Electromagnetic Induction (approx. 1.5 h) (7/18/19)

Introduction

It's hard to imagine a time when humans saw the world as unknowable. Increased breadth within the social and natural sciences, verified through mathematics including statistics, accelerated the shift from a perpetuation to the advancement of knowledge. Such advancements lead to discoveries through experimentation that previous generations viewed as a mystery. In the early 19th century, Danish Scientist Hans Christian Oersted observed a compass needle deflected when placed near a current-carrying wire, thus finding the connection between electricity and magnetism. American Scientist and first Secretary of the Smithsonian Institution, Joseph Henry (you can see Henry's electromagnetic apparatus within the Smithsonian archive in Washington D.C.) made simultaneously, but independent observations that British Scientist, Michael Faraday, performed on the magnetic field surrounding a current-carrying wire. These experiments and observations established the basis for the electromagnetic theory, an event that transformed our daily existence. Our world has never been the same!

From Cosmos: A Spacetime Odyssey (2014), narrated by Neil DeGrasse Tyson we see Michael Faraday manipulating light with an electric current. Cosmos dedicates an entire episode entitled, "The Electric Boy," providing an overview of the nature of electromagnetism discovered by Michael Faraday.

Michael Faraday made our world the way it is today by (a) communicating his findings related to electromagnetic induction; (b) pointing us in the direction to use electricity to refashion the way we work and communicate; (c) devoting his life to teaching; he initiated lectures and science demonstrations starting from 1865 to the present day that involves prominent scientists including Desmond Morris (Zoologist), Sir David Attenborough (Naturalist), and Carl Sagan (Cosmologist); and (d) campaigning for a scientifically literate society by demystifying science for the masses.

Equipment

- PASCO 550 or 850 interface
- PASCO galvanometer
- PASCO Voltage Sensor
- PASCO Basic Coil Set (2) 200 turn coils, (1) 400 turn coil, (1) 800 turn coil and Iron Core
- Colored Pencils
- compass
- magnet set
- 4 banana patch cords

Basic Electromagnetism Part 1: Relationship Between Electricity and Magnetism
Using a coil from the Basic Coil Set **Figure: 1**, it's easy to demonstrate that current carrying conductors produce magnetic fields.

The relationship between electric currents and magnetic fields is confirmable by establishing a current in a coil (try the 200, 400, or 800-turn coil) with the PASCO interface and then observing changes in the magnetic field with a compass.

Figure 1: PASCO Basic Coil Set and Iron Core

Connect banana plugs from the positive and negative terminal of the power supply as seen in **Figure: 2** to the plug input on one of the coils (e.g., 400-turn coil). After connecting the interface power supply to the 400-turn coil with banana plugs, launch the capstone file linked on the next page.

Figure 2: PASCO 550 interface power supply outputs (red positive/black negative)

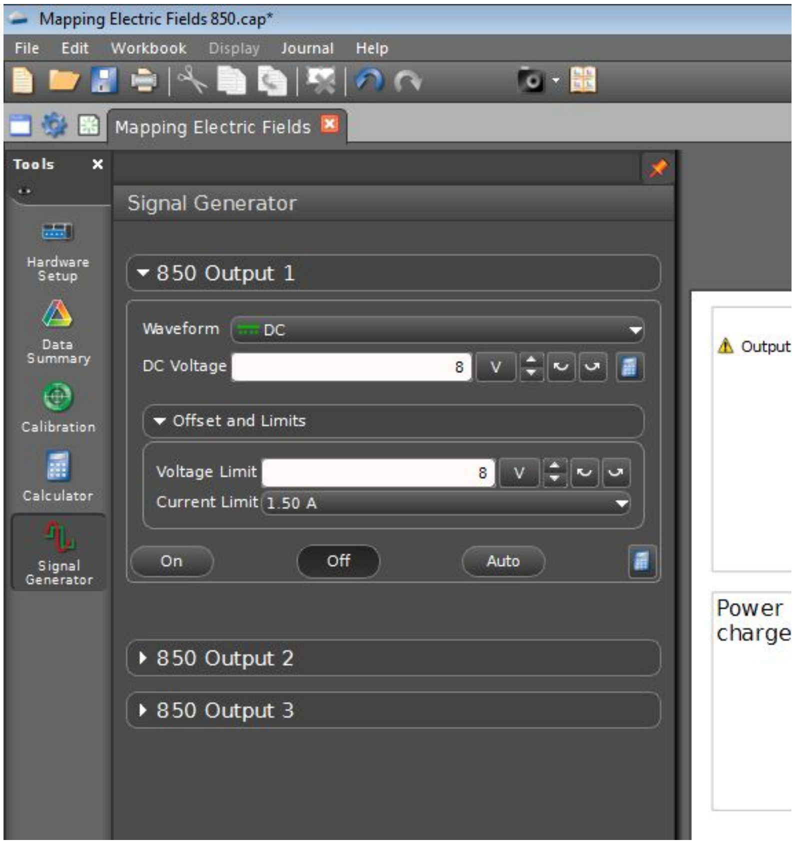
<u>DOWNLOAD AND LAUNCH THE PASCO CAPSTONE FILE NEEDED FOR THIS INVESTIGATION.</u>

