When a circuit is linked to itself via a self-inductance, then
(A) the self inductance depends only on geometric factors and magnetic material properties.
(B) the induced EMF is proportional to the rate of change of the current.
(C) the resistance to change can be thought of as analogous to inertia in mechanics (according to the instructor).
(D) all of the above.
(E) none of the above.

When two circuits are linked via a mutual inductance, then
(A) the mutual inductance which links circuit one to circuit two is the same as the mutual inductance which links circuit two to circuit one.
(B) the mutual inductance depends only on geometric factors and magnetic material properties.
(C) a change in the current in one circuit produces an EMF in the other.
(D) all of the above.
(E) none of the above.

Suppose we have two closely wound circular coils of wire with the same number of turns, but the second coil has twice the radius of the other. Then when we compare the second coil to the first
(A) because the magnetic field for a given current is half the strength, but distributed over 4 times the area, the self inductance of the second coil should be twice that of the first.
(B) because the magnetic field for a given current is twice the strength, but distributed over 4 times the area, the self inductance of the second coil should be 8 times that of the first.
(C) because the magnetic field for a given current is the same strength, but distributed over 4 times the area, the self inductance of the second coil should be twice that of the first.
(D) because the magnetic field for a given current is half the strength, but distributed over twice the area, the self inductance of the second coil should be twice that of the first.
(E) the self inductance will be the same because they have the same number of coils!

A coil has a self inductance of $L=.05 \, \text{H}$. The current in the coil increases uniformly, at a rate of $0.02 \, \text{A/s}$. The magnitude of the induced EMF in the coil is
(A) 0 mV.
(B) 1 mV.
(C) 25 mV.
(D) 40 mV.
(E) none of the above.

A current $i$ goes through an inductor as shown at right. If the current is increasing, then
(A) the potential at (a) is higher than at (b).
(B) the potential at (a) is the same as that than at (b).
(C) the potential at (a) is lower than at (b).
(D) the potential at (a) is independent of the potential at (b).
(E) none of the above.
A current $i$ goes through an inductor as shown at right. If the current is decreasing, then
(A) the potential at (a) is higher than at (b).
(B) the potential at (a) is the same as that than at (b).
(C) the potential at (a) is lower than at (b).
(D) the potential at (a) is independent of the potential at (b).
(E) none of the above.

A current $i$ goes through an ideal inductor as shown at right. If the current is constant, then
(A) the potential at (a) is higher than at (b).
(B) the potential at (a) is the same as that than at (b).
(C) the potential at (a) is lower than at (b).
(D) the potential at (a) is independent of the potential at (b).
(E) none of the above.

To store $3.6 \times 10^6$ J (1 kWh) in a uniform magnetic field confined to a volume of 0.125 m$^3$ requires a magnetic field strength of
(A) 72 T.
(B) 36 T.
(C) 8.5 T.
(D) 6.0 T.
(E) none of the above.

The LRC series circuit is analogous to
(A) the simple harmonic oscillator.
(B) the damped harmonic oscillator.
(C) sliding friction on an inclined plane.
(D) free fall.
(E) none of the above.

An ideal series L-C circuit is connected to a switch. The capacitor is initially charged when the switch is closed at $t=0$. Which graph below best describes the current as a function of time?

(A)  
(B)  
(C)  
(D)  
(E) none of the above.
An ideal series R-L circuit is connected to a switch. The switch is closed at \( t=0 \). Which graph below best describes the current as a function of time?

(A)  
(B)  
(C)  
(D)  
(E) none of the above.

An series LRC circuit is connected to a switch. The capacitor is initially charged when the switch is closed at \( t=0 \). Which graph below best describes the voltage across the capacitor as a function of time?

(A)  
(B)  
(C)  
(D)  
(E) none of the above.

The LRC series circuit is analogous to
(A)  the simple harmonic oscillator.
(B)  the damped harmonic oscillator.
(C)  sliding friction on an inclined plane.
(D)  free fall.
(E) none of the above.

The impedance of a series RLC circuit as a function of frequency
(A)  is zero.
(B)  is actually constant.
(C)  is a maximum at the resonant frequency.
(D)  is a minimum at the resonant frequency.
(E)  is negative at frequencies above the resonant frequency.
A capacitor will have a lower reactance at
(A) higher frequencies.
(B) lower frequencies.
(C) higher voltages.
(D) lower voltages.
(E) none of the above affect the reactance of a capacitance.

