
IMH TEP'S

LEGACY ACADEMY

**Exploiting Magnetism and Thermodynamics:
Fireproof Paper and a Magnetic Heat Engine**

Grade 8 Activity Plan

8.10 Exploiting Magnetism and Thermodynamics: Fireproof Paper and a Magnetic Heat Engine

Objectives:

1. To observe the difference in heat conduction of metal and paper.
2. To observe the how magnetic metals lose their magnetism above a certain temperature.
3. To create a simple heat engine using a candle, a ceramic magnet, and a magnetic pendulum, based on the Curie Effect.
4. To use a battery to separate water into hydrogen and oxygen gases, and use a pH indicator to reveal an invisible magnetic field.

Keywords/concepts: magnetism, pendulum, heat conduction, Curie Effect, rare earth magnet, neodymium, electron, ferromagnetism, paramagnetism, electromagnet, convection, radiation.

Curriculum Outcomes:

Grade 7: 210-11, 210-12, 308-2, 308-3, 308-4, 308-5, 308-7.

Grade 9: 109-14, 208-7, 307-12, 307-14.

Take-home product: Electrolysis device.

Written by: Dario Brooks, August 2016.

Segment	Details
African Proverb and Cultural Relevance (5 min.)	Patience attracts happiness; it brings near that which is far. Swahili
Pre-test (10 min.)	Have a group discussion to share personal experiences involving heat conduction in materials and magnetism in metals, separately. Quiz students on their knowledge of how both heat conduction and magnetism work.
Background (15 min.)	Give a brief description of thermodynamics, heat conduction, and magnetism. Explain what happens to a solid object when extensively heated, relating to atomic theory. Explain magnetism using atomic theory and the concept of electrons.
Activity 1 (15 min.)	Wrap a piece of paper around an aluminum rod. Place one end of the rod into a candle flame and observe how the paper does not catch fire, while the metal rod underneath heats up.
Activity 2 (30 min.)	Build a thermomagnetic heat engine using a pendulum, candle flame, and common magnets. Observe the effect of intense heat on magnetic materials.
Post-test (15 min.)	Water electrolysis and magnetic field lines

Suggested interpretation of the proverb: When one is faced with something time-consuming and frustrating, having patience will eventually give the greatest reward. When one practices patience, it will make even the most difficult tasks easier and lead to accomplishments one may never have thought possible.

BACKGROUND INFORMATION

Thermodynamics is the theory explaining thermal energy transfer and the physical processes involving temperature and thermal energy content due to heating and cooling. Thermodynamics seeks to explain processes such as heat conduction, thermal radiation, heat convection, changing states of matter such as freezing and evaporating, and conservation of thermal energy. **Convection** is the energy transfer process in liquids and gases caused by the motion of the fluid itself; an example of convection is how a pool of water becomes warmer when a heat source such as a Bunsen burner is placed near it without touching the water. **Thermal radiation** is the energy transfer process by use of electromagnetic waves; we experience thermal radiation when we feel the sensation of heat coming from a fireplace or the rays of the sun. **Heat conduction** is the process where thermal energy is transmitted through a material as a result of collisions of atoms, molecules, and other particles; an example of conduction is heating a stove element to boil water in a pot which is sitting on the element. **Statistical mechanics** is the study of these microscopic particle collisions themselves (among other topics), where Thermodynamics is the study of the overall result of these particle collisions; statistical mechanics is the **microscopic theory** of thermal energy transfer, and thermodynamics is the **macroscopic theory** of thermal energy transfer. The molecules in a fluid such as a liquid or gas are free to flow, while the molecules in a solid cannot flow and only vibrate in place. When a solid object is heated, the individual particles of the object gain thermal energy. This causes the particles to vibrate faster and more violently. Melting takes place when a solid is heated so much that its molecules vibrate so hard that they break free from the molecular bonds holding them together and begin to flow.