The Capstone file contains multiple workbook tabs that you will use in this investigation (e.g., Basic Electromagnetism, Measuring Current and Voltage, Transformer with Positive Square Function, Transformer with Sine Function)

Click this link (or type) this link to download the file for PASCO 550 interface
https://tinyurl.com/y7uasrfm

Click this link (or type) this link to download the file for PASCO 850 interface
https://tinyurl.com/y6fh495y

After launching the PASCO Capstone software suite, you will see a SIGNAL GENERATOR control screen **Figure 2a** allowing users to configure the power supply output parameters (e.g., waveform function shape, applied voltage, voltage/current limit, frequency, etc).



Waveform DC
DC Voltage 8 V
Voltage Limit 8 V
Current Limit 1.50 A

Figure 2a: Signal Generator Screenshot

Procedure

1)Check the Capstone software to ensure the power supply is OFF before establishing electrical connections.
2)Connect a PASCO coil to the power supply using banana plugs.
3)Orient the PASCO coil bore perpendicular to the Earth's magnetic field (e.g., in the east/west plane).
4)Place a compass around 5cm from the end of the coil bore as seen in **Figure 3**.

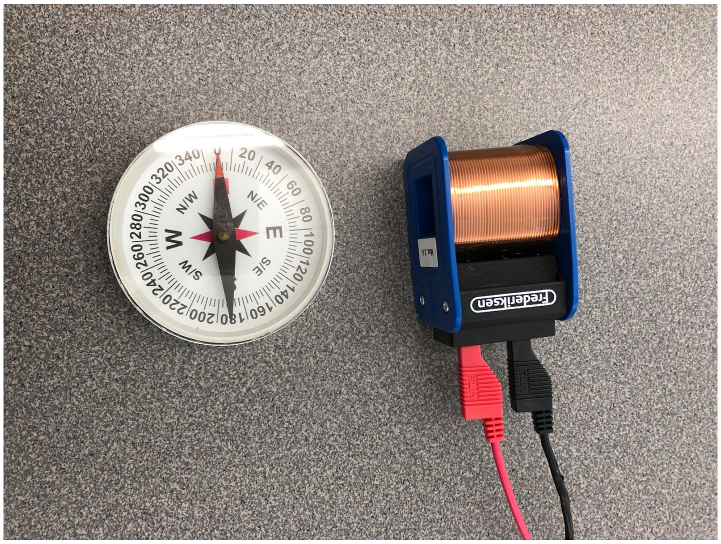
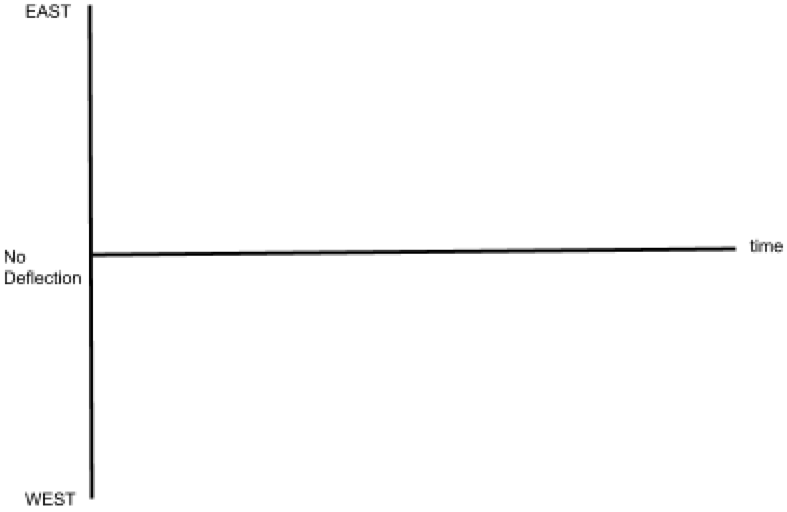


