MAGNETISM AND TEMPERATURE

PLANNING YOUR EXPEDITION

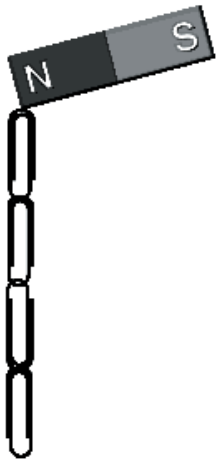
You will need to assemble all materials prior to the day that you are going to use this Expedition. A hot plate or an electric kettle is necessary because hot tap water will not yield noticeable results. If you wish to leave out the section with hot water, do so. The reason for doing this activity is to make a connection to superconductors, so the cold temperature magnet is the focus. Ice cubes will be required and you will need to copy the worksheet on temperature scales for the homework assignment to be completed.

This is a good time to revisit safety issues with your class.

Set up the class in groups of six (two students per magnet construction). In this activity your students will use the same procedure they used for "Use Electricity to Make a Magnet" or "Build a Stronger Electromagnet?" Once they have their electromagnet built, students will investigate yet another variable, temperature, and its affect on magnetic field strength. This investigation will lead directly into a discussion on superconductors, their discovery, and practical applications.

Remind students that they have dealt with variables in previous activities and, again, they will be manipulating only one variable at a time. Students should use ice water before hot water. Also, instruct students to keep cold and hot water results separate in their Alpha Logs. It is assumed at this point that your students are able to find a way to record their data so that it can be used later to create a graph. However, if you find it necessary, you can create a data table for them.

Students will be testing three electromagnets under three conditions: room temperature, very cold, and very hot. As they test and retest each condition, students will record all information in their Alpha Logs. Before they proceed , students make a plan for recording their data. At this point students should have enough experience with recording data to determine their own method.



NOTE: Instruct students to place paper clips on the magnet (or on one another) instead of just holding the magnet over a bunch of clips. Since the variations are so small (one or two paper clips), this is important (see diagram).

1. Students construct and test (using paper clips) three electromagnets.
2. Each of the electromagnets will be used to test a variable: room temperature water, hot water, and ice water.
3. After constructing three electromagnets, students test each by either leaving the solenoid as it is, by placing it in very hot water, or by submerging it in ice water.
4. Each condition should be tested 10 times to create a large enough data set to graph as a culminating activity.
5. In the Alpha Log, students answer questions regarding magnet strength and temperature. Anticipated results are that the cooler magnet will pick up the most paper clips and the very hot magnet the least number of paper clips.
6. Students will then devise a way to present their findings graphically to the rest of the class. Encourage students to use computer graphing capabilities to display all three test averages.

BACKGROUND INFORMATION

An overview of superconducting magnets can be found in Driving Force by James D. Livingston (ISBN 0-674-21645-8). A short article geared to middle school readers can be found in Odyssey Magazine, January 1997 (available from Cobblestone Publishing, 7 School Street, Peterborough, NH 03458). A concise book, Superconductivity: From Discovery to Breakthrough provides an excellent overview of the history and current status of this field (see Appendix C).

In order to understand the concept of superconductivity, it is necessary to do a short review of resistance, because it is the lack of resistance at very cold temperatures that is important. Metals are good conductors of electricity because of the number of free electrons per atom (one to three). A free electron is one that is not held by the electrical attraction of the nucleus. Materials that have no free electrons are insulators like glass or plastic. Materials that have a few are called semiconductors. Each atom of copper has one free electron, so it is a good conductor of electricity. The insulated wire that is used in these activities is copper. As electricity (from the battery) is "pushed through" the wire, the free electron bumps into other electrons resulting in resistance. Because of this the wire heats up. In many cases, this is desirable; for instance, in heaters. However, when creating high-field electromagnets, this resistance is a problem, because the magnets heat up to a point where they can no longer contain the heat so they explode.

Developing a material that would withstand the heat produced by a high magnetic field was the challenge that faced early experimenters with magnetism. Early in the twentieth century, a Dutch physicist, Heike Kamerlingh Onnes noted the relationship between lowering temperatures and, at the same time, lowering resistance. He began a search for absolute zero which is 0 Kelvin (-273.16 Celsius) at which there would be zero resistance. This led him to temperatures so low that gas would turn to liquid.

