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I have completed at least 50% of the reading and study-guide assignments associated with the lecture, as indicated on the course schedule.  A. True  B. False

Today: New terms: inductance (L), Henry, Back emf, \( \lambda \)

Hint:
Let us look at the first 3 problems from chapter 31.

24-1 asked us to find emf if B field changed as cosine.

24-2 asked us to think about how I(t) varying as cosine in a solenoid produces a B-field of the type used in 24-1.

24-3 asked us to think about a spinning loop generating a sinusoidal current.

That I(t) could be used as the current in 24-1 or -2.
Problem 2 is especially telling:

• When we think about the sinusoidal current flowing through the solenoid what keeps the current from rising infinitely high?

• Well resistance, the internal resistance of the source and the wire but,

• There is one thing more. Think about the coil in problem 2. It has an emf induced in it. That emf will cause a current to flow in the loop.

• But the solenoid itself. What happens in it?
Self Inductance \((L)\)

\[ N\Phi_B \propto I \]

\[ \mathcal{E} = -\frac{d(N\Phi_B)}{dt} \propto -\frac{dI}{dt} \]

\[ L \equiv -\frac{\mathcal{E}}{dI/dt} = \frac{d(N\Phi_B)/dt}{dI/dt} = \frac{N\Phi_B}{I} \quad \text{steady-state} \]

**SI unit of inductance is the Henry = Weber/Amp.**

If the current through a wire loop is double, its self-inductance \((L)\) will be:  
(A) doubled  
(B) halved  
(C) unchanged.
27-1. A 10.0-mH inductor carries a current of \( I = I_{\text{max}} \sin \omega t \) with \( I_{\text{max}} = 5.00 \) A and \( \omega/2\pi = 60.0 \) Hz. What is the magnitude of the back emf at \( t = [01] \) \[\text{s} \]?
\[0.0, \ +20.0 \ \text{V}\]
Doubling the \( (B) \) will:  
(A) double the flux per linkage  
(B) double the inductance  
(C) quadruple the inductance

Doubling the winding number \( N \) at constant winding density \( n \) will:  
(A) double the flux per linkage  
(B) double the inductance  
(C) quadruple the inductance
Magnetic field energy

\[ dU_B = \frac{dU_B}{dt} dt = I \mathcal{E} dt \]

\[ = I \left( L \frac{dI}{dt} \right) dt = LI dI \]

\[ L \equiv \frac{N \Phi_B}{I} \]

\[ U_B = \frac{1}{2} LI^2 = \frac{1}{2} \left( \frac{N \Phi_B}{L} \right)^2 \]

\[ u_B = \frac{U_B}{vol} = \frac{1}{2} LI^2 = \frac{1}{2} \left( \frac{\mu_0 n^2 vol}{\mu_0} \right) I^2 = \frac{1}{2} \left( \frac{\mu_0 n I}{\mu_0} \right)^2 = \frac{1}{2} \frac{B^2}{\mu_0} \]
## Resistor/Capacitor/Inductor similarities

<table>
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<th>Capacitor</th>
<th>Inductor</th>
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<td>( R \equiv \frac{V}{I} )</td>
<td>( C \equiv \frac{Q}{V} )</td>
<td>( L \equiv \frac{(N\Phi)}{I} )</td>
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<tr>
<td>( P = I^2R = \frac{V^2}{R} )</td>
<td>( U_E = \frac{1}{2}CV^2 = \frac{1}{2} \frac{Q^2}{C} )</td>
<td>( U_B = \frac{1}{2}LI^2 = \frac{1}{2} \frac{(N\Phi)^2}{L} )</td>
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<tr>
<td>wire ( R = \frac{\rho L}{A} )</td>
<td>parallel-plates ( C = \varepsilon_0\frac{A}{d} )</td>
<td>solenoid ( L = \mu_0n^2vol )</td>
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<tr>
<td>( E = \frac{V}{d} )</td>
<td>( E = \frac{V}{d} )</td>
<td>( B = \mu_0nI )</td>
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27-2. For the $RL$ circuit shown, let $L = 3.00 \, \text{H}$, $R = 8.00 \, \Omega$, and $\mathcal{E} = [02] \, \text{V}$. The switch is closed at $t = 0$.

(a) Calculate the ratio of the potential difference across the resistor to that across the inductor when $I = 2.00 \, \text{A}$.

(b) Calculate the voltage across the inductor $[03] \, \text{s}$ after the switch is closed. [(a) 0.60, 1.20 (b) 0.100, 0.800 V]
\[ V - I_f R (1 - e^{-t/\tau}) - \frac{L}{\tau} I_f e^{-t/\tau} = (V - I_f R) + I_f \left( R - \frac{L}{\tau} \right) e^{-t/\tau} = 0 \]

\[ I_f = \frac{V}{R} \quad \text{and} \quad \tau = \frac{L}{R} \]

\[ I(t) = \frac{V}{R} \left( 1 - e^{-t/(L/R)} \right) \]

\[ \frac{V}{R} \]

\[ \frac{63.2\%}{\tau = \frac{L}{R}} \]
\[ I(t) = \frac{V}{R} \left(1 - e^{-t/\tau}\right) \]

charge

\[ I(t) = \frac{V}{R} e^{-t/\tau} \]

discharge

\[ \tau = \frac{L}{R} \]
Close and reopen switch (charge & discharge)

Which curve corresponds to the smallest resistor $R$?