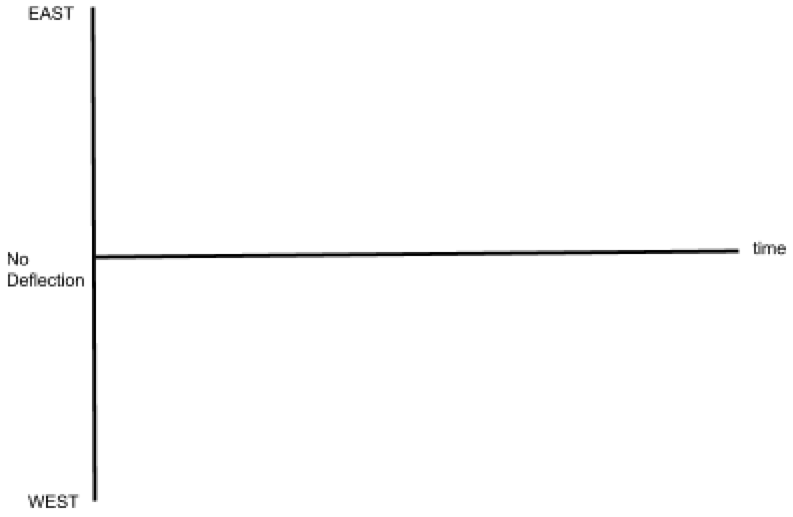
Figure 3. Coil connected to power supply with banana plugs and oriented in the East/West plane (note: no current is running through coil in this image; the compass needle is oriented in the "ambient" magnetic field)

5)Change the voltage output in Capstone to -5V, press the ON button and observe the compass needle.

6)Observe the compass needle for voltage increments from -5V to +5V, turn off the power supply, and record your findings below. Sketch the deflection of the compass needle for (two of the recommended voltages as a function of time on the graph below.



7)Next, change the waveform output from DC to Sine, change the frequency to 0.25 Hz, set the voltage amplitude to 1V, press ON, observe and record your findings below. Next, double the frequency of oscillation to 0.5 Hz and observe the effect. Sketch the deflection of the compass needle as a function of time on the graph below.



What is the relationship between the applied voltage (current), the number of coil turns (e.g., 200 turns, 400 turns, 800 turns), and the ***<u>magnitude and direction</u>*** of the magnetic field produced by a current carrying coil? Develop and then investigate your procedure *and* communicate your results in the space below. Cite experimental evidence to justify your reasoning and claims.

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Electromagnetic Induction with a Bar Magnet Part 2: Relationship Between Electricity and Magnetism

Using a coil, a bar magnet, and the PASCO PASPort galvanometer, it is easy to demonstrate that a moving coil of wire near a magnet, or a moving magnet near a coil of wire will induce a voltage (and therefore a current) in the coil. In this part of the investigation, you will use a sensitive meter called a *galvanometer* to observe the magnitude and direction of *induced* voltages (and corresponding currents) in coils due to (a) time changing and (b) constant magnetic field within the coil core.

Simply *moving* a magnet in and out of a coil results in a time changing magnetic flux. The magnetic flux ($\boldsymbol{\Phi}_B$) is defined as the product of the uniform magnetic field (**B**) and the cross-sectional area of the coil bore (**A**). ($\boldsymbol{\Phi}_B = \mathbf{B}_{//}\mathbf{A}$). When the magnetic field within the coil bore changes over time, so does the magnetic flux.

The induced voltage (V) across the coil dependent on (a) the number of coil turns (N) and (b) the rate at which the magnetic flux ($\boldsymbol{\Phi}_B$) of the coil changes.

$$V = - N \Delta\boldsymbol{\Phi}_B/\Delta t = N ((\Delta \mathbf{B}_{//})(\Delta A))/\Delta t$$

In preparation for measurement, you will connect a galvanometer to the PASCO 550 or 850 interface in the blue PasPort input as seen in **Figure 4.**

Figure 4: Connect galvanometer to the PasPort 1 input (red).

The galvanometers used within this investigation measure differential voltage in the range of −2 V to +2 V and can also be used in combination with a resistor as a current sensor.

Figure 5: PASPort galvanometer assembly illustration. (Banana plugs are used to connect the galvanometer and solenoid)

Sensor Set-up

Connect the Galvanometer Sensor to a PASPORT interface. For measuring voltage, connect the included cable or binding post adapter to the sensor's BNC connector, or connect a device to the Galvanometer with a BNC cable. Before making a measurement, short the + and − inputs together and press the Tare button on the sensor. This adjusts the sensor's measurement to 0 V. After completing the process to connect and zero the galvanometer, connect the coil (e.g., 200 turn, 400 turn, 800 turn) and galvanometer with banana plug leads.

After making measurements, adjust the scale of the graphical data to view a trends in voltage (or current) data.

Now that the hardware is installed, click on the workbook tab in the Capstone file entitled **Measuring Current and Voltage** to make measurements.

IMPORTANT: Since galvanometers have very low resistance and are designed only for very small currents it is important <u>to never connect them directly to a voltage source</u> without making sure the current will be limited to an acceptable range.