Superconductivity was found in certain metals; that is, they demonstrated no electrical resistance at extremely low temperatures. Onnes received the Nobel Prize for Physics in 1913 for his experiments. Subsequently, other scientists were awarded Nobel prizes for their work in superconductivity and magnets: John Bardeen, Leon N. Cooper, and John Robert Schrieffer in 1972 and J. Georg Bednorz and K. Alex Muller in 1987. (See the CD-ROM for more information.)

EXCURSIONS

Have students investigate superconductivity on the CD-ROM or other media (print or video). Their task will be to define terms including absolute zero and then to link this with the study of high magnetic fields. Reports should include practical applications of the technology created as a result of developing superconducting materials and present research efforts (what kinds of research are scientists doing right now in this area?). Encourage students to look at the National High Magnetic Field Laboratory homepage for answers to some of their questions (www.magnet.fsu.edu). Presentations of material could be in report form, a poster, an oral presentation, a demonstration, guest speaker, etc. Any form that students decide upon is acceptable if it indicates a relationship between the evidence from their experiments and the explanation of what is being done presently.

SC.B.1.3.4, SC.C.2.3.1-3, SC.H.1.3.1-7, 3.3.5-7

MA.A.1.3.1, 3-4

LA.A.1.3.1-4, 2.3.1-8, LA.B.1.3.1-3, 2.3.1-4, LA.C.3.3.3, LA.D.2.3.1-2

Students can research Nobel Prize winners associated with the study of superconductivity: Kamerlingh Onnes (1913), John Bardeen, Leon N. Cooper, and John Robert Schrieffer (1972), and J. Georg Bednorz and K. Alex Muller (1986). Encourage students to show in their research how each scientist or group of scientists built upon the work that came before them. This assignment points out that many individuals contribute to each discovery. Seldom are discoveries the work of just one person.

SC.B.1.3.4, SC.C.2.3.1-3, SC.H.1.3.1-7, 3.3.5-7

LA.A.1.3.1-4, 2.3.1-8, LA.B.1.3.1-3, 2.3.1-4, LA.D.2.3.1-2

SS.A.1.3.1-3, 2.3.3

For the more sophisticated students, an in-depth look at atoms and molecules would be appropriate here. Have students research various metals that are good conductors and diagram atomic and molecular structure. The diagram should explain the free electron concept so that if another student is still not clear about it, this could be a visual aid. Students could compare diagrams of conductors versus insulators. When finished, students should be encouraged to show other students and attempt to explain the concept using only their diagrams.

SC.A.1.3.3-4, 2.3.2, SC.C.2.3.1-3, SC.H.1.3.1-7, 3.3.5-7

MA.A.1.3.1-4

LA.B.2.3.1-4, LA.C.3.3.3, LA.D.2.3.1-2

An investigation of states of matter and the way that atoms are configured in the different states—gas, liquid, solid, plasma—would be appropriate at this point, particularly for more advanced students. Although a simple activity or discussion would suffice for some students, a more in-depth look

at the distance between atoms in each state would help clarify the discussion of superconductivity. Student research and presentation of findings take them from a look at the results of scientific endeavor to the science that led to those results. Students articulate why super cold temperatures create virtually no resistance.

SC.A.1.3.3-4, 2.3.2, SC.B.1.3.4-6, SC.C.1.3.2, 2.3.1-3, SC.H.1.3.1-7, 3.3.5-7

LA.A.2.3.1-8, LA.B.2.3.1-4, LA.C.3.3.3, LA.D.2.3.1-2

Have students read "A Day's Wait" by Ernest Hemingway (found in The Snows of Kilimanjaro and Other Stories ISBN 0-684-71807-3) or you can read it aloud to them. Discuss how easily confused a person could be about the difference in the Celsius and Fahrenheit scales. Brainstorm other commonly known temperatures (besides body temperature) that could be used in a story, for example the expression "room temperature" as recommended for certain foods or comfort, at 72 degrees Fahrenheit. You could take this one step further and have students write their own short stories.

