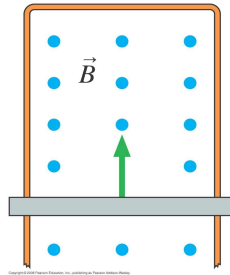


Solutions for conceptual questions

34.1



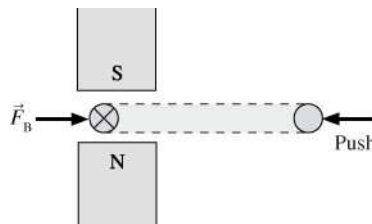
The induced current will be counterclockwise (ccw).

As the bar moves upward through the constant magnetic field region, the area of the loop decreases, so the flux through the loop decreases. By Lenz's law, any induced current will tend to oppose the decrease. Using right hand rule we know that magnetic field inside the loop due to a ccw current comes out of the plane. Therefore a ccw current will create a stronger magnetic field inside the loop, tending to increase the flux.

34.2

One has to push the loop against a repulsive force.

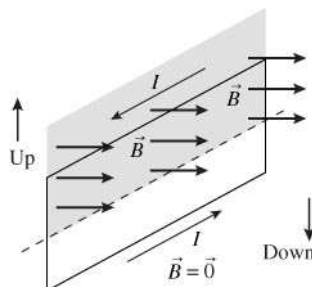
As the loop enters the region between the poles the magnetic flux linked with the loop increases. Therefore the motion of the loop in the magnetic field induces a current in the loop in the direction shown. This induced current tends to oppose the flux increase by creating a magnetic field opposite in direction to that which existed due to the magnetic poles. In other words the induced current is such that the force the loop experiences due to this current opposes the loop to enter the region between the poles (Lenze's law). The magnetic poles of the induced current loop are also shown in the diagram. The net magnetic force on the loops is to the right.



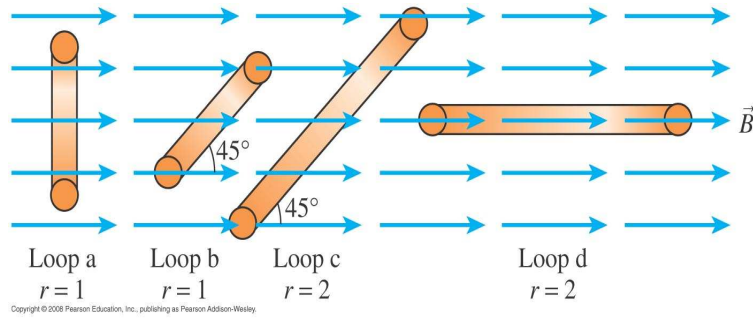
34.3

Yes.

As the loop falls the magnetic flux linked with the loop decreases hence there is an induced current in the loop in the direction shown in the diagram. The net force due to this current is up since there is only an upward force on the top side of the loop and no force on the bottom side since it is not in a magnetic field. Whereas the other two sides experience forces which are equal and opposite in direction and hence they cancel each other.



34.4



Order: $\Phi_3 > \Phi_1 > \Phi_2 > \Phi_4$

Explanation:

$$\Phi = B \cdot A \cdot \cos \theta = B(\pi r^2) \cos \theta$$

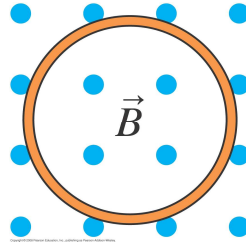
$$\Phi_1 = B\pi(1)^2 \cos 0^\circ = \pi B$$

$$\Phi_2 = B\pi(1)^2 \cos 45^\circ = 0.707 \Phi_1$$

$$\Phi_3 = B\pi(4) \cos 45^\circ = 2.83 \Phi_1$$

$$\Phi_4 = B\pi(4) \cos 90^\circ = 0$$

34.5



a. Clockwise. Since the 'dot' field is increasing hence the induced magnetic field is 'cross', i.e. into the page and by the right-hand rule the induced current is clockwise.

b. No current. A changing magnetic flux induces a current but here it is constant.

c. Counterclockwise. Since the 'dot' field is decreasing hence the induced magnetic field is 'dot', i.e. Out of the page and by the right-hand rule the induced current is counter clockwise.

34.6

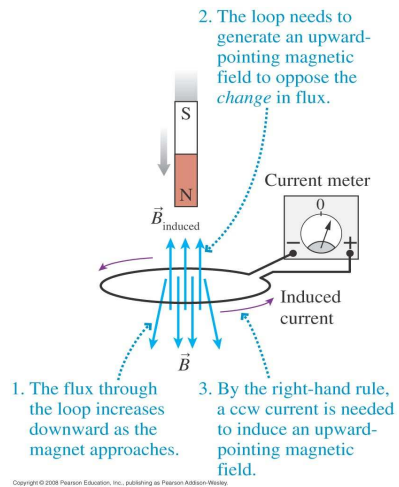
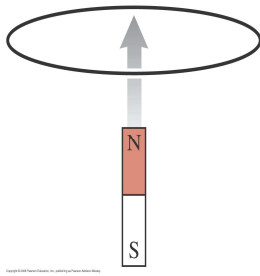
a. No current. No magnetic flux is changing, so no magnetic field is induced.

b. Clockwise. An increasing counterclockwise (from above) current in the lower loop creates an increasing upward-point magnetic field in the upper loop. Thus the flux through the upper loop is increasing, and an induced downward magnetic field is created, resulting from a clockwise current in the upper loop.

c. No current. The current through the lower loop is constant, so there is no change in the flux through the upper loop.

d. Counterclockwise. The decreasing current in the lower loop causes the flux through the upper loop to decrease, inducing an upward magnetic field.

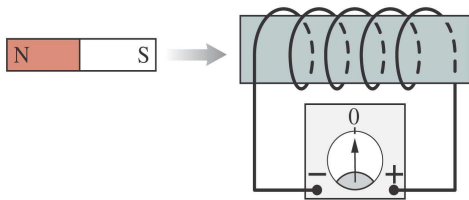
34.7



The figure 34.20 illustrates how current is induced in a coil due to an approaching magnetic pole.

- a. Clockwise from above. The increasing flux through the loop is due to the upward-pointing field of the magnet, so the induced magnetic field is downward.
- b. Yes, up. The induced downward field is like a magnet with its north pole on the bottom, which is repulsed by the bar magnet.
- c. Yes, down. By Newton's third law, the bar magnet experiences an equal and opposite force and hence is pushed down.

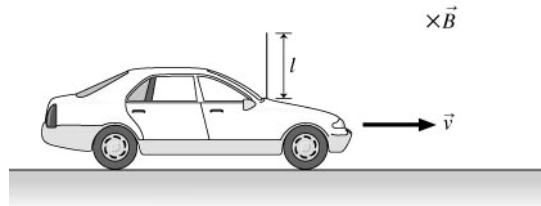
34.9



- a. Left to right. As seen from the side of the approaching magnet the current inside the coil should be clockwise so that the induced magnetic pole on the left side of the coil is 'south' and it tends to repel the approaching magnet (Lenze's Law), hence the magnet's field inside the coil points from right to left (opposite to the increasing magnetic field). This induced clockwise current actually flows from left to right of the current meter.
- b. No current. The flux through the coil is not changing.
- c. Right to left. Flux through the loop decreases as the magnet is withdrawn. There fore to prevent this change (Lenze's Law) the induced current flows in such direction that a north pole is induced at the left side of the coil and it attracts the south pole of the retreating bar magnet. Hence the current as seen from the retreating bar magnet side is counterclockwise. Therefore this time the induced current flows from right to left in the current meter.

Exercise and problems

34.1. Visualize:



As shown in the diagram let's assume that the antennae is vertical, the magnetic field is into the paper and the car is moving horizontally. Then using Equation 34.3. for the emf induced in a straight wire in a magnetic field we have .

$$\mathcal{E} = v l B$$

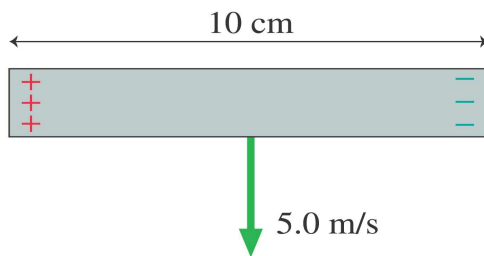
Which gives us,

$$v = \frac{\mathcal{E}}{l B} = \frac{1.0 \text{ V}}{(1.0 \text{ m})(5.0 \times 10^{-5} \text{ T})} = 2.0 \times 10^4 \text{ m/s}$$

Assess: This is an unreasonable speed for a car. It's unlikely you'll ever develop a volt.

34.2. Model: Assume the magnetic field is uniform.

Visualize:



Since a motional emf was developed the field must be perpendicular to \vec{v} . The positive charges experienced a magnetic force to the left. By the right-hand rule if the force experienced by positive charge is to the left and the velocity is downward then the field must be out of the page so that $\vec{v} \times \vec{B}$ is to the left since $q \vec{v} \times \vec{B}$ is the force experienced by moving charges.

Solve: This is a straightforward use of Equation 34.3

$$\mathcal{E} = v l B$$

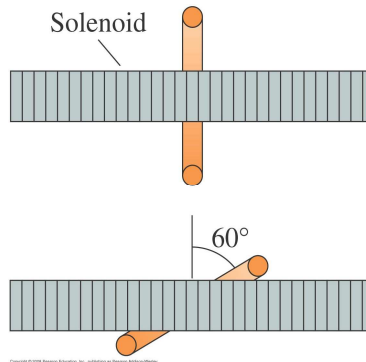
. We have

$$B = \frac{\mathcal{E}}{v l} = \frac{0.050 \text{ V}}{(5.0 \text{ m/s})(0.10 \text{ m})} = 0.10 \text{ T}$$

Assess: This is reasonable. Laboratory fields are typically up to a few teslas in magnitude.