Using a magnet with marked North and South poles, two coils with different number of turns (e.g., 200 turns and 400 turns, 200 turns and 800 turns, etc), and the PASCO galvanometer, make measurements of induced voltages experimenting with the effect that time changing and constant magnetic fields (see Figure 5) have on induced voltages. Tabulate your data in the space provided on the next page.

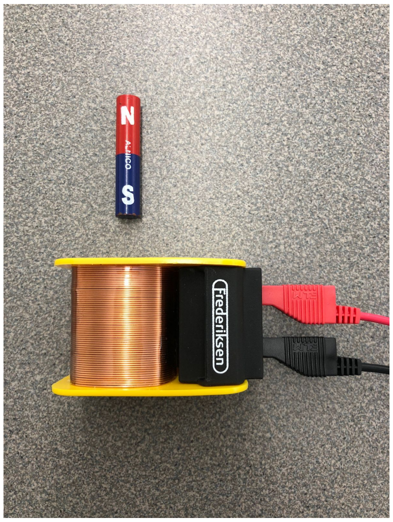

Figure 5: You will observe induced voltages in coils by (a) placing a stationary magnet in the bore; (b) move quickly in; (c) move quickly out, (d) move slowly in; (e) move slowly out with 1) a north pole and then 2) a south pole for a coil with a small number of turns and then repeat the measurement for a coil with a large number of turns.

<u>You can measure the peak (maximum) currents by using the coordinate tool on the current graph within the capstone software.</u>

	#of coil turns____________ (small # of turns)		#of coil turns____________ (large # of turns)	
North Pole	Maximum Current,	Sign of Current	Maximum Current,	Sign of Current
Moves quickly inward				
Stationary inside				
Moves quickly outward				
Moves slowly inward				
Moves slowly outward				
South Pole	Maximum Current,	Sign of Current	Maximum Current,	Sign of Current
Moves quickly inward				
Stationary inside				
Moves quickly outward				
Moves slowly inward				
Moves slowly outward				

How do your experimental findings compare with Faraday's Law of Induction $V = - N\ \Delta\boldsymbol{\Phi}_B/\Delta t = N\ ((\Delta\ \mathbf{B}_{\parallel})\ (\Delta A))/\Delta t$? Use experimental evidence related to each variable (e.g., number of turns, rate of change of magnetic flux) to justify your claims.

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Transformers are electrical devices consisting of two or more coils of wire used to transfer electrical energy by means of a changing magnetic field. When an alternating current (AC) passes through a coil of wire, it produces an alternating magnetic field. A time changing magnetic field is precisely the condition needed for the electromagnetic induction to take place in the second coil of wire. In other words, a time-varying magnetic field associated with the primary coil induces a voltage in the secondary coil.

We observed a similar effect in Part 2 of this lab. Thrusting a magnet into the coil results in an increase of the magnetic flux through the coil, causing a voltage spike. Quickly removing the magnet results in a decrease of the magnetic flux through the loops, inducing a voltage spike (of opposite sign/polarity) across the coil.

Setting up the coils on the iron core (as seen in Figure 1) allows for the investigation of Faraday's Law of Induction. In the case of the transformer used in this investigation, the two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the "core." This soft iron core is not solid but made up of individual laminations connected to increase the efficiency of energy transfer by decreasing eddy currents which heat up the core and dissipate energy from the device. You will learn about Eddy Currents within the E&M portion of your course, or you can investigate this phenomenon independently. The two coils are electrically insulated from each other. However, the coils are magnetically linked through the iron core or other ferromagnetic materials. Typically, magnetic cores have high magnetic properties (permeabilities) that "confine and guide" magnetic fields in electrical devices (e.g., electromagnets, transformers, electric motors, generators) and are often made of ferromagnetic materials (e.g., iron, cobalt, nickel). The high permeability of the core compared to the surrounding air, causes a concentration of the magnetic field within the core increasing the efficiency of transmission of energy from the primary to the secondary coil. When a potential difference applied across the primary coil, establishes a magnetic field in and around the core which, in turn, induces a voltage across the secondary coil.

A single-phase transformer can operate to either increase or decrease the voltage applied to the primary coil. When a transformer is used to "increase" the voltage across the secondary coil to the primary, it is called a step-up transformer. When it is used to "decrease" the voltage across the secondary winding to the primary, it is called a step-down transformer. The difference in voltage between the primary and the secondary windings is achieved by changing the number of coils turns in the primary winding (NP) compared to the number of coils turns on the secondary winding (NS).

The turns ratio (i.e., Number of Primary Coil Turns/Number of Secondary Coil Turns), which has no units, represents the ratio of the primary to secondary windings, such as 2:1 (2-to-1). In this example, if there are 2 Volts applied across the primary coil there will be 1 Volt on the secondary coil; this is a step-down transformer. Then we can see that if the ratio between the number of turns changes the resulting voltages must also vary by the same proportion.

