On-line activities for electromagnetic induction labs

Below is the list of experiments (real, video based, simulations-based, and data-based) that students can perform as labs for electromagnetic induction. For each experiment we provide goals, equipment and rubrics for self-assessment. Rubrics can be found at https://sites.google.com/site/scientificabilities/rubrics

1. Observational experiment

Goal: to find a pattern for the processes that lead to a current inside a coil that is not connected to a battery.

Rubrics for self-assessment Ability to conduct an observational experiment B5 and B7.

In the experiments that you will analyze in this activity we use a galvanometer to detect current. If you are not familiar with a galvanometer, use

a. Watch the following video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-21-1-1 and describe what you observed. What patterns do you notice? Note that the circuit with the galvanometer does not have any battery in it.

b. Develop a rule: Devise a preliminary rule that summarizes the condition(s) needed to induce a current in a coil. What are the assumptions that you made?

c. Does the rule you devised in part **b** explain the outcomes of the experiments in the following video? https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-experiment-video-43.

2.Testing experiment

Goal: to test the pattern constructed in Experiment 1 for the processes that lead to a current inside a coil that is not connected to a battery.

Rubrics for self-assessment Ability to conduct a testing experiment C4, C7 and C8.

In the following experiments you will have one coil (coil 1)connected to a battery/power supply through the switch. The other coil (coil 2) is connected to the galvanometer.

Experiment 1. Use the rule devised in Observational Experiment 1 part **b**. to predict what will happen if you move coil 1 relative to coil 2.

Experiment 2. Use your current rule to predict what will happen when you place a coil connected to a galvanometer next to the coil connected to the battery/power supply (so that axes of the coils coincide). Then you

(1) close the switch without moving either coil,

(2) let the current run for a period of time, and finally

(3) open the switch.

a. Describe the experiments in words and sketches and make the predictions of their outcomes using the rule you invented in Activity 21.1.1.

b. Watch both experiments here [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-21-1-2] and compare the outcomes to the predictions.

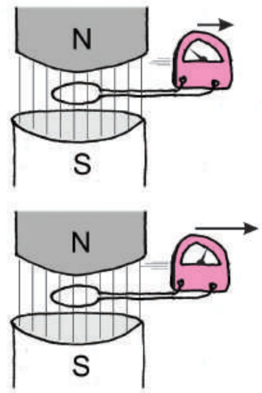
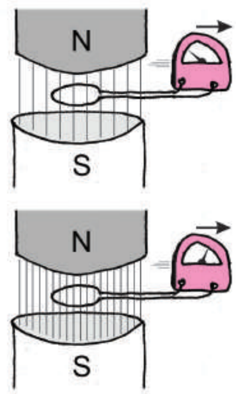
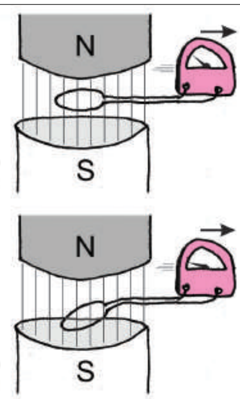
c. Make a judgment concerning the rule that you're testing. If necessary, revise your rule to incorporate your new findings. Note that your revised rule should be consistent with *all* the experiments you've conducted up to this point.

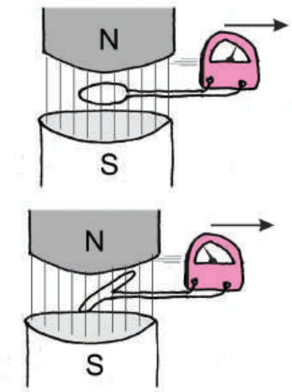
3. Observational experiment

Goal: to devise a mathematical expression that relates the *magnitude* of the induced current to various properties of the magnetic field, relative motion of the coil with respect to the magnet, and properties of the coil.

Rubrics for self-assessment Ability to conduct an observational experiment B7 and B8.

The table that follows describes five new experiments using a galvanometer, an electromagnet, and a coil. The outcomes of the experiments are included.

Experiment	**Illustration**	**Outcome**
a. Position a coil so that the $\vec{B}$ field lines are perpendicular to it and move it slowly out of the magnetic field. Repeat the experiment, moving the coil quickly.		The quicker the coil's motion, the larger the induced current.
b. Position the magnet and the coil as in experiment **a**. and move the coil slowly out of the magnetic field. Repeat the experiment using a stronger magnet.		A stronger magnet induces a stronger current in the coil compared to a weaker magnet when the coils move at the same speed with respect to the magnet.
c. Position a magnet perpendicular to the coil and the coil as in experiment **a**. and move the coil slowly out of the magnetic field. Then position the coil so that the plane of the coil makes some other angle with the $\vec{B}$ field lines. Keep the speed the same.		When the $\vec{B}$ field lines are perpendicular to the plane of the moving coil, the strongest current is induced.

d. Use two identical coils. Fold part of the wire of one coil to make a loop with a smaller area (see the figure). Position each coil and the magnet as in experiment **a**. Move the coils out of the magnetic field at the same speed with respect to the magnet.		A stronger current is induced in the coil with the larger area.