SC.A.1.3.1, 1.3.3, 1.3.4, 2.3.3

LA.A.1.3.1-4, LA.B.1.3.1-3, LA.E.2.3.1-8

FOR YOUR PLANBOOK: Magnetism and Temperature

Suggested time: 1-2 hours

Gear: 3 D-cell batteries, 3 battery holders, insulated wire, 3 styrofoam cups, 3 iron rods, a thermometer, ice, very hot water, room temperature water, paper clips

National Science Content Standards: A, B, E, F, G

Sunshine State Standards Benchmarks: SC.A.1.3.3, SC.A.1.3.4, SC.A.2.3.2, SC.B.1.3.5, SC.H.1.3.1, SC.H.1.3.2, SC.H.1.3.3, SC.H.1.3.4, SC.H.1.3.5, SC.H.1.3.6, SC.H.1.3.7, SC.H.3.3.5, SC.H.3.3.6, SC.H.3.3.7

Sunshine State Standards Benchmarks -- Math: MA.A.1.3.1-4, MA.B.1.3.1-4, 2.3.1-2, 3.3.1, 4.3.1-2, MA.C.3.3.2, MA.D.1.3.1-2, MA.E.1.3.1-3, 2.3.1, 3.3.1

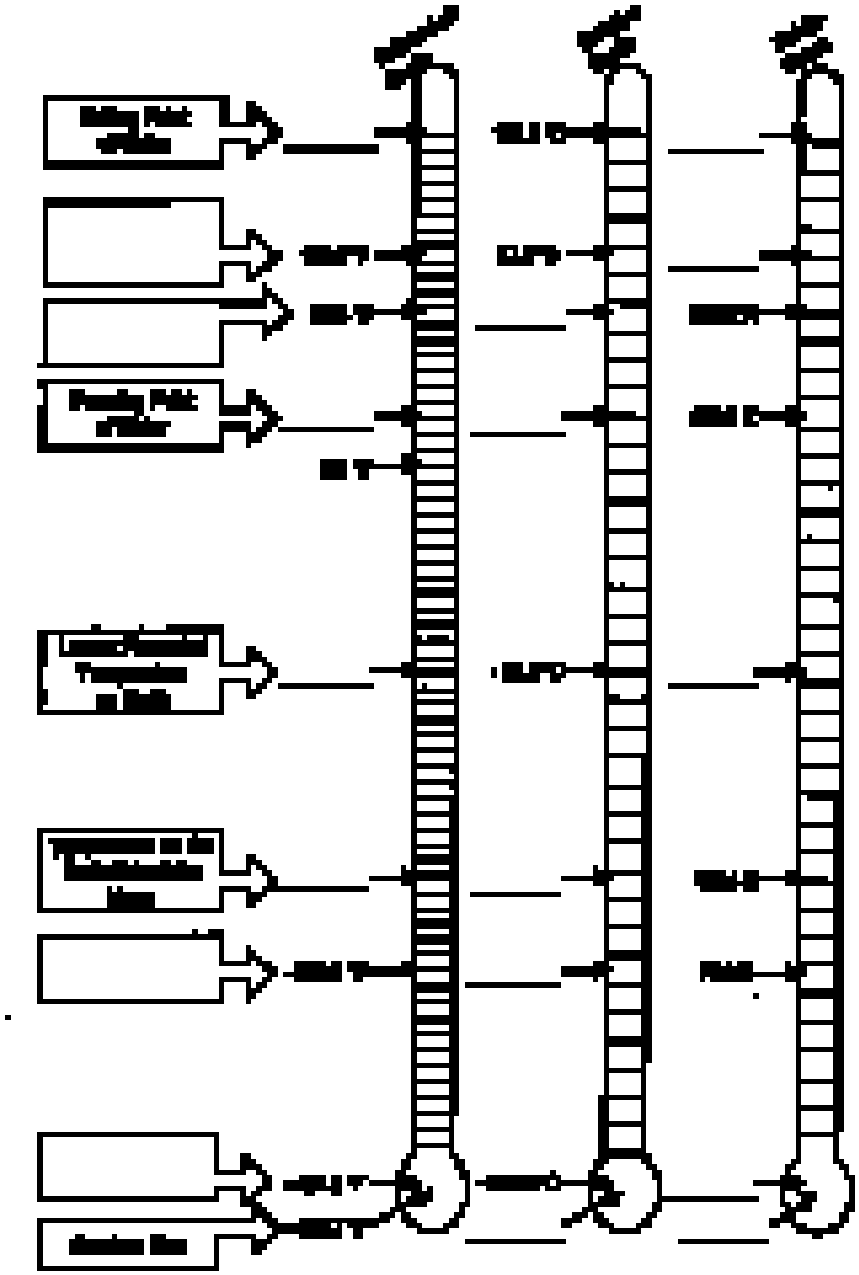
Homework: Compare the three temperature scales: Celsius, Fahrenheit, and Kelvin. Using the worksheet provided, students answer several questions comparing the three temperature scales giving them a frame of reference for completing this series of experiments. It is suggested that you allow several nights for the completion of this assignment.