An ideal transformer assumes that the flux through the primary is equivalent to the flux through the secondary.

$\boldsymbol{\Phi}_{B(\text{primary})} = \boldsymbol{\Phi}_{B(\text{secondary})}$ and since the two coils are connected with the same iron core, and $V = -N\,\Delta\boldsymbol{\Phi}_B/\Delta t$, we can determine the relationship between $N_{p,}$ N_s, V_p, and V_s:

$$\boldsymbol{\Phi}_{B(\text{primary})} = \boldsymbol{\Phi}_{B(\text{secondary})} \text{ and } \Delta\boldsymbol{\Phi}_B = V\Delta t/N$$

where V represents the primary and/or secondary voltage, N represents the number of turns on the primary or secondary coil, and Δt represents the time interval through which the voltage alternates.

To restate, if $\boldsymbol{\Phi}_{B(\text{primary})} = \boldsymbol{\Phi}_{B(\text{secondary})}$ and we substitute $V_{\text{primary}}\Delta t/N_{\text{primary}} = V_{\text{secondary}}\Delta t/N_{\text{secondary}}$.

And we assume the time interval through which the voltage changes across each coil is the same, then time cancels

$$V_{\text{primary}}\cancel{\Delta t}/N_{\text{primary}} = V_{\text{secondary}}\cancel{\Delta t}/N_{\text{secondary}}$$

revealing the relationship between the $N_{p,}$ N_s, V_p, and V_s as

$$V_{\text{primary}}/N_{\text{primary}} = V_{\text{secondary}}/N_{\text{secondary}}$$

the relationship is typically rearranged expressing the ratio of the primary-to-secondary voltages and the ratio of the primary-to-secondary number of turns as

$$\boxed{V_{\text{secondary}}/V_{\text{primary}} = N_{\text{secondary}}/N_{\text{primary}}}$$

The above derivations shows that the number of turns on the primary coil compared to the number of turns on the secondary coil, determines the voltage across the secondary coil. However, if the primary and secondary coils are electrically isolated from each other, how is the secondary voltage produced? As previously stated, a simple transformer consists of two coils mounted around a common soft iron core. When an alternating voltage (V_p) is applied across the primary coil, a current flows through the coil which in turn sets up magnetic field loops (around the coil and through the bore). As the magnetic field changes (e.g., increases and decreases) due to the alternative voltage across the primary coil, the strength of the magnetic field (**B**) and the magnetic flux ($\boldsymbol{\Phi}_B$) through the coil oscillates from zero to a maximum positive value, decreases to zero, increases to a maximum negative value and again falls to zero repeatedly. The time changing magnetic field and magnetic flux of the primary coil results in a time changing and temporary magnetization of the entire soft iron core. As the magnetic field set up by the primary coil expands outward, the laminated soft iron core forms a path and concentrates the magnetic field and magnetic flux throughout the entire iron core. The magnetic field and flux within the core links both coils as the voltage across the primary coil oscillates (e.g., increases and decreases) using the Capstone function generator (e.g., step or sine function) a time changing magnetic field is established and propagates through the iron core. When the magnetic field flows through the core to the secondary coil, the field results in a time changing flux through the secondary, thus inducing a voltage across the secondary coil.

Part 3: Electromagnetic Induction with a Time Changing Flux in Transformers: Relationship Between Electricity and Magnetism (SQUARE FUNCTION SWITCHING ON AND OFF VOLTAGE/CURRENT)

First, remove the PASPort Galvanometer and place the sensor back in the storage bag. You will not use the galvanometer for the remainder of the experiment.

To demonstrate the basic function of a transformer, mount a primary *and* a secondary coil on the laminated iron core as seen in Figure 1 (Note: The figure shows (2) 400 turn coils mounted on the iron core). During the portion of this investigation you should mount primary and secondary coils on the core of (a) equal numbers of turns (e.g., 400 turn primary and 400 turn secondary), (b) *two* step-up transformer configurations (e.g., 200 turn primary and 400 turn secondary, 200 turn primary and 800 turn secondary); and (c) *one* step-down transformer configuration of your choice (e.g., 400 turn primary to 200 turn secondary).

PROCEDURE
1)Mount the desired primary and secondary coils on the soft iron core with the cross bar installed and screwed into the "u" shaped core. (See Figure 1)
2)Connect the primary coil to the interface power supply using banana plug cables.
3)Connect the secondary coil to the voltage sensor and then connect the voltage sensor to Analog Port (Figure 6))
4)Click on the TRANSFORMER WITH POSITIVE SQUARE FUNCTION Capstone workbook tab.
5)The SIGNAL GENERATOR is preconfigured to generate a 2V amplitude, 1 Hz frequency, meaning the voltage switches on and off from 0V to +2V every second.
6)The graphs are preconfigured to simultaneously display the power supply output voltage signal across the primary (top graph) and the induced voltage signal across the secondary coil (bottom graph).
7)You will collect and compare the secondary voltage data for signals generated at low (e.g.,+2V) and then high (e.g., +4V) voltage amplitudes. Remember the to use the ON/OFF buttons to energize the circuit and the press RECORD to display data.

