17-2 Electromagnetic Induction

Magnetic Flux and Induced Voltage

Vocabulary **Flux:** The number of magnetic field lines passing through a given area.

$$\textbf{flux} = (\textbf{area})(\textbf{perpendicular component of the magnetic field})$$

or $\phi = AB$

The unit for flux is the **weber (Wb)**, which equals one **tesla·meter squared ($\mathbf{T \cdot m^2}$).**

Therefore, if a loop of wire lies perpendicular to a magnetic field, the maximum possible number of lines of flux will pass through the loop. If the loop of wire lies parallel to the field, the flux through the loop will be zero.

Vocabulary **Faraday's Law:** If the flux through a given area changes over time, a voltage will be induced in the wire and a current will momentarily flow. If the number of turns of wire is increased, the voltage will increase proportionally.

$$\textbf{potential difference} = \frac{(\textbf{number of turns})(\textbf{change in flux})}{\textbf{elapsed time}}$$

or $V = \dfrac{N\Delta\phi}{\Delta t}$

Note: This potential difference is also referred to as the **induced voltage**.

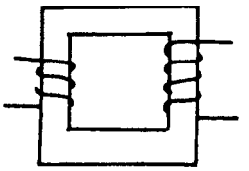
Vocabulary **Lenz's Law:** An induced voltage always produces a magnetic field that opposes the field that originally produced it.

In other words, if the original magnetic field, and thus the flux, is going toward the north, the induced voltage will produce an opposing field and flux that goes toward the south.

Transformers

Vocabulary **Transformer:** A device that produces a change in voltage in an alternating current circuit.

A transformer consists of an iron core wound with a primary coil and a secondary coil. An alternating current placed through the primary coil induces a changing magnetic field through the core, which, in turn, induces a voltage in the secondary coil.



$$\frac{\textbf{voltage in primary coil}}{\textbf{voltage in secondary coil}} = \frac{\textbf{turns in primary coil}}{\textbf{turns in secondary coil}} \quad \text{or} \quad \frac{V_\text{p}}{V_\text{s}} = \frac{N_\text{p}}{N_\text{s}}$$

If the primary coil has more turns than the secondary coil, the transformer will step down, or decrease, the incoming voltage. If the primary coil has fewer turns than the secondary coil, the transformer will step up, or increase, the incoming voltage.

Solved Examples

Example 3: Tyrone is pedaling his bike down the street perpendicular to Earth's magnetic field of 5.5×10^{-5} T. What is the flux through the metal rim of his bicycle wheel, if the wheel has an area of 1.13 m^2?

Given: $A = 1.13\ \text{m}^2$
$B = 5.5 \times 10^{-5}\ \text{T}$

Unknown: $\phi = ?$
Original equation: $\phi = AB$

Solve: $\phi = AB = (1.13\ \text{m}^2)(5.5 \times 10^{-5}\ \text{T}) = \mathbf{6.2 \times 10^{-5}\ Wb}$

Example 4: If the bicycle in Example 3 takes 2.0 s to make a 90° turn onto a northbound street, what is the induced voltage in one metal rim of the bicycle?

Given: $N = 1$ turn
$\phi = 6.2 \times 10^{-5}$ Wb
$\Delta t = 2.0$ s

Unknown: $V = ?$
Original equation: $V = \dfrac{N\Delta\phi}{\Delta t}$

Solve: $V = \dfrac{N\Delta\phi}{\Delta t} = \dfrac{(1\ \text{turn})(6.2 \times 10^{-5}\ \text{Wb})}{2.0\ \text{s}} = \mathbf{3.1 \times 10^{-5}\ V}$

Example 5: While out for a walk with his mother, Lance notices a large, cylindrical gray box high atop a telephone pole. His mother explains that it is a transformer. This transformer takes 6000. V from the power company and steps it down to the 240 V supplied to each of the houses on the street, with the use of a secondary coil containing 100. turns. How many turns are there in the primary coil?

Given: $V_\text{p} = 6000.\ \text{V}$ *Unknown:* $N_\text{p} = ?$

$V_\text{s} = 240\ \text{V}$ *Original equation:* $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$

$N_\text{s} = 100.\ \text{turns}$

Solve: $N_\text{p} = \dfrac{V_p N_s}{V_s} = \dfrac{(6000.\ V)(100.\ \text{turns})}{240\ \text{V}} =$ **2500 turns**

Practice Exercises

Exercise 5: Patty is driving down the expressway on her way to the office in a town where the horizontal component of Earth's magnetic field is 3.5×10^{-5} T to the north. The driver's side window of Patty's car has an area of 0.40 m^2. a) What is the magnitude of the flux through the window if the car is moving south? b) How does it differ if the car is moving west?

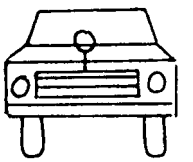
Answer: **a.** _____

Answer: **b.** _____

Exercise 6: A medical process called *magnetic resonance imaging* (MRI) replaces X-rays in some instances where pictures are required to study internal organs. Eleanor is undergoing an MRI procedure and is placed inside a chamber housing the coil of a large electromagnet that has a radius of 25.0 cm. A flux of 0.290 Wb passes through the coil opening. What is the magnetic field inside the coil?

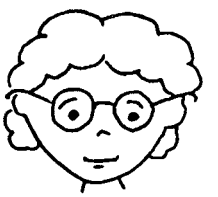
Answer: _____

Exercise 7: The hood ornament on Abe's sedan is shaped like a ring 8.00 cm in diameter. Abe is driving toward the west so that Earth's 5.00×10^{-5} T field provides no flux through the hood ornament. What is the induced voltage in the metal ring as Abe turns from this street onto one where he is traveling north, if he takes 3.0 s to make the turn?



Answer: _____

Exercise 8: Becky wears glasses whose wire frames are shaped like two circles, each with an area of 2.0×10^{-3} m^2. The horizontal component of Earth's magnetic field in Becky's hometown is 1.9×10^{-5} T. If Becky turns her head back and forth, rotating it through 90° every 0.50 s, what is the induced voltage in the wire frame of one eyepiece?



Answer: _____

Exercise 9: Audrey disassembles the control box of her electric train and finds a small transformer inside. Its primary coil is made up of 600. turns and the secondary coil is made up of 60. turns. a) If the household voltage supplied to the train is 120 V, what voltage is required to make the train run? b) Is this a step-up or a step-down transformer?

Answer: **a.** _____

Answer: **b.** _____

Exercise 10: A hydroelectric plant in Niagara Falls sends 3000 V to the transformer in a substation that steps it up to 120 000 V for transmission to homes in New York City. If the primary coil contains 2000 turns, how many turns are there in the secondary coil of the step-up transformer?

Answer: _____

5. a) Zero
   b) 1.4×10^{-5} Wb
7. 8.4×10^{-8} V
9. a) 12 V