Wireless Electricity

NGSS: HS-PS2 Motion and Stability: Forces and Interactions

Overview

Students will learn about electromagnetic induction then will apply that understanding to develop and optimize wireless electricity transfer devices. Students will research applications of wireless power transmission in modern devices and homes.

NGSS

HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

College Board Standards

- Apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [LO2.D.1.1, SP 2.2]
- Use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor [LO 3.C.3.1, SP 1.4]
- Construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area [LO 4.E.2.1, SP 6.4]

Lesson Objectives:

- Students will participate in a lesson on magnetism and mutual induction.
- Students will understand how electricity can be transmitted without wires.
- Students will follow instructions to build a basic wireless power transmitter.
- Students will utilize the engineering design process to optimize their transmitters.
- Students will research applications for wireless power transfer.

Assessment and Evaluation

Students will have to use their prior knowledge of electrical circuits, magnetic fields and the behavior of charged particles in a magnetic field. After participating in a lesson on magnetism and mutual inductance the students should understand how a wireless power transmission (WPT) system works. A guided inquiry activity will prepare students to take their designs further on their own to develop and optimize a functional WPT system. Students will conclude the lesson by researching applications for WPT in modern devices and homes. This activity should take approximately 3 days. The lesson will be presented on day one. Creating and optimizing the WPT systems will take the second day. The final day will be spent researching applications for this technology. If time is short, research may be assigned for homework on the night between the lesson and lab activity (cont on next page).

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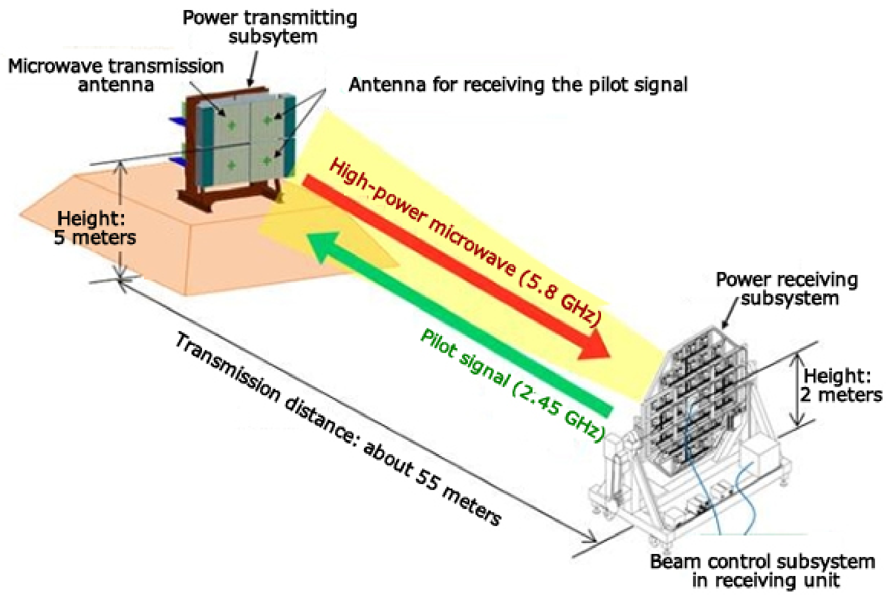
Assessment and Evaluation (cont).

To assess the quality of student knowledge gained from this activity, look at the lab reports created and the discussion posts of each individual student. Teachers might also want to hold students accountable for their discussion in class. This is a way to quickly determine the effectiveness of the activity and clarify any misunderstandings. The College Board style Free Response Problem should be the majority of the grade for this activity since it is the culmination of all parts of the project.

Materials

- Magnet Wire size 26-30 AWG- 6 spools
- AA Batteries- 24 count
- 2 AA Battery Holder with wire leads- 12 count
- 360 W resistors- 100 count
- 2N2222 Transistor- 25 count
- LED- 100 count
- Electrical tape- 10 pack
- Ferrite Rods- 5 pack

Each group of students will need basic electronics components. They can be purchased separately, in bulk, fairly inexpensively. Alternatively, a kit that contains a range of parts may supply other items that the students may wish to use as they optimize their systems. An example: https://www.robotshop.com/en/ibotz-basic-parts-kit.html?gclid=CjwKCAjwsJ3ZBRBJEiwAtuvtlN6tqhFx8OTAEWTzp7hPGWXkfLWTIuFIYtswFvQdM2ZOfQCbfDTrKRoCh7sQAvD_BwE



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Activating Strategy

Nikola Tesla envisioned supplying power to the world without the need for a tangle of wires strung everywhere. The closest he ever came to realizing wireless transmission was the Tesla coil, which he created in 1891. However, his dreams were much bigger, encompassing a global wireless power grid that any home, business, or vehicle could tap into at will. Would you like to use your understanding of electromagnetic induction to create a wireless power transmission system of your own?

