Superconductivity, Magnetic Levitation and Marty McFly's Hoverboard

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Subject: Physics
Grade Level: Hoverboard (grades 8, 11 and 12) Superconductor (grades 11 and 12)
Standards: *New York State* **–** *Physics (www.emsc.nysed.gov/ciai/)*
Standard 1**–** Analysis, Inquiry and Design
Standard 4.1 **–** Observe and describe transmission of various forms of energy.
New York State – Intermediate Science
Standard 4.4 **–** Observe and describe the properties of sound, light, magnetism, and electricity.

Schedule: **Four or more class periods**

Students will:

- Observe the characteristic interactions between magnets
- Experiment with the phenomenon of magnetic levitation
- Determine an experimental design using their knowledge of magnetic interactions to fulfill a design challenge
- Observe the phenomenon of superconductivity in a high temperature superconductor
- Experimentally determine the critical temperature for the high temperature super conductor
- Observe and discuss the phenomenon known as quantum locking

Safety:

Use goggles and gloves to avoid skin contact with liquid nitrogen

Vocabulary:

Superconductivity
Absolute Zