Lesson Title	Faraday's Law of Induction
Length of Lesson	1 class period (50 min)
Created By	Charles Vaughan
Subject	Physics
Grade Level	11-12
State Standards	5a
DOK Level	DOK 2 - Graph, Interpret, Make Observations, Construct
DOK Application	Describe the cause/effect of a particular event. Identify patterns in events or behavior.
National Standards	9-12: B: Physical Science
Graduate Research Element	My research involves volatiles and ionized gasses emitted from comets. These ionized particles are easily influenced by charged particles and magnetic fields emanated from the sun. Faraday's Law show the relationship between magnetic flux and induced electric potential.

Student Learning Goal:

<u>MS Physics</u>:
5a (Physical Science): Analyze and explain the relationship between electricity and magnetism.

- Magnetic poles, magnetic flux and field, Ampère's law and Faraday's law

<u>National Standards for Grades 9-12</u>:
B: Physical Science:

- MOTION AND FORCES. Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. These effects help students to understand electric motors and generators.

Materials Needed (supplies, hand-outs, resources):

- Computer with Data Studio software
- Pasco interface hardware
- Solenoid coils of wire (two tall solenoids, one wider than the other, and one short solenoid)
- Small refrigerator magnets
- One large horseshoe magnet
- Wires for making connections
- Iron rod

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Lesson Performance Task/Assessment:
This activity will be composed of three parts. First, students will move a permanent magnet through a conducting coil of wire and measure the electric potential (voltage) produced. Next, students will take a stationary magnet and rotate a coil of wire near the magnet to measure the electric potential as well. Last, students will build a transformer, and they will attempt to optimize its design using an iron rod as a core.

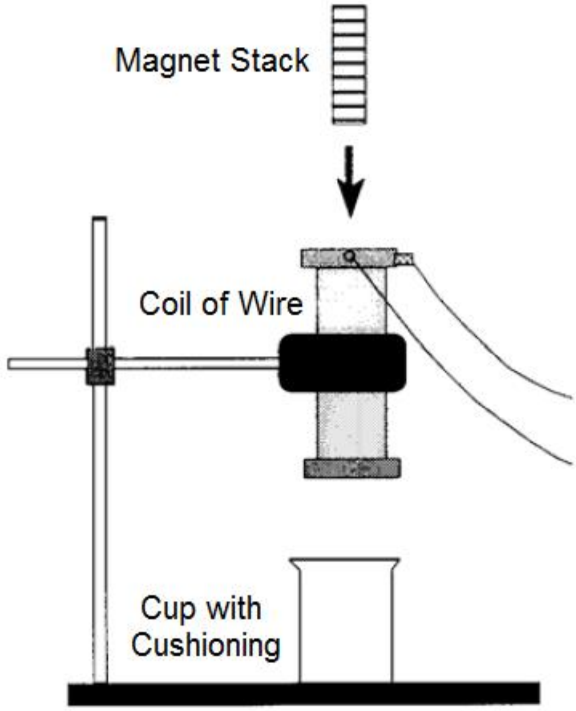
Lesson Relevance to Performance Task and Students:
Understanding Faraday's Law is critical to understanding the relationship between electricity and magnetism. In practical use, electric motors and generators would not work without the fundamental understanding of this law.

Anticipatory Set/Capture Interest:
"By now you know that there is a relationship between electricity and magnetism, but you have perhaps never seen this. In order for electric motors, generators, and transformers to work, we have to understand this relationship. Faraday's Law states that a changing magnetic flux within a conducting material can induce an electric potential (i.e., voltage) in the material. In this lesson, you will explore these phenomena and learn how to create a voltage source using simple magnets."

Guided Practice:
It is strongly advised that the teacher have some familiarity with Data Studio before attempting this lesson. Show students how to set up the software (Data Studio) and make the required connections to the Pasco Interface. They will need help setting up the graphs on the computer and having appropriate scaling.

Independent Practice:

<u>Part 1:</u>
Set up a voltage vs. time graph using Data Studio. Connect cables from the large solenoid to the Pasco Interface. Take a single stack of ordinary magnets and drop it through the solenoid, allowing it to freely fall through the spool (see image below). Pay attention to which side of the magnet stack falls first (you may need to place a sticker on one side of the magnet stack). It is recommended that a cup with cushioning be placed beneath the spool so that the magnets do not break.