Magnetism is the physical phenomenon where objects are attracted or repelled by an invisible force field called a **magnetic field**. Everyone has encountered magnetism in everyday life in things such as fridge magnets and some toy train sets. Materials that are naturally magnetic are called **permanent magnets**, and their natural ability to create magnetic fields is called **ferromagnetism**. Ferromagnetic materials include metals such as iron in the form of **lodestone** and **magnetite**; these are most commonly found in everyday magnets. The magnetic field from permanent magnets is caused by the tiny **electrons** of its atoms, which are tiny negatively-charged particles. The electrons surround the **nucleus** of the atom which contains two other types of tiny particles: the **neutrons** with no electric charge, and **protons** with positive electric charge. The electrons move around the nucleus, which creates a magnetic field based on the physical principal that moving electric charges create magnetic fields. All of the electrons in a permanent magnet move in such a way that the tiny magnetic fields produced by each electron add together to create a large magnetic field which can be felt by other magnetic objects nearby. Magnetic effects from a material can be effected by properties such as temperature and external magnetic fields produced by other objects nearby.

Activity 1: Making a fireproof paper wand

Purpose: To examine how heat conduction of metal can protect paper from igniting in a flame.

Item	Quantity (10 students)
Candle	10
Aluminum Rod	10
Printer paper sheet	10
Oven glove	10
Barbeque lighter	1
Transparent tape	10

Procedure:

1. Tightly wrap and tape a piece of paper around the metal rod. You may need another student to tape the paper in place while you hold it tightly wrapped around the rod.
2. Use the oven glove to hold one end of the wrapped metal rod.
3. **Mentors:** Light each student's candle using the barbeque lighter.
Important note: Warn students that the bar will quickly get extremely hot when held in the flame, and so it is important that they keep the oven glove on at all times.
4. Hold the other end of the wrapped rod in the candle flame. The paper will not catch fire, but the metal rod underneath will become very hot.
Note: The paper will not catch fire, but it will burn. Only leave the paper-wrapped rod in the flame for a few seconds to demonstrate the effect.

Explanation: The metal rod conducts heat away from the paper it is wrapped in. The aluminum in the metal rod conducts heat so well that the heat is carried away from the paper and absorbed by the rod before the paper can reach the temperature required for it to ignite.

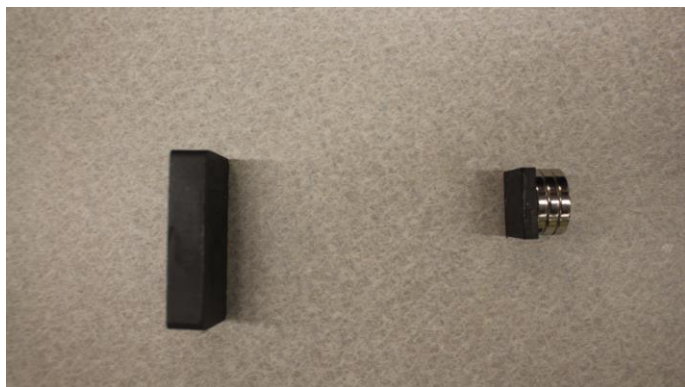
Activity 2: Building a heat engine using magnets, a flame, and a pendulum

Purpose: To exploit the Curie Effect to design a simple magnetic heat engine.

Item	Quantity (10 students)
Small neodymium magnet	15
Birthday candle or tea light	5
Large ceramic magnet	5
One foot of copper or brass wire	5
Barbeque lighter	1
Ball bearing swivel	5
Tape	5

Procedure:

1. **Mentors:** Pair up students.
2. Place a stack of three small neodymium magnets on one end of one of the large faces of the ceramic magnet.