An inductor will have a lower reactance at
(A) higher frequencies.
(B) lower frequencies.
(C) higher voltages.
(D) lower voltages.
(E) none of the above affect the reactance of an inductor.

A resistor will have a higher resistance at
(A) higher frequencies.
(B) lower frequencies.
(C) higher voltages.
(D) lower voltages.
(E) none of the above affect the resistance of a resistor.

In a given series R-L-C circuit, if the inductance were to be decreased, then
(A) the impedance of the series combination would decrease.
(B) the impedance of the series combination would increase.
(C) the impedance of the series combination would remain constant.
(D) the impedance of the series combination could increase, decrease or remain the same.
(E) the impedance of the series combination would necessarily be zero.

In a given series R-L-C circuit the current through the inductor
(A) is the same as the current through the resistor.
(B) is higher or lower than the current in the resistor depending upon the frequency.
(C) leads the current in the resistor by 90°.
(D) lags the current in the resistor by 90°.
(E) is necessarily zero.

In a series R-L-C circuit operated at some fixed frequency, the phase of the current in the capacitor
(A) lags the phase of the current in the resistor by 90°.
(B) lags the phase of the current in the inductor by 180°.
(C) leads the phase of the current in the resistor by 90°.
(D) leads the phase of the current in the resistor by 180°.
(E) is in phase with the current of both the inductor and the resistor.

The impedance of a series RLC circuit at resonance is
(A) less than R.
(B) equal to R.
(C) greater than R.
(D) any of the above depending upon the circumstances.
(E) negative.
The impedance of a series RLC circuit as a function of frequency
(A) is zero.
(B) is actually constant.
(C) is a maximum at the resonant frequency.
(D) is a minimum at the resonant frequency.
(E) is negative at frequencies above the resonant frequency.

The unit of reactance is:
(A) Farads.
(B) Ohms.
(C) Henries.
(D) Mhos.
(E) Hertz.

The unit of capacitive reactance is:
(A) Farads.
(B) Ohms.
(C) Henries.
(D) Mhos.
(E) radians per second.

The device for which the AC current amplitude depends upon the voltage amplitude, but is independent of the frequency:
(A) Capacitor.
(B) Inductor.
(C) Transducer.
(D) Resistor.
(E) Transmorgrifier.

The average power delivered to an AC circuit depends upon
(A) the voltage amplitude.
(B) the current amplitude.
(C) the phase between the instantaneous voltage and the instantaneous current.
(D) all of the above.
(E) none of the above.

The voltage at the secondary coil of a transformer is induced by
(A) a varying electric field.
(B) a varying magnetic field.
(C) the iron core of the transformer.
(D) motion of the primary coil.
(E) a steady current in the primary.

A step-up transformer, such as the one used in the often demonstrated Jacob’s Ladder,
(A) “steps up” the voltage power at the secondary compared to that at the primary.
(B) “steps down” the current at the secondary compared to that at the primary.
(C) conserves energy by delivering the same power to the secondary as is delivered to the primary.
(D) all of the above.
The power delivered by the secondary in a step-up transformer is
(A) greater than that delivered to the primary.
(B) less than that delivered to the primary.
(C) the same as that delivered to the primary.
(D) independent of that delivered to the primary.
(E) none of the above.

A power supply uses a transformer which is designed to supply 10V (at the secondary) from a 120V source (at the primary). The ratio of secondary to primary turns should be
(A) 1/12.
(B) 1/20.
(C) 12.
(D) 20.
(E) none of the above.

A power supply uses a transformer which is designed to supply 24,000V (at the secondary) from a 120V source (at the primary). The ratio of primary to secondary turns should be
(A) 1/120.
(B) 1/200.
(C) 120.
(D) 200.
(E) none of the above.

The radiation pressure exerted on a reflecting surface is
(A) twice that exerted on an absorbing surface.
(B) half that exerted on an absorbing surface.
(C) equal to that exerted on an absorbing surface
(D) twice that exerted on a transparent surface.
(E) half that exerted on a transparent surface.
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Electromagnetic waves in vacuum
(A) travel at a speed which is independent the frequency of the waves.
(B) are consistent with Maxwell's equations.
(C) carry energy.
(D) carry momentum.
(E) all of the above.

Electromagnetic waves in vacuum
(A) travel at a speed which depends upon the frequency of the waves.
(B) are inconsistent with Maxwell’s equations.
(C) dissipate energy.
(D) carry momentum.
(E) are impossible, no waves can travel in vacuum!