To restate, you will apply a POSITIVE SQUARE FUNCTION voltage signal across the primary coil from the interface power supply and then measure induced voltages across the secondary using the PASCO Voltage Sensor.

Figure 6: Analog Input A for Voltage Sensor.

The power supply will (a) apply a time changing voltage (e.g., POSITIVE SQUARE FUNCTION, SINE FUNCTION) across the primary coil and (b) a voltage sensor will measure induced voltages, if any, across the secondary coil. The primary and secondary voltages will be measured and displayed using the Capstone software. In parts 3 and 4, you will simultaneously plot and compare the primary and secondary coil voltages as a function of time for (a) a POSITIVE SQUARE FUNCTION and (b) a SINE FUNCTION.

In part 3, you will apply a POSITIVE SQUARE FUNCTION voltage across the primary coil and observe the voltage output across the secondary coil. In part one you used the SIGNAL GENERATOR to generate a DC Voltage output, however, in this portion of the investigation you will use a POSITIVE SQUARE FUNCTION for a voltage output to when powering or energizing the primary coil of the transformer.

The POSITIVE SQUARE FUNCTION power output models the behavior of a switch (ON/OFF). The step function causes abrupt, and somewhat instantaneous changes of the voltage and current across and through the primary coil. Turning the voltage and current ON and OFF, results in a time changing flux throughout the iron core and induces a voltage and current across and through the secondary coil.

Change the amplitude of potential on and off at small steps (e.g., 0V to +2V; turning on, +2V to 0V; turning off) (Figure 7) and then large steps (e.g., 0V to +4V; turning on, +4V to 0V; turning off) and (a) observe the induced voltages across any primary and secondary coil combination (e.g., 400 turn primary and 400 turn secondary); AND THEN (b) observe the impact of the ratio of the number of turns (e.g., #turns primary/#turns secondary) on induced voltages across a variety of step-up and step-down transformer coil combinations.

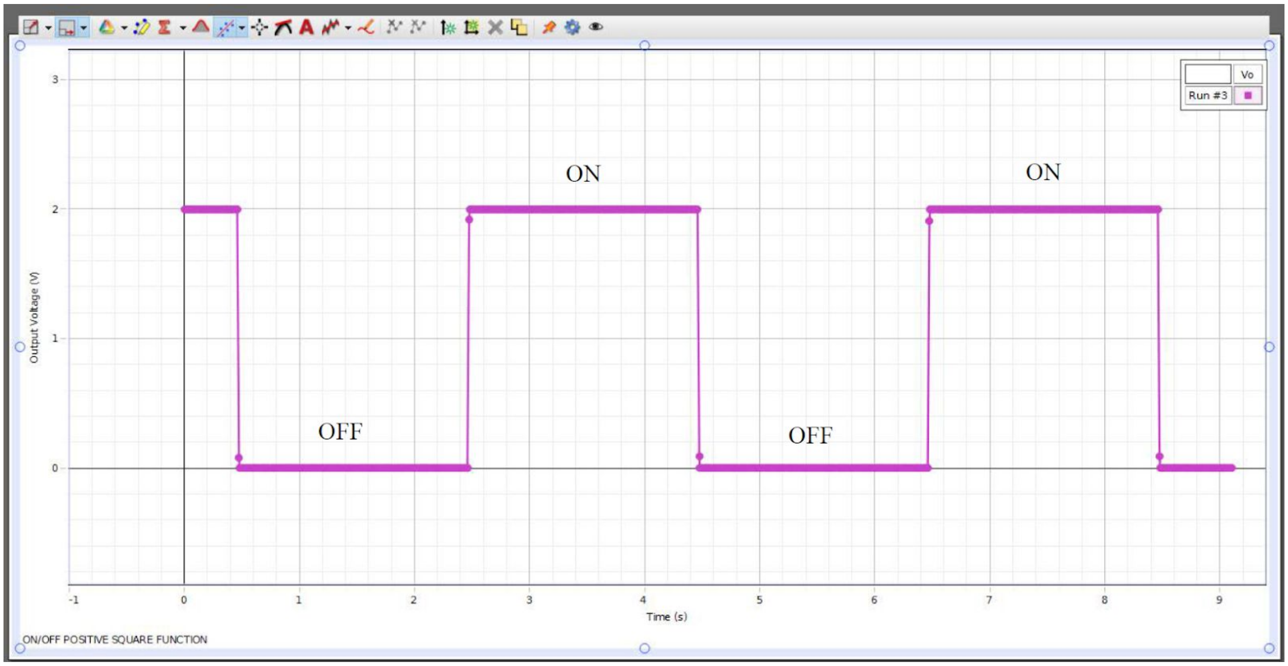

Figure 7: POSITIVE SQUARE FUNCTION generated with the PASCO Capstone SIGNAL GENERATOR

How do your experimental findings compare with Faraday's Law of Induction as related to the function of single phase transformers described by the equations $V = - N \Delta\boldsymbol{\Phi}_B/\Delta t$ and $V_{secondary}/V_{primary} = N_{secondary}/N_{primary}$?