3. Loop one end of the copper wire through the small keychain-like metal hoop of the ball bearing swivel.

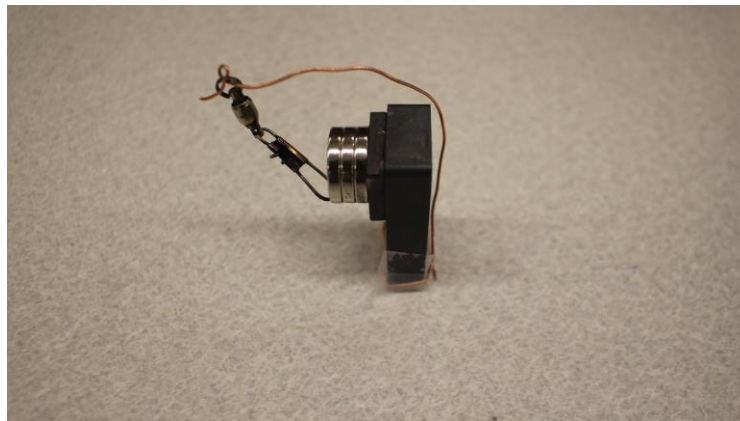
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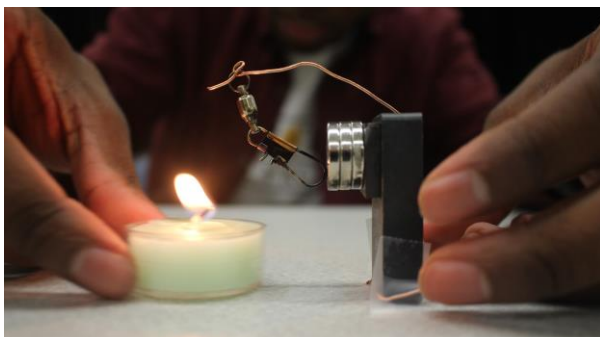
the other end
copper wire
the end of
large ceramic
magnet

without the small magnets on it, and then bend the wire up over the ceramic magnet and in front of the small neodymium magnets so that the larger hoop on the ball bearing swivel *just* connects to the neodymium magnet from magnetic attraction.

5. Tape the bottom of the ceramic magnet to the table so that it stands up solidly (the bottom of the ceramic magnet is the end without the neodymium magnets on it).



6. Place the candle beneath the neodymium magnets so that when the wick is lit, the flame will just barely be in contact with both the front of the neodymium magnet and the ball bearing swivel.
7. **Mentors:** Go to each pair of students and light the candle sitting underneath the neodymium magnet. Assist the students in adjusting their copper wire and ball bearing swivel so that the flame just touches the



bottom of the ball bearing swivel and the face of the neodymium magnet.

8. **CAUTION:** Do not touch the neodymium magnet or the ball bearing swivel after it has been in the candle flame. The magnet will get very hot and may burn you if you touch it. Ask a mentor to assist you if you have to touch the magnet itself or the swivel for any reason.

Explanation: As the temperature of both the neodymium magnet and the nickel ball bearing swivel rises within the flame, they begin to lose their permanent magnetism (**ferromagnetism**). The magnet and the nickel completely lose their magnetism and become **paramagnetic** at a certain temperature, called the **Curie temperature**, which is different for every material. Since the nickel is no longer magnetic, gravity is strong enough to pull the nickel ball bearing swivel away from the neodymium magnet, causing the pendulum to swing. The nickel swivel begins to cool down when it is away from the flame, and so it quickly regains its ferromagnetism. Once the nickel fully regains its magnetic properties, the **magnetic fields** produced by the neodymium magnet are again strong enough to overcome gravity and (ideally) pull the nickel swivel back up to the magnet. However, if the candle is still burning the flame will cause the nickel swivel to rise in temperature and reach its Curie temperature again, making the whole process repeat.

Note: the pendulum may not work exactly as explained; it can be very difficult to set up the apparatus perfectly, and so the nickel ball bearing swivel may not jump back up to the magnet after cooling if it is not close enough.