Procedure

1. Begin by reviewing the behavior of charged particles in a magnetic field and the effects of magnetic fields on current carrying wires. Explain how these phenomena lead to mutual inductance. Ask students: Do you know how mutual inductance is utilized in electrical transformers? Show the diagram of a simple transformer and describe how coupled inductance is used to change the voltage between two circuits.

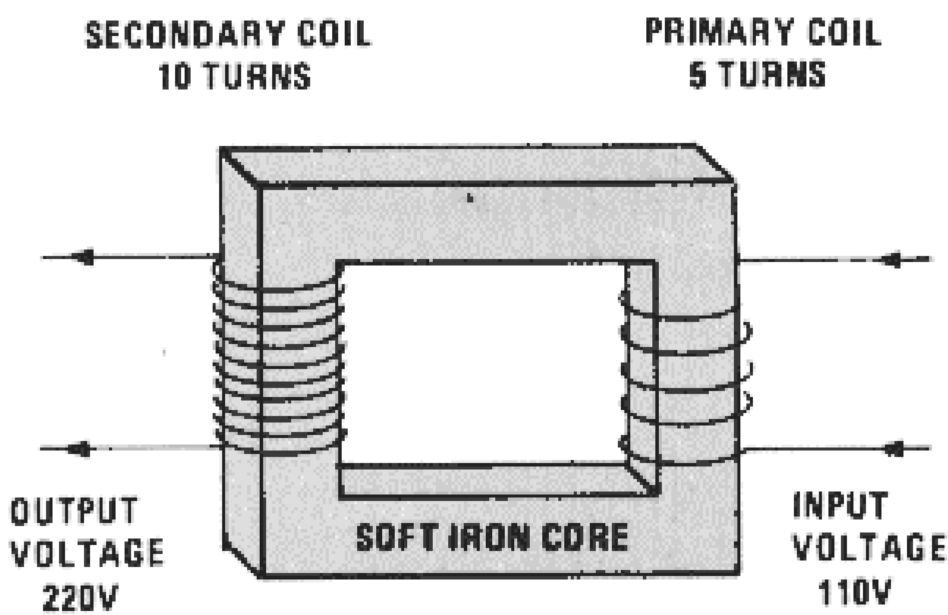

Figure 2: Simple Transformer. Image taken from

https://www.school-for-champions.com/science/ac_transformers.htm#.Wx_gd4pKg2w

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2. Ask students what they think will happen to the two coils if the iron core is removed.

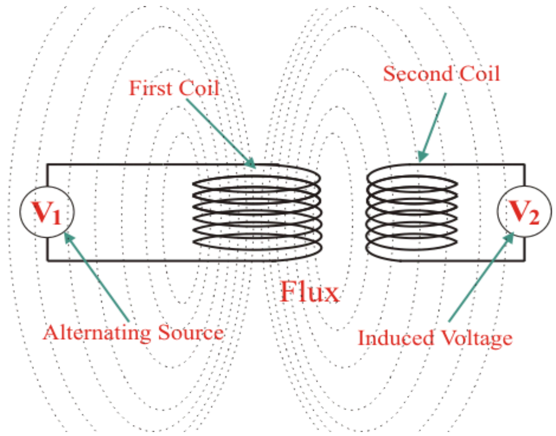

Figure 3: Air Coil Magnetic Inductor Diagram. Image taken from: https://www.quora.com/What-is-an-air-core-transformer

3. Lead students in a discussion about benefits and challenges surrounding wireless power transmission systems. Be sure to emphasize the proximity constraints associated with magnetic fields. Ideally, students will bring up issues related to AC and DC currents. If they do not teachers may wish to begin this part of the conversation, or may decide to let students discover this obstacle on their own.