34.5. Model: Consider the solenoid to be long so the field is constant inside and zero outside.

Visualize:



. The field of a solenoid is along the axis. The field is constant inside the solenoid so we will use Equation 34.10

$$\Phi_m = \vec{A} \cdot \vec{B}$$

The flux through the loop is only nonzero inside the solenoid. Since the loop completely surrounds the solenoid, the total flux through the loop will be the flux through the solenoid cross section,

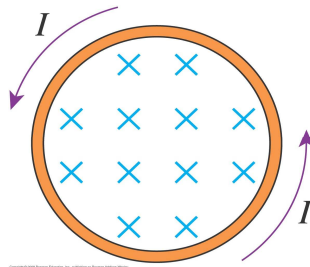
$$\Phi = \vec{A}_{\text{loop}} \cdot \vec{B}_{\text{loop}} = \vec{A}_{\text{sol}} \cdot \vec{B}_{\text{sol}} = \pi r_{\text{sol}}^2 B_{\text{sol}} \cos \theta = \pi (0.010 \text{ m})^2 (0.20 \text{ T}) = 6.3 \times 10^{-5} \text{ Wb}$$

When the loop is tilted it still encloses the solenoid. Now initially the area of the loop was perpendicular to the field but now it is tilted hence we can use the formula

$$\Phi_m = A_{\text{eff}} B = AB \cos \theta$$

Where the effective area through which the field lines pass remains the same because when the loop is tilted the component of \vec{B} in the direction of \vec{A} is less, but the effective area of the loop surface through which the magnetic field lines cross is increased by the same factor. Hence the flux remains the same as the previous case as long as the loop is enclosing the solenoid.

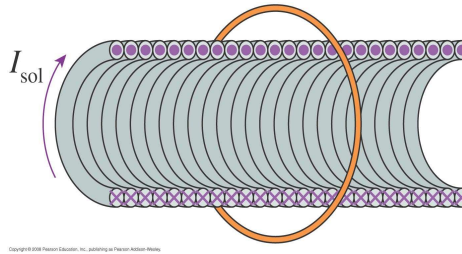
34.7. Model: Assume the field strength is uniform over the loop.



According to Lenz's law, the induced current creates an induced field that opposes the *change* in flux.

Solve: The original field is into the page within the loop and is changing strength. The induced, counterclockwise current produces a field out of the page within the loop that is opposing the change. This implies that the original field must be *increasing in strength* so the flux into the loop is increasing.

34.9.



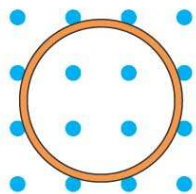
The changing current in the solenoid produces a changing flux in the loop. By Lenz's law there will be an induced current and field to oppose the change in flux.

We assume that the solenoid is long enough such that there is not field outside the solenoid, and therefore the flux through the cross section of the solenoid is the flux through the loop.

Solve: The current shown produces a field to the right inside the solenoid (using right hand rule). So there is flux to the right through the surrounding loop. As the current in the solenoid increases there is more field and more flux to the right through the loop. There is an induced current in the loop that will oppose the *change* by creating an induced field and flux to the left. This requires a *counterclockwise* current when seen from the left end of the solenoid.

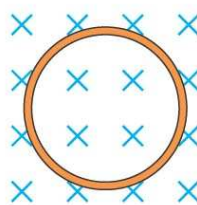
34.11. **Model:** Assume the field is uniform.

(a) B increasing at 0.50 T/s

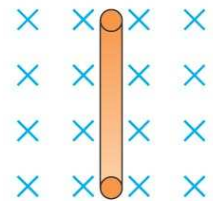


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(b) B decreasing at 0.50 T/s



(c) B decreasing at 0.50 T/s



If the changing field produces a changing flux in the loop there will be a corresponding induced emf and current.

(a) The induced emf is $\mathcal{E} = |d\Phi/dt|$ and the induced current is $I = \mathcal{E}/R$. The field B is changing, but the area A is not. Take \vec{A} to be out of the page and parallel to \vec{B} , so $\Phi = AB$. Thus,

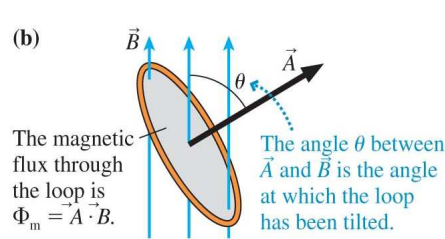
$$\mathcal{E} = \left| A \frac{dB}{dt} \right| = \left| \pi r^2 \frac{dB}{dt} \right| = \left| \pi (0.050 \text{ m})^2 (0.50 \text{ T/s}) \right| = 3.9 \times 10^{-3} \text{ V} = 3.9 \text{ mV}$$

$$I = \frac{\mathcal{E}}{R} = \frac{3.93 \times 10^{-3} \text{ V}}{0.2 \Omega} = 2.0 \times 10^{-2} \text{ A} = 20 \text{ mA}$$

The field is increasing out of the page. To *prevent the increase*, the induced field needs to point into the page. Thus, the induced current must flow *clockwise*.