Scientifically, what is happening takes place at a sub-microscopic scale, too small to see even with our most powerful microscopes. The magnetism of any ferromagnetic metal is caused by **electrons**, which are tiny negatively-charged particles and are part of the atoms in the metal. The electrons surround the **nucleus** of the atom which contains two other types of tiny particles: the **neutrons** with no electric charge, and **protons** with positive electric charge. Electrons move two different ways: they orbit the nucleus like the planets orbit the sun, and they spin on their axis like a basketball spins on a player's finger. These two movements create a tiny magnetic field. In permanent magnets like the neodymium and ceramic magnets used in this experiment, the orbits and spins of the electrons in all of the atoms line up in the same direction. The small magnetic fields from each electron add together to create one large, strong magnetic field. However, when intense heat is applied to the magnet or the nickel metal, the electrons gain **thermal energy**. This increase in energy influences the atoms to vibrate and the electrons to move more freely. At a high enough temperature the electrons are moving so radically that their orbits and spins no longer line up with each other, and so the magnetic field dies off causing the magnet or the metal to lose its attraction. This temperature is the Curie temperature, and the effect of losing magnetic properties above the Curie temperature is called the **Curie Effect**.

References and additional resources:

Background information:

<https://www.grc.nasa.gov/www/k-12/airplane/thermo.html>

<http://www.livescience.com/50776-thermodynamics.html>

<http://www.arborsci.com/cool/thermodynamics-the-heat-is-on>

- "Thermodynamics and an Introduction to Thermostatistics, 2nd edition" by Herbert B. Callen. Published by Wiley.

<http://www.livescience.com/38059-magnetism.html>

<http://www-spod.gsfc.nasa.gov/Education/Imagnet.html>

- "Introduction to Electrodynamics, 3rd edition" by David J. Griffiths. Published by Pearson.
- "Electricity and Magnetism for Mathematicians" by Thomas A. Garrity. Published by Cambridge University Press.

Activity 1:

<http://www.arborsci.com/cool/thermodynamics-the-heat-is-on>

Activity 2:

[http://www.all-science-fair-](http://www.all-science-fair-projects.com/science_fair_projects/58/387/2da8a4d9c356d0cabb2b7a8ee1e0eb46.html#curie_effect)

[projects.com/science_fair_projects/58/387/2da8a4d9c356d0cabb2b7a8ee1e0eb46.html#curie_effect](http://www.all-science-fair-projects.com/science_fair_projects/58/387/2da8a4d9c356d0cabb2b7a8ee1e0eb46.html#curie_effect)

Post-Test:

<http://www.exploratorium.edu/snacks/indicating-electrolysis>

Post Test

Using Electrolysis to Reveal Magnetic Fields

Mentors: Prepare a large pot of cabbage juice indicator before beginning the activity, to save time:

1. Chop up a small head of purple cabbage.
2. Heat a saucepan of water until steady boiling.
3. Turn off the heat and add cabbage.
4. Let the pot of cabbage and water steep until the water is a deep purple colour.
5. Strain the solution and discard the cabbage. The cabbage juice indicator is now ready to use for the experiment.

For this activity you will need:

- Two stainless-steel screws, 1.5 inches long.
- One 9-volt battery.
- Two rubber bands.
- One shallow clear container, such as a petri dish, half-filled with water.
- Epsom salts.
- Cabbage juice, to be used as an acid-base indicator.
- One ceramic magnet.
- Safety goggles.
- One spoon for mixing.
- Hot plate and saucepan for boiling.

Wrap one rubber band lengthwise around the 9-volt battery so that it lays across both battery terminals. Wrap the second rubber band lengthwise around the 9-volt battery so that it crosses the first rubber band between the battery terminals (it may be needed to double-wrap the rubber bands to ensure they are tight around the battery). Slide the end of one stainless steel screw under the rubber band on top of each of the battery terminals; ensure that the heads of the screws are pointing in the same direction and not touching. **Do not let the ends of the screws touch, it may cause a spark.** This is your **electrolysis** device, and the screws are the **electrodes**.