(A) blue    (B) orange

Let $L = 1$ mH and $R=100$ Ω. How long (in seconds) will it take for the current to reach half its maximum value?
Resistor & inductor voltages sum to equal constant source voltage.

\[ I(t) = \frac{V_0}{R} \left(1 - e^{-t/\tau}\right) \]

\[ V_R(t) = I(t)R = V_0 \left(1 - e^{-t/\tau}\right) \]

\[ |V_L(t)| = L \left| \frac{dI}{dt} \right| = \frac{L}{\tau} \frac{V_0}{R} e^{-t/\tau} = V_0 e^{-t/\tau} \]
Inductive flyback (back emf)

Sharp blue spikes represent inductive kick or flyback.
Single-loop self inductance

\[ L = (3.12 \times 10^{-8} \text{ H}) r \left( \ln \left( \frac{16r}{d} \right) - 2 \right) \]

(d and r measured in meters)
Mutual inductance

\[ \varepsilon_1 = -L_1 \frac{dI_1}{dt} \quad L_1 = \frac{N_1 \Phi_1}{I_1} \]

\[ \varepsilon_1 = -M \frac{dI_2}{dt} \]

\[ \varepsilon_2 = -M \frac{dI_1}{dt} \]

\[ M = \frac{N_2 \Phi_{21}}{I_1} = \frac{N_1 \Phi_{12}}{I_2} \]
27-3. Two coils, held in fixed positions, have a mutual inductance of 130 $\mu$H. What is the peak voltage in one when a sinusoidal current given by $I(t) = I_{\text{max}} \sin(\omega t)$ flows in the other? $I_{\text{max}} = 12.0$ A and $\omega = [04] \quad \text{_________} \quad \text{s}^{-1}$. [1.00, 1.50 V]
27-4. A [05] ________ -V battery, a 5.00-Ω resistor, and a 12.0-H inductor are connected in series. After the current in the circuit has reached its maximum value, calculate (a) the power being supplied by the battery, (b) the power being delivered to the resistor, (c) the power being delivered to the inductor, and (d) the energy stored in the magnetic field of the inductor. [(a) 20.0, 99.0 W (b) 20.0, 99.0 W (c) 0.0, 99.0 W (d) 20.0, 99.0 J]
Ideal Transformer

\[ M = \frac{N_1 \Phi_{12}}{I_2} = \frac{N_2 \Phi_{21}}{I_1} \]

If \( \Phi_1 = \Phi_2 \) (perfectly linked), then

\[ M^2 = \frac{N_1 \Phi}{I_2} \frac{N_2 \Phi}{I_1} = \frac{N_1 \Phi}{I_1} \frac{N_2 \Phi}{I_2} = L_1 L_2 \]

\[ M = \sqrt{L_1 L_2} \]
Ideal Transformer

If \( \Phi_{12} = \Phi_{21} \equiv \Phi \) (perfectly linked), then

\[
\frac{\varepsilon_1}{\varepsilon_2} = \left(- N_1 \frac{d\Phi_{12}}{dt}\right) \div \left(- N_2 \frac{d\Phi_{21}}{dt}\right) = \left(- N_1 \frac{d\Phi}{dt}\right) \div \left(- N_2 \frac{d\Phi}{dt}\right) = \frac{N_1}{N_2}
\]

\[
M = \frac{N_1 \Phi_{12}}{I_2} = \frac{N_2 \Phi_{21}}{I_1} = \frac{N_1 \Phi}{I_2} = \frac{N_2 \Phi}{I_1}
\]

\[
\Rightarrow \frac{I_1}{I_2} = \frac{N_2}{N_1}
\]

\[
\frac{P_1}{P_2} = \frac{I_1}{I_2} \frac{V_1}{V_2} = \left(\frac{N_2}{N_1}\right) \left(\frac{N_1}{N_2}\right) = 1
\]

\[
\Rightarrow \frac{\varepsilon_2}{\varepsilon_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}
\]

\[
\Rightarrow P_1 = P_2
\]
An electric train set comes with a small transformer \((N_2/N_1 = 5)\) that converts 120 VAC from the wall outlet into the 24 VAC needed by the train engine. If you accidentally wire the transformer backwards, reversing the primary and secondary leads, what voltage do you end up delivering to the train?

(A) 24 V  (B) 120 V  (C) 600 V

If the train is designed to draw 0.6 Amps of current at 24 VAC, what current will it actually draw in the inverted config (assuming that it survives the experience)?