Figure 4: Recent applications of wireless power charging

https://www.researchgate.net/figure/Recent-applications-of-wireless-power-charging-system-in-our-daily-life_fig1_267512972

4. Ask students if they can think of any solutions to the near field constraint imposed by induction WPTs? Introduce the concept of magnetic resonance. Describe how magnetic resonance works and what the advantages and disadvantages of resonance systems are.

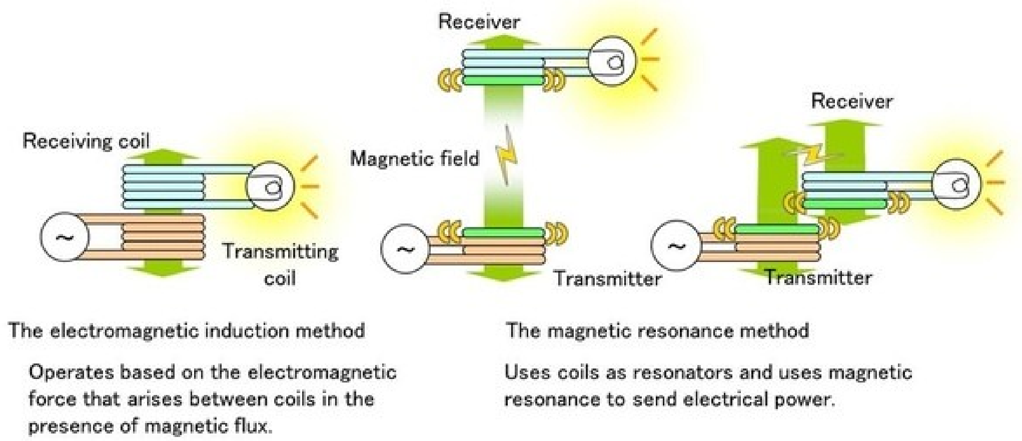

Figure 5: Comparison between Induction and Resonance methods of Induction. Image taken from https://www.quora.com/Which-mechanism-is-used-in-wireless-charging

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Day Two:

1. Engage students by showing them how a changing magnetic field driven by a cell phone playing music can produce sound from a cassette tape player. (Demo instructions and video here: https://drive.google.com/file/d/1eyNauPVzoo8gn6jnixpPzDTq7xFIxjHS/view?usp=sharing)

2. Challenge students to apply their understanding from the previous day's lesson to explain what they observe. Correct any misconceptions. Then, explain to students that they will create their own wireless power transmission system.

3. Students should work in groups of 2 or 3. Students will work with provided materials and instructions to build a basic WPT set up. Then students will utilize other materials and configurations of their choosing to optimize power transfer. Students should consider the following questions as they work:
   How does it work? Create an illustration of the process.
   Which components of the set up are variable? Identify the change that would result from modifying each variable.
   What are the advantages of this set up?
   How could the set up be improved?

Students will use the following instructions to complete the lab portion of this lesson
https://drive.google.com/file/d/1M03W5g1M6rOzvoor_wzskjGZdZU59wZb/view?usp=sharing
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After groups have had time to create the basic WPT system they will decide on one variable to manipulate in order to optimize the performance of their system. Students should try several iterations of the variable, record data and draw conclusions. If time permits, students can manipulate another variable.

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Teacher- The teacher should put out a variety of materials that students my use to experiment with as they try to optimize their systems. Ex: additional wire in a range of gauges, magnets, ferrite rods, a range of resistors. While students are experimenting the teacher may circulate to answer questions that will arise. The teacher should not "give away the answer", but may pose guiding questions or correct misconceptions that are revealed as the students work. The teacher will open the discussion board for students to post for homework.

Students - Students will discuss potential parameters to vary to optimize their systems. They will develop a procedure for testing that variable and create a data table in which to record their data.

Extension: Induction based wireless power transmission has severe limitations: only one device can be coupled to the transmitter at a time and the distance between the transmitter and receiver must be fairly small. Students should research resonance based induction to understand how it works, what advantages it has over induction and what barriers exist to it's implementation. Finally, students will close by summarizing findings about optimizing an induction based WPT system based on what they have learned. English Language Learners may benefit from the use of sentence frames to complete this part of the assignment. Students who finish this part of the assignment quickly may be allowed to revisit their lab from the previous day to see if they can apply their new understandings to improving their WPT systems.

