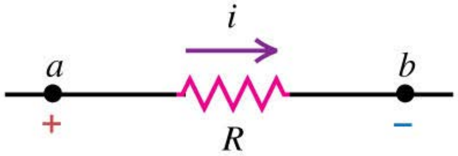
Potential across an inductor

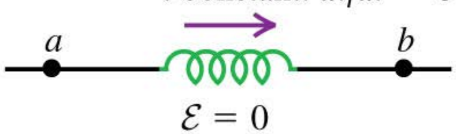
(a) Resistor with current i flowing from a to b: potential drops from a to b.



$V_{ab} = iR > 0$

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

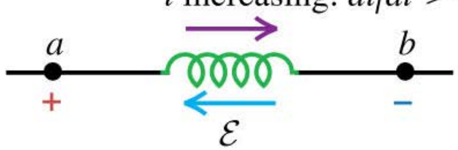
i constant: $di/dt = 0$



$V_{ab} = L\dfrac{di}{dt} = 0$

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

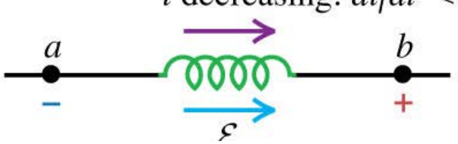
i increasing: $di/dt > 0$



$V_{ab} = L\dfrac{di}{dt} > 0$

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

i decreasing: $di/dt < 0$



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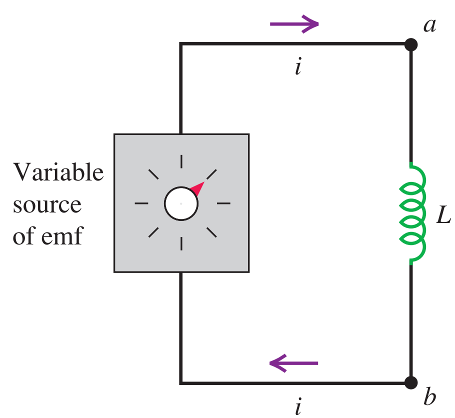

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Faraday's Law: line integral of E_n = negative of the change of the rate of flux

$$\oint \vec{E}_n \cdot d\vec{l} = -L\frac{di}{dt}$$

Potential across an inductor

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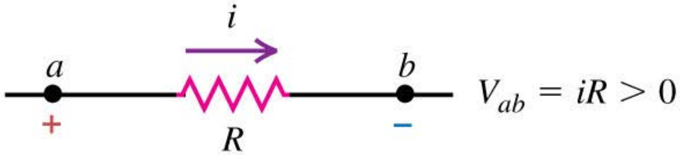

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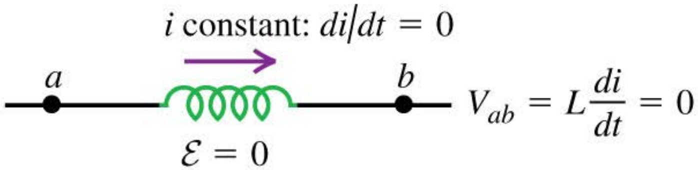

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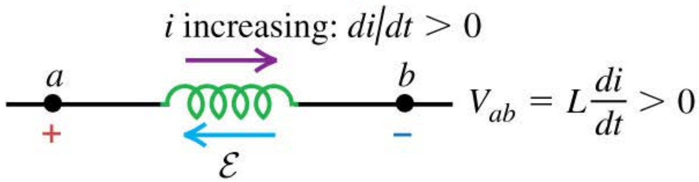

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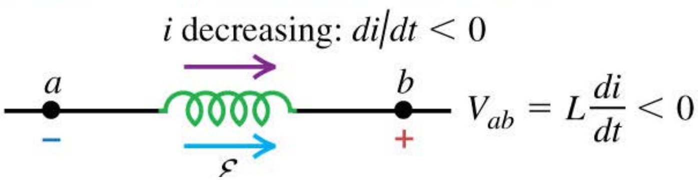

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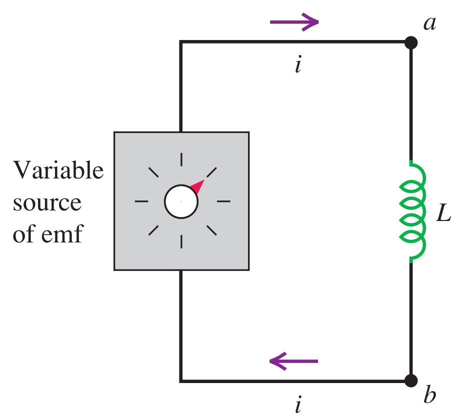

