

10.1.2 Lenz's Law

The direction of the induced current is determined by Lenz's law:

The induced current produces magnetic fields which tend to oppose the change in magnetic flux that induces such currents.

To illustrate how Lenz's law works, let's consider a conducting loop placed in a magnetic field. We follow the procedure below:

1. Define a positive direction for the area vector \vec{A} .
2. Assuming that \vec{B} is uniform, take the dot product of \vec{B} and \vec{A} . This allows for the determination of the sign of the magnetic flux Φ_B .
3. Obtain the rate of flux change $d\Phi_B / dt$ by differentiation. There are three possibilities:

$$\frac{d\Phi_B}{dt}: \begin{cases} > 0 \Rightarrow \text{induced emf } \varepsilon < 0 \\ < 0 \Rightarrow \text{induced emf } \varepsilon > 0 \\ = 0 \Rightarrow \text{induced emf } \varepsilon = 0 \end{cases}$$

4. Determine the direction of the induced current using the right-hand rule. With your thumb pointing in the direction of \vec{A} , curl the fingers around the closed loop. The induced current flows in the same direction as the way your fingers curl if $\varepsilon > 0$, and the opposite direction if $\varepsilon < 0$, as shown in Figure 10.1.6.

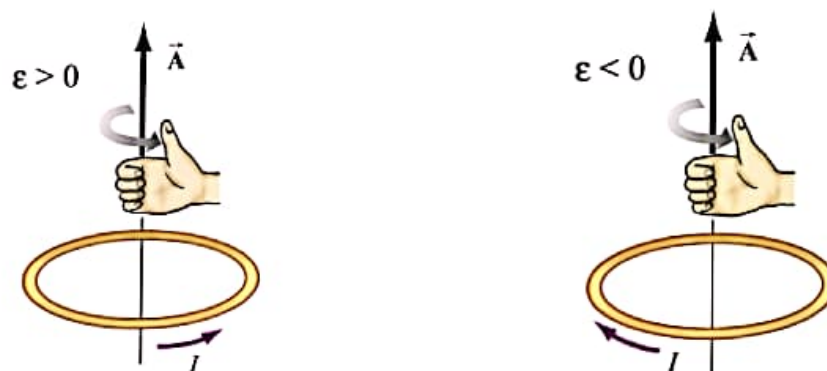


Figure 10.1.6 Determination of the direction of induced current by the right-hand rule

In Figure 10.1.7 we illustrate the four possible scenarios of time-varying magnetic flux and show how Lenz's law is used to determine the direction of the induced current I .

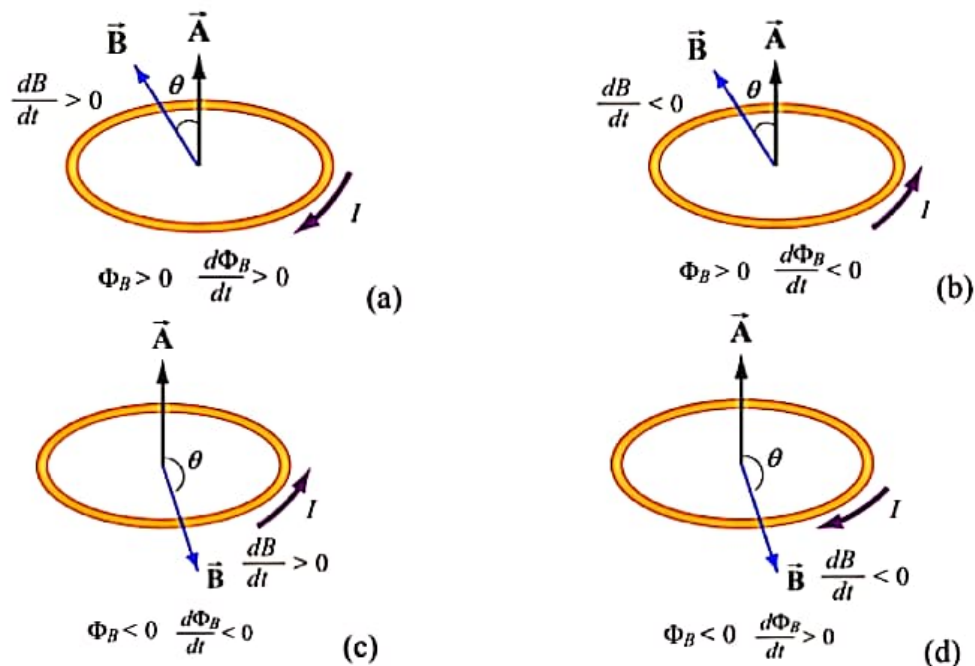


Figure 10.1.7 Direction of the induced current using Lenz's law

The above situations can be summarized with the following sign convention:

Φ_B	$d\Phi_B/dt$	\mathcal{E}	I
+	+	-	-
	-	+	+
-	+	-	-
	-	+	+

The positive and negative signs of I correspond to a counterclockwise and clockwise currents, respectively.

As an example to illustrate how Lenz's law may be applied, consider the situation where a bar magnet is moving toward a conducting loop with its north pole down, as shown in Figure 10.1.8(a). With the magnetic field pointing downward and the area vector \vec{A} pointing upward, the magnetic flux is negative, *i.e.*, $\Phi_B = -BA < 0$, where A is the area of the loop. As the magnet moves closer to the loop, the magnetic field at a point on the loop increases ($dB/dt > 0$), producing more flux through the plane of the loop. Therefore, $d\Phi_B/dt = -A(dB/dt) < 0$, implying a positive induced emf, $\mathcal{E} > 0$, and the induced current flows in the counterclockwise direction. The current then sets up an induced magnetic field and produces a *positive* flux to counteract the change. The situation described here corresponds to that illustrated in Figure 10.1.7(c).

Alternatively, the direction of the induced current can also be determined from the point of view of magnetic force. Lenz's law states that the induced emf must be in the direction that opposes the change. Therefore, as the bar magnet approaches the loop, it experiences