When answering the above question, collect and tabulate data from appling the POSITIVE STEP FUNCTION and corresponding secondary coil voltage readings for (a) transformers with equal primary and secondary windings (e.g., 400 turn primary and 400 turn secondary), (b) *two* step-up transformer configurations (e.g., 200 turn primary and 400 turn secondary, 200 turn primary and 800 turn secondary); and (c) *one* step-down transformer configuration of your choice (e.g., 400 turn primary to 200 turn secondary).

You can measure and then compare peak voltage spikes for various SQUARE FUNCTION amplitudes (e.g., +2V, +4V) and transformer coil configurations (e.g., step-up, step-down) with the Capstone coordinate tool (the eighth icon from the left on the top of any graph display in Capstone); you can drag this tool around your graph to measure the voltage value for any data point.

Use experimental evidence to justify your claims for the effect of varying the (a) amplitude of the POSITIVE SQUARE function *and* (b) the ratio of primary and secondary turns to the primary and secondary voltages.

How are these findings similar or different to the results from Part 2 where you induced a voltage in a coil with a moving magnet? Under which circumstances are voltages induced across the secondary coils? (*Hint: Refer back to the Part 2 of this investigation where you moved a magnet near a coil.)*

Do the ratios of $V_{secondary}/V_{primary} = N_{secondary}/N_{primary}$ equal one another? Use the peak induced voltage values (maximum voltage) from the secondary when evaluating the above equation. Explain your findings.

Create and tabulate your data to clearly communicate findings. Again, be sure to use empirical evidence to justify all claims.

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Part 4: Electromagnetic Induction with a Time Changing Flux in Transformers: Relationship Between Electricity and Magnetism (SINE FUNCTION ALTERNATING THE MAGNITUDE AND SIGN OF VOLTAGE/CURRENT)

The amount of voltage induced in the secondary is determined by the number of turns and the time rate of change of the magnetic flux through the secondary coil. As the magnetic flux oscillates sinusoidally, $\boldsymbol{\Phi}_B = \boldsymbol{\Phi}_{B(max)} \sin(\boldsymbol{\Theta})$ where $\boldsymbol{\Theta} = \omega t$ and $\omega = 2\pi/T$ *or* $\omega = 2\pi f$ then,

$$\boldsymbol{\Phi}_B = \boldsymbol{\Phi}_{B(max)} \sin(\boldsymbol{\Theta}) = \boldsymbol{\Phi}_{B(max)} \sin(\omega t) = \boldsymbol{\Phi}_{B(max)} \sin((2\pi/T)t) = \boldsymbol{\Phi}_{B(max)} \sin(2\pi f t)$$

$$\text{and } V = - N\, \Delta\boldsymbol{\Phi}_B/\Delta t$$

$$\text{then } V_{secondary} = - (N_{secondary}\, \boldsymbol{\Phi}_{B(max)} \sin(2\pi f t))/\Delta t$$

$$\text{written in differential form } V_{secondary} = - N_{secondary}\, (d\boldsymbol{\Phi}_{B(max)}/dt)$$

$$\text{differentiating } V_{secondary} = - (N_{secondary}\, d\boldsymbol{\Phi}_{B(max)} \sin(2\pi f t))/dt$$

$$\text{yields } V_{secondary} = N_{secondary}\, \omega\, \boldsymbol{\Phi}_{B(max)} \cos(\omega t) = N_{secondary}\, 2\pi f\, \boldsymbol{\Phi}_{B(max)} \cos(2\pi f t)$$

To clarify, the induced voltage in the secondary coil depends on (a) the number turns in the secondary coil; (b) the extent of the magnetic flux which is indirectly influenced by the primary coil; and (c) the frequency of oscillation of the magnetic flux, again produced and indirectly influenced by the primary coil; and last, the $V_{secondary}$ is represented with a cosine function and is observed out-of-phase (by 90° or $\pi/4$ radians or ¼ of an oscillation) when compared to the $V_{primary}$, a sine function

The main purpose of this experience involves a qualitative understanding of the phenomenon of induced voltages across transformers using the Capstone software.

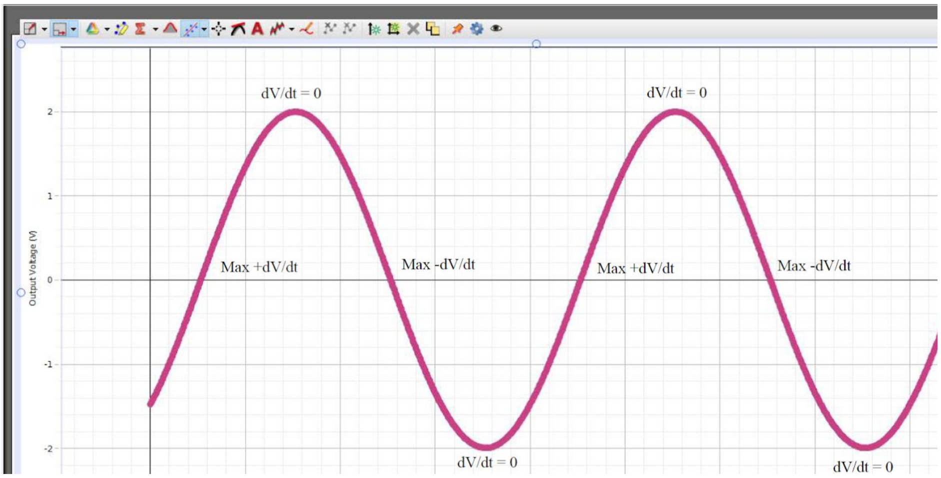
PROCEDURE:

1)Configure the transform with a similar number of primary and secondary coils (e.g., 400 turn primary and 400 turn secondary).
2)Connect the primary coil to the interface power supply using banana plug cables.
3)Connect the secondary coil to the voltage sensor (connect the voltage sensor to Analog Port A)
4)Click on the TRANSFORMER WITH SINE FUNCTION Capstone workbook tab.
5)The SIGNAL GENERATOR is preconfigured to generate a 3V amplitude, 0.25 Hz frequency sine function.
6)The graphs are preconfigured to simultaneously display the power supply output voltage signal across the primary and the induced voltage signal across the secondary coil.

While the PASCO basic coils are generally sufficient for observing induced voltages associated with alternating primary coil voltages, some artifacts occur when collecting voltage data across the secondary coil. You can minimize the artifacts by collecting data using signals generated at low frequencies (< 1.0 Hz).

7)You will collect and compare the secondary voltage data for signals generated at low (e.g., 0.25Hz) and then high (e.g., 0.5 Hz) frequencies. You can alter the signal frequency using the SIGNAL GENERATOR Remember the to use the ON/OFF buttons to energize the circuit and the press RECORD to display data.

How are the primary and secondary voltage functions (graphs) similar and different?



Above is a sample graph of the voltage across the primary coil similar to your data. Notice at certain points the values for the time rate change of voltages (dV/dt) alternate between (a) maximum positive values; (b) zero; and (c) maximum negative values- repeatedly.

How do the voltage values across the secondary compare to the corresponding values of dV/dt across the primary coil? In other words, what are the values of the voltages across the secondary when dV/dt of the primary is at (a) a maximum positive value; (b) zero; and (c) a maximum negative value?

You can differentiate and then display the voltage output (e.g., primary coil voltage function) by:
1)Clicking the Calculator in the Tools Palette. (the calculator dialog opens)
2)Click *New* and the Rename *Calc1* to *dV/dt.*
3)After renaming, right click to the right of the equals sign. then Insert Function, then Special, the Derivative.
4)After inserting the function. click the right bracket bar “[“ and then select the Output Voltage from the dropdown list.
5)Press Enter to apply the formula, display, and then compare the dV/dt and Secondary Voltage (Voltage Sensor Data). Try this with the data collected at 3V amplitude and 0.25 Hz.

Compare the derivative of the primary voltage output (dV/dt) to the secondary voltage readings. How do these functions compare? If the primary voltage output is represented by a sine function, which function represents the voltage across the secondary coil.

How do these results compare to $V_{secondary} = N_{secondary}\,\omega\,\Phi_{B(max)}\cos(\omega t) = N_{secondary}\,2\pi f\,\Phi_{B(max)}\cos(2\pi f t)$?

What effect did increasing the frequency from 0.25 Hz to 0.5 Hz have on the peak voltage output across the secondary coil? (Compare the peak secondary voltages for 0.25 Hz and 0.5 Hz).
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Extension: How will varying the type of material (e.g., soft iron core, aluminum core, air core) or shape (e.g., cross bar attached vs. unattached) of the core impact the function of the transformer device? Research the concept of the permiability of various magnetic materials and then develop an experiment to test your predictions.

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