Devise a mathematical expression that relates the *magnitude* of the induced current to various properties of the magnetic field, relative motion of the coil with respect to the magnet, and properties of the coil.

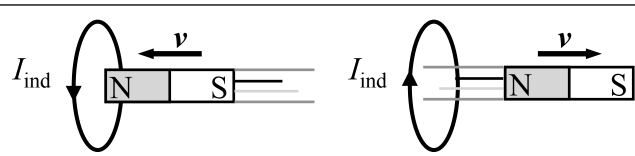
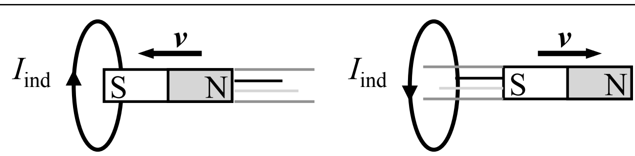
4. Observational experiment

Goal: to find a in the direction of the induced current.

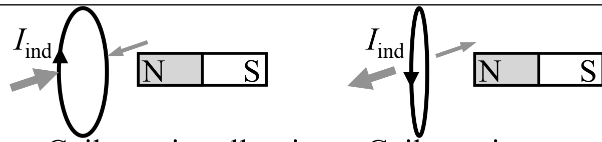
Rubrics for self assessment Ability to conduct an observational experiment B7 and B9.

The experiments below repeat earlier experiments that used a galvanometer, a bar magnet, and a coil and in which a current was induced. The direction of the induced current is shown in the illustrations.

a. Analyze the 6 experimental scenarios in the table below. For *each* case, on your whiteboard, draw $\vec{B}_{\text{ext}}$ field vectors through the coil caused by the moving magnet. Indicate whether the external $\vec{B}_{\text{ext}}$ field vectors through the coil are decreasing or increasing in magnitude. Draw induced magnetic field vectors $\vec{B}_{\text{ind}}$ created by the induced current in the coil.

Experiments:



Experiments:



Coil area is collapsing Coil area is expanding

b. Devise a rule relating the direction of the induced current in the coil and the change of external magnetic flux through it. *Hints:* (1) Focus on the direction in which $\vec{B}_{ext}$ is changing rather than the direction of $\vec{B}_{ext}$ itself. (2) Compare the direction of the induced magnetic field vectors $\vec{B}_{ind}$ in relation to $\Delta\vec{B}_{ext}$.

c. Formulate a general rule: How does the direction of the induced current in a coil relate to the *change* of external magnetic flux through it?

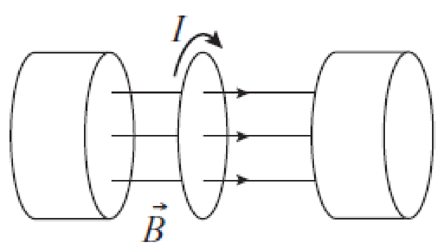
d. Watch the following video https://youtu.be/TikiH3WR54E Describe what you observed. Use your rule from part **c** to explain the observations.

5. Observational experiment

Goal: to find a pattern for the emf causing the induced current.