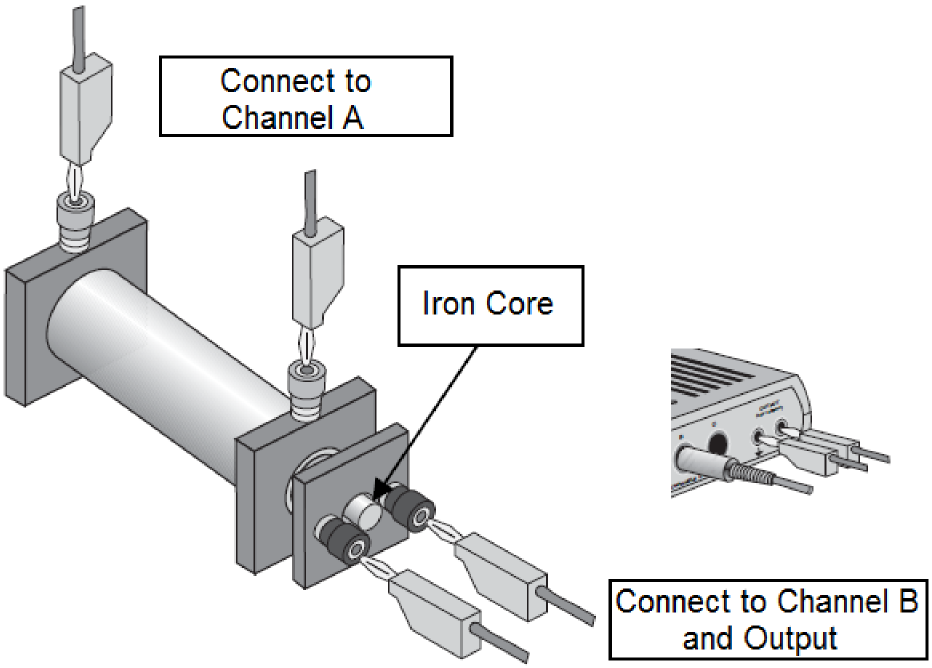
Notice the plot of voltage vs. time that is generated. What is the area beneath the first voltage peak? What is the area beneath the second peak? How do the shapes of these two peaks compare? Is one peak shorter and wider than the other? Repeat this procedure, except flip the magnet stack upside down and drop it through the coil. What is different about the orientation of these peaks? Last, take the magnet stack and just hold it stationary inside the solenoid. Why is no voltage induced from this?

Part Two:

Take the smaller solenoid and connect it to the Pasco Interface. Bring up a voltage vs. time graph again. Using the large horseshoe magnet, take the smaller solenoid and spin it between the poles of the magnet. Try spinning the solenoid about its two different axes. Which spin orientation will induce a voltage? Why won't the other spin orientation create this same voltage? For the induced voltage, what is the shape of the graph?

Part Three:

Using the two tall solenoids, place the smaller one inside the larger one. Insert the iron rod in the smaller solenoid. Connect the outer coil to channel A and the inner coil to channel B on the Pasco Interface. Also, make an additional connection from the smaller coil to the output terminal on the Pasco Interface (see picture below).



Open the signal generator window in Data Studio and set the voltage to 0.100 volts and the frequency to 60Hz. Open the "Scope" in Data Studio to view the oscilloscope readings for channels A and B. Note that only the inner core (channel B) is directly receiving the output signal. How is the electrical signal being sent to the outer coil, even though it's not directly connected to any source? (Hint: The current in the inner coil creates a magnetic field, and because the current is changing, the strength of the magnetic field is changing as well.) What is the ratio of the amplitudes for these two signals (i.e. outer/inner)? What would happen if a DC (rather than AC) signal were used for this inner coil? Remove the iron core and notice what happens to the signal amplitude for channel A. Why does a material such as iron improve the efficiency of this transformer? What other materials might work in this case?

Remediation and/or Enrichment:
Remediation – IEP

For more advanced (or longer) classes, have students determine the pole orientation of their magnets. They will need to understand the mathematical relationship between the magnetic field and current direction as the magnetic flux changes.

Check(s) for Understanding:
By the end of the lesson, students should be able to understand that a *changing* magnetic flux is responsible for inducing an electric potential. There are two possible ways to do this: (1) vary the strength of the magnetic field through the coil (e.g., bring the magnet closer to or further from the conducting coils), or (2) vary the area of the coil on which the magnetic field acts by changing its orientation or shape. In parts one and three, the strength of the magnetic field was changing which induced a voltage, and in part two, the area of effect was changing as the coil was rotated through a static magnetic field.

Closure:
Using Faraday's Law, what has to happen to induced a current in a coil of wire using just a magnet? Is it possible to keep both the magnet and the coil stationary and still produce this current? Why does an iron core improve the efficiency of a transformer?

Possible Alternate Subject Integrations:
Pre-Engineering, Physical Science

Teacher Notes:
It is strongly advised that the teacher have some familiarity with Data Studio before attempting this lesson. Many of the ideas and questions in this lesson were incorporated from a similar lesson taught in General Physics III and Calculus-based Physics II at Mississippi State University.

Source: http://physics.msstate.edu/labs/