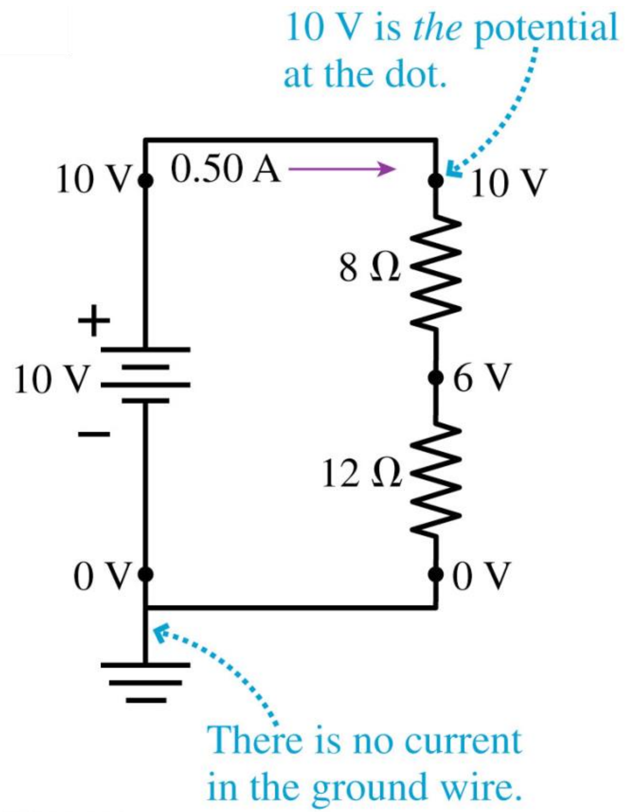
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Science A Physics

Lectures 23-30:

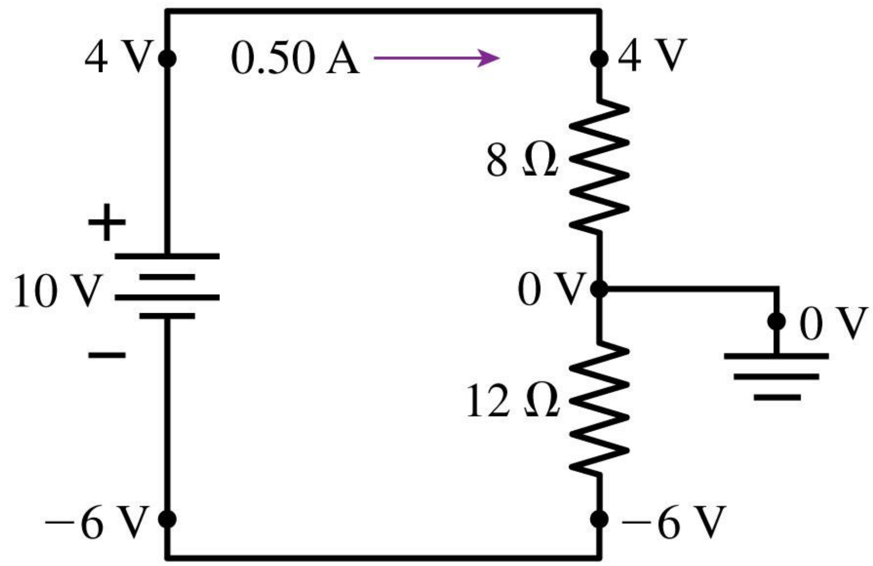
Answers to Additional Problems: Magnetism, Induction, Reactance, and Series Resonance

A Grounded Circuit



Q.1 Suppose the circuit above were grounded at the junction between the two resistors instead of at the bottom. Find the potential at each corner of the circuit.

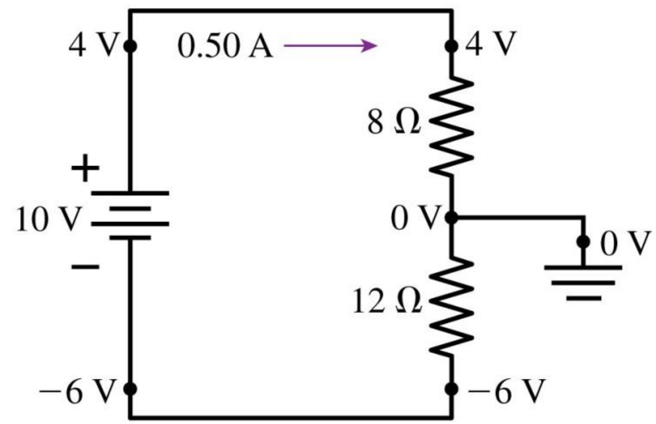
A Grounded Circuit



VISUALIZE:

The figure above shows the new circuit. It is convention to draw the ground symbol so that its 'point' is always down.

A Grounded Circuit

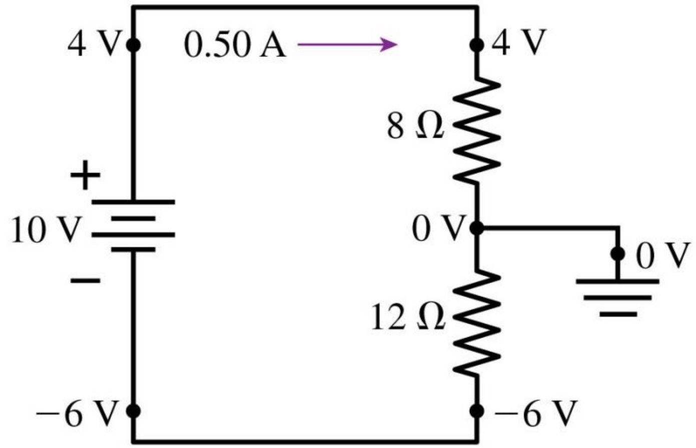


SOLVE:

Changing the ground point does not affect the circuit's behavior. The current is still 0.50 A, and the potential differences across the two resistors are still 4 V and 6 V. All that has happened is that we have moved the V = 0 V reference point.

Because the earth has V_{earth} = 0 V, the junction itself now has a potential of 0 V. The potential decreases by 4 V as charge flows through the 8 Ω resistor. Because it ends at 0 V, the potential at the potential at the top of the 8 Ω resistor must be +4 V.

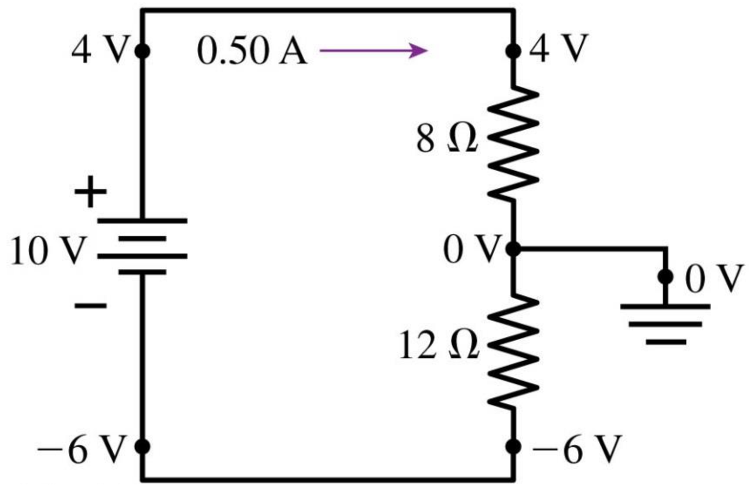
A Grounded Circuit



Similarly, the potential decreases by 6 V through the 12 Ω resistor. Because it ***starts*** at 0 V, the bottom of the 12 Ω resistor must be at -6 V. The negative battery terminal is at the same potential as the bottom of the 12 Ω resistor, because they are connected by a wire, so V_{neg} = -6 V.

Finally, the potential increases by 10 V as the charge flows through the battery, so V_{pos} = +4 V, in agreement, as it should be, with the potential at the top of the 8 Ω resistor.

A Grounded Circuit



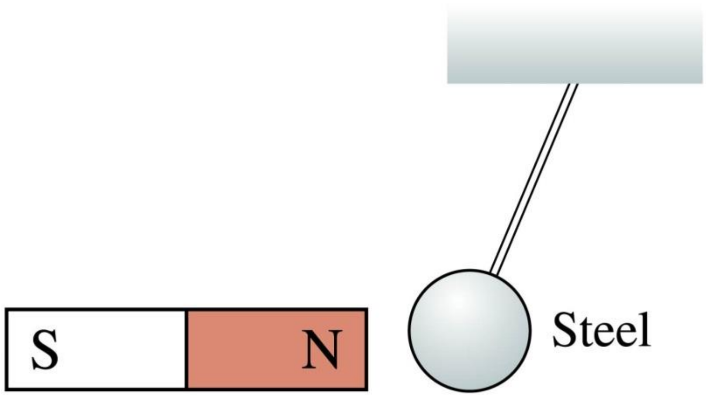
ASSESS: A negative voltage means only that the potential at that point is less than the potential at some other point that we chose to call $V = 0$ V.

Only potential differences are physically meaningful, and only ***potential differences*** enter into Ohm's law: $I = \Delta V/R$. The potential differences across the 12 Ω resistor in this example is 6 V, decreasing from top to bottom, regardless of which point we chose to call $V = 0$ V.

Magnetism

Q.2 If the bar magnet is flipped over and the south pole is brought near the hanging ball, the ball will be

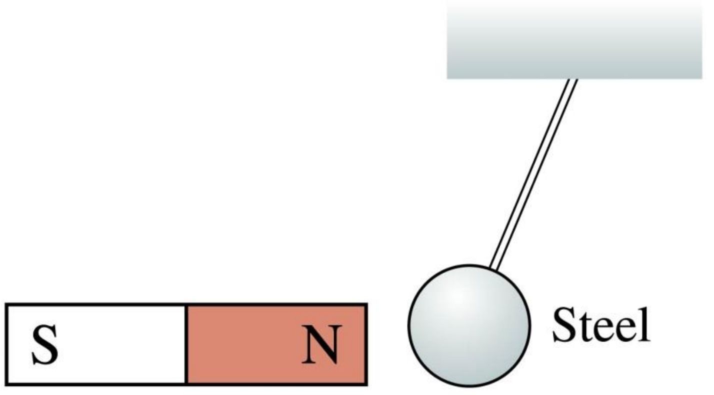
a) Attracted to the magnet.
b) Repelled by the magnet.
c) Unaffected by the magnet.
d) I'm not sure.



Magnetism

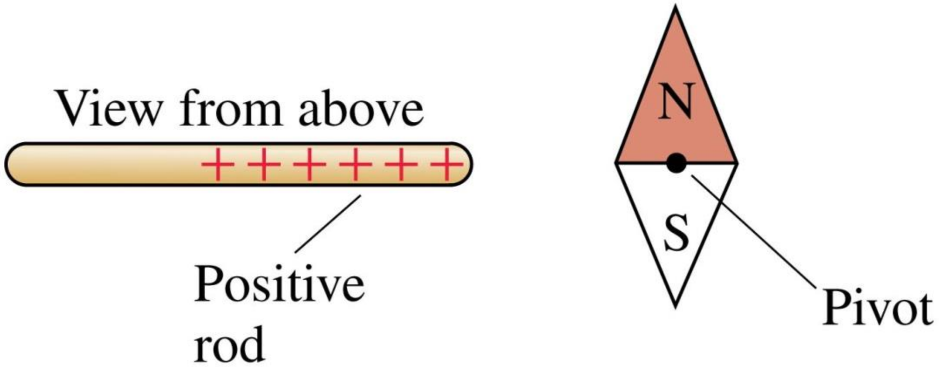
Q.2 If the bar magnet is flipped over and the south pole is brought near the hanging ball, the ball will be

a) **Attracted to the magnet.**
b) Repelled by the magnet.
c) Unaffected by the magnet.
d) I'm not sure.



Magnetism

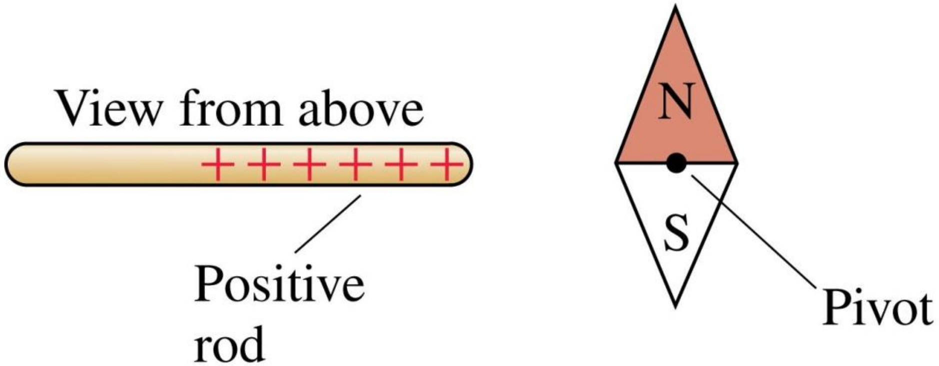
Q.3 The compass needle can rotate on a pivot in a horizontal plane. If a positively charged rod is brought near, as shown, the compass needle will



a) Rotate clockwise.
b) Rotate counterclockwise.
c) Do nothing.
d) I'm not sure.

