Lenz's Law

The direction that an induced current travels around a coil of wire can be determined using **Lenz's law**. This law states that an induced current flows in a direction such that its magnetic field opposes the change that created it.

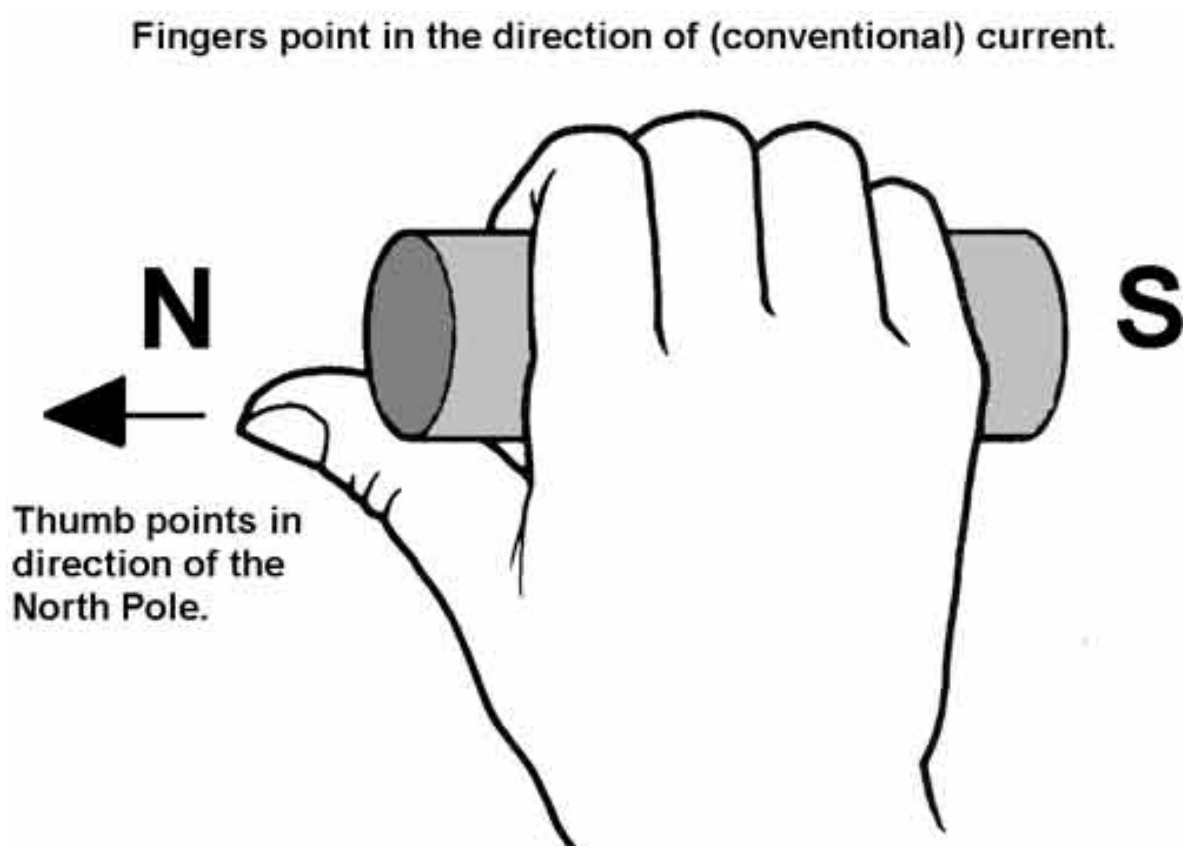
It is extremely important to note that we are now discussing two distinct magnetic fields:

1. The changing magnetic field or flux that induces the current (primary field).
2. The magnetic field produced by the induced current (secondary field).

The secondary field opposes the change in the primary one.

Coupled with the right hand rule, Lenz's law can be used to determine the direction of the induced current for a number of situations.

RH Rule
If the fingers of the right hand are "wrapped around" the coil in the same direction that the current flows, then the thumb (when extended) will point in the direction of the magnetic field lines inside the coil.

