Answer to Essential Question 20.7: Because the current in the secondary coil is constant, the magnetic flux through the secondary coil is constant. Because the flux through the secondary coil does not change, there is no induced emf in the secondary, and thus there is also no current. Transformers work very well for alternating current, but they do not work for direct current.

Chapter Summary

Essential Idea: Electromagnetic Induction.

One of the most practical applications of physics, the generation of electricity, relies on electromagnetic induction. Exposing a conducting loop to a changing magnetic flux (a change in the number of magnetic field lines passing through the loop) will induce an emf, or voltage, in the loop. In a complete circuit, this induced emf will gives rise to an induced current in the loop.

Magnetic Flux

Magnetic flux is a measure of the number of magnetic field lines passing through an area. The symbol we use for flux is the Greek letter capital phi, Φ .The equation for magnetic flux is:

$$\Phi = BA\cos\theta \, , \qquad \text{(Equation 20.1: \textbf{Magnetic flux})}$$

where θ is the angle between the magnetic field $\vec{B}$ and the area vector $\vec{A}$.

Faraday's Law of Induction

Exposing a loop or coil to a ***changing*** magnetic flux gives rise to a voltage, called an **induced emf.** Following Ohm's law, the induced emf gives rise to an **induced current** in the loop or coil. The emf induced by a changing magnetic flux in each turn of a coil is equal to the time rate of change of that flux. Thus, for a coil with *N* turns, the net induced emf is given by:

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} = -N\frac{\Delta\left(BA\cos\theta\right)}{\Delta t} \, . \qquad \text{(Eq. 20.2: \textbf{Faraday's Law of Induction})}$$

In many cases, graphing the magnetic flux as a function of time can be helpful because the induced emf is proportional to the negative of the slope of the graph of flux versus time.

Lenz's Law

Lenz's Law is associated with the minus sign in Faraday's Law. Lenz's Law states that 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.

A pictorial method for applying Lenz's Law to determine the direction of induced current

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.

Applying the pictorial method: an example

The magnetic field, directed into the page through a wire loop, is decreasing in magnitude. In which direction is the current induced in the loop?

Figure 20.29: The situation described here is similar to that of Figure 20.29. In the "To Oppose" picture, the field created by the induced current must also be directed into the page, to oppose the loss in field lines into the page the loop experiences.

Motional emf

A conductor moving with a velocity $\vec{v}$ through a magnetic field $\vec{B}$ has an induced emf, generally referred to as motional emf, across it given by:

$$\varepsilon = -vBL \,. \qquad \text{(Equation 20.3: \textbf{Motional emf})}$$

where L is the length of the conductor that is perpendicular to both $\vec{v}$ and $\vec{B}$. The moving conductor thus acts like a battery. Note that in many motional emf situations, and in other induced emf situations, Ohm's Law ($\varepsilon = IR$) is often used to determine the current resulting from the motional or induced emf.

Eddy currents

Eddy currents are swirling currents that are set up in conductors that are exposed to a changing magnetic flux. Consistent with Lenz's law, these swirling currents create their own magnetic field that tends to oppose the original change in flux. A practical application of eddy currents is in train brakes, in which braking forces arise from the interaction of the eddy currents in the train wheel and the magnetic field of an electromagnet. The field is turned on, and the eddy currents are set up, only when the operator of the train applies the brakes.

Electric generators

Alternating current can be generated very easily, simply by spinning a conducting loop at a constant rate in a uniform magnetic field. To avoid wires being twisted, in some cases the magnets producing the field are rotated around a conducting loop that is held fixed.

As a function of time, the emf of an electric generator, in which either the loop or the magnetic field spins at a constant angular velocity $\vec{\omega}$, oscillates sinusoidally. Expressed as an equation, the emf is:

$$\varepsilon = \omega NBA \sin(\omega t) = \varepsilon_{\max} \sin(\omega t) \,. \qquad \text{(Equation 20.4: \textbf{emf from an electric generator})}$$

The peak voltage, $\varepsilon_{\max}$, is the product of ω, N (the number of turns in the loop), B (the strength of the magnetic field), and A (the area of the loop).

Transformers

A transformer is a device for changing the voltage of an alternating current (AC) signal from one value to a higher or lower value. Transformers usually consist of two coils wrapped around a ferromagnetic core. An emf is induced in the secondary coil by a changing flux produced by the changing current in the primary coil. If no energy is lost in the transformation process, we say that the transformer is ideal.

$$\frac{\Delta V_p}{\Delta V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s} \,. \qquad \text{(Equation 20.5: \textbf{Relations for an ideal transformer})}$$

The subscripts p and s stand for primary and secondary, respectively. ΔV represents the potential difference across the coil, I is the current, and N is the number of turns in the coil. Equation 20.5 is generally used to relate peak values of current or voltage in the primary to their corresponding peak values in the secondary, or to relate rms values in one coil to rms values in the other coil.