Put on the safety goggles and half fill the shallow plastic container with lukewarm water. Put about 1/3 of a teaspoon of Epsom salts into the petri dish and then fill the rest of the petri dish with cabbage juice. Stir the solution with a spoon, then carefully place the petri dish on top of the ceramic magnet. Place the exposed ends of the screws in the solution

and watch the colourful reaction! **Caution:** Do not allow the battery to get wet. You should be able to place the ends of the screws closely or directly above the magnet so that the device rests in the solution with the battery standing up on an angle.

Observations: It should be possible at first to see bubbles forming around the submerged ends of the screws, with more bubbles forming around the screw touching the negative terminal (the **negative electrode**) than the screw touching the positive terminal (the **positive electrode**). Colour changes in the solution will appear shortly after, with a greenish colour appearing around the negative electrode and a pinkish colour appearing around the positive electrode. Finally, colour swirls will begin to form on each side of the petri dish; there will be a greenish swirl by the negative electrode and a pinkish swirl by the positive electrode.

Explanation: The electrolysis device is using electricity to separate the water into oxygen gas and hydrogen gas: Negative electric current is flowing from the negative terminal, down the screw and into the purple mixture. The electrons from the negative current travel through the mixture and then up the other screw, into the positive terminal on the battery. This flow of electric current breaks the water molecules into their separate elements, hydrogen and oxygen. This process is called **water electrolysis**. The chemical formula for water is **H₂O**, meaning the water molecules are made of two hydrogen atoms and one oxygen atom. The hydrogen gas is bubbling out of the solution around the negative electrode, and the oxygen is bubbling out of the solution around the positive electrode. There are two hydrogen atoms for every oxygen atom, which is why there are twice as many bubbles around the negative electrode as there are around the positive electrode. This is also the reason for the colour changes: the cabbage juice is used to tell us whether the water-salt mixture is **basic** (lacking in hydrogen ions) or **acidic** (rich in hydrogen ions). (**Note:** an **ion** is a positively- or negatively-charged atom or molecule; an ion has an unequal number of protons and electrons.) Finally, the Epsom salt is used to aid in the conduction of the electricity through the water, since water is naturally a poor conductor of electricity.

The colourful swirls in the solution are created by the magnetic field from the ceramic magnet below the dish. The charged oxygen and hydrogen ions come under the influence of the magnetic field, and the ions begin to follow the path of the magnetic field lines, causing the solution to swirl around.

Materials list

Materials	Store	Cost
18-Pack scented tealights	Wal-Mart	\$5.50
3/8"x3" round aluminum rod	Home Depot	\$10.24
Home Trends oven mitt pair	Wal-Mart	\$6.97
King Utility barbeque lighter	Wal-Mart	\$1.98
6 Piece .47" neodymium super magnets	Home Hardware	\$10.99
Ceramic Block Magnets, 2 pcs	Home Depot	\$4.95
1.5-inch Stainless steel screws	Canadian Tire	\$3.29
Copper wire	Home Depot	\$5.24
Westcott Kleen Earth 8" Scissors; 3 pack	Wal-Mart	\$9.97
Rubber bands, assorted	Staples	\$1.51
Petri dishes	Dal bio stores	??
Chemical safety goggles	Dal chem stores	??
Eveready Gold 9-volt Batteries, 2-pack	Wal-Mart	\$5.48
Great Value plastic spoons, 48-pack	Wal-Mart	\$2.57
Head of red cabbage	Sobeys or Superstore	(market price)
Aroma AHP Single Hot Plate	Amazon	\$26.59
Starbasix 2.4-quart saucepan with lid	Wal-Mart	\$14.97
Danielson Ball Bearing Snap Swivels, Nickel plated	Canadian Tire	\$3.49
equate Epsom Salts, 2 kg	Wal-Mart	\$4.96