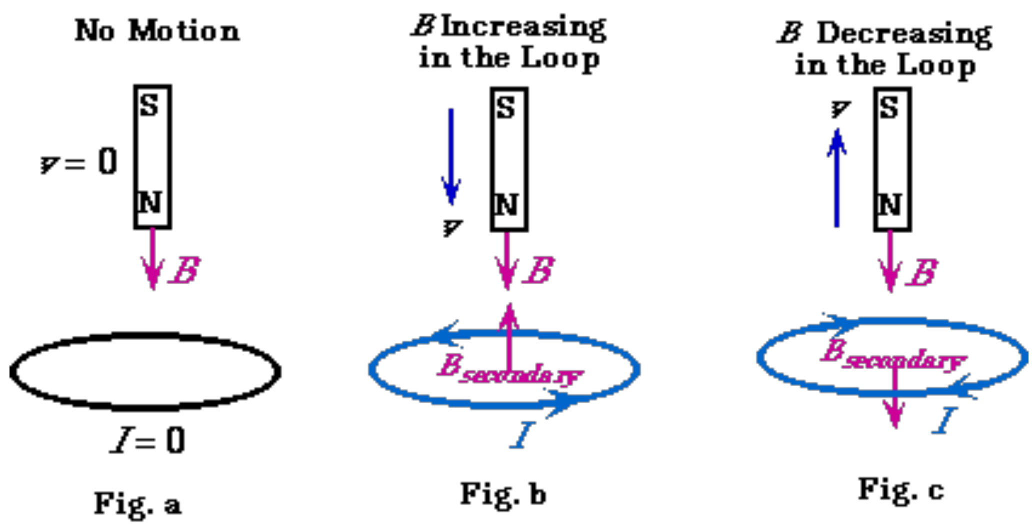


Example 1

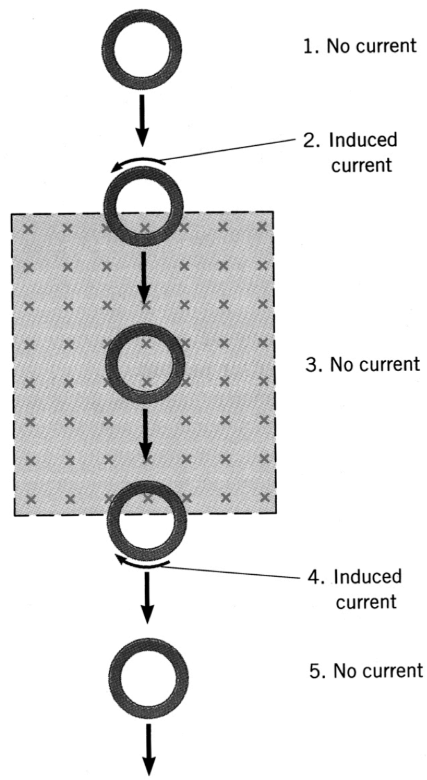
A bar magnet is moved towards a coil of wire, as shown below (Fig. b). As the magnet approaches, the magnetic field inside the coil increases. This change will create an induced current in the coil.

The current that is produced in the coil will, in turn, produce its own magnetic field (separate from the magnetic field of the bar magnet). This secondary magnetic field will be oriented in such a way as to oppose the increasing magnetic field due to the bar magnet:

- To oppose an increasing magnetic field, the secondary magnetic field must point in the opposite direction.
- To oppose a decreasing magnetic field, the secondary magnetic field must point in the same direction.



Example 2
In the diagram below there is a constant magnetic field in a rectangular region of space. This field is directed perpendicularly into the plane of the paper. Outside of this region there is no magnetic field. A copper ring slides through the region, from position 1 to position 5. For each of the five positions, determine if an induced current exists in the ring and, if so, find the direction of the current.



Position 1: No magnetic field passes through the ring, because the magnetic field is zero outside the rectangular region. Therefore, **there is no induced current**.

Position 2: As the ring moves into the field region, the strength of the field inside the ring increases (from 0 to some value). The direction of the induced current must be such that the secondary magnetic field points in the *opposite* direction to the original magnetic field, namely out of the page. According to the RHR, **the induced current must be counterclockwise**, as shown.

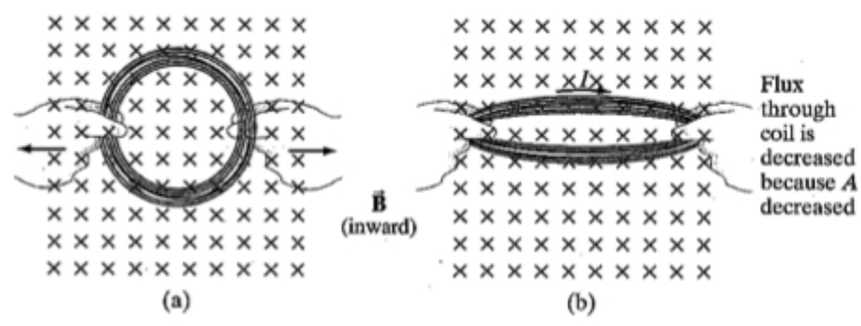
Position 3: Even though the magnetic field passes through the ring, **there is no induced current**, because the strength of the field is constant.

