

Answer to Essential Question 20.2: To find the current of the largest magnitude, we apply Ohm's Law, using the induced emf of the largest magnitude. The resistance was given as 3.0Ω in Exploration 20.2, so we get $I_{\max} = \epsilon_{\max} / R = (0.075 \text{ V}) / (3.0 \Omega) = 0.025 \text{ A}$.

20-3 Lenz's Law and a Pictorial Method for Faraday's Law

Thus far we have discussed the fact that exposing a coil to a changing magnetic flux induces an emf in the coil. If there is a complete circuit, this emf gives rise to an induced current. In what direction is this induced current? The direction of the current also relates to the negative sign in Faraday's law. That negative sign is associated with a whole other law, Lenz's law.

Lenz's law: The emf induced by a changing magnetic flux tends to produce an induced current. The induced current produces a magnetic flux that acts to oppose the original change in flux.

Let's go over a pictorial method for determining the direction of the induced current. As part of this method, recall from chapter 19 that, as shown in Figure 20.12, a current directed clockwise around a loop gives rise to a magnetic field directed into the page inside the loop, while a counterclockwise current produces a field directed out of the page in the loop. This can be confirmed with the right-hand rule. Curl the fingers on your right hand in the direction of the current, and your thumb points in the direction of the field inside the loop.

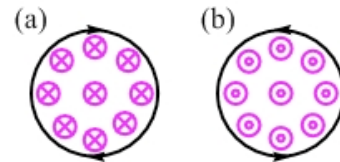


Figure 20.12: (a) A loop with a clockwise current gives rise to a magnetic field directed into the page within the loop. (b) The magnetic field within the loop is directed out of the page if the current is counterclockwise.

EXPLORATION 20.3 – A pictorial method for determining current direction

Step 1 – The loop in Figure 20.13 is moved from the Before position to the After position, closer to a long straight wire that carries current to the left. Sketch a diagram showing the magnetic field lines, produced by the current in the straight wire, that pass through the loop when the loop is in the Before position.

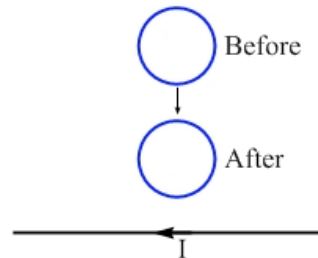


Figure 20.13: A conducting loop, above a long straight current-carrying wire, is moved from the Before position to the After position, closer to the wire.

Let's use the right-hand rule to find the direction of the field from the wire. Point the thumb on your right hand in the direction of the current. Then, curl your fingers on your right hand – they show the direction the field lines circle around the wire. This tells us that, above the wire, where the loop is, the field lines from the wire are directed into the page, as in Figure 20.14.



Figure 20.14: When the loop is in the Before position, the field from the long straight wire passes through the loop into the page.

Step 2 – Sketch a diagram showing the magnetic field lines, produced by the current in the straight wire, that pass through the loop when the loop is in the After position. If the flux changes from Before to After, show this on the diagram. The loop is above the wire in the After position, so the field is still directed into the page. However, the loop is now closer to the wire, where the field is larger, so we show more field lines on the diagram in Figure 20.15.



Figure 20.15: When the loop moves to the After position, coming closer to the wire where the field from the wire is stronger, we draw more field lines passing through the loop.

Step 3 – Draw a “To Oppose” picture, with one field line representing the direction of the field the induced current in the loop creates to oppose the change in flux the loop experiences in moving from the Before position to the After position. Based on the direction of the field in the To Oppose picture, determine the direction of the induced current. To oppose the increase in magnetic flux that occurs as the loop moves closer to the wire, the induced current in the loop creates a magnetic field in the opposite direction, out of the page. The pictorial method is qualitative, so we only need to draw one field line directed into the page in Figure 20.16.



Figure 20.16: To oppose the change in flux as the loop moves from Before to After, the loop creates a magnetic field out of the page with a counterclockwise induced current.

Using the right-hand rule, when the thumb is directed out of the page, the fingers curl counterclockwise, in the direction of the induced current.

Key ideas for the pictorial method: A pictorial method can be used to determine the direction of the induced current in a loop or coil that experiences a change in magnetic flux. The steps are:

1. Draw a Before picture, showing the field lines passing through before a change is made.
2. Draw an After picture, showing the field lines passing through after a change is made.
3. Draw a To Oppose picture, with a single field line to represent the direction of the field needed to oppose the change from the Before picture to the After picture. Then, apply the right-hand rule to find the direction of the induced current needed to produce this field.

Related End-of-Chapter Exercises: 18 – 20, 22.

EXAMPLE 20.3 – A quantitative analysis

Rank the four single-turn loops in Figure 20.17 based on the magnitude of their induced current, from largest to smallest. The loops are either moving into or out of a region of uniform magnetic field. The field is zero outside the region.

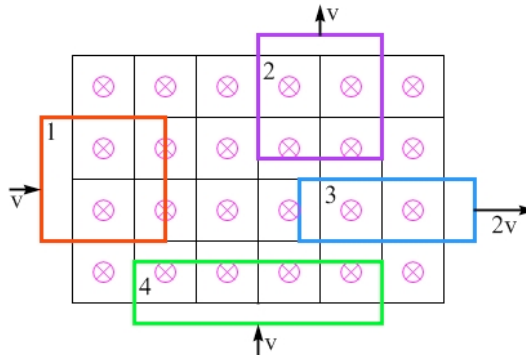


Figure 20.17: Four conducting loops, all of the same resistance, are moving with the velocities indicated either into (loops 1 and 4) or out of (loops 2 and 3) a region of uniform magnetic field.

SOLUTION

Combining Ohm’s law with Faraday’s law, we find that the magnitude of the current is given by:

$$I_{\text{induced}} = \frac{\varepsilon}{R} = \frac{1}{R} \left(\frac{\Delta(BA \cos\theta)}{\Delta t} \right)$$

$$\cos\theta = 1, \text{ and } B \text{ does not change with time so: } I_{\text{induced}} = \frac{\varepsilon}{R} = \frac{B}{R} \left(\frac{\Delta A}{\Delta t} \right).$$

$$\text{Writing the area in terms of the length } L \text{ and width } W: I_{\text{induced}} = \frac{B}{R} \left(\frac{\Delta(LW)}{\Delta t} \right).$$

Defining L as the length of the loop perpendicular to the velocity, which is constant, then the magnitude of $\Delta W / \Delta t$ is the speed. The magnitude of the current is thus: $I_{\text{induced}} = BLv / R$.

The field and resistance are the same, so the induced current for the loops is proportional to the product of the speed multiplied by the length of the loop that is perpendicular to the velocity. This gives a ranking by current magnitude of $4 > 1 = 2 = 3$. Loop 3 has half the length, perpendicular to its velocity, as loops 1 and 2, but makes up for that factor of two in its speed.

Essential Question 20.3: Find the direction of the induced current in the loops in Figure 20.17.