The radiation pressure exerted on a reflecting surface is
(A) twice that exerted on an absorbing surface.
(B) half that exerted on an absorbing surface.
(C) equal to that exerted on an absorbing surface
(D) twice that exerted on a transparent surface.
(E) half that exerted on a transparent surface.

The radiation pressure exerted on an transparent surface is
(A) twice that exerted on a absorbing surface.
(B) half that exerted on a absorbing surface.
(C) equal to that exerted on a reflecting surface.
(D) twice that exerted on a reflecting surface.
(E) zero.

In electromagnetic radiation, the Poynting vector
(A) is parallel to \( B \), the magnetic field.
(B) is parallel to \( E \), the electric field.
(C) is perpendicular to \( \mathbf{v} \), the wave velocity.
(D) has average magnitude equal to the radiation intensity.
(E) all of the above.

In electromagnetic radiation, the Poynting vector
(A) is perpendicular to \( B \), the magnetic field.
(B) is perpendicular to \( E \), the electric field.
(C) is parallel to \( \mathbf{v} \), the wave velocity.
(D) has average magnitude equal to the radiation intensity.
(E) all of the above.

At an instant in time the Electric and Magnetic fields at a point in space where there is an electromagnetic wave. The electric field is directed in the east and the magnetic field is directed up. The direction in which the wave is moving is
(A) east.
(B) up.
(C) south.
At an instant in time the Electric and Magnetic fields at an instant in space where there is an electromagnetic wave. The magnetic field is directed in the +x direction and the electric field is directed in the +y direction. The direction in which the wave is moving is
(A) +x direction.
(B) +y direction.
(C) +z direction.
(D) –z direction.
(E) none of the above.

The energy stored in an electromagnetic wave
(A) is split evenly between the electric and magnetic fields.
(B) is stored entirely in the magnetic field.
(C) is stored entirely in the electric field.
(D) is 0, energy cannot be stored in mathematical abstractions.

The light from a flashlight carries momentum. The reason that the person holding the flashlight does not notice any recoil (analogous to the recoil of a rifle when fired) is that
(A) the momentum in light is simply a mathematical construct, it is not real momentum.
(B) visible light generally has zero momentum.
(C) the recoil force is very small (but not zero).
(D) the light is quickly absorbed, so that the momentum is quickly dissipated.

Red visible light is an electromagnetic wave with a wavelength of about 700nm in air (where the speed of electromagnetic waves is $3.00\times10^8 \text{ m/s}$). The frequency of the red light is
(A) $4.28\times10^14 \text{ Hz}$.
(B) $4.28\times10^5 \text{ Hz}$
(C) $2.33 \mu\text{s}$.
(D) $210 \text{ s}$.
(E) none of the above.

An electromagnetic wave of frequency 10.5 GHz propagates in air (where the speed of electromagnetic waves is $3.00\times10^8 \text{ m/s}$). The spacing between successive nodes in a standing wave are (remember: nodes are spaced every half wavelength)
(A) .7 cm.
(B) 1.4 cm.
(C) 2.8 cm.
(D) 10.5 cm.
(E) none of the above.
Self inductance of a coaxial cable: A small solid conductor with radius $a$ is supported by insulating disks on the axis of a thin walled tube with inner radius $b$. The inner and outer conductors carry equal currents $i$ in opposite directions. From work done with Ampere’s Law earlier this semester, we know that in the region between the two conductors the magnetic field strength is given by

$$B(r) = \frac{\mu_0 i}{2\pi r}.$$

a) Write the expression for the flux $d\Phi_B$ through a narrow strip of length $L$ and width $dr$, parallel to the at and a distance $r$ from the inner conductor lying in a plane containing the axis of the coaxial cable.

b) Integrate your expression to find the total flux produced in the region between the conductors.

c) From the last result, derive an expression for the inductance of a length $L$ of coaxial cable. The result should be expressed in terms of the variables $i$, $a$, $b$, and $L$.

A long, straight solenoid has $N$ turns, a uniform cross-section area $A$, length $l$, and is filled with a material with magnetic permeability $\mu$. If the solenoid carries a current $I$,

(A) determine the magnetic field within the solenoid in terms of the parameters given above,

(B) determine the magnetic flux through the cross section of the solenoid in terms of the parameters given above,

(C) use the above information to determine the self inductance in terms of the parameters given above.