Position 4: As the ring leaves the field region, the strength of the magnetic field inside the ring decreases. The direction of the induced current must be such that the secondary magnetic field points in the *same* direction as the original magnetic field. According to the RHR, **the induced current must be clockwise**, as shown.

Position 5: As in position 1, **there is no induced current**, since the magnetic field is zero.

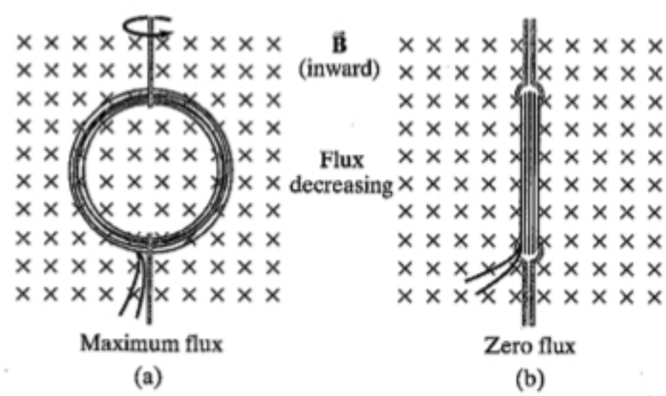
It is important to note that a voltage is induced whenever there is a change in flux through the coil. This can occur when the magnetic field strength changes, as in Example 1 and 2. It can also occur when either the area of the loop changes, or the orientation of the loop changes.

Example 3
In the diagram below, a circular coil is stretched into an oval. This decreases its area, which in turn decreases the amount of flux passing through the coil.



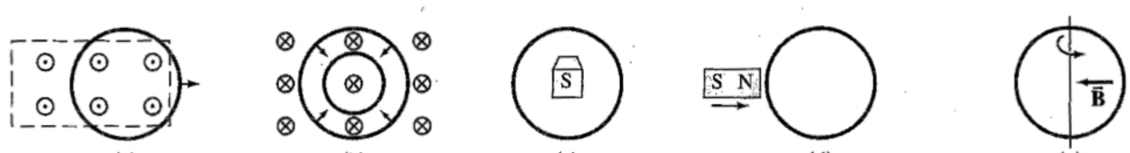
During the brief time that the area is changing, a current will be induced in the coil.

Example 4
In the diagram below, a circular coil is initially perpendicular to a magnetic field (maximum flux). It is then rotated until it is parallel to the field (zero flux).



As it is being rotated, the flux through the coil decreases. This decreasing flux will result in a current being induced in the coil.

Example 5
In what direction is the current induced in the loop for each situation in the following picture?



(a) Pulling the loop to the right out of a magnetic field which points out of the page

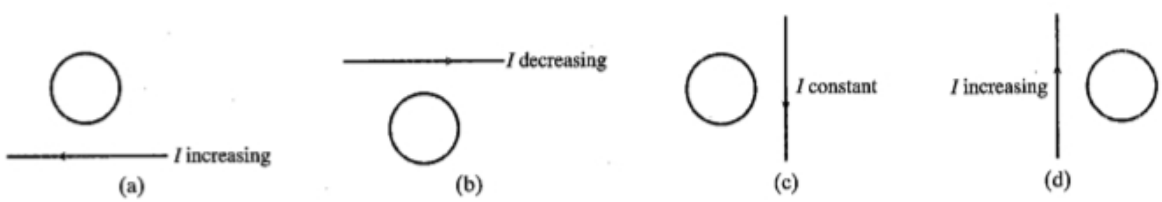
(b) Shrinking a loop in a magnetic field pointing into the page

(c) N magnetic pole moving toward loop into the page

(d) N magnetic pole moving toward the loop in the plane of the page

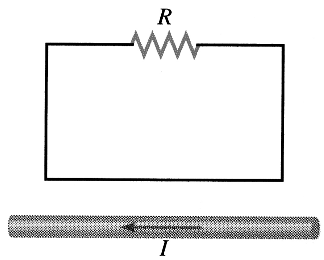
(e) Rotating the loop by pulling the left side toward us and pushing the right side in; the magnetic field points from right to left

Example 6
In what direction is the current induced in the loop for each situation in the following picture?