Magnetism

Q.3 The compass needle can rotate on a pivot in a horizontal plane. If a positively charged rod is brought near, as shown, the compass needle will



a) Rotate clockwise.

b) Rotate counterclockwise.

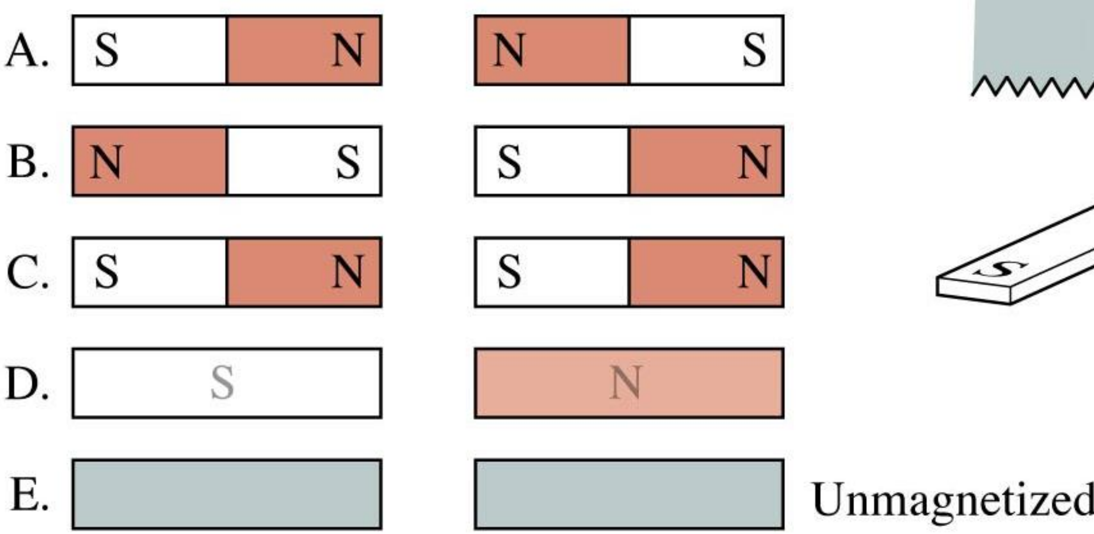
c) Do nothing.

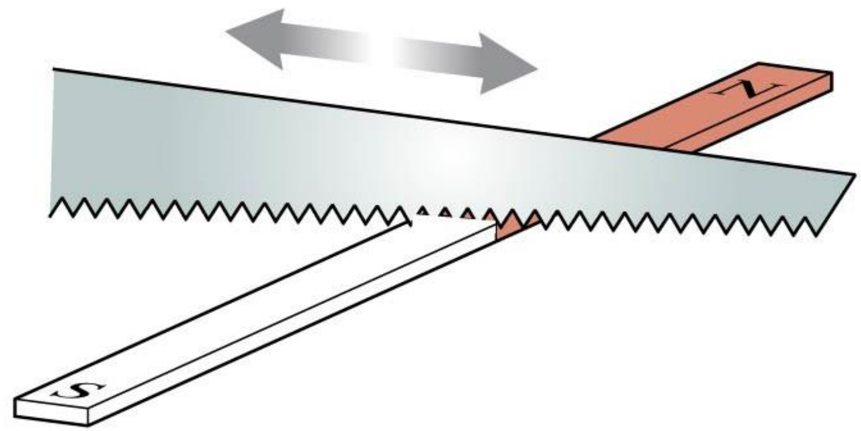
d) I’m not sure.

Magnetic poles are ***not*** the same as electric charges.

Magnetism

Q.4 If a bar magnet is cut in half, you end up with





Magnetism

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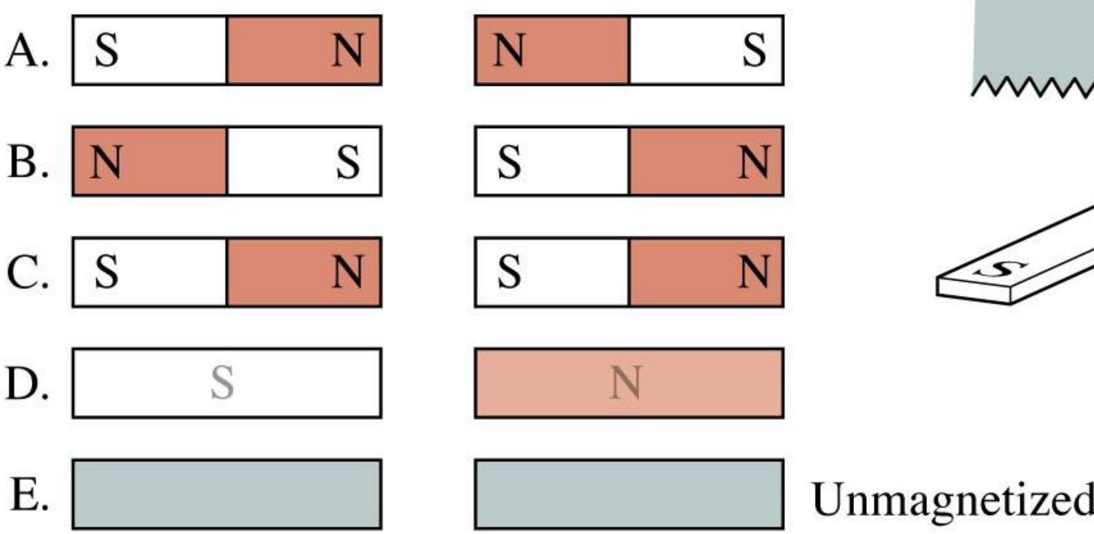
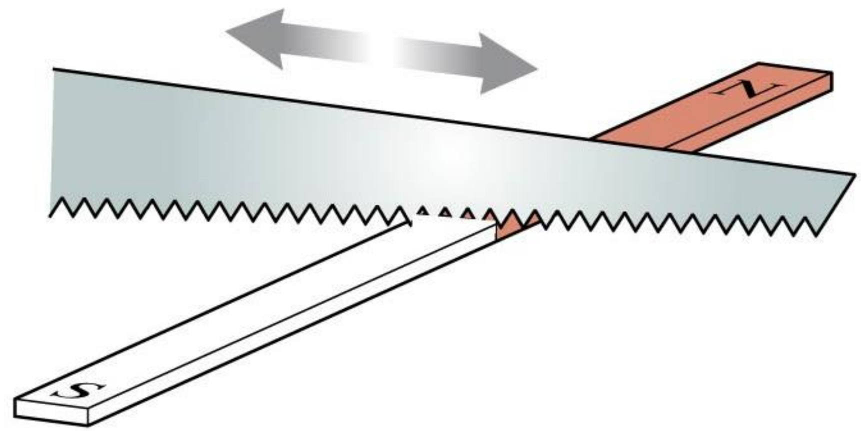
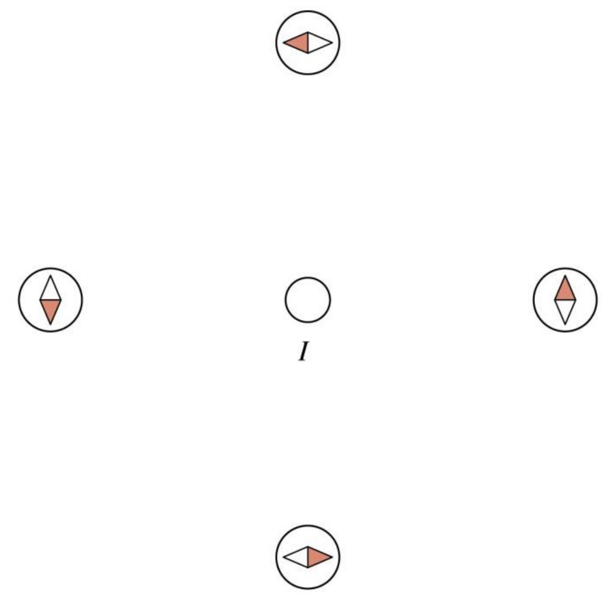




Magnetism

Q.5 A long, straight wire extends into and out of the screen. The current in the wire is

a) Into the screen.
b) Out of the screen.
c) There is no current in the wire.
d) Not enough info to tell the direction.



Magnetism

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a) Into the screen.

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c) There is no current in the wire.

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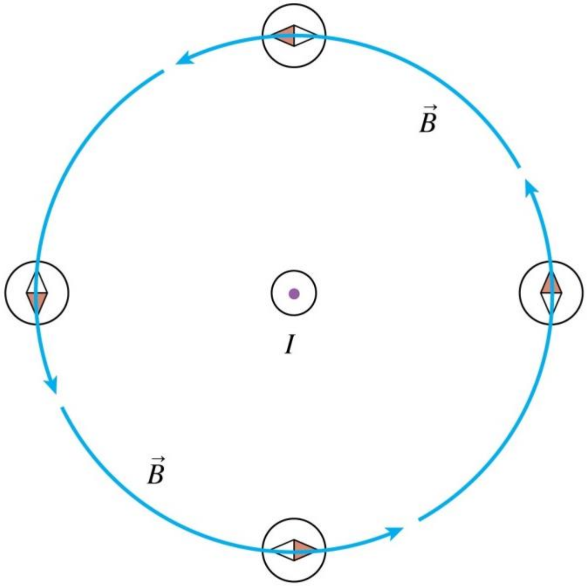
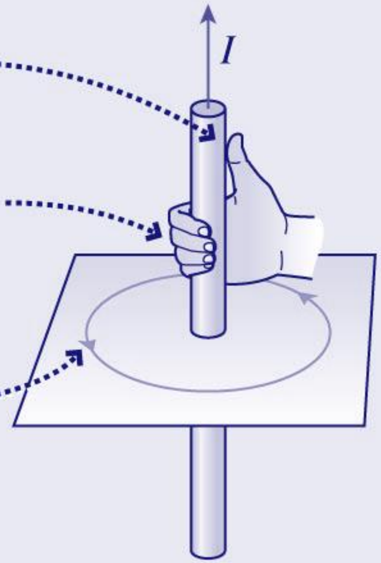
Right-hand rule



TACTICS BOX 32.1 **Right-hand rule for fields**



1. Point your *right* thumb in the direction of the current.
2. Curl your fingers around the wire to indicate a circle.
3. Your fingers point in the direction of the magnetic field lines around the wire.

Exercises 6–8

Magnetism

Q.6 Where is the north magnetic pole of this current loop?

a) Top side.
b) Bottom side.
c) Right side.
d) Left side.
e) Current loops don’t have north poles.

Magnetism

Q.6 Where is the north magnetic pole of this current loop?

a) Top side.

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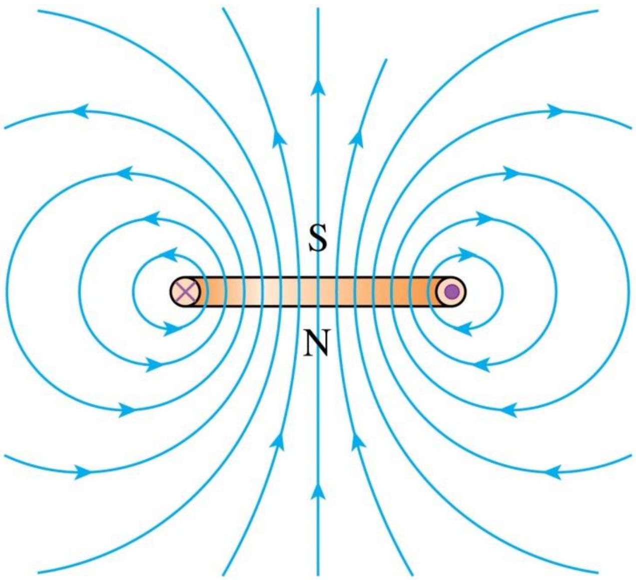
c) Right side.

d) Left side.

e) Current loops don't have north poles.



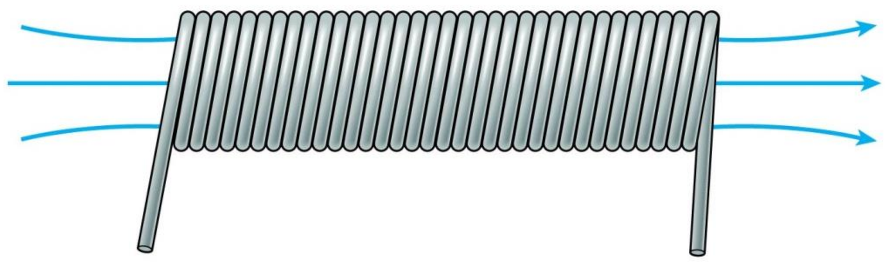
Magnetism

Q.7 The current in this solenoid

a) Enters on the left, leaves on the right.

b) Enters on the right, leaves on the left.

c) Either A or B would produce this field.