(b) As in part (a), $\mathcal{E} = A(dB/dt) = 3.9 \text{ mV}$ and $I = 20 \text{ mA}$. Here the field is into the page and decreasing. To *prevent the decrease*, the induced field needs to point into the page. Thus the induced current must flow *clockwise*.

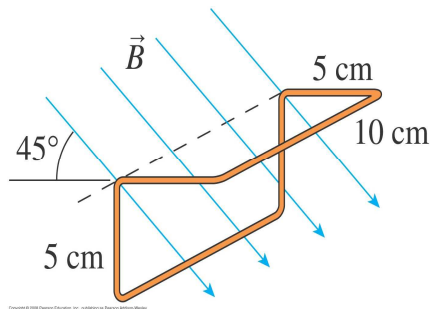
(c) The diagram illustrating the expression of magnetic flux is as follows



Now \vec{A} (left or right) is perpendicular to \vec{B} and so $\vec{A} \cdot \vec{B} = 0 \text{ Wb}$. That is, the field does not penetrate the plane of the loop. If $\Phi = 0 \text{ Wb}$, then $\mathcal{E} = |d\Phi/dt| = 0 \text{ V/m}$ and $I = 0 \text{ A}$. There is *no* induced current.

Assess: Note that the induced field opposes the change.

34.27.



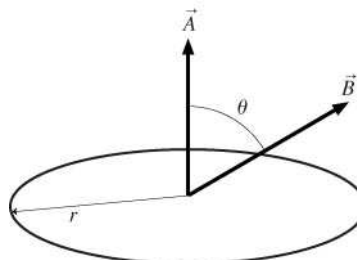
To calculate the flux we need to consider the orientation of the normal of the surface relative to the magnetic field direction. We will consider the flux through the surface in the two parts corresponding to the two different directions of the surface normals (for the horizontal part of the loop area vector is vertically downward and for the vertical part of the loop it is horizontally directed towards the right).

Solve: The flux is the sum of the fluxes linked with each half of the loop

$$\begin{aligned} \Phi &= \Phi_{\text{top}} + \Phi_{\text{left}} = \vec{A}_{\text{top}} \cdot \vec{B} + \vec{A}_{\text{left}} \cdot \vec{B} = A_{\text{top}} B \cos 45^\circ + A_{\text{left}} B \cos 45^\circ \\ &= 2 \times (0.050 \text{ m} \times 0.10 \text{ m})(0.050 \text{ T}) \cos 45^\circ = 3.5 \times 10^{-4} \text{ Wb} \end{aligned}$$

34.32. **Model:** Assume that B changes uniformly with time.

Visualize:



The magnetic strength is changing so the flux is changing and this will create an induced emf. The magnetic field is at an angle $\theta = 60^\circ$ to the normal of the plane of the coils.

Solve: The flux for a single loop of the coil is $\Phi_m = \vec{A} \cdot \vec{B}$ Or $\Phi_m = A_{\text{eff}}B = AB \cos \theta$ The radius and angle don't change with time, but B does.

At any given time the flux linked with one turn of the coil is $\Phi = \pi r^2 B \cos \theta$ and therefore the net flux linked with the coil is *number of turns* $\times \Phi$.

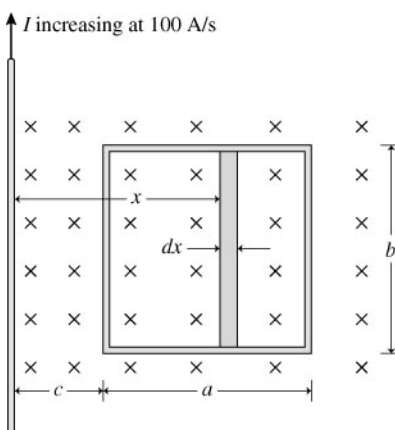
There fore according to Faraday's law, the induced emf is proportional to the rate of change of the net flux linked with the coil given by,

$$E = N \left| \frac{d\Phi}{dt} \right| = NA \cos \theta \left| \frac{dB}{dt} \right| = N\pi r^2 \cos \theta \left| \frac{\Delta B}{\Delta t} \right|$$

$$= 100\pi(0.010 \text{ m})^2 (\cos 60^\circ) \left| \frac{1.50 \text{ T} - 0.50 \text{ T}}{0.60 \text{ s}} \right| = 2.6 \times 10^{-2} \text{ V} = 26 \text{ mV}$$

34.37. Model: Assume the wire is long enough so we can use the formula for the magnetic field of an "infinite" wire.

Visualize:



The magnetic field in the vicinity of the loop is due to the current in the wire and is perpendicular to the loop. The current is changing so the field and the flux through the loop are changing. This will create an induced emf and induced current in the loop.

Solve: The induced current depends on the induced emf and is

$$I_{\text{loop}} = \frac{E_{\text{loop}}}{R} = \frac{1}{R} \left| \frac{d\Phi}{dt} \right|$$

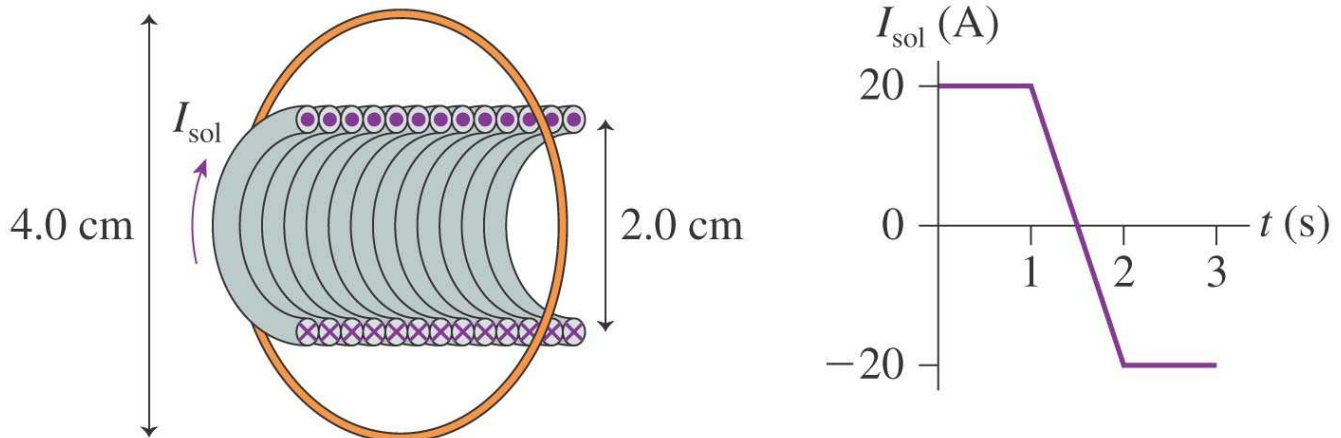
The flux through a rectangular loop due to a wire was found in Example 34.5. The total flux is

$$\Phi = \frac{\mu_0 I b}{2\pi} \ln \left(\frac{c+a}{c} \right)$$

$$\Rightarrow I_{\text{loop}} = \frac{1}{R} \frac{\mu_0 b}{2\pi} \ln \left(\frac{c+a}{c} \right) \frac{dI}{dt} = \frac{(4\pi \times 10^{-7} \text{ T m/A}) (0.020 \text{ m})}{(0.010 \Omega) 2\pi} \ln \left(\frac{0.030 \text{ m}}{0.010 \text{ m}} \right) (100 \text{ A/s}) = 44 \mu\text{A}$$

34.40. Model: Since the solenoid is fairly long compared to its diameter and the coil is located near the center, assume the solenoid field is uniform inside and zero outside.

Visualize:



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As we have seen in problem 34.5 that the flux through the coil is the same as the flux through the solenoid cross section since the loop of the coil surrounds completely the solenoid. The solenoid's magnetic field is parallel to the coil's axis and creates a flux through the coil. This flux changes as the solenoid's current changes, causing an induced emf and corresponding induced current in the coil.

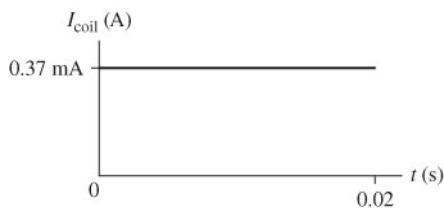
Solve: The induced current from the induced emf is given by Faraday's law. We have

$$I_{\text{coil}} = \frac{\mathcal{E}_{\text{coil}}}{R} = \frac{1}{R} N_{\text{coil}} \left| \frac{d\Phi_{\text{coil}}}{dt} \right| = \frac{N_{\text{coil}} \pi r_{\text{coil}}^2}{R} \left| \frac{d(\mu_0 N I)}{dt} \right| = \frac{N_{\text{coil}} \pi r_{\text{coil}}^2 \mu_0 N}{R l} \left| \frac{dI}{dt} \right|$$

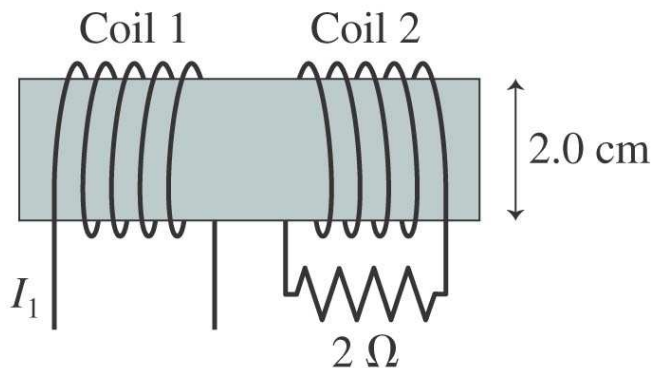
We used the fact that the coil flux is confined to the area $A_{\text{coil}} = \pi r_{\text{coil}}^2$ of the coil, *not* the larger area of the solenoid. The current is changing uniformly over the interval $0 \text{ s} \leq t \leq 0.02 \text{ s}$ at the rate $|dI/dt| = 50 \text{ A/s}$ so the induced current during this interval is

$$I_{\text{coil}} = \frac{5\pi(0.0050 \text{ m})^2 (4\pi \times 10^{-7} \text{ T m/A})(120)}{(0.10 \Omega)(0.080 \text{ m})} (50 \text{ A/s}) = 3.7 \times 10^{-4} \text{ A} = 0.37 \text{ mA}$$