Directions for the temperature worksheets: Have students complete the temperature comparison worksheet for homework before completing the Expedition. Explain the table and give an example or two of how to transfer the information to the thermometer worksheet itself. In addition to the worksheets, require students to answer the questions on the back of the worksheet. These questions ask students to make a critical analysis

of the relationship among the temperature scales.

Homework Assessment: Unless the students have some basic information, it will be difficult for them to imagine the ultra-cold temperatures represented by the Kelvin scale. Learning the correct way to write each measurement is necessary if students are going to describe their work to others. By completing this assignment students will be able to state relationships among the three scales as well as making sense of their predictions in the Expedition.

Assessment: Students' presentations of results of the series of experiments should reflect a relationship between the strength of the magnet and temperature. Cooler magnets should pick up more paper clips. Graphs should present this information so that they can be looked at separately and together. Some students will choose to use computer programs; others might use transparency overlays; still others will draw graphs by hand. However the information is displayed the result will be a clear communication of data modeling real-world information sharing that is done by scientists as they critique one another's work.



MagLab: Alpha

	Fahrenheit scale (˚F)	Celsius scale (˚C)	Kelvin scale (K)
Highest known temperature	918,000,000.0	509,999,982.2	510,000,255.4
Sun's core temperature	27,719,540.0	15,399,726.9	15,400,000.0
Sun's surface temperature	9,945.0	5,507.2	5,780.4
Hottest planet's (Venus) surface temperature	864.0	462.2	735.4
Lighted side of the moon	243.0	117.2	390.4
Boiling point of water	212.0	100.0	
Highest recorded temperature on Earth	136.0	57.8	
Average human body temperature	98.6	37.0	
Freezing point of water	32.0	0.0	
Lowest recorded temperature on Earth	-128.6	-89.2	
Dark side of the moon	-261.0	-162.8	
Liquid nitrogen	-320.8	-196.0	
Liquid helium	-452.2	-269.0	
Interstellar space	-454.0	-270.0	
Absolute zero*	-459.67	-273.15	

* The lowest temperature theoretically possible when all atomic motion stops

Answer the following questions in your Alpha Log:

1. Which is colder, the dark side of the moon, or the temperature of liquid nitrogen?

2. You take your temperature, and the thermometer reads 36.8˚C. Do you have a fever?

3. Which is warmer, 0˚F or 0˚C?

4. Below are four pairs of temperatures. Choose those that represent the same temperatures.

   a. 0.0˚C, 0.0K
   b. 32.0˚F, 273.2K
   c. 77K, -196.0˚C
   d. -270.0˚C, 0.0K

5. What is the lowest recorded temperature on Earth? Is 0.0K warmer or colder than the lowest temperature recorded on earth?