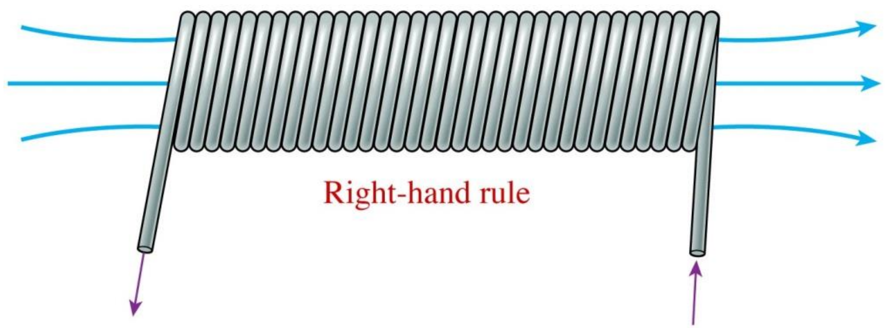
Magnetism

Q.7 The current in this solenoid

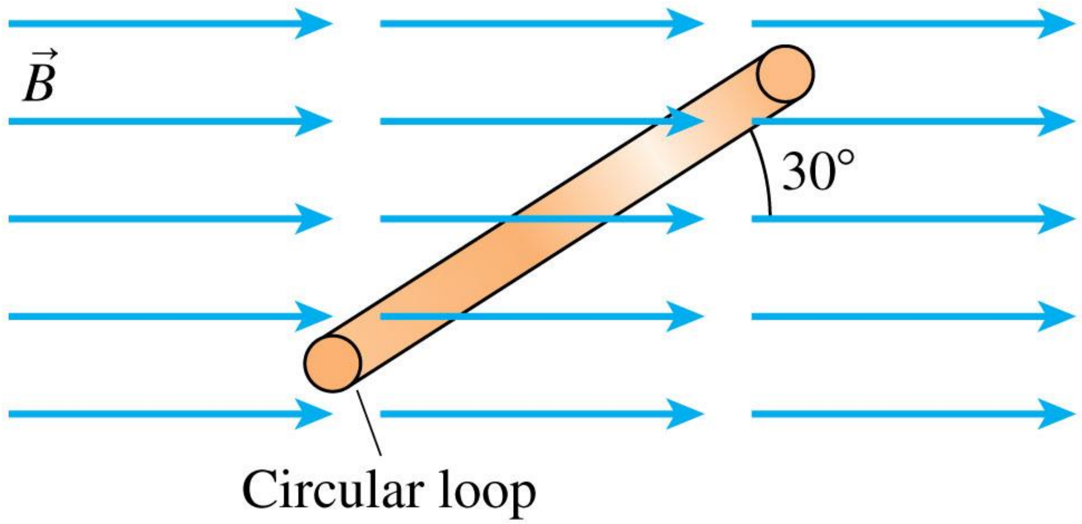
a) Enters on the left, leaves on the right.

b) Enters on the right, leaves on the left.

c) Either A or B would produce this field.

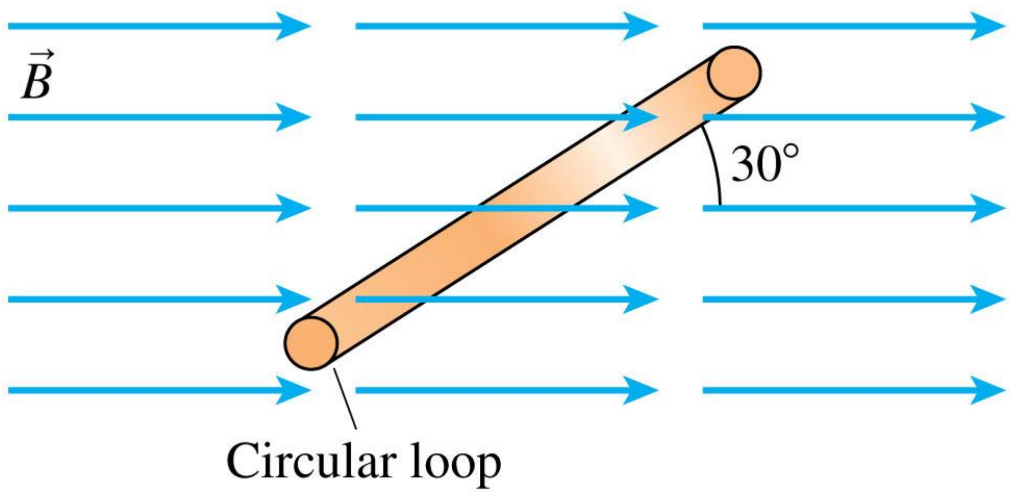


A Circular Loop in a Magnetic Field



Q.8 The figure above is an edge view of a 10-cm-diameter circular loop in a uniform 0.050 T magnetic field. What is the magnetic flux through the loop?

A Circular Loop in a Magnetic Field



SOLVE: Angle θ is the angle between the loop's area vector $\vec{A}$, which is perpendicular to the plane of the loop, and the magnetic field $\vec{B}$. In this case, $\theta = 60°$, not the 30° angle shown in the figure. Vector $\vec{A}$ has magnitude $A = \pi r^2 = 7.85\times10^{-3}\ m^2$. Thus, the magnetic flux is

$$\Phi_m = \vec{A}\cdot\vec{B} = AB\cos\theta = 2.0 \times 10^{-4}\ \mathrm{Wb}$$

Magnetic Flux

Q.9 Which loop has the larger magnetic flux through it?

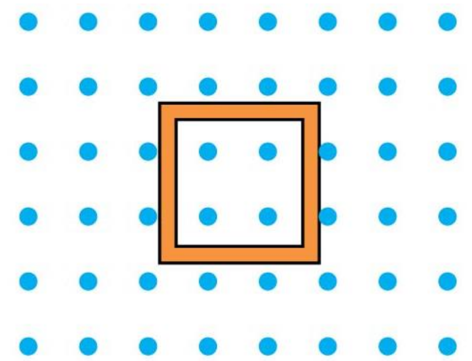
a) Loop A.

b) Loop B.

c) The fluxes are the same.

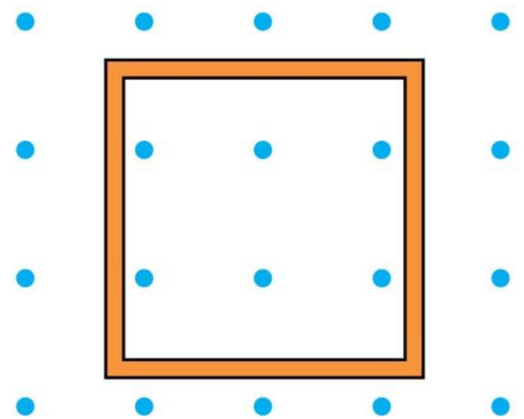
d) Not enough information to tell.

A.



This field is twice as strong.

B.



This square is twice as wide.

Magnetic Flux

Q.9 Which loop has the larger magnetic flux through it?

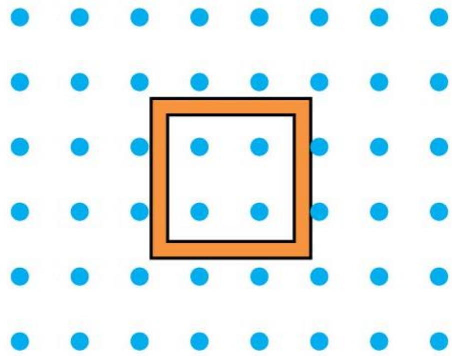
a) Loop A.

b) Loop B. $\Phi_m = L^2 B$

c) The fluxes are the same.

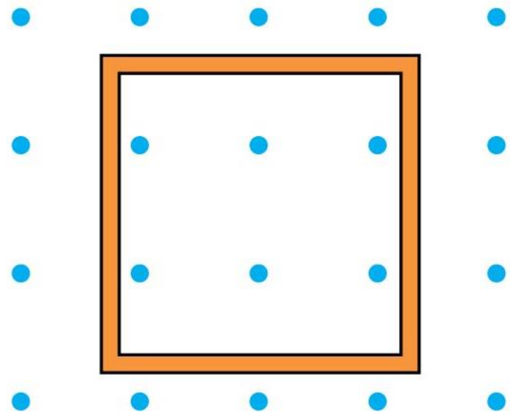
d) Not enough information to tell.

A.



This field is twice as strong.

B.



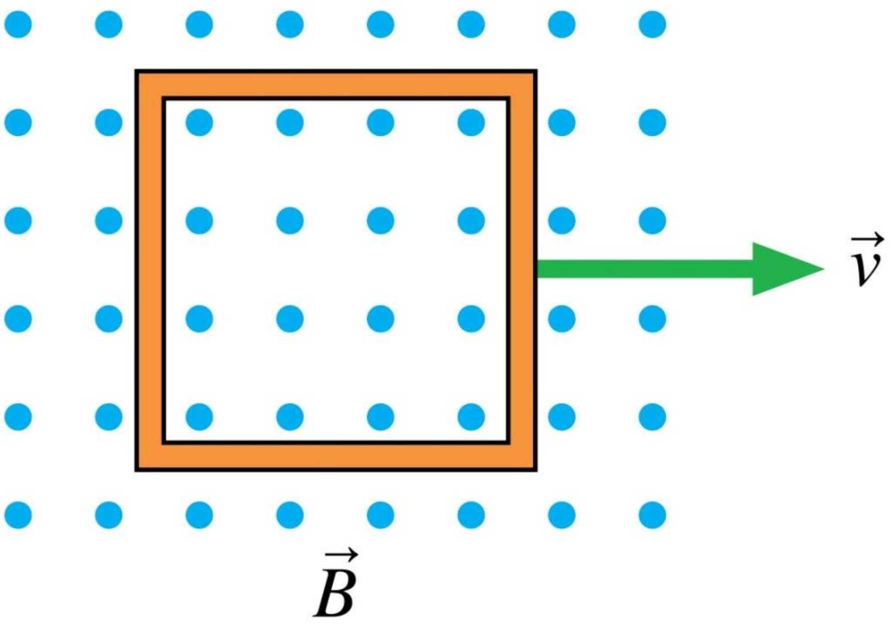
This square is twice as wide.

Magnetic Flux

Q.10 The metal loop is being pulled through a uniform magnetic field. Is the magnetic flux through the loop changing?

a) Yes.

b) No.



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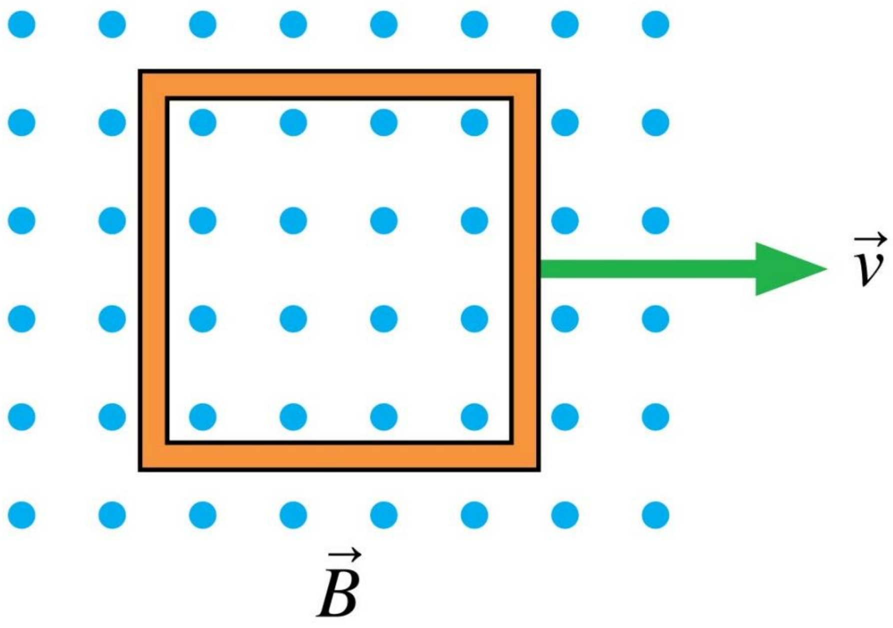
b) No.

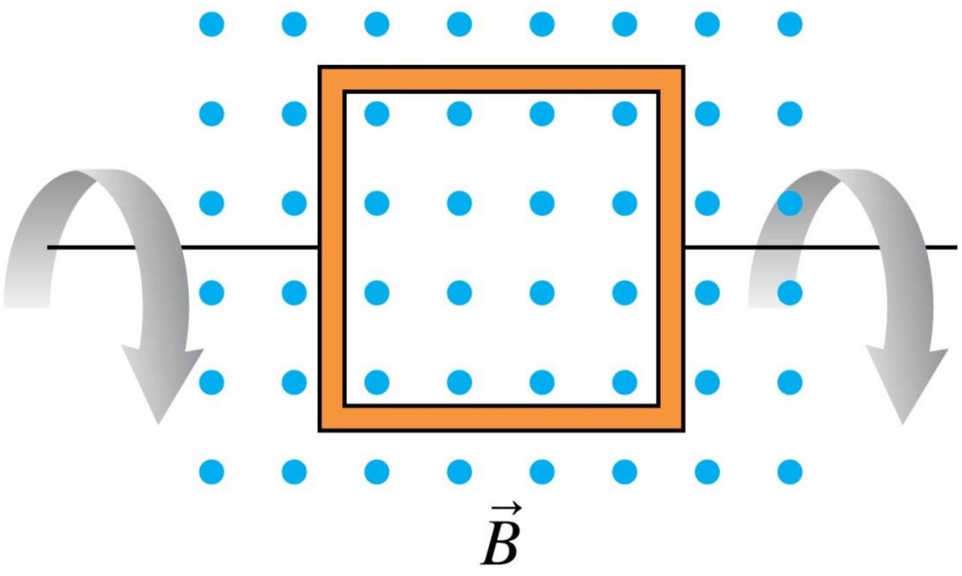


Magnetic Flux

Q.11 The metal loop is rotating in a uniform magnetic field. Is the magnetic flux through the loop changing?

a) Yes.

b) No.



Magnetic Flux

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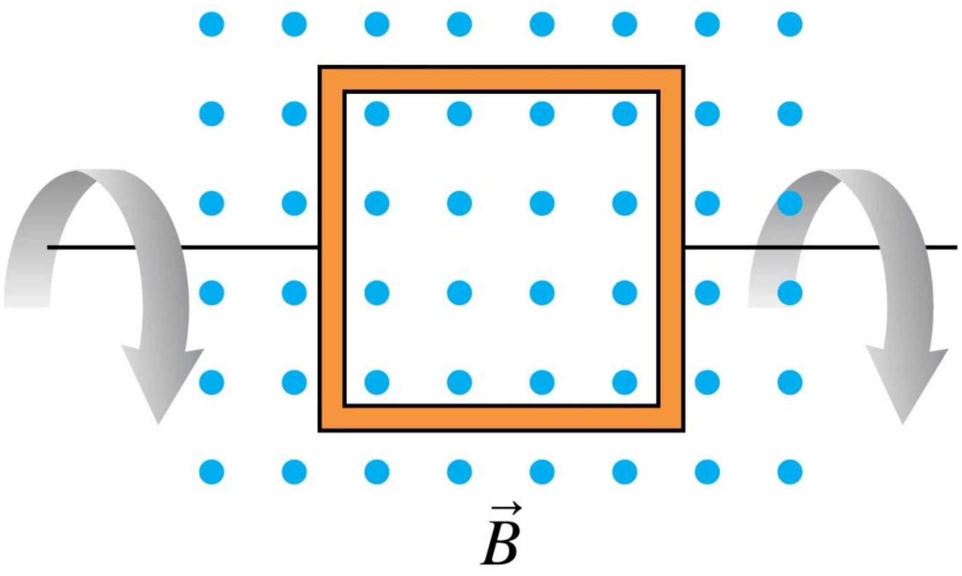


a) Yes.

b) No.

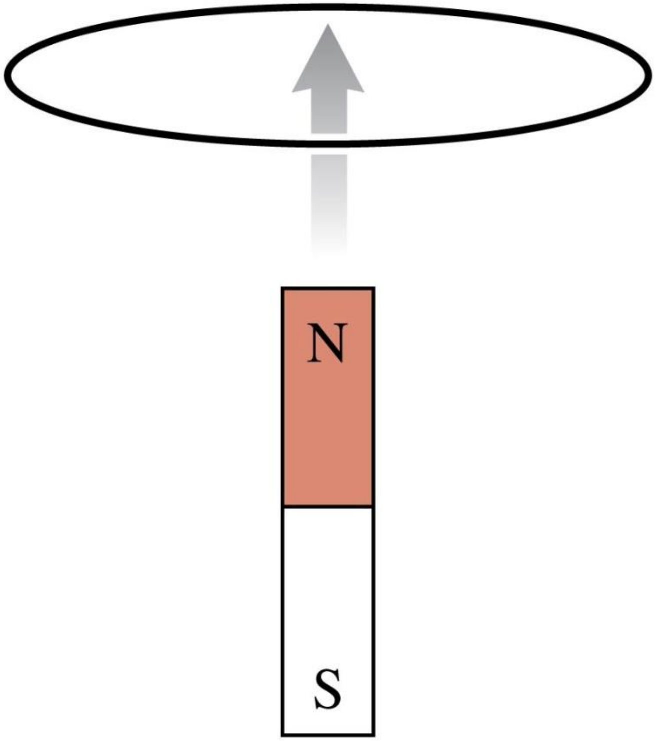
Lenz's Law

Q.12 The bar magnet is pushed toward the center of a wire loop. Which is true?

a) There is a clockwise induced current in the loop.

b) There is a counterclockwise induced current in the loop.

c) There is no induced current in the loop.



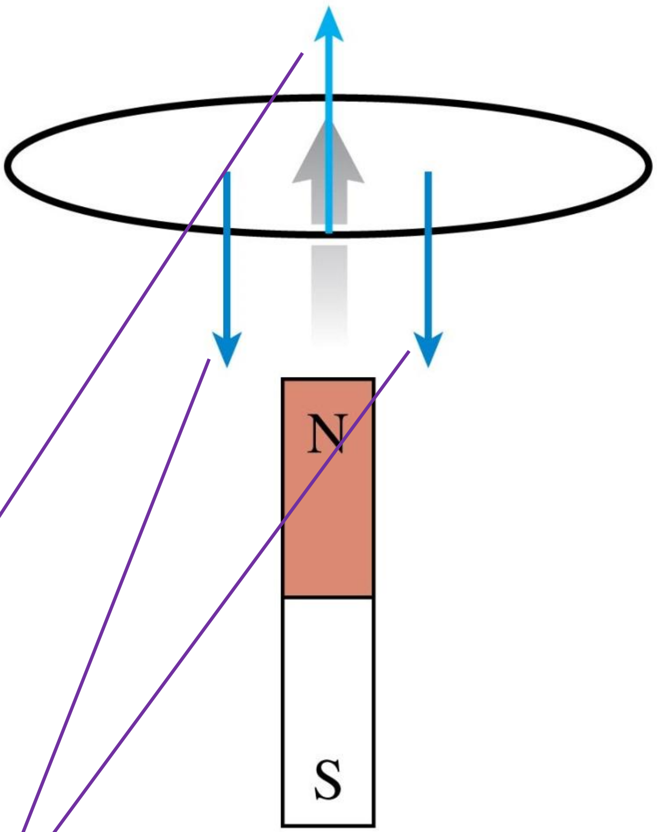
Lenz's Law

Q.12 The bar magnet is pushed toward the center of a wire loop. Which is true?

a) There is a clockwise induced current in the loop.

b) There is a counterclockwise induced current in the loop.

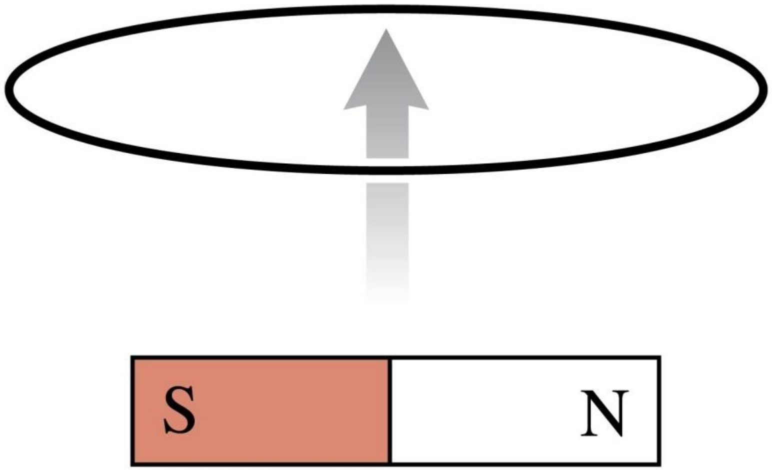
c) There is no induced current in the loop.



1) Upward flux from magnet is <u>increasing</u>.
2) To oppose the <u>increase</u>, the field of the induced current points down.
3) From the right-hand rule, a downward field needs a cw current.

Lenz’s Law

Q.13 The bar magnet is pushed toward the centre of a wire loop. Which is true?



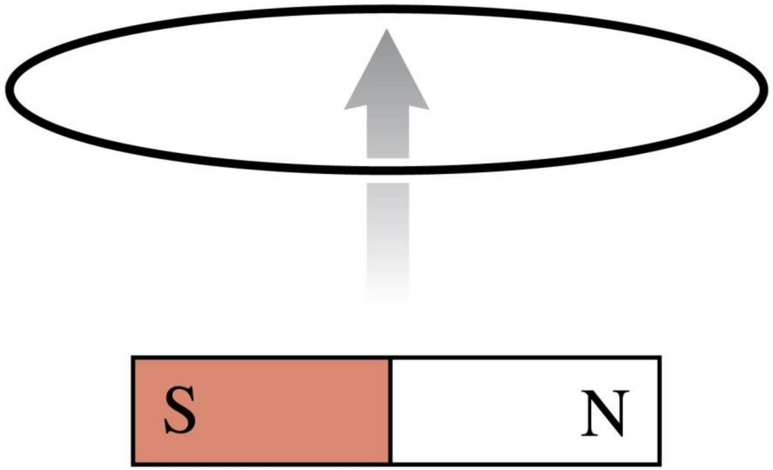
a) There is a clockwise induced current in the loop.

b) There is a counterclockwise induced current in the loop.

c) There is no induced current in the loop.

Lenz's Law

Q.13 The bar magnet is pushed toward the centre of a wire loop. Which is true?



a) There is a clockwise induced current in the loop.

b) There is a counterclockwise induced current in the loop.

c) There is no induced current in the loop.

Magnetic flux is zero, so there's no change of flux.

TACTICS BOX 33.1

Using Lenz's law

❶ **Determine the direction of the applied magnetic field.** The field must pass through the loop.

❷ **Determine how the flux is changing.** Is it increasing, decreasing, or staying the same?

❸ **Determine the direction of an induced magnetic field that will oppose the *change* in the flux.**

- Increasing flux: the induced magnetic field points opposite the applied magnetic field.
- Decreasing flux: the induced magnetic field points in the same direction as the applied magnetic field.
- Steady flux: there is no induced magnetic field.

❹ **Determine the direction of the induced current.** Use the right-hand rule to determine the current direction in the loop that generates the induced magnetic field you found in step 3.

Exercises 10–14

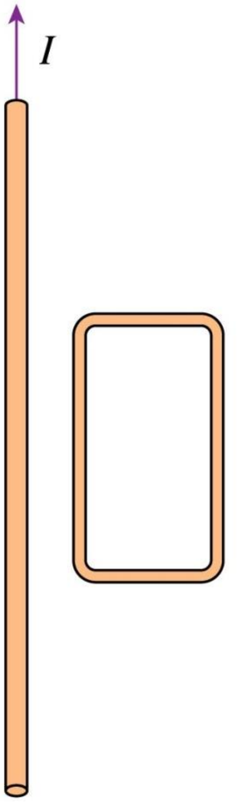
Lenz's Law

Q.14 The current in the straight wire is decreasing. Which is true?

a) There is a clockwise induced current in the loop.

b) There is a counterclockwise induced current in the loop.

c) There is no induced current in the loop.



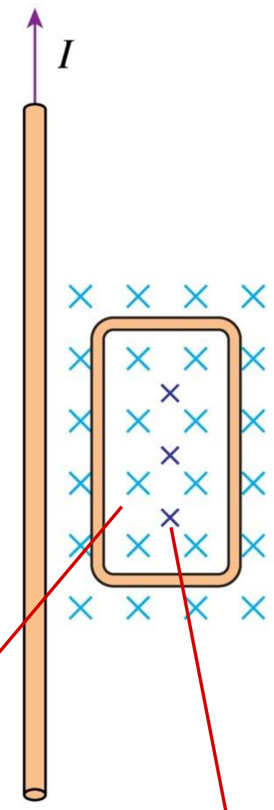
Lenz's Law

Q.14 The current in the straight wire is decreasing. Which is true?

a) **There is a clockwise induced current in the loop.**

b) There is a counterclockwise induced current in the loop.

c) There is no induced current in the loop.



1) The flux from wire's field is <u>into</u> the screen and <u>decreasing</u>.
2) To oppose the <u>decrease</u>, the field of the induced current must point <u>into</u> the screen.
3) From the right-hand rule, an inward field needs a cw current.

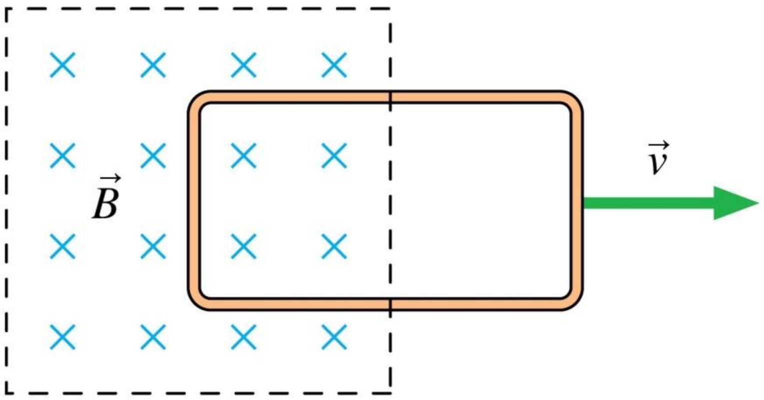
Lenz's Law

Q.15 The magnetic field is confined to the region inside the dashed lines; it is zero outside. The metal loop is being pulled out of the magnetic field. Which is true?

a) There is a clockwise induced current in the loop.

b) There is a counterclockwise induced current in the loop.

c) There is no induced current in the loop.



Lenz's Law

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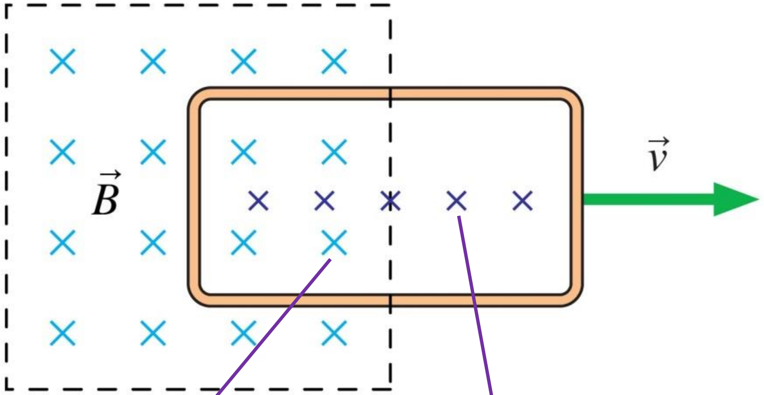
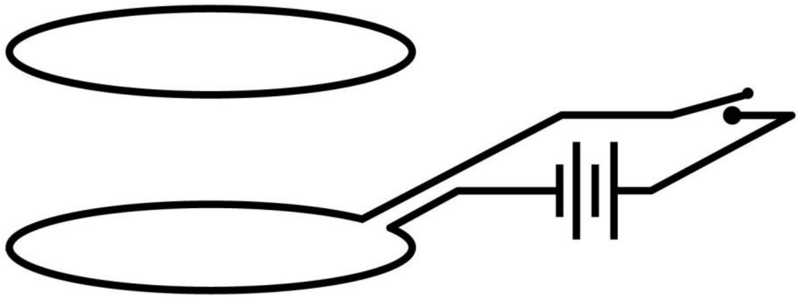


1) The flux through the loop is into the screen and decreasing.
2) To oppose the decrease, the field of the induced current must point into the screen.
3) From the right-hand rule, an inward field needs a cw current.

Lenz's Law

Q.16 Immediately after the switch is closed, the lower loop exerts _____ on the upper loop.



a) a torque

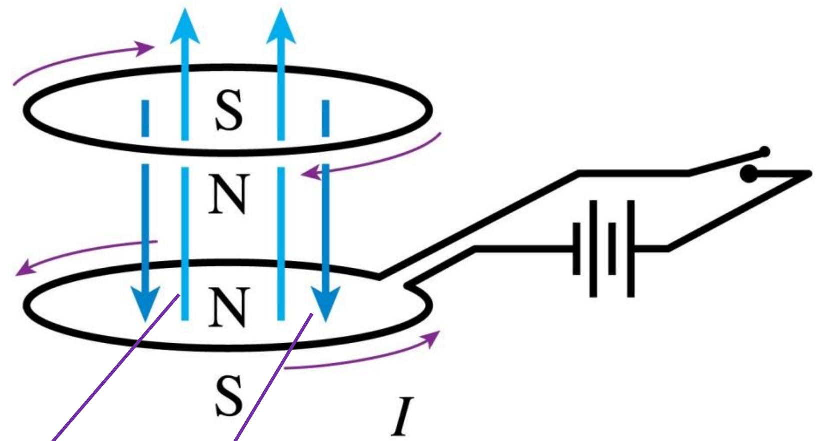
b) an upward force

c) a downward force

d) no force or torque

Lenz's Law

Q.16 Immediately after the switch is closed, the lower loop exerts _____ on the upper loop.



a) a torque

b) an upward force

c) a downward force

d) no force or torque

1) The battery drives a ccw current that, briefly, increases rapidly.
2) The flux through the top loop is upward and increasing.
3) To oppose the increase, the field of the induced current must point downward.
4) From the right-hand rule, a downward field needs a cw current.
5) The ccw current in the lower loop makes the upper face a north pole. The cw induced current in the upper loop makes the lower face a north pole.
6) Facing north poles exert repulsive forces on each other.

PROBLEM-SOLVING STRATEGY 33.1

Electromagnetic induction

MODEL Make simplifying assumptions about wires and magnetic fields.

VISUALIZE Draw a picture or a circuit diagram. Use Lenz's law to determine the direction of the induced current.

SOLVE The mathematical representation is based on Faraday's law

$$\mathcal{E} = \left|\frac{d\Phi_{\mathrm{m}}}{dt}\right|$$

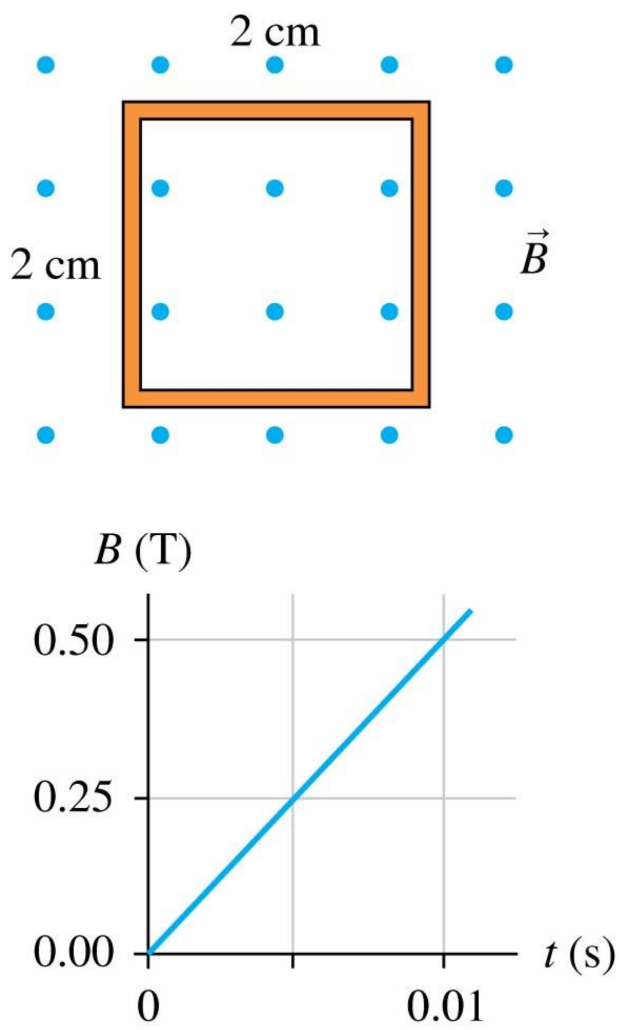
For an N-turn coil, multiply by N. The size of the induced current is $I = \mathcal{E}/R$.

ASSESS Check that your result has the correct units, is reasonable, and answers the question.

Exercise 18

Electromagnetic Induction

Q.17 The induced emf around this loop is



a) 200 V.

b) 50 V.

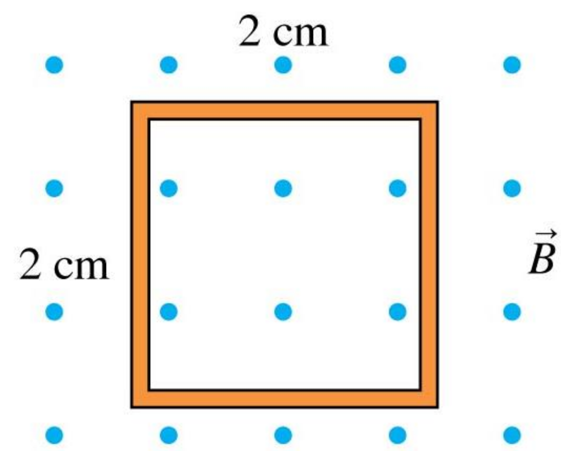
c) 2 V.

d) 0.5 V.

e) 0.02 V.

Electromagnetic Induction

Q.17 The induced emf around this loop is



a) 200 V.

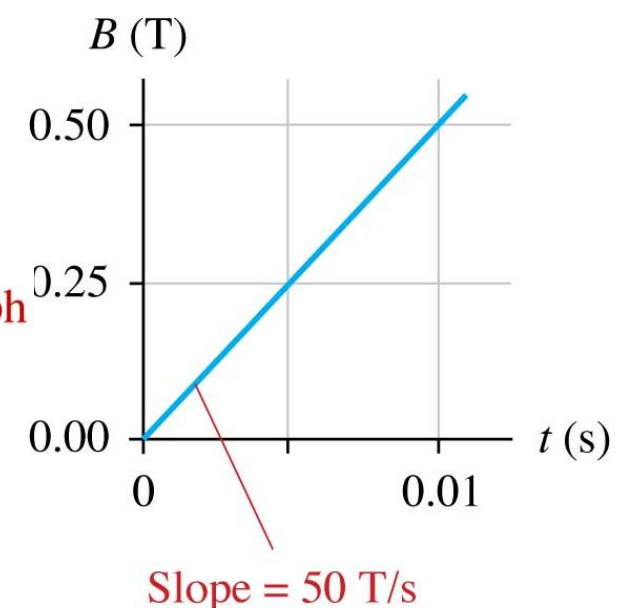
b) 50 V.

c) 2 V.

d) 0.5 V.

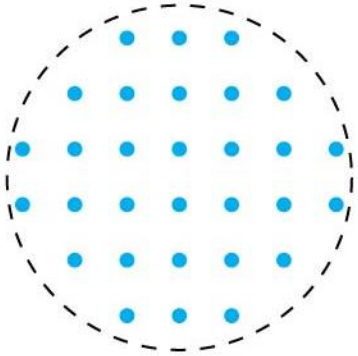
e) 0.02 V.

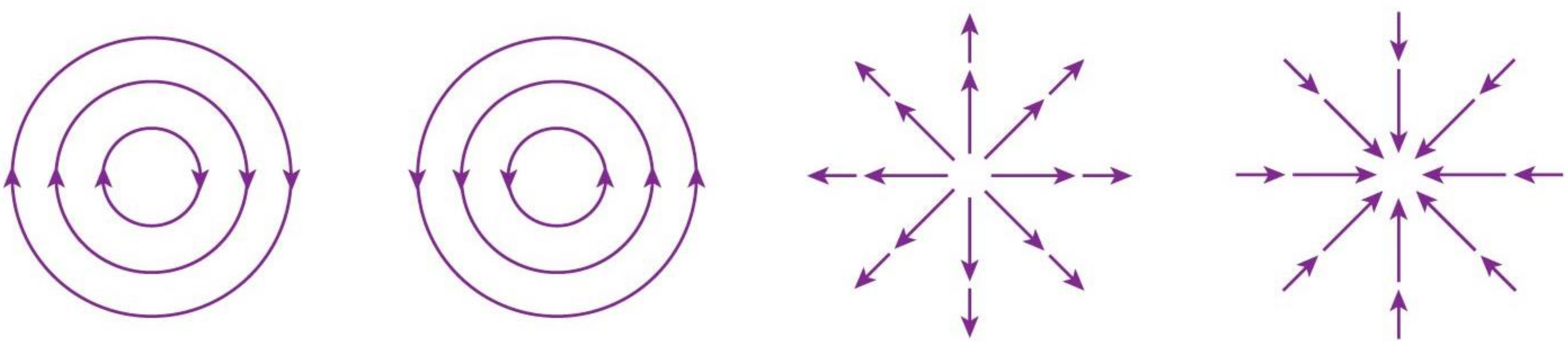
$$\mathcal{E} = \frac{d\Phi_{\mathrm{m}}}{dt} = A\frac{dB}{dt} = A \times \text{slope of graph}$$



Electromagnetic Induction

Q.18 The magnetic field is decreasing.
Which is the induced electric field?



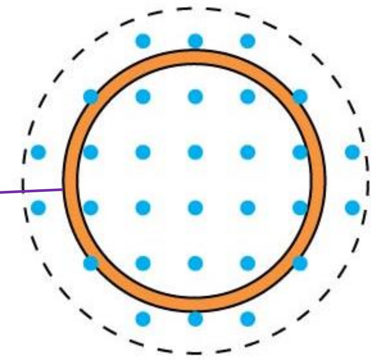


A. B. C. D.

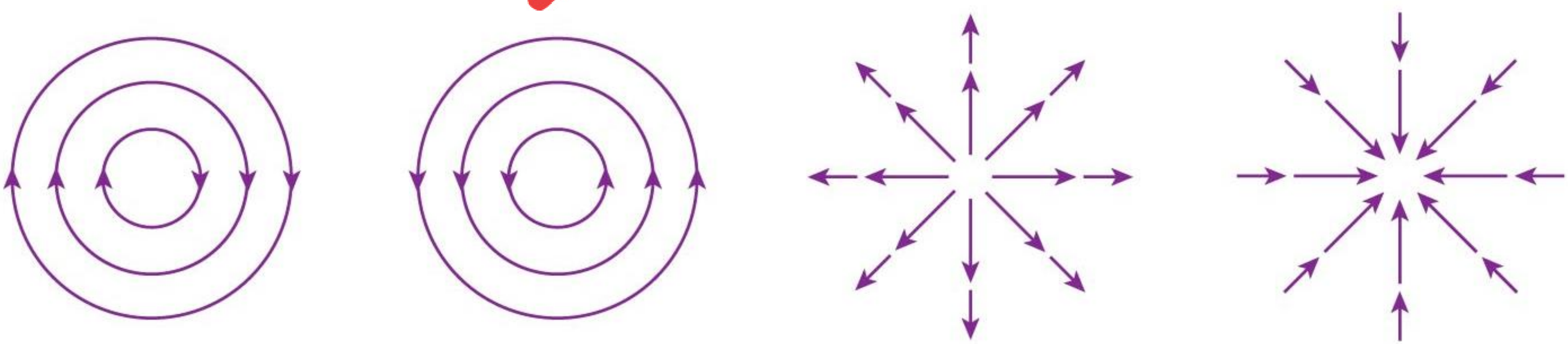
E. There's no induced field in this case.

Electromagnetic Induction

Q.18 The magnetic field is decreasing.
Which is the induced electric field?



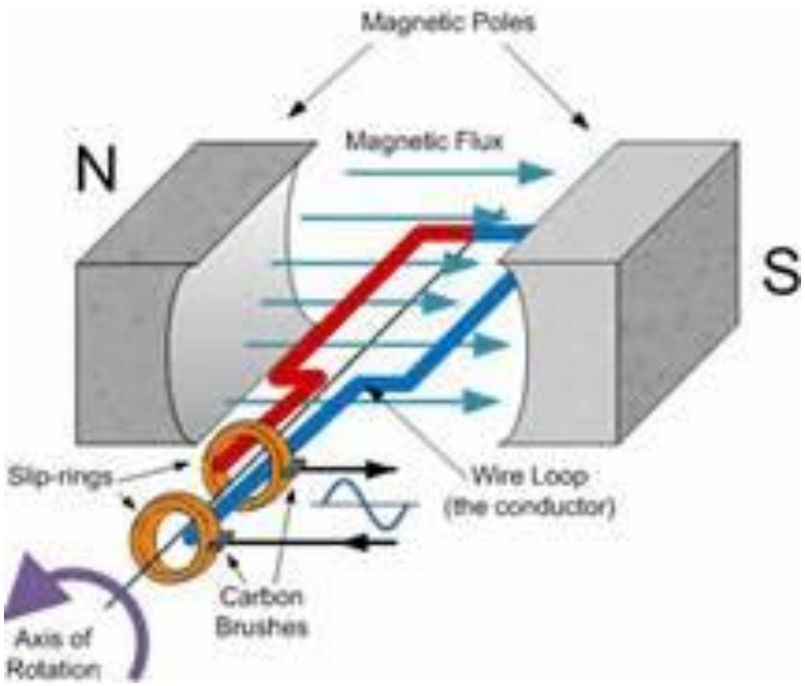
The field is the same direction as induced current would flow if there were a loop in the field.



A. B. C. D.

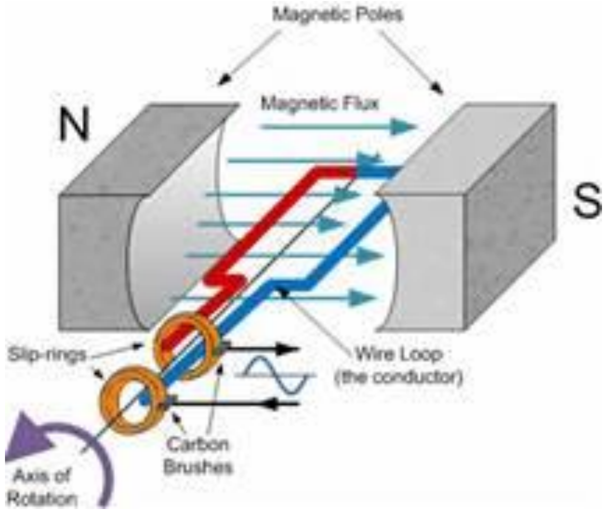
E. There's no induced field in this case.

An AC Generator



Q.19 A coil with area 2.0 m^2 rotates in a 0.010 T magnetic field at a frequency of 60 Hz. How many turns are needed to generate a peak voltage of 160 V?

An AC Generator



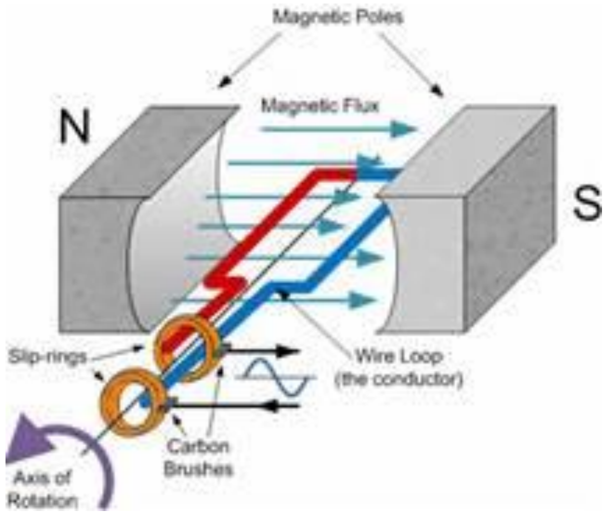
SOLVE: The coil's maximum voltage is:

$$\varepsilon_{\max} = \omega ABN = 2\pi f ABN$$

The number of turns needed to generate $\varepsilon_{\max} = 160\text{ V}$ is

$$N = \frac{\varepsilon_{\max}}{2\pi f AB} = \frac{160\text{ V}}{2\pi(60\text{ Hz})(2.0\text{ m}^2)(0.010\text{ T})} = 21\text{ turns}$$

An AC Generator



ASSESS:

A 0.010 T field is modest, so you can see that generating large voltages is not difficult with large ($2.0\ \mathrm{m}^2$) coils. Commercial generators use water flowing through a dam, rotating windmill blades, or turbines spun by expanding steam to rotate the generator coils. Work is required to rotate the coil.

Thus, a generator is a device that turns motion (mechanical energy) into a current (electric energy). A generator is the opposite of a motor, which turns a current into motion.

Potential Difference Across an Inductor

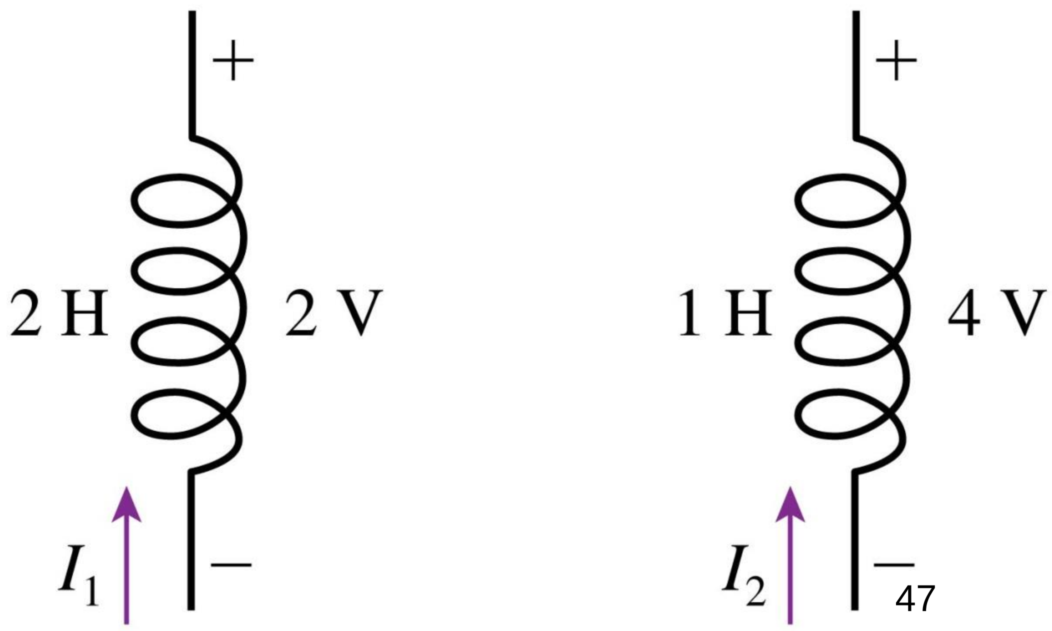
Q.20 Which current is changing more rapidly?

a) Current I_1.

b) Current I_2.

c) They are changing at the same rate.

d) Not enough information to tell.



Potential Difference Across an Inductor

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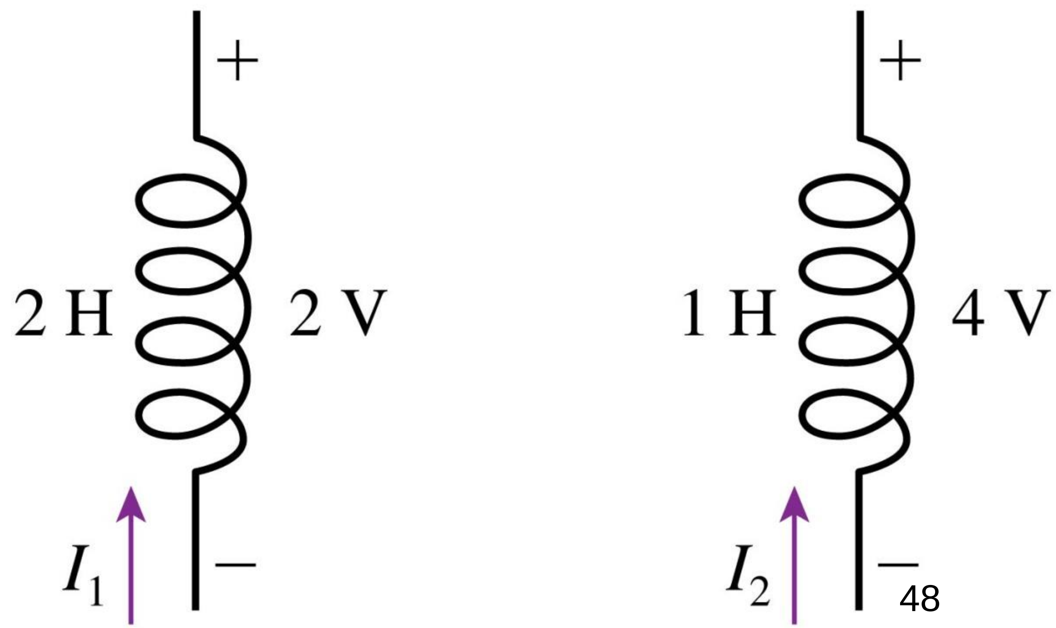
d) Not enough information to tell.

$$\Delta V_L = -L\frac{dI}{dt}$$



Large Voltage Across an Inductor

Q.21 A 1.0 A current passes through a 10 mH inductor coil. What potential difference is induced across the coil if the current drops to zero in 5.0 μs?

MODEL: Assume this is an ideal inductor, with $R = 0\ \Omega$, and that the current decrease is linear with time.

Large Voltage Across an Inductor

SOLVE: The rate of current decrease is

$$\frac{dI}{dt} \approx \frac{\Delta I}{\Delta t} = \frac{-1.0\ A}{5.0 \times 10^{-6}\ \mathrm{s}} = -2.0 \times 10^{5}\ \mathrm{A/s}$$

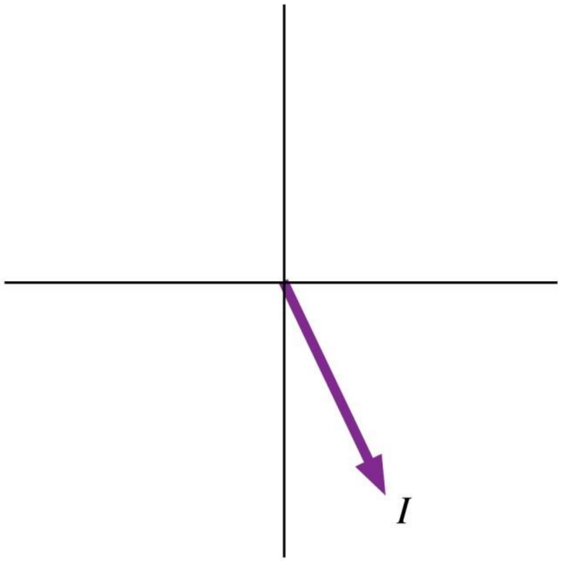
The induced voltage is

$$\Delta V_{\mathrm{L}} = -L\frac{dI}{dt} \approx -(0.010\ \mathrm{H})(-2.0 \times 10^{5}\ \mathrm{A/s}) = 2000\ \mathrm{V}$$

ASSESS: Inductors may be physically small, but they can pack a punch if you try to change the current through them too quickly.

Phasors

Q.22 This is a current phasor. The magnitude of the instantaneous value of the current is



a) Increasing.

b) Decreasing.

c) Constant.

d) Can’t tell without knowing which way it is rotating.