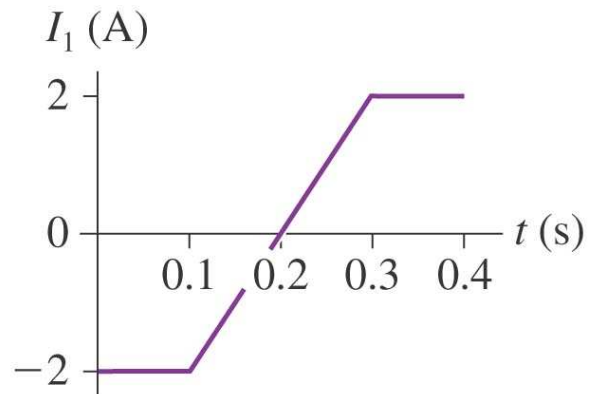
The current in the solenoid is changing steadily so the induced current in the coil is constant. The current is initially positive so the field is initially to the right and decreasing. The induced current will *oppose this change* and will therefore produce an induced field to the right. This requires an induced current in the coil coming out of the page at the top, so it is also positive. That is, it is clockwise when seen from the left.



34.41.



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Assume that the magnetic field of coil 1 passes through coil 2 and that we can use the magnetic field of a solenoid for coil 1.

The field of coil 1 produces flux in coil 2. The changing current in coil 1 gives a changing flux in coil 2 and a corresponding induced emf and current in coil 2.

Solve: (a) From 0 s to 0.1 s and 0.3 s to 0.4 s the current in coil 1 is constant so the current in coil 2 is zero. Thus $I(0.05 \text{ s}) = 0$ A.

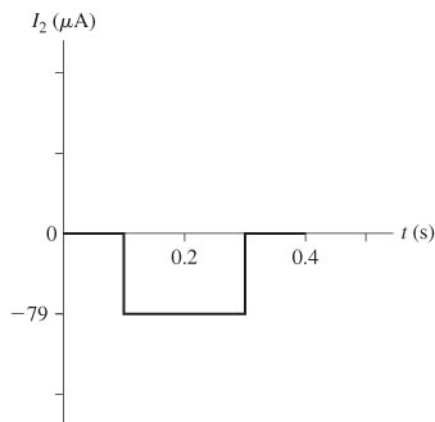
(b) From 0.1 s to 0.3 s, the induced current from the induced emf is given by Faraday's law. The current in coil 2 is

$$I_2 = \frac{E_2}{R} = \frac{1}{R} N_2 \left| \frac{d\Phi_2}{dt} \right| = \frac{1}{R} N_2 A_2 \left| \frac{dB_1}{dt} \right| = \frac{1}{R} N_2 \pi r_2^2 \left| \frac{d}{dt} \left(\frac{\mu_0 N_1 I_1}{l_1} \right) \right| = \frac{N_2 \pi r_2^2 \mu_0 N_1}{R l_1} \left| \frac{dI_1}{dt} \right|$$

$$= \frac{20\pi (0.010 \text{ m})^2 (4\pi \times 10^{-7} \text{ T m/A})(20)}{(2\Omega)(0.020 \text{ m})} |20 \text{ A/s}| = 7.95 \times 10^{-5} \text{ A} = 79 \mu\text{A}$$

We used the facts that the field of coil 1 is constant inside the loops of coil 2 and the flux is confined to the area $A_2 = \pi r_2^2$ of coil 2.

Also, we used $l_1 = N_1 d = 20(1.0 \text{ mm}) = 0.020 \text{ m}$ and $|dI/dt| = 20 \text{ A/s}$. From 0.1 s to 0.2 s the current in coil 1 is initially negative so the field is initially to the right and the flux is decreasing. The induced current will *oppose this change* and will therefore produce a field to the right. This requires an induced current in coil 2 that comes out of the page at the top of the loops so it is negative. From 0.2 s to 0.3 s the current in coil 1 is positive so the field is to the left and the flux is increasing. The induced current will *oppose this change* and will therefore produce a field to the right. Again, this is a negative current. Hence $I(0.25 \text{ s}) = 79 \mu\text{A}$ right to left through the resistor.



34.43. Model: Assume the magnetic field is uniform over the plane of the loop.

Visualize: The oscillating magnetic field strength produces a changing flux through the loop and an induced emf in the loop.

Solve: (a) The normal to the surface of the loop is in the same direction as the magnetic field so that $\Phi = \vec{A} \cdot \vec{B} = BA$. The induced emf is

$$E = \left| \frac{d\Phi}{dt} \right| = A \left| \frac{dB}{dt} \right| = \pi r^2 \left| \frac{dB}{dt} \right| = \pi r^2 \omega B_0 |\cos \omega t|$$

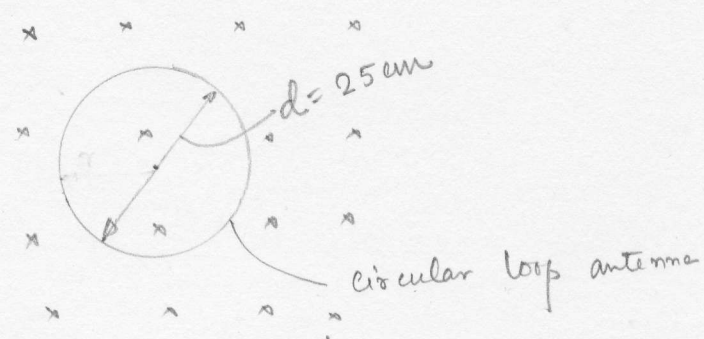
The cosine will oscillate between +1 and -1 so the maximum emf is

$$E_{\max} = \pi r^2 \omega B_0 = \pi r^2 (2\pi f) B_0 = 2\pi^2 (0.125)^2 (150 \times 10^6 \text{ Hz})(20 \times 10^{-9} \text{ T}) = 0.93 \text{ V}$$

(b) If the loop is rotated so that the plane is perpendicular to the electric field, then the normal to the surface will be parallel to the magnetic field. There is no magnetic flux through the loop and no induced emf.

Alternate solution

8.34.43.



\vec{B} is perpendicular to the plane of the loop.
 \vec{B} is along the loop axis. (loop normal)

(a) Then we have magnetic flux linked with the loop is

$$|\Phi_B| = \vec{B} \cdot \vec{A}_{loop}$$

$$= |\vec{B}| \pi r^2$$

(assuming that the area vector of loop is along \vec{B})

Induced emf is

$$\mathcal{E}_{mf} = \left| \frac{d}{dt} \Phi_B \right| = \pi r^2 \left| \frac{dB}{dt} \right|$$

we have $B = (20 \text{ mT}) \sin \omega t$

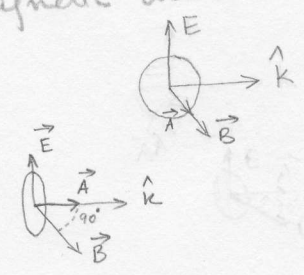
then $\mathcal{E}_{mf} = \pi r^2 (20 \text{ mT}) \omega |\cos \omega t|$

now frequency $f = 150 \times 10^6 \text{ Hz}$

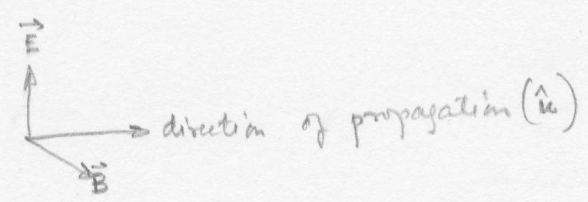
$\omega = 2\pi f = 2\pi \times 150 \times 10^6 \text{ Hz}$

$\mathcal{E}_{mf \text{ max}} = \pi \left(\frac{0.25}{2}\right)^2 \times 2\pi \times 150 \times 10^6 \times 20 \times 10^{-3}$
 $= 0.93 \text{ V}$

(b) for an electromagnetic wave initially loop is like



final orientation is



$\therefore \vec{A} \perp \vec{B} \therefore \Phi_B = 0$
 hence 'no' induced emf.

34.45. Model: Assume an ideal transformer.

Visualize: An ideal transformer changes the voltage, but not the power (energy conservation).

Solve: (a) The primary and secondary voltages are related by Equation 34.30. We have

$$V_2 = \frac{N_2}{N_1} V_1 \Rightarrow N_1 = \frac{V_1}{V_2} N_2 = \frac{15,000}{120} 100 = 12,500 \text{ turns}$$

(b) The input power equals the output power and we recall that $P = I\Delta V$, so

$$P_{\text{out}} = P_{\text{in}} \Rightarrow I_1 \Delta V_1 = I_2 \Delta V_2 \Rightarrow I_1 = \frac{I_2 \Delta V_2}{\Delta V_1} = \frac{(250 \text{ A}) 120 \text{ V}}{15,000 \text{ V}} = 2.0 \text{ A}$$

Assess: These values seem reasonable, because houses have low voltage and high current while transmission lines have high voltage and low current.

34.51. Model: Assume that the magnetic field is uniform in the region of the loop.

Visualize: Please refer to Figure P34.51. The rotating semicircle will change the area of the loop and therefore the flux through the loop. This changing flux will produce an induced emf and corresponding current in the bulb.

Solve: (a) The spinning semicircle has a normal to the surface that changes in time, so while the magnetic field is constant, the area is changing. The flux through in the lower portion of the circuit does not change and will not contribute to the emf. Only the flux in the part of the loop containing the rotating semicircle will change. The flux associated with the semicircle is

$$\Phi = \vec{A} \cdot \vec{B} = BA = BA \cos \theta = BA \cos(2\pi ft)$$

where $\theta = 2\pi ft$ is the angle between the normal of the rotating semicircle and the magnetic field and A is the area of the semicircle. The induced current from the induced emf is given by Faraday's law. We have

$$\begin{aligned} I &= \frac{\mathcal{E}}{R} = \frac{1}{R} \left| \frac{d\Phi}{dt} \right| = \frac{1}{R} \left| \frac{d}{dt} BA \cos(2\pi ft) \right| = \frac{B \pi r^2}{R} 2\pi f \sin(2\pi ft) \\ &= \frac{2(0.20 \text{ T})\pi^2 (0.050 \text{ m})^2}{2(1.0\Omega)} f \sin(2\pi ft) = 4.9 \times 10^{-3} f \sin(2\pi ft) \text{ A} \end{aligned}$$

where the frequency f is in Hz.

(b) We can now solve for the frequency necessary to achieve a certain current. From our study of DC circuits we know how power relates to resistance:

$$P = I^2 R \Rightarrow I = \sqrt{P/R} = \sqrt{4.0 \text{ W}/1.0\Omega} = 2.0 \text{ A}$$

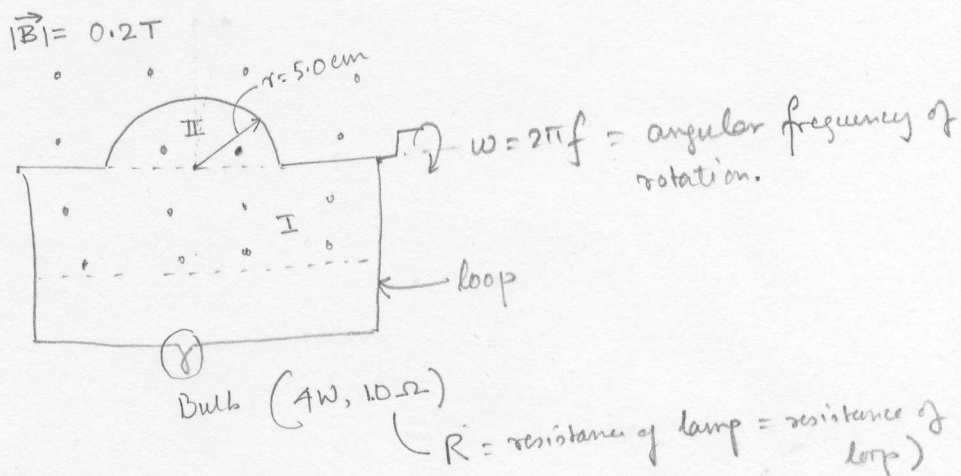
The maximum of the sine function is +1, so the maximum current is

$$I_{\text{max}} = 4.9 \times 10^{-3} f \text{ A s} = 2.0 \text{ A} \Rightarrow f = \frac{2.0 \text{ A}}{4.9 \times 10^{-3} \text{ A s}} = 4.1 \times 10^2 \text{ Hz}$$

Assess: This is not a reasonable frequency to obtain by hand.

Alternate Solution

Figure.



(a) Let's assume that the field is uniform.

We divide the loop into Area I and Area II

Let Area I = A

Area II = $\frac{1}{2}\pi r^2$

then the area \perp to the \vec{B} field is given by
 $A_{\text{net}} = A + \frac{1}{2}\pi r^2 \cos \theta$
 where $\theta = \text{angle between Area II normal and } \vec{B}$.

Then the net flux through this area can be given by

$$\Phi_B = B \left[A + \left(\frac{1}{2}\pi r^2 \right) \cos \theta \right] = B \left[A + \frac{1}{2}\pi r^2 \cos \omega t \right]$$

where $\theta = \omega t = \text{angle made by the area normal of Area II with the } \perp \text{ of this paper. } \omega = 2\pi f = \text{angular frequency with which the loop is rotated (f = frequency of rotation)}$

then $\mathcal{E}_{\text{mf}} = \left| \frac{d\Phi_B}{dt} \right| = \omega \frac{\pi r^2}{2} B \sin \omega t$

\therefore Current induced is.

$$\begin{aligned} \therefore I &= \frac{\mathcal{E}_{\text{mf}}}{R} = \frac{B}{R} \frac{\pi r^2}{2} 2\pi f \sin 2\pi f t = \frac{2 (0.20 \text{ T}) \pi^2 (0.050 \text{ m})^2}{2 (10 \Omega)} f \sin(2\pi f t) \\ &= 4.9 \times 10^{-3} f \sin(2\pi f t) \text{ A} \end{aligned}$$

(b) $I_{\text{max}} = |4.9 \times 10^{-3} f \sin(2\pi f t)|_{\text{max}}$

$= 4.9 \times 10^{-3} f \text{ Amp}$

Now for lamp $P = 4W = I^2 R \quad \therefore I = \sqrt{\frac{4}{10}} \text{ A} = 2 \text{ A}$

then $f = \frac{2}{4.9 \times 10^{-3}} = 4.1 \times 10^2 \text{ Hz}$

This cannot be obtained by rotating with hand.