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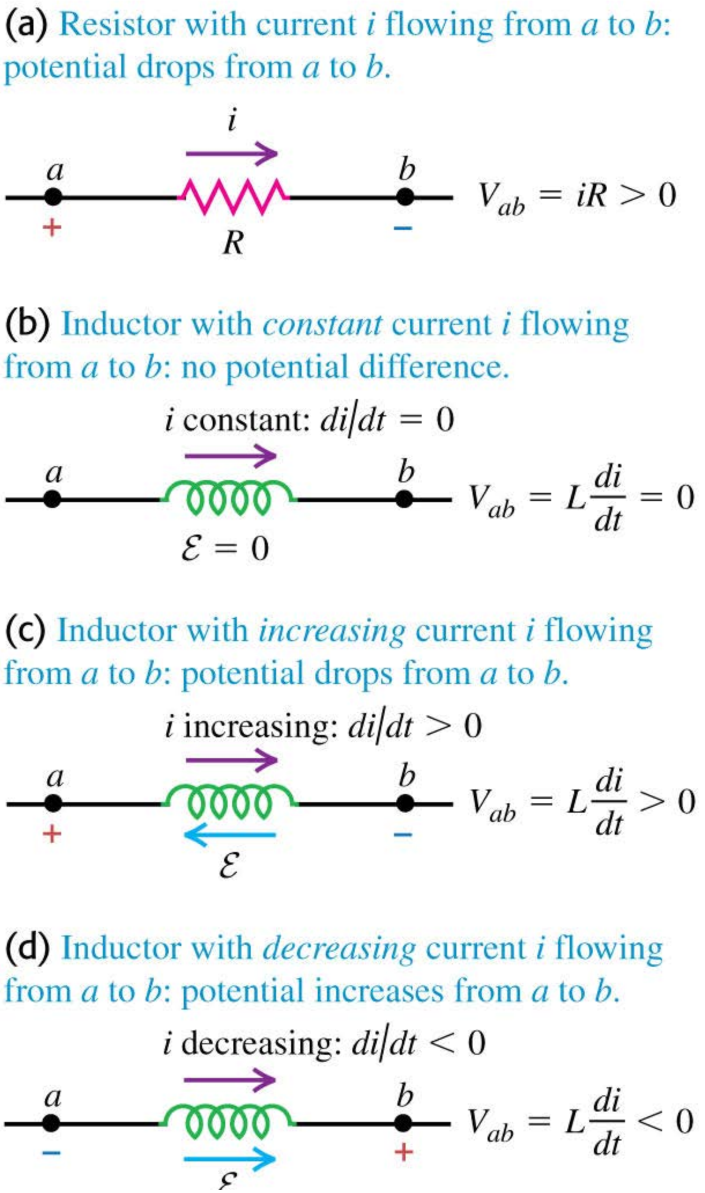

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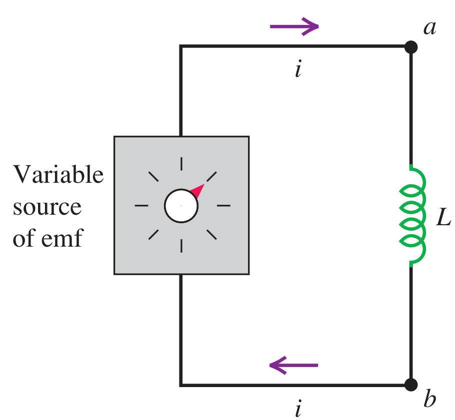

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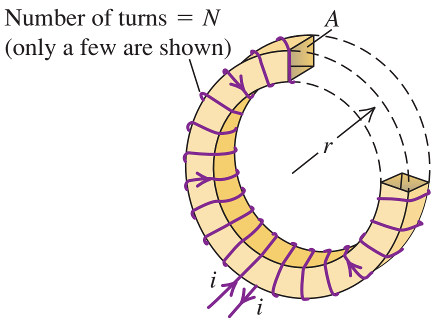
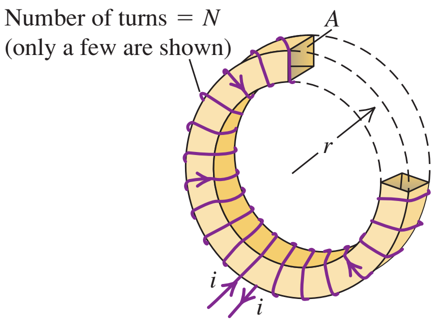