Phasors

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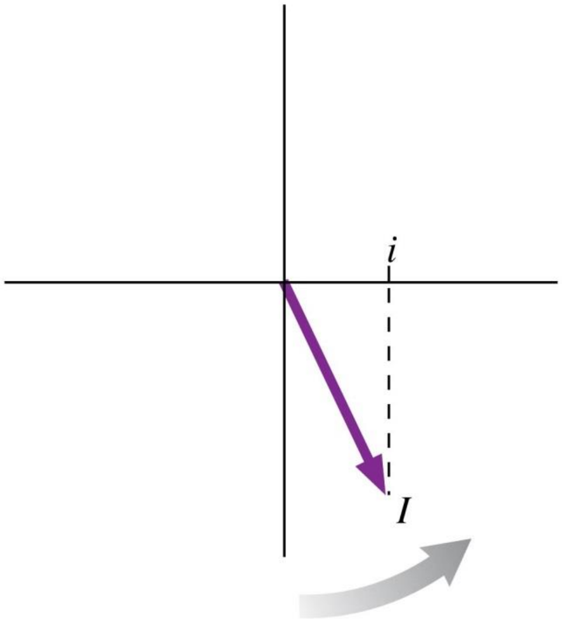


a) Increasing.

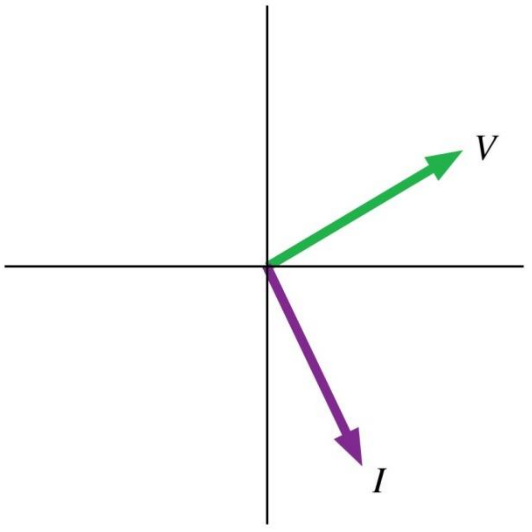
b) Decreasing.

c) Constant.

d) Can’t tell without knowing which way it is rotating.

Phasors

Q.23 In the circuit represented by these phasors, the current _____ the voltage



a) leads

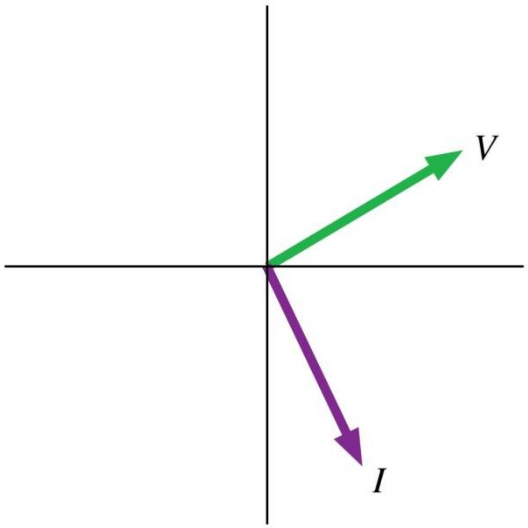
b) lags

c) is perpendicular to

d) is out of phase with

Phasors

Q.23 In the circuit represented by these phasors, the current _____ the voltage



a) leads

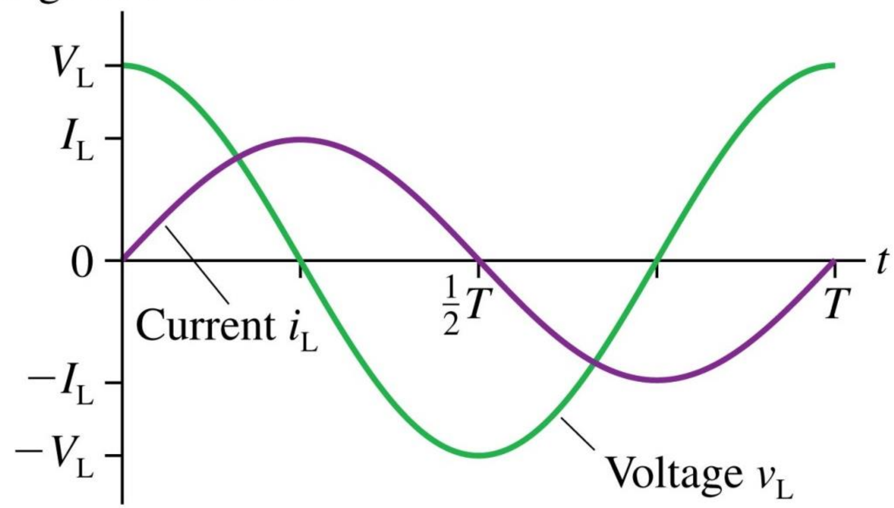
b) lags

c) is perpendicular to

d) is out of phase with

Sinusoidal Graphs

Q.24 In the circuit represented by these graphs, the current _____ the voltage



a) leads

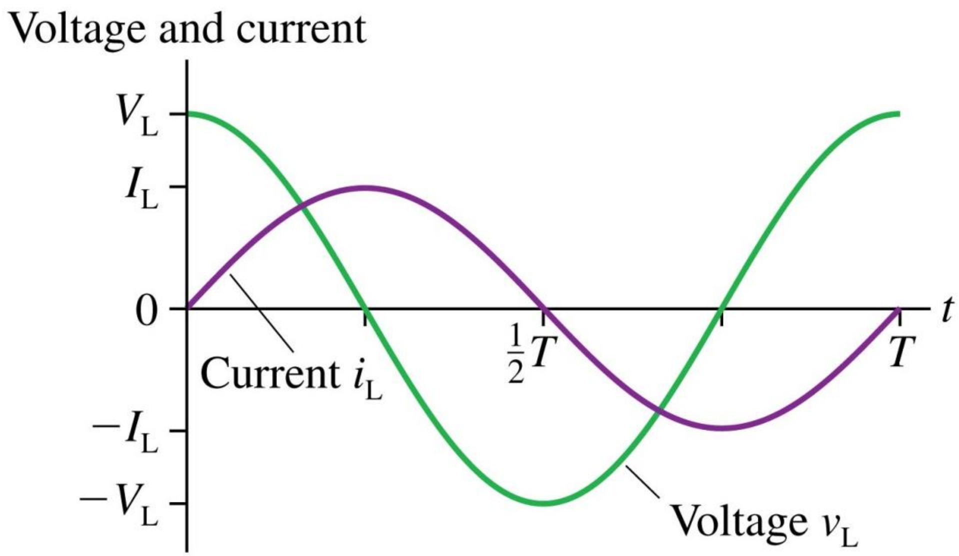
b) lags

c) is less than

d) is out of phase with

Sinusoidal Graphs

Q.24 In the circuit represented by these graphs, the current _____ the voltage



a) leads

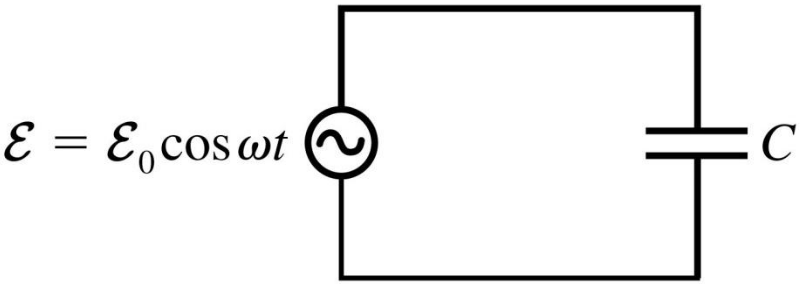
b) lags

c) is less than

d) is out of phase with

Reactance

Q.25 If the value of the capacitance is doubled, the capacitive reactance



a) Is quartered.

b) Is halved.

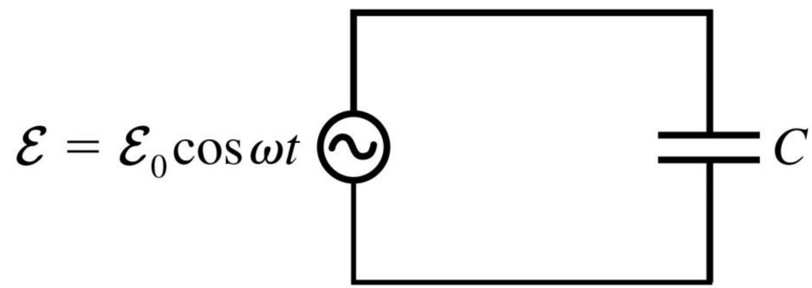
c) Is doubled.

d) Is quadrupled.

e) Can't tell without knowing ω.

Reactance

Q.25 If the value of the capacitance is doubled, the capacitive reactance



a) Is quartered.

b) Is halved.

$$X_C = \frac{1}{\omega C}$$

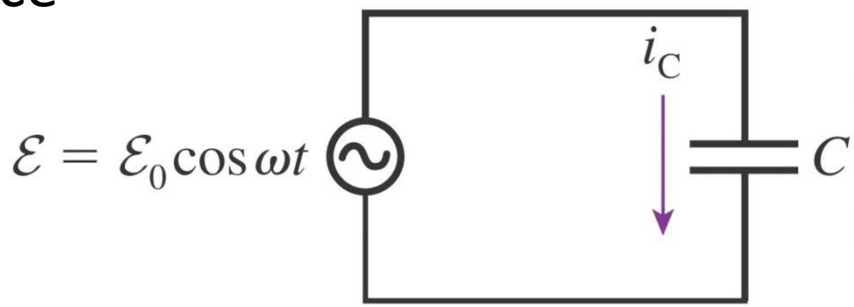
c) Is doubled.

d) Is quadrupled.

e) Can't tell without knowing ω.

Reactance

Q.26 If the value of the capacitance is doubled, the peak current



a) Is quartered.

b) Is halved.

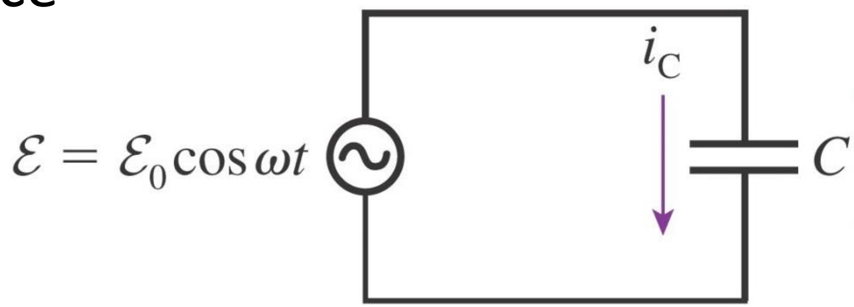
c) Is doubled.

d) Is quadrupled.

e) Can't tell without knowing *C*.

Reactance

Q.26 If the value of the capacitance is doubled, the peak current



a) Is quartered.

b) Is halved.

c) Is doubled.

$$I_C = \frac{V_C}{X_C} = \frac{\mathcal{E}}{X_C}$$

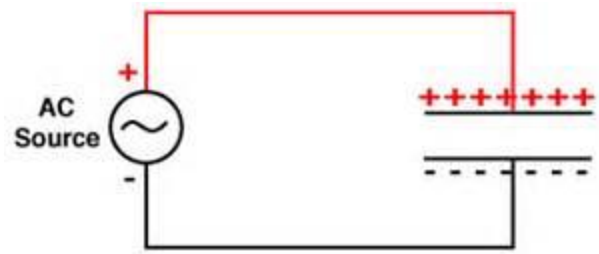
d) Is quadrupled.

e) Can't tell without knowing *C*.

Capacitive Reactance

Q.27 What is the capacitive reactance of a 0.10 μF capacitor at a 100 Hz audio frequency and at a 100 MHz FM-radio frequency?

Capacitive Reactance



SOLVE: At 100 Hz,

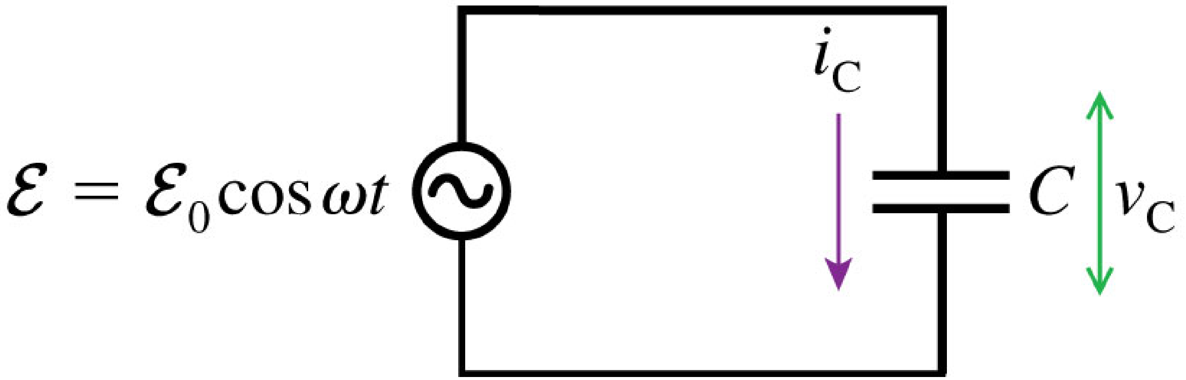
$$X_C(at\ 100\ \mathrm{Hz}) = \frac{1}{\omega C} = \frac{1}{2\pi(100\ \mathrm{Hz})(1.0 \times 10^{-7}\ \mathrm{F})} = 16{,}000\ \Omega$$

Increasing the frequency by a factor of 10^6 decreases X_C by a factor of 10^6, giving

$$X_C(at\ 100\ \mathrm{MHz}) = 0.016\ \Omega$$

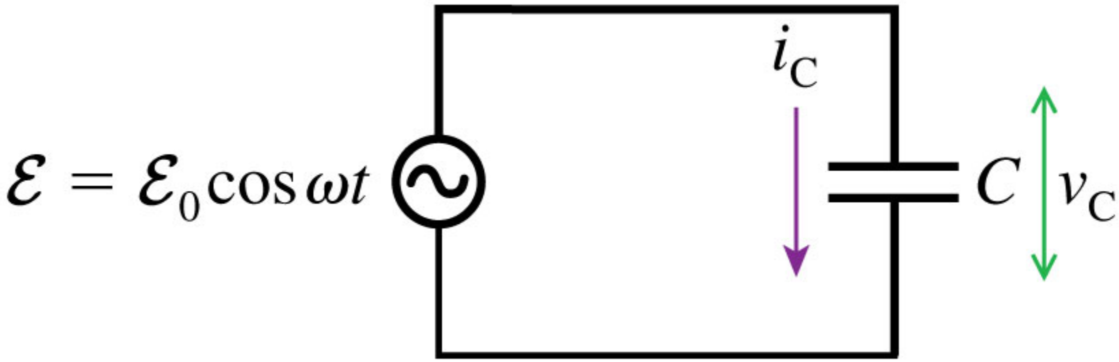
ASSESS: A capacitor with a substantial reactance at audio frequencies has virtually no reactance at FM-radio frequencies.

Capacitor Current



Q.28 A 10 μF capacitor is connected to a 1000 Hz oscillator with a peak emf of 5.0 V. What is the peak current to the capacitor?

Capacitor Current



SOLVE: The capacitive reactance at $\omega = 2\pi f = 6280\ \mathrm{rad/s}$ is

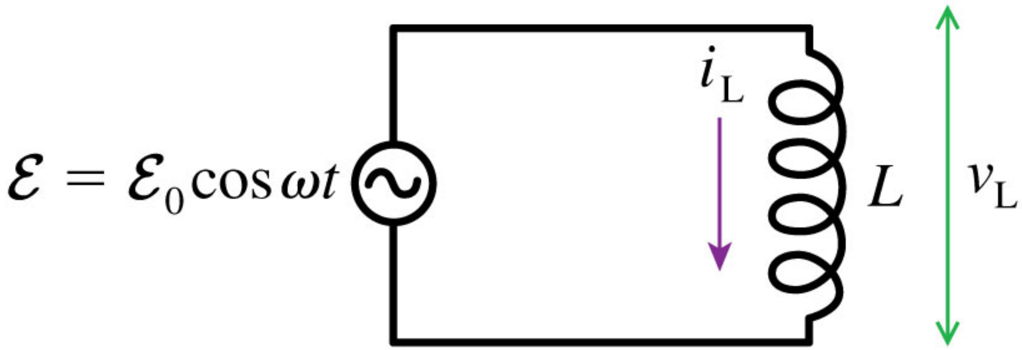
$$X_C = \frac{1}{\omega C} = \frac{1}{(6280\ \mathrm{rad/s})(10 \times 10^{-6}\ \mathrm{F})} = 16\ \Omega$$

The peak voltage across the capacitor is $V_C = \varepsilon_0 = 5.0\ \mathrm{V}$; hence the peak current is

$$I_C = \frac{V_C}{X_C} = \frac{5.0\ \mathrm{V}}{16\ \Omega} = 0.31\ \mathrm{A}$$

ASSESS: Using reactance is just like using Ohm’s law, but don’t forget it applies to only the peak current and voltage, not the instantaneous values.

Current & Voltage of an Inductor



Q.29 A 25 μH inductor is used in a circuit that oscillates at 100 kHz. The current through the inductor reaches a peak value of 20 mA at *t* = 5.0 μs. What is the peak inductor voltage, and when, closest to *t* = 5.0 μs, does it occur?

MODEL The inductor current lags the voltage by 90°, or, equivalently, the voltage reaches its peak value one-quarter period *before* the current.

Current & Voltage of an Inductor

SOLVE:

The inductive reactance at f = 100 kHz is

$$X_{\mathrm{L}} = \omega L = 2\pi(1.0 \times 10^{5}\ \mathrm{Hz})(25 \times 10^{-6}\ \mathrm{H}) = 16\ \Omega$$

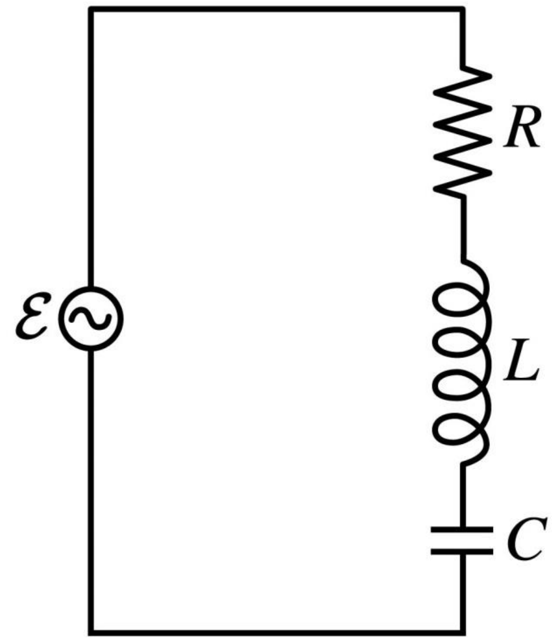
Thus, the peak voltage is $V_L = I_L X_L$ = (20 mA)(16 Ω) = 320 mV. The voltage peak occurs one-quarter period before the current peaks, and we know that the current peaks at t = 5.0 μs.

The period of a 100 kHz oscillation is 10.0 μs, so the voltage peaks at

$$t = 5.0\ \mu s - \frac{10.0\ \mu s}{4} = 2.5 \mu s$$

Series Resonance

Q.30 If the value of R is increased, the resonance frequency of this circuit



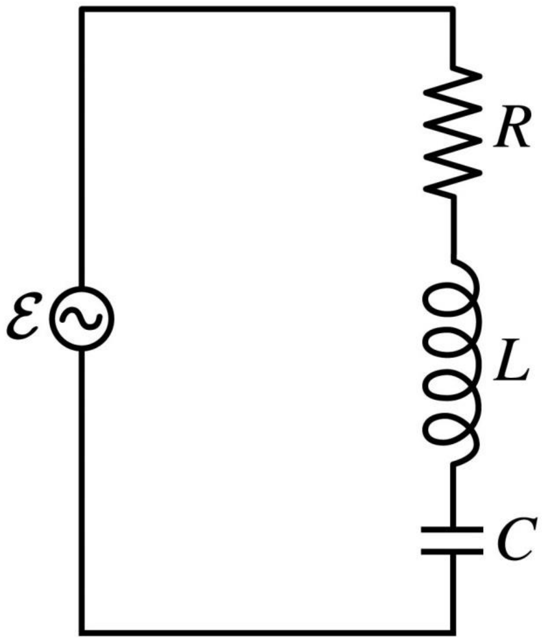
a) Increases.

b) Decreases.

c) Stays the same.

Series Resonance

Q.30 If the value of *R* is increased, the resonance frequency of this circuit



a) Increases.

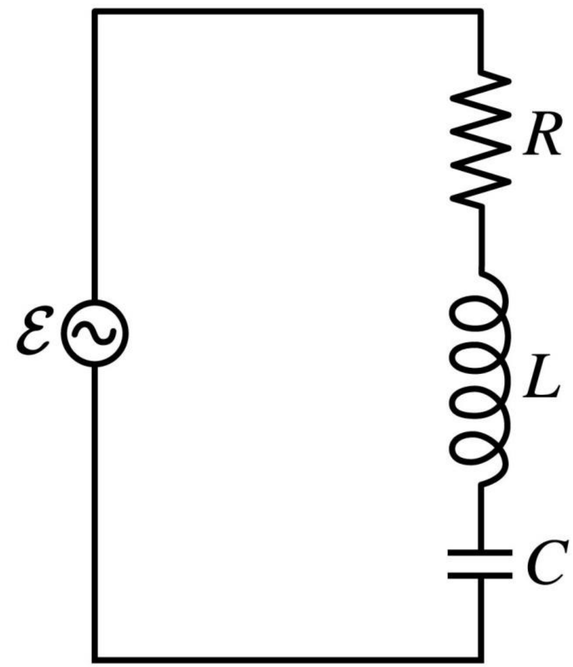
b) Decreases.

c) Stays the same.

The resonance frequency depends on *C* and *L*, but not on *R*.

Series Resonance

Q.31 The resonance frequency of this circuit is 1000 Hz. To change the resonance frequency to 2000 Hz, replace the capacitor with one having capacitance



a) C/4.

b) C/2.

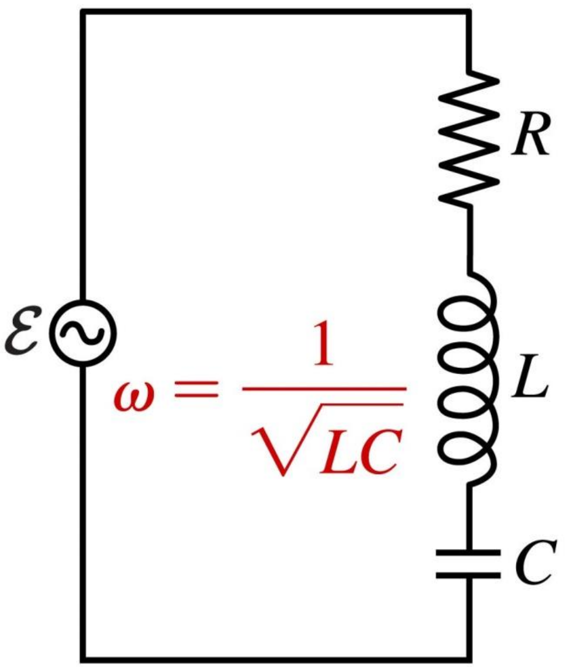
c) 2C.

d) 4C.

e) It's impossible to change the resonance frequency by changing only the capacitor.

Series Resonance

Q.31 The resonance frequency of this circuit is 1000 Hz. To change the resonance frequency to 2000 Hz, replace the capacitor with one having capacitance



a) C/4.

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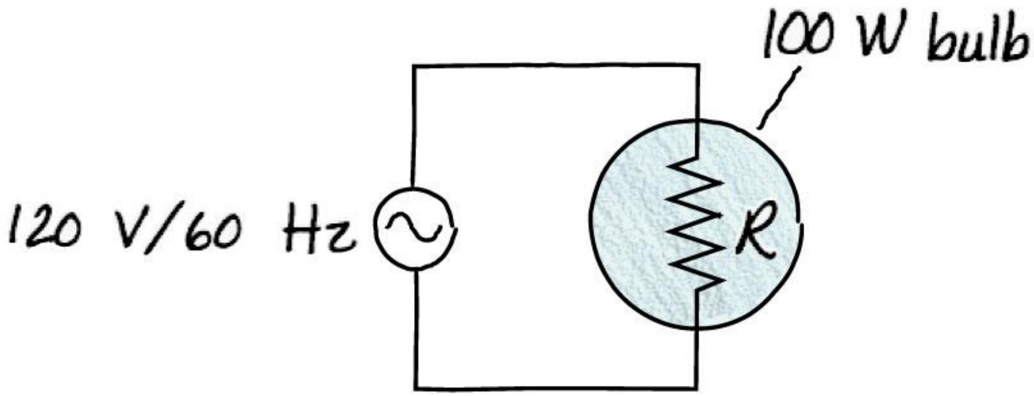
e) It's impossible to change the resonance frequency by changing only the capacitor.

Lighting a Bulb



Q.32 A 100 W incandescent lightbulb is plugged into a 120 V/60 Hz outlet. What is the resistance of the bulb's filament? What is the peak current through the bulb?

Lighting a Bulb

SOLVE: A bulb labelled 100 W is designed to dissipate an average 100 W at V_{rms} = 120 V. We can use

$$R = \frac{(V_{\text{rms}})^2}{P_{\text{R}}} = \frac{(100\ \text{V})^2}{100\ \text{W}} = 144\ \Omega$$

The rms current is then found from

$$I_{\text{rms}} = \frac{P_{\text{R}}}{V_{\text{rms}}} = \frac{100\ \text{W}}{120\ \text{V}} = 0.833\ \text{A}$$

The peak current is $I_{\text{R}} = \sqrt{2} I_{\text{rms}}$=1.18 A.

ASSESS: Calculations with rms values are just like the calculations for DC circuits.