Closure

The class will use their discoveries to discuss how a range of parameters affect the efficacy of an induction based WPT. Students will compare their systems with a resonance based system in order to form an opinion about future energy policy. Students will then write a discussion board post detailing what they have learned about both methods of WPT, their development, their limitations, and applications within real-world situations.

Discussion Board Prompt:

Explain what you have learned about wireless power transmission, it's limitations, current developments and applications within real-world situations. What is a highly coupled induction system used for? How does it work? In what way do resonant systems vary from inductive systems? What are the challenges and benefits to both methods? What are their most important characteristics? (Your answer to this prompt should 2-3 paragraphs in length and you should address all questions.)

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Power Point (use for lesson on the first day):

- Motors, Generators and Mutual Inductance: https://drive.google.com/file/d/15QVoK46aXSVw1-YaZ7KobIS9eZeuMAsB/view?usp=sharing

Videos (watch before the activity on the second day):

- *Wireless Power Project Instructions*: https://www.youtube.com/watch?v=VAavp8N1l_M
- *How to Make Wireless Power Transmission*: https://www.youtube.com/watch?v=xUQYMfPac0g

Online Articles (read on the third day):

- *Cutting the Cord: Wireless Electricity*: http://www.physics.org/featuredetail.asp?id=40
- *The Journal of Wireless Power Transfer*: https://www.cambridge.org/core/journals/wireless-power-transfer
- *Research progress of wireless power transmission technology and the related problems*: https://aip.scitation.org/doi/pdf/10.1063/1.4977407
- *Optimal design and analysis of wireless power transfer system with converter circuit*: https://link.springer.com/article/10.1186/s13638-017-0813-7

Quizzes (take before and after the activity):

- Basic Electrical Engineering Questions and Answers – Mutual Inductance: https://www.sanfoundry.com/basic-electrical-engineering-questions-answers-mutual-inductance/
- Electromagnetic Induction: https://www.proprofs.com/quiz-school/story.php?title=nja0nzgx

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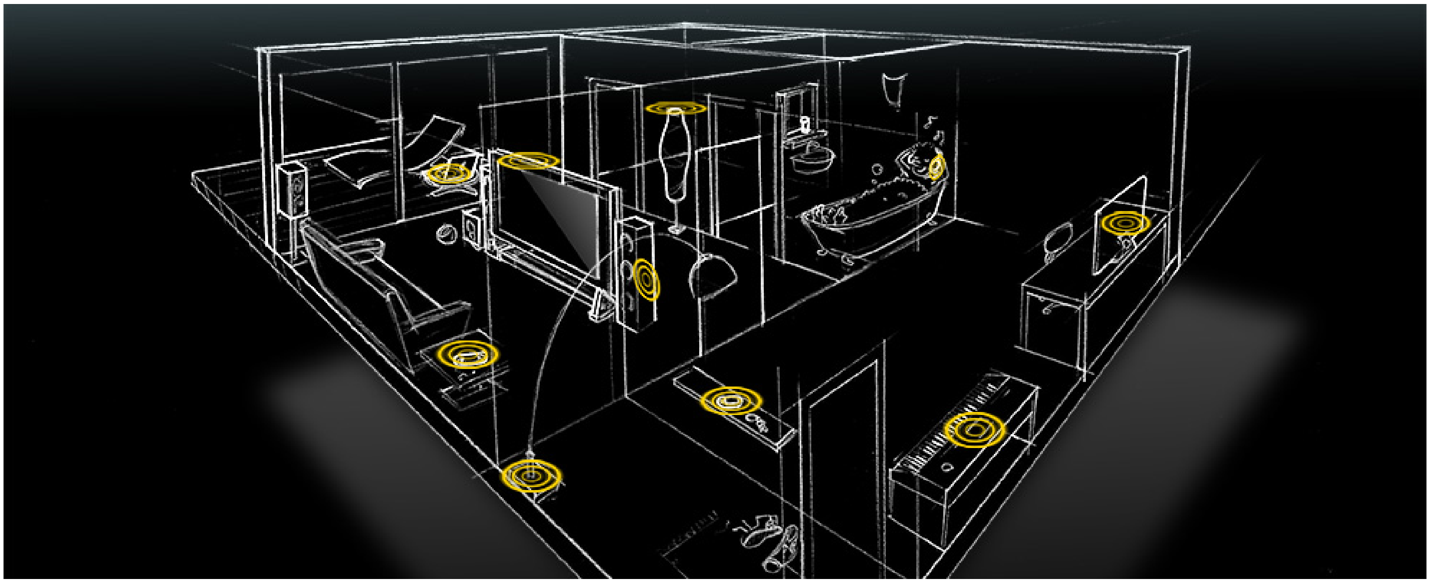

