Energy Conversion using Magnetic Materials

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Activity Summary
The Kawasaki lab is developing GdAuGe thin film materials that could have magnetic and superconductive properties when placed under strain. Thin film materials range from less than a nanometer to a few micrometers in thickness. This material's strong magnetic properties makes it suitable for generating electric currents. Stronger and more compacted magnetic materials, such as the ones being developed in the Kawasaki lab, could be used to develop more effective generators, which could improve the efficacy of renewable energy production methods.

Audience
10th-12th grade environmental science
Ideal class size would be 24 students (groups of 4).

Time Frame
Set-up: 15 minutes (including pre-lab)
Activity: Day 1: 40 minutes, Day 2: 1 hour 15 minutes
Clean-up: 5 minutes

Objectives
1. Students will explore the relationship between the movement of magnets, the generation of electricity, and the factors that affect the efficiency of the generator.
2. Students will understand the principles of electromagnetic induction by constructing a homemade generator using magnets.
3. Students will design a generator using their knowledge of electromagnetic induction and material science.
4. Students will investigate the impact materials have on energy producing systems.

Standards Addressed
1. HS-PS2-5 Motion and Stability: Forces and Interactions - 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.
2. HS-PS3-3 Energy - Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
3. HS-ETS1-2 Engineering Design - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
4. NGSS Science Skills:
    a. Asking questions and defining problems

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b. Planning and carrying out investigations
c. Constructing explanations and designing solutions

Engineering Principles

1. Project planning/Design - Students must design a functioning generator. They must produce a plan prior to building their design.
2. Modeling - Students are modeling how a motor and generator works in the investigation.
3. Analysis/optimization - Students are about to modify their generator design after analyzing its electricity output.
4. Collaboration/team building - Students will be working in lab groups during the electromagnetism investigation and generator build.

Activity Materials

- AA Batteries - 1 per group
- Small neodymium Magnets 10x3mm (3 per group)
- Large neodymium magnets 20x3mm (1 per group)
- 28 AWG Magnet Wire - Enameled Copper Wire - 0.0122" Diameter - 1 spool per group
- 10 cm of 16 Gauge bare copper, aluminum, and any other metal wire - 1 of each metal per group
- Paperclips - 2 per group
- Voltmeter - 1 per group
- Wire cutters - 1 per group
- Masking tape - 1 roll per group
- Steel wool
- generator engineering supplies
  - Cardboard
  - Cups
  - Nail
  - Etc…

Safety

Gloves - The wire can get hot during the investigation, so something to protect students fingers would be ideal.

Activity Instructions

Set-up (5 minutes)

1. Give each group all materials
2. The activity is quicker and has a higher success rate if wires are pre-bent and coiled. (20 minutes one time)

Introduction (5 minutes)

Discussion:

1. How do most forms of energy production produce electricity? - Generators

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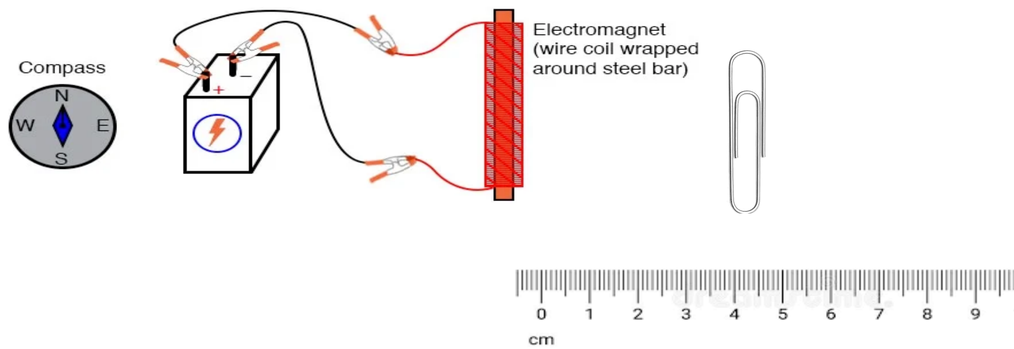
2. Generators operate by converting rotational kinetic energy into electrical energy.
3. More magnetic materials would allow for the development of more effective generators.