A long, straight solenoid has $N_s$ turns, a uniform cross-section area $A$, length $L$, and is filled with a material with magnetic permeability $\mu$. A coil with $N_c$ turns and radius $r$ is loosely wrapped around the outside of the solenoid as shown. If the solenoid carries a current $I$,

(A) determine the magnetic field within the solenoid in terms of the parameters given above,

(B) determine the total magnetic flux through the coil in terms of the parameters given above,

(C) use the above information to determine the mutual inductance in terms of the parameters given above.

It is proposed to store 1.00 kWh = $3.60 \times 10^6$ J of electrical energy in a uniform magnetic field.

(A) If the energy is to stored in a field with magnitude $.500$ T. What volume of magnetic field is required?

(B) If the volume is to be $0.125$ m$^3$, what strength magnetic field is required?
A transformer has 40 turns in its primary winding and 80 turns in its secondary winding. The primary AC voltage is $V_{rms} = 120$ V and a resistance of 15 $\Omega$ is placed across the secondary.

(a) What is the secondary rms Voltage?
(b) What is the rms current delivered by the secondary?
(c) What is the average power delivered by the secondary?
(d) What rms current is delivered to the primary?
(e) What average power is delivered to the primary?

Show that the differential equation
\[
\frac{d^2 q}{dt^2} + \frac{1}{LC} q = 0
\]
is satisfied by
\[
q(t) = Q \cos(\omega t + \phi) \quad (Q, \omega, \phi \text{ are constants}) \quad \text{when} \quad \omega = \frac{1}{\sqrt{LC}}.
\]

Do this by “plugging in” the expression for $q$ into the differential equation, evaluating the derivatives, and showing that the equality holds.

A variable capacitor to be used in the tuner for a radio has a maximum capacitance of 30.0 pF.

(A) What is the inductance of a coil connected to this capacitor if the minimum natural frequency of the L-C circuit is to be 540 kHz (the low end of the AM radio broadcast band)?

(B) What should the minimum capacitance of the variable capacitor be if the natural frequencies of the L-C circuit are to extend to 1600 kHz (the high end of the AM broadcast band)?

For an LC circuit, the charge as a function of time is given by
\[
q(t) = Q \cos(\omega t + \phi) \quad (Q, \omega, \phi \text{ are constants})
\]
and the relation between the charge and the current is
\[
i = \frac{dq}{dt}.
\]
The total energy of the circuit is given by the sum of the inductor's stored energy and the capacitor's stored energy:
\[
E = U_L + U_C = \frac{1}{2} L i^2 + \frac{1}{2C} q^2.
\]
Show that rate of change of total energy,
\[
\frac{dE}{dt} = \frac{d}{dt} \left( \frac{1}{2} L i^2 + \frac{1}{2C} q^2 \right),
\]
is equal to zero (that is, the total energy is constant!)

The relation between the net force and acceleration in the damped harmonic oscillator is given by
\[
-kx - b \frac{dx}{dt} = m \frac{d^2 x}{dt^2},
\]
(Equation 1)
and the resulting frequency of oscillation is given by
\[
\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}
\]
(Equation 2)

(A) In Equation 1, substitute $q$ for $x$, $L$ for $m$, $1/C$ for $k$ and $R$ for the damping constant $b$. Compare your result with the result from applying Kirchoff’s loop rule to an undriven LRC series combination:
\[
-\frac{q}{C} - Ri - L \frac{di}{dt} = 0
\]
Are they the same?

(B) Make the same set of substitutions in Equation 2 to determine the frequency of oscillations for the undriven series LRC circuit.
You are asked to design an L-C circuit in which the stored energy is $3.00 \times 10^{-4}$ J and the natural frequency is $\omega_0 = 6.00 \times 10^4$ rad/s. Because of the limited dielectric strength of the material used in the capacitor, the maximum voltage across it is to be 60.0 V.

(A) Determine the capacitance required, knowing that the voltage across the capacitance will be a maximum at the same points in time when all the energy in the circuit is stored in the capacitor.

(B) Determine the inductance of the inductor given the natural frequency and the capacitance determined in part (A).

An L-R-C series circuit is constructed with a 100 $\Omega$ resistor, a 2.00 H inductor and a 2.00 $\mu$F capacitor. Determine

(A) the resonant frequency (in rad/s) of this circuit,

(B) the quality factor of this circuit.

(C) the frequency width (in rad/s) of the resonance.