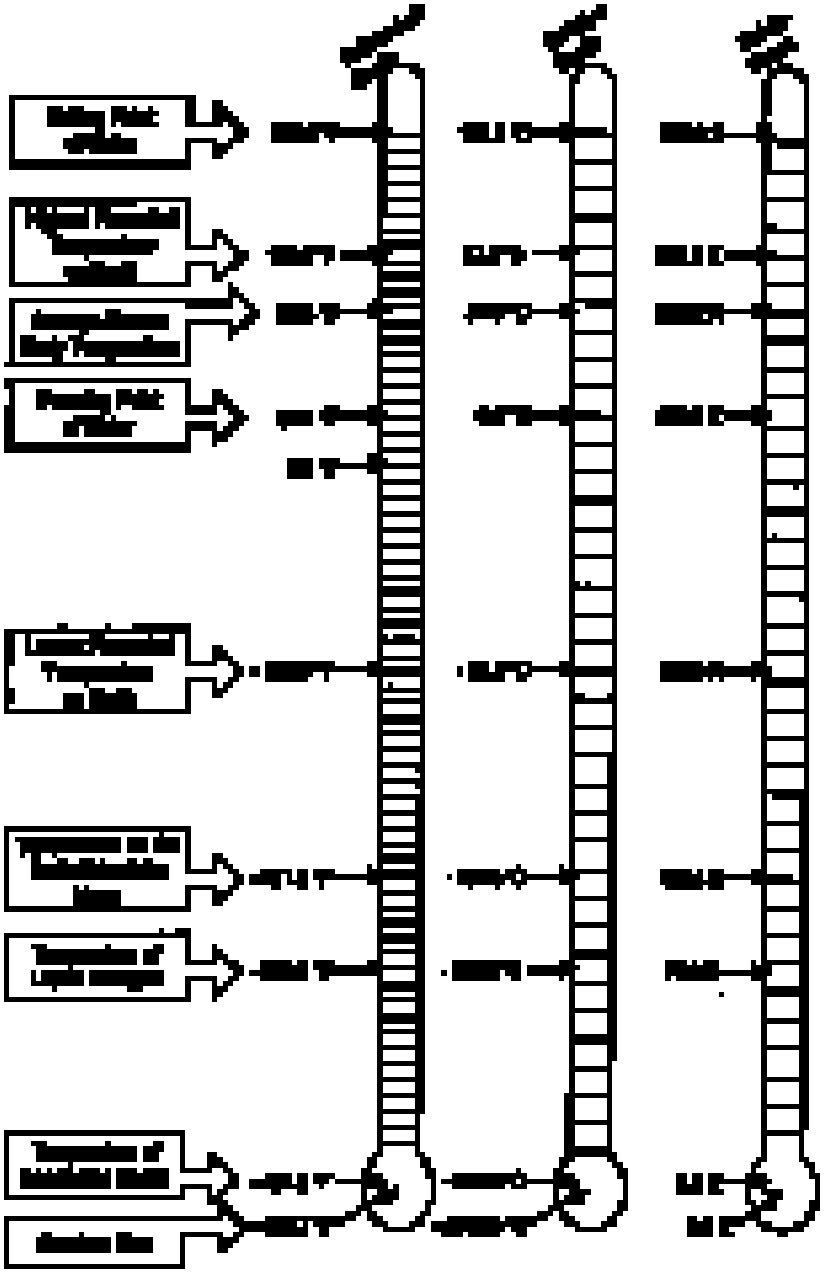
6. Consider these three temperatures: 0.0˚C, 273.2K, 32.0˚F. How are they related?

7. What is the name for the temperature at which all atomic motion is predicted to stop?

8. Write two temperatures representing absolute zero.

9. Rank these temperatures from coldest to warmest: 32.0˚F, 32.0˚C, 32.0K.

10. Why do you think scientists have developed three different temperature scales?



Answers

1. Which is colder, the dark side of the moon, or the temperature of liquid nitrogen?
   Liquid Nitrogen

2. You take your temperature, and the thermometer reads 36.8˚C. Do you have a fever?
   No. 37˚C is normal body temperature.

3. Which is warmer, 0˚F or 0˚C?
   0˚C

4. Below are four pairs of temperatures. Choose those that represent the same temperatures.

   a. 0.0˚C, 0.0K
   b. 32.0˚F, 273.2K
   c. 77K, -196.0˚C
   d. -270.0˚C, 0.0K

5. What is the lowest recorded temperature on Earth? Is 0.0K warmer or colder than the lowest temperature recorded on earth?
   -128.6˚F, or -89.2˚C, or 183.9K. 0.0K is colder.

6. Consider these three temperatures: 0.0˚C, 273.2K, 32.0˚F. How are they related?
   They are all the freezing point of water.