(A) 0.02 A  (B) 0.12 A  (C) 0.6 A  (D) 3.0 A  (E) 15 A

What will be the primary current drawn at the wall outlet?
Given the $V_0$, load resistance $R_L$, and transformer winding ratio $N_s/N_p$, calculate the primary and secondary currents.

\[ \frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p} \]

\[ R_L = \frac{V_s}{I_s} \quad R_{L}' = \frac{V_p}{I_p} \]

\[ \frac{R_{L}'}{R_L} = \frac{V_p}{I_p} / \frac{V_s}{I_s} = \frac{V_p}{V_s} \frac{I_s}{I_p} = \left( \frac{N_p}{N_s} \right) / \left( \frac{N_s}{N_p} \right) = \left( \frac{N_p}{N_s} \right)^2 \]
Given the $V_0$, resistances $R_1$ and $R_2$, and transformer winding ratio $N_s/N_p$, calculate the primary and secondary currents.

$$R_2' = R_2 \left(\frac{N_p}{N_s}\right)^2 \quad I_p = \frac{V_0}{R_1 + R_2'} \quad I_s = I_p \frac{N_p}{N_s}$$

How about the primary and secondary voltages?

$$V_s = I_s R_2 \quad V_p = I_p R_2'$$
If $R_1 = R_2$ and $N_s/N_p = 1/2$, then $P_2/P_1 =$?

(A) 0.25  (B) 0.5  (C) 1.0  (D) 2  (E) 4

$$P_1 = I_p^2 R_1 \quad P_2 = I_s^2 R_2$$

$$\frac{P_2}{P_1} = \left(\frac{I_s}{I_p}\right)^2 \frac{R_2}{R_1} = \left(\frac{N_p}{N_s}\right)^2 \frac{R_2}{R_1} = \left(\frac{N_p}{N_s}\right)^2$$
If \( R_1 = R_2 \) and \( N_s/N_p = 1/2 \), then \( P_2/P_1 = ? \)

(a) 0.25   (b) 0.5   (c) 1.0   (d) 2   (e) 4

\[
P_1 = \frac{V_p^2}{R_1} \quad P_2 = \frac{V_s^2}{R_2}
\]

\[
\frac{P_2}{P_1} = \left(\frac{V_s}{V_p}\right)^2 \frac{R_2}{R_1} = \left(\frac{N_s}{N_p}\right)^2 \frac{R_2}{R_1} = \left(\frac{N_s}{N_p}\right)^2
\]
28-1. The switch in the circuit shown is connected to point \(a\) for a long time. \(R = 14.0\ \Omega,\)
\(L = 0.110\ H,\ C = [01] \quad \mu\text{F},\) and \(\mathcal{E} = 12\ \text{V}.\) After the switch is thrown to point \(b,\)
what are (a) the frequency of oscillation of the \(LC\) circuit, (b) the maximum charge that
appears on the capacitor, (c) the maximum current in the inductor, and (d) the total
energy the circuit possesses at \(t = 3.00\ \text{s}?)\n
[(a) 400, 500\ \text{Hz} \quad (b) 10.0, 20.0\ \mu\text{C}]
(c) 30.0, 50.0\ \text{mA}
(d) \(7.00 \times 10^{-5}, 9.90 \times 10^{-5}\ \text{J}\)
28-2. In the figure, let \( R = 7.60 \, \Omega \), \( L = \boxed{02} \) mH, and \( C = 1.80 \, \mu F \). (a) Calculate the frequency of the damped oscillation of the circuit. (b) What is the critical resistance? 

[(a) \( 2.00 \times 10^3 \), \( 3.00 \times 10^3 \) Hz (b) 60.0, 90.0 \( \Omega \)]
28-3. The switch in the figure is thrown closed at $t = 0$.

$R = 75$ $\Omega$, $E = [03] \quad \text{V}$, $C = 1.80$ $\mu$F, and

$L = 2.20$ mH. Before the switch is closed, the capacitor is uncharged and all currents are zero. The instant after the switch is closed, determine the currents in (a) $L$, (b) $C$, and (c) $R$. Also determine the potential differences across (d) $L$, (e) $C$, and (f) $R$. A long time after the switch is closed, determine the potential differences across (g) $L$, (h) $C$, and (i) $R$. [(a) 0.000, 0.500 A (b) 0.000, 0.500 A (c) 0.000, 0.500 A (d) 0.0, 40.0 V (e) 0.0, 40.0 V (f) 0.0, 40.0 V (g) 0.0, 40.0 V (h) 0.0, 40.0 V (i) 0.0, 40.0 V]
29-1. An inductor is connected to a 20.0-Hz power supply that produces a 50.0-V peak voltage. What inductance is needed to keep the instantaneous current in the circuit below [01] _________ mA? [4.00, 7.00 H]