If the circuit is driven by a 2.00 V (amplitude) source with a frequency of 300 rad/s, calculate the

(D) inductive reactance of the inductor,

(E) capacitive reactance of the capacitor,

(F) impedance of the series combination,

(G) the current amplitude for the current through the combination

(H) the phase angle for the current relative to the voltage

(I) the voltage amplitude for the resistor

(J) the voltage amplitude for the capacitor

(K) the voltage amplitude for the inductor

A small helium-neon laser emits light at a wavelength of 632.8 nm with a power of 5 mW in a narrow beam that has a diameter of 4.00 mm. (*The beam is not radiated in all directions!*)

(A) What is the frequency (in Hz) of the light?

(B) What is the intensity of the light in the beam?

(C) What is the electric field amplitude?

(D) What is the magnetic field amplitude?

(E) What is the energy density associated with the light?

(F) What is the force exerted by the light on a mirror (ideal reflector) 10cm x 10cm if it is used to reflect the beam back upon itself?

A monochromatic light source with power output 2.00 kW radiates light of wavelength 450nm uniformly in all directions. At a distance of 2.00 m, determine

(A) the frequency (in Hz) of the light,

(B) the intensity of the light,

(C) the electric field amplitude,

(D) the magnetic field amplitude,

(E) the average energy density associated with the light.

(F) What is the force exerted by the light on a mirror (ideal reflector) 2cm x 2cm if it is used to reflect the light back upon itself?

(G) What is the force exerted by the light on a 1cm x 1cm flat black material oriented face towards the light source?
An L-R-C series circuit is constructed with a 2.00 H inductor, two resistors in series \((R_1 = 200 \, \Omega, \, R_2 = 40 \, \Omega)\), and a 2.50 µF capacitor. If the circuit is driven by a 4.00 V (amplitude) source with a frequency of 200 rad/s, calculate the

(A) inductive reactance of the inductor,
(B) capacitive reactance of the capacitor,
(C) impedance of the entire series combination,
(D) the current amplitude for the current through the combination,
(E) the phase angle for the current relative to the voltage,
(F) the voltage amplitude for the capacitor,
(G) the voltage amplitude for the resistor \(R_2\),
(H) the impedance of just the series combination of the inductor and \(R_1\), and
(I) the voltage amplitude across just the series combination of the inductor and \(R_1\).

Solar Sailing: A solar sailboat is to use the radiation pressure from the sun for thrust by using a large, low mass totally reflecting sail. The total power output from the sun is 3.9x10^{26} \, W

(A) At a distance from the sun corresponding to Earth’s orbit \((1.5 \times 10^{11} \, m)\), what is the intensity of the sunlight?
(B) What is the radiation pressure on a perfect reflector at this distance from the sun?
(C) What is the force of gravitational attraction of the sun on a 5000 kg object? Recall Newton’s Law of universal gravitation

\[ F = \frac{GMm}{r^2} \]

\[ G = 6.673 \times 10^{-11} \, \frac{N \cdot m^2}{kg^2} \]

and note that the mass of the sun is 1.99x10^{30} kg.

(D) What are sail would be required for the force due to light pressure to just balance the force of gravitational attraction for the 5000kg object?

2 point bonus: The answer to part (D) would be higher, lower or the same if the object were closer to the sun.

It is proposed that powerful ground based lasers can provide means of propulsion for a space probe (similar to a solar sail). A 50 Kg payload is supported by a circular reflecting sail 5 km in radius. The weight (i.e. force of gravitational attraction) just above the atmosphere is about 500N. The force that must be provided by the sail is to just balance the gravitational attraction.

(A) What is the necessary radiation pressure on the sail (assume that sail is completely and uniformly illuminated)
(B) What is the radiation intensity required for this pressure to be exerted on the reflecting sails?
(C) What is the minimum total power of the laser beam?
(D) What is the electric field amplitude within the beam?
(E) What is the magnetic field amplitude within the beam?
A monochromatic light source with power output 100 W radiates light of wavelength 500 nm uniformly in all directions. At a distance of 4.00 m, determine

(A) the frequency (in Hz) of the light,
(B) the intensity of the light,
(C) the electric field amplitude,
(D) the magnetic field amplitude,
(E) the average energy density associated with the light.
(F) What is the force exerted by the light on a mirror (ideal reflector) 2 cm x 4 cm if it is used to reflect the beam back upon itself?
(G) What is the force exerted by the light on a 1 cm x 1 cm flat black material?