Activity 1: Demonstrate Electromagnetic Induction (10 minutes)

1. The wire will become HOT in this demo, so place some tape over the side of the wire you will be touching.
2. Connect each end of a coiled wire to the battery.
3. Hold the wire coil up to the paper clip. Then hold the wire coil up to the magnet.



***Investigation Note**: Magnetic strength of different coil amounts could be measured by measuring the distance of repulsion between the coil and paperclip when a magnetic field is induced with a current.

Activity 2: Apply to Create a Motor (10 minutes)

1. Place the battery directly on top of the neodymium magnet (positive side down)
2. Bend a small hook on the top of the wire and bend a 2 cm in diameter loop on the bottom of the wire.
3. Balance the wire hook on top of the battery. Ensure that the magnet side is close to the bottom of the wire.
4. *Investigation Note - this model should be investigated with different wire materials and shapes available. Effectiveness of motor material could be connected to properties such as conductivity.

Activity 3: Create a More Complex Motor Model (15 minutes)

1. Bend one end of the paperclip.
2. Place a small magnet on each side of the AA battery.
3. Place the open end of the paperclip on the magnets. Tape over this to secure the paperclips.
4. Tape a magnet in the center of the battery.
5. Make a coil by wrapping 0.0122" diameter enameled wire around a AA battery 20 times. Leave some excess wire to tie the coil. Scrape the excess wire ends with steel wool to remove the enamel coating. *Note: This can be done beforehand to speed up the activity.
6. Hang a coil through the paper clips, directly over the AA battery.

(Williamson, C., Templar, M., & Jody, 2023)

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Activity 4: Simple Generator Investigation (20 minutes)
Research Question: How does the number of coils impact the voltage produced?
Procedure:
1. Connect your coil to the voltmeter with clamps.
2. Move a stack of three small neodymium magnets back and forth through your coil.
3. Observe the voltage reading fluctuation, record the highest value.

Activity 5: Engineering a Generator (40 minutes)
1. Students will work in groups to engineer their own generator set-up.
2. They must submit a sketch and group plan prior to building. They must also consider the materials they use.
3. Generators will be evaluated on their electrical output.

Conclusion (20 min)
- Develop generator engineering parameters to guide student design. (emphasizing magnetic materials)
- Develop a student conclusion assignment -whiteboarding task or group reflection/share out
- Application Assignment - connecting material science and environmental science

Assessment
How will you assess your activity?
1. What role do generators have in energy production? Why are they important for renewable energy?
2. How does a generator produce usable electricity?
3. What factors impact a generator's effectiveness?
4. Research and discuss the different types of generators used in power plants. Identifying materials used.
5. Investigating materials and current technology being developed to improve generator design. How does material science connect to environmental science?

Background/Prior Knowledge
1. Intro to Electromagnetism - https://www.youtube.com/watch?v=cy6kba3A8vY
2. Electromagnetism in depth - https://www.youtube.com/watch?v=-bVi1w0m8x8

Supplemental Materials
- Generator Engineering Challenge Student Handout
- 2023- Final Activity Presentation
- Electromagnetism - Magnetic Force: The Four Fundamental Forces of Physics #4b

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Scaffolding and Extensions

- Reading Extension - How to build a better magnet (Levin, 2022)

https://engineering.stanford.edu/magazine/how-build-better-magnet

Cross-Content Connections

- This activity is an excellent connection between material science, physics, and environmental science.

References

Levin, D. (2022, March 22). *How to build a better magnet*. Stanford University School of Engineering. https://engineering.stanford.edu/magazine/how-build-better-magnet

Williamson, C., Templar, M., & Jody. (2023, January 17). *What is a homopolar motor and how does one work? - FIRST4MAGNETS: Blog*. FIRST4MAGNETS. https://www.first4magnets.com/us/blog/what-is-a-homopolar-motor-and-how-does-one-work/#:~:text=First%20created%20in%201821%2C%20the,really%20easy%20to%20experiment%20with.

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