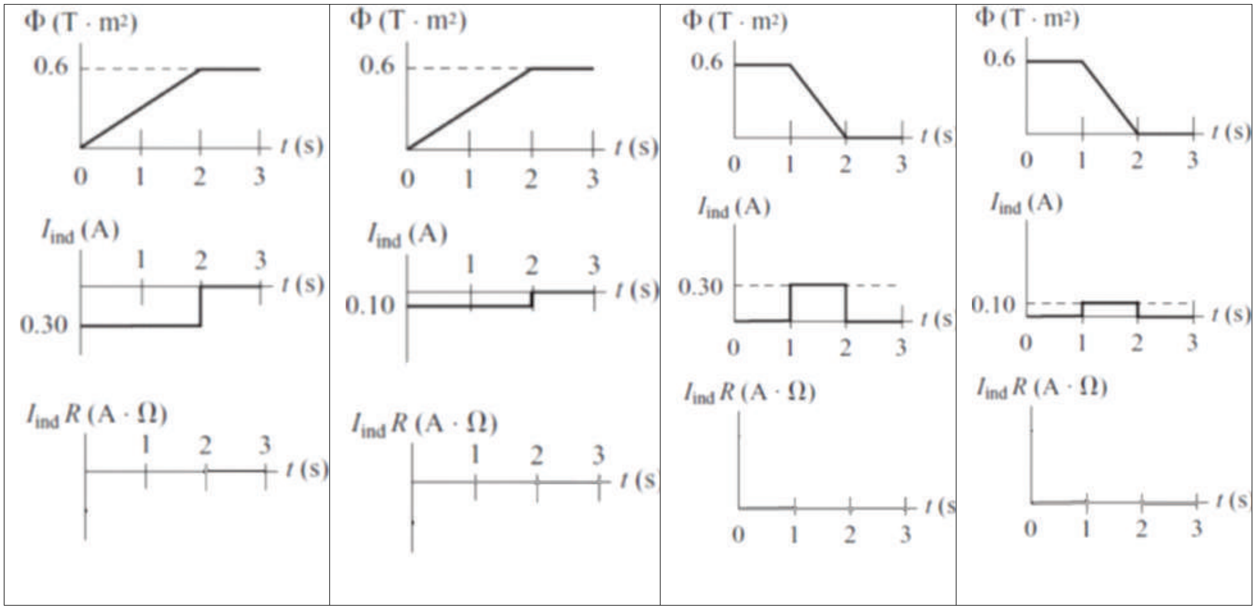
Rubrics for self-assessment Ability to conduct an observational experiment B7, B8 and B9.

In the table that follows, the results of four experiments are shown in which a changing magnetic field produced by an electromagnet passes through a loop, as illustrated to the right. This changing $\vec{B}$ field causes a changing flux Φ through the loop and an induced current I_{ind} around the loop of resistance R. The product $I_{ind}R$ is also plotted as a function of time.



a. Draw the third graph that shows the product $I_{ind}R$.

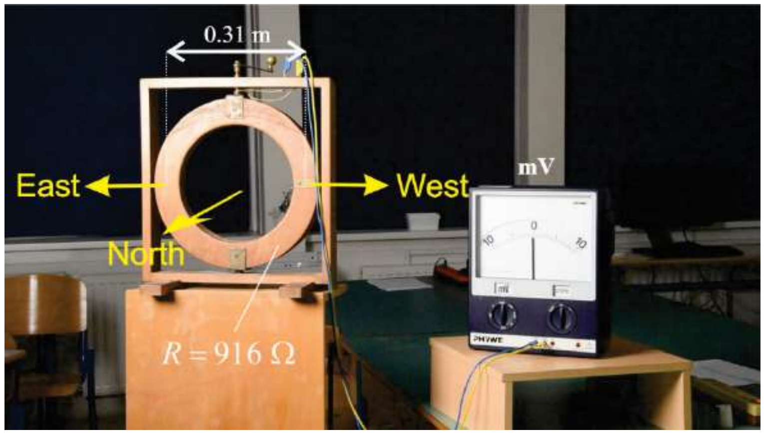
Coil resistance is 1.0 Ω	**Coil resistance is 3.0 Ω**	**Coil resistance is 2.0 Ω**	**Coil resistance is 6.0 Ω**



b. Discuss what the meaning of the product $I_{\text{ind}}R$ is and which equivalent quantity this product may represent. Then devise a relationship between $\dfrac{\Delta\Phi}{\Delta t}$ and that quantity. Do not forget the sign to indicate direction!

6. Application experiment

You have a large coil with 1500 turns of copper wire and a voltmeter that can measure potential differences between –10 mV and 10 mV. The average diameter of the coil is 0.31 m and the resistance of the coil is $916\ \Omega$. The coil is mounted in the wooden frame so that it can rotate around the axis that coincides with the coil diameter. The video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-21-5-14] shows two experiments. In both experiments, the voltmeter is connected to the coil ends. The experiments were performed on the Northern hemisphere. The photo below shows the initial orientation of the coil (the normal to the plane of the coil points towards the geographical North).



a. Watch the video and propose a qualitative explanation for the outcome of both experiments. Make sure your group's explanation accounts for all changes in the magnitude and in the sign of the voltmeter reading.

You can treat the voltmeter as a device that measures potential difference across its own internal resistor, which has very large resistance (several megaohms). If you connect such a voltmeter across the coil as shown above and an induced emf appears in the coil, then the voltage measured by the voltmeter is equal to the induced emf in the coil.

b. Make a list of physical quantities that you can estimate based on data given above and analyzing the video. The video was recorded at 30 frames per second. (*Note*: for a vector quantity, you can estimate its magnitude, direction or both). Estimate two of them.