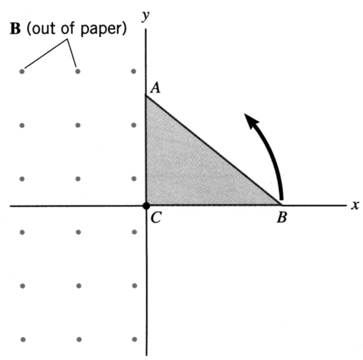


Induction Worksheet

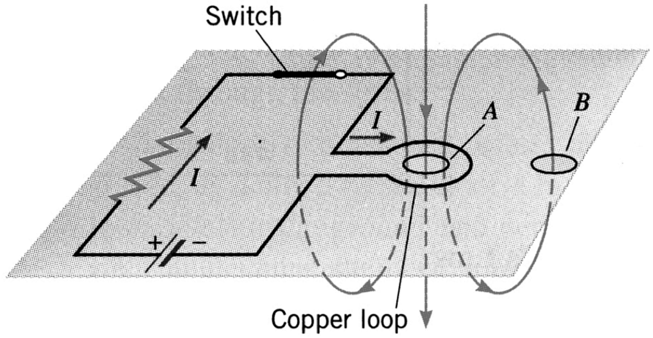
1. What is the direction of the induced current through R in the drawing as the current I increases? Explain your answer.



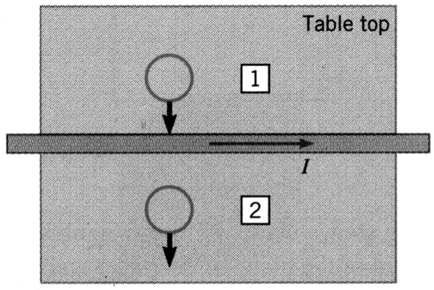
2. The drawing shows that a uniform magnetic field is directed perpendicularly out of the plane of the paper and fills the entire region to the left of the y-axis. There is no magnetic field to the right of the y-axis. A rigid triangle ABC is made of copper wire. The triangle rotates counter clockwise about the origin at point C. What is the direction (clockwise or counterclockwise) of the induced current when the triangle is crossing
   a. the $+y$-axis?
   b. the $-x$-axis?
   c. the $-y$-axis?
   d. the $+x$-axis?



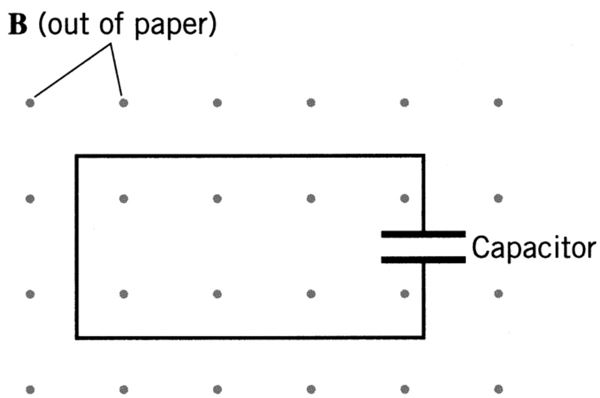
3. As the picture shows, a loop of copper wire is lying flat on a table and is attached to a battery via a switch. The current I in the loop establishes the magnetic field lines shown. There are also two smaller conducting loops A and B lying flat on the table but not connected to batteries. Determine the direction of the induced current (clockwise or counterclockwise, as viewed from above the table) in loops A and B when the switch is
   a. opened.
   b. closed.



4. A long, straight wire lies on a table and carries a current I. As the drawing shows, a small circular loop of wire is pushed across the top of the table from position 1 to position 2. Determine the direction of the induced current, clockwise or counterclockwise, as the loop moves past
   a. position 1.
   b. position 2.



5. Indicate the direction of the electric field between the plates of the parallel plate apparatus shown in the drawing if the magnetic field is decreasing in time. Explain your answer.



6. A circular loop of wire rests on a table. A long, straight wire lies on this loop, directly over its center, as the drawing illustrates. The current I in the straight wire is increasing. In what direction is the induced current, if any, in the loop? Explain your answer.