7. What is the name for the temperature at which all atomic motion is predicted to stop?
   Absolute Zero

8. Write two temperatures representing absolute zero.
   -459.7˚F, -273.15˚C, 0.0K

9. Rank these temperatures from coldest to warmest: 32.0˚F, 32.0˚C, 32.0K.
   32.0K, 32.0˚F, 32.0˚C

10. Why do you think scientists have developed three different temperature scales?

Notes:

MAGNETISM AND TEMPERATURE

Itinerary

You will be investigating the effect of temperature on magnets. In doing so, you will be manipulating (handling) a variable in two ways, so be sure to keep your results separate in your Alpha Log. In this experiment, you will be changing the temperature of the electromagnet to determine what effect, if any, temperature has on its strength.

Measure the strength of your magnets by the number of paper clips it can pick up. This will be the simplest and most graphic representation of the strength of the magnet.

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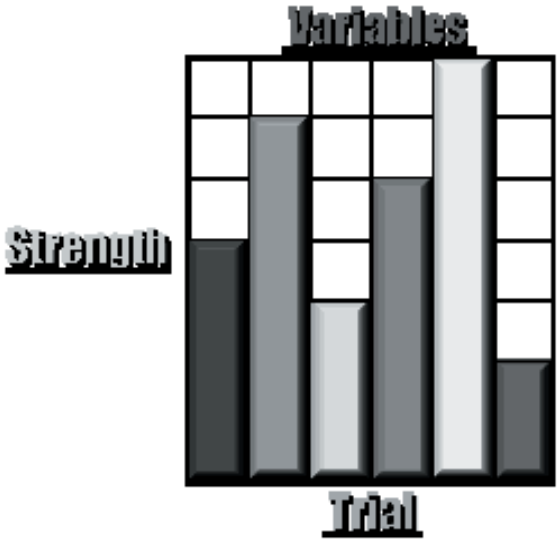
Part I

Your group will construct and test three electromagnets at one time. Divide the group so that two of you are testing the electromagnet at room temperature; two at very hot temperatures; and two at very cold temperatures.

1. The Materials Manager should assemble all of the materials that you need to run this experiment: 3 D cell batteries, 3 battery holders, insulated wire, 3 styrofoam cups, 3 iron rods, a thermometer, ice, very hot water (see your teacher about this), and paper clips.

2. Prepare your Alpha Log for recording the following data: magnet strength, temperature for 10 trials, average strength, and average temperature.
3. Construct three electromagnets as you did before. Wrap the iron rod with 60 coils of wire and record this in your Alpha Log so if you need to replicate your work to perform additional tests, you will use exactly the same specifications.
4. Test your electromagnets using the paper clips. Place the paper clips on the magnet. Record both the room temperature and the number of paper clips that your magnet picks up (its strength) in your Alpha Log. Repeat this test 10 times, recording each trial in your Alpha Log.
5. Figure out the average strength of your magnet at an average temperature and record both in your Alpha Log.
6. Now it is time to introduce the temperature variable. Respond to the following in your Alpha Log: Will reducing or increasing the temperature of the magnet affect its strength? Keeping in mind the background information that you read above, predict how many paper clips you think your cooled magnet will pick up and then do the same for the heated magnet.
7. Place the wrapped iron rod of the electromagnet in the styrofoam cup. Add crushed ice to cover the rod. Add enough water to make a slushy solution that covers the rod completely. Allow the rod to remain in the solution for a few minutes. Record the temperature of the ice water.
8. Take the coil from the cup and test the strength of your cooled magnet. Repeat the test 10 times. Remember as you repeat your strength test to record the temperature of the water each time. Then, calculate the average strength and the average temperature.

Part II

9. You will now run this experiment using hot water. With the experience and information that you gained from Part I, in your Alpha Log write a prediction about the effect that warming the magnet will have on its strength.
10. Place the magnet in the styrofoam cup and CAREFULLY pour in very hot water to cover the iron rod.
11. Record the temperature of the water in your Log and test the strength of your magnet. Repeat the test 10 times, each time recording the temperature of the water.
12. Calculate the average strength of your magnet (measured by the number of paper clips picked up) and the average temperature and record these in your Alpha Log.
13. Find the average strength for each of the three temperatures that you tested (room temperature, very cold, and very hot). What can you say about the results? Does temperature appear to affect magnet strength? How could you make an even stronger magnet?
14. Design a way to graph your results. Construct your graph in a way that can be shared with the class.