EXTENSIONS

Figure 1: Wireless home. Image taken from
https://www.rrc-wireless-power.com/en/applications.html

Wireless Power Transfer via Strongly Coupled Magnetic Resonances
http://science.sciencemag.org/content/317/5834/83

The Convenience of Wireless Charging: It's just physics
http://cdn-cw.mediatek.com/Mediatek_Wireless_Charging.pdf

College Board Style Free Response Question
https://drive.google.com/file/d/18IlvqcVdQQII-PWDeHgCMVN-XS48kRgy/view?usp=sharing

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Demonstration: Modulated magnetic field to drive a cassette tape player

Materials:

- Wire or sandpaper if you are using wire with lacquer insulation
- About 3 feet (1 meter) of insulated copper wire—#20 or #22 solid wire with plastic insulation; stranded wire with plastic insulation or thinner solid magnet wire with enamel insulation can also be used
- Steel bolt, about 1/4 inch in diameter and 2 inches long (nut optional)
- Two alligator clips
- Audio cable that has a 1/8-inch phone connector on one end. The other end will be cut, so it doesn't matter what's on it
- iPhone, iPod, or small transistor radio
- Portable tape cassette player with speaker

Set up:

Use a wire stripper to remove about a 1/2 inch (1.2 cm) of insulation from each end of the wire. (If you have enamel-insulated wire instead of plastic-insulated wire, use sandpaper to remove the enamel.)

If you have a nut for the bolt, screw it onto the end of the bolt (it may help keep the wire that you're about to wrap onto the bolt in place, but it isn't essential).

Leaving about 1 inch (2.5 cm) of wire free, wrap the remaining length of wire around and around the bolt. Begin at one end, wind until you reach the other end then continue back to the first end. Repeat until you are almost out of wire. When you've finished wrapping, leave another 1 inch (2.5 cm) of wire free. Attach the alligator clips to the stripped, free ends.

(Continued on next page)

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Cut the end of your aux cable leaving the 1/8 in phone connector in place. Strip the cut end to expose the wires inside. Most contain 3 wires: red, white and a bare ground wire. Bend the bare wire back against the wire to keep it out of the way. Strip the ends of the red and white wires.

Use the alligator clips attached to the two ends of the wire wrapped around the bolt to attach the red and white wires in the aux cable to the bolt.

Turn on phone and make sure you have a strong, clear signal. Insert the phone plug at the end of the audio cable into the headphone jack on phone.

Be sure there is no tape in the tape player, and then press the play button. Bring the wire-wrapped bolt near the play head of the tape player (where the exposed portion of the magnetic tape in a cassette would be located if the cassette was in place). You should hear the sound from the phone playing through the speaker of the tap

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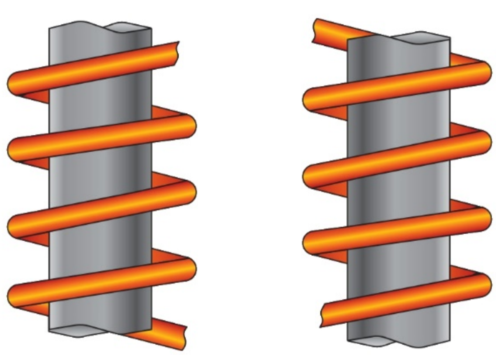
Wireless Power Transmission/Magnetic Induction Lab

Objectives:
Build a wireless power transfer system.
Predict and test the effects of changing variables in the system to optimize the system.

Materials:

Item	Quantity
30 gauge magnetic wire	6 m
Alligator clips with leads	2
2N2222 NPN-Type transistor	1
360 W resistor	1
Electrical tape	20 cm
Low-power LED	1
Plastic Ruler	1
Scissors	1
Pliers/wire cutters	1
Battery (AA, 1.5 V)	2
Soldering gun, Solder	1
Cylinder with 2cm diameter	1

Initial Thoughts:
Consider a positive current increasing in the downward direction in the left coil. Sketch a diagram of (1) the magnetic field on the left coil (2) the induced current in the right coil and (3) the induced field in the right coil.