Applications of Inductors

$$L = N\Phi_B/i \qquad B = \mu_0 N i / 2\pi r$$



Applications of Inductors

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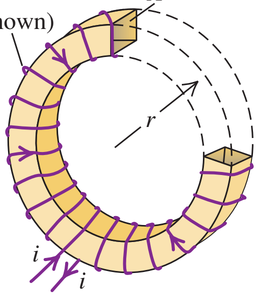
Applications of Inductors



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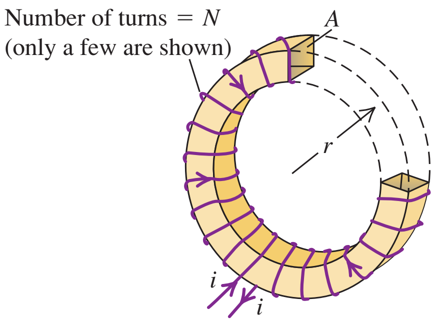
Suppose N = 200 turns, A = 5.0 cm^2 = 5.0x10^{-4} m^2, and r = 0.10 m

$$\Rightarrow L = \frac{(4\pi \times 10^{-7}\ \text{Wb/A}\cdot\text{m})(200)^2(5.0 \times 10^{-4}\ \text{m}^2)}{2\pi(0.10\ \text{m})} = 40 \times 10^{-6}\ \text{H} = 40\ \mu\text{H}$$

Applications of Inductors



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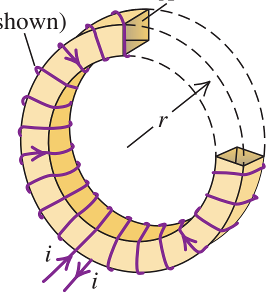
If the current in the toroidal solenoid in the example increases uniformly from 0 to 6.0 A in 3.0 μs, find the magnitude and direction of the self-induced *emf*.

Applications of Inductors



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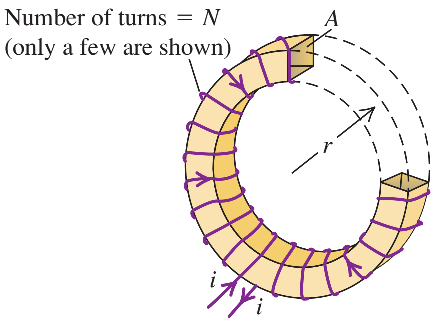
Applications of Inductors



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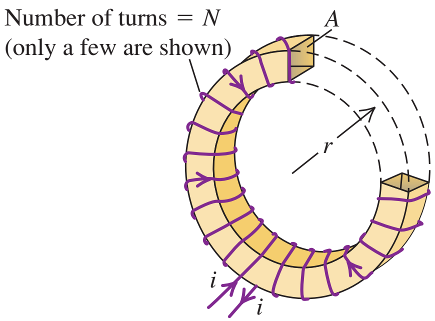
Applications of Inductors



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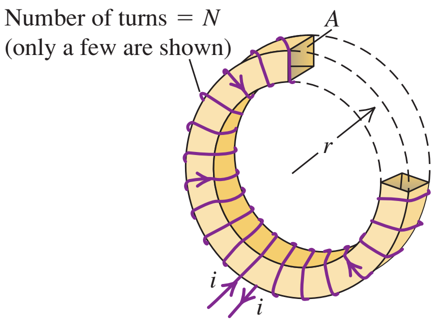
➔ *di/dt* = *Δi/Δt* = (6.0 – 0.0) A / 3.0x10^{-6} s = 2x10^6 A/s

$$|\mathcal{E}| = L\left|\frac{di}{dt}\right| = (40 \times 10^{-6}\ \mathrm{H})(2.0 \times 10^6\ \mathrm{A/s}) = 80\ \mathrm{V}$$

Applications of Inductors



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The current is increasing, so according to Lenz's law the direction of the emf is opposite to that of the current.
This corresponds to the situation in fig.
the emf is in the direction from b to a, like a battery with a as the + terminal and b the - terminal, tending to oppose the current increase from the external circuit.

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