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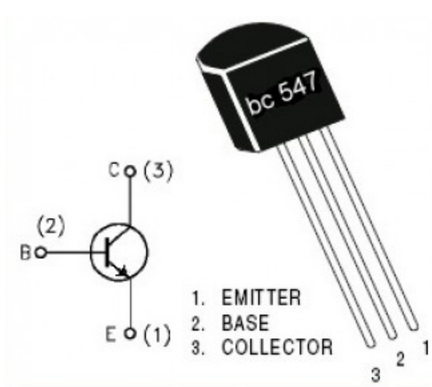
2. Find the voltage in the secondary (right above) coil in a system of two coils with diameters of 2 cm and 20 turns each if the magnetic field increases by 1 T in 10 seconds. If this system has an inductance of 20 H, what is the change in current in the primary coil?

Procedure:

1. To build the Inducer Coil, measure out 3 meters of 30 gauge magnetic wire. Then take the cut wire and begin wrapping it around your cylinder, leaving a sizable lead. After about half of the wire has been used (about 15 turns) create the center tap. This is done by pulling about 2 cm of wire away from the coil and twisting it. Do not cut the wire! Next, finish wrapping the wire around the cylinder, leaving another lead. To prevent unwinding, put 3 pieces of electrical tape on the coil. This will not affect the overall electrical output. You are now finished with the inducer/transmitter coil.
2. The receiver coil is made like the inducer coil, but without the center tap. To accomplish this, simply keep winding the coil without stopping. Pro Tip: Scrape off the enamel coating on the ends of the wire to ensure a good connection.

3. To properly connect the transistor, you need to attach the correct coil leads to the correct transistor terminals (emitter, base, and receiver). The transistor will be soldered on. **Emitter** will go to the negative of the 1.5 V battery holder. **Base** will go to the resistor then to one inducer coil lead. **Collector** will go to the other inducer coil lead. Simply solder the terminals directly to the leads, and the connection will be secure.



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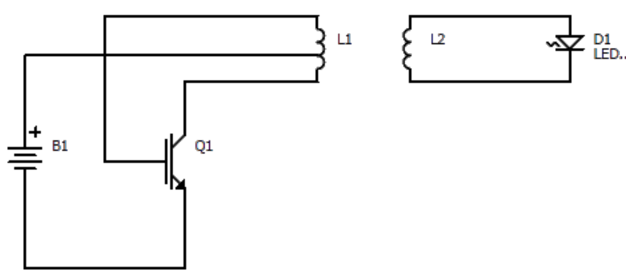
4. The LED will be soldered to the two leads of the receiver coil. This allows the LED to be powered easily when the receiver coil is moved around the magnetic field. Each LED terminal will be connected to one lead of the receiver coil. Pro Tip: trim the ends of the LED terminals so that it does not awkwardly stick out from the receiver coil

5. This set up is powered by one two 1.5 V AA batteries in a battery holder. The **Emitter** will go to the negative of the battery pack. The **Center Tap** will go to the positive of the battery pack. Pro Tip: only connect the power to the coil when it is in use, as long periods of connection will deplete the battery and may fry the transistor. The full project is represented in the schematic below.



6. To operate the system, move the receiver coil over the transmitter coil. If you have constructed the circuits correctly the LED should light.

7. Make some observations and collect data as you experiment with the system. Create a data table in which to record your data.

8. Decide on one variable to manipulate to improve the function of your system. Write a procedure for testing the effect of changing this variable. Try it! Create a data table in which to record your data. If you are unable to improve your system with this variable, try another one.

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Conclusions:
Answer each of the following in a paragraph or two at the end of your lab report.
Describe the behavior of system in its original configuration, and state if you saw evidence of induction in the way you expected. What data did you collect to verify this?

Explain the why you selected the variable you chose to manipulate. Describe how this affected the behavior of the system. Write a mathematical expression that describes the relationship you observed.

Induction is a result of a changing magnetic field, but this system operates on direct current. Explain why this doesn't prevent induction from occurring.

How is this system related to commercial wireless charging products? What do they have in common? What is different?

What have you learned during this experiment about challenges and limitations of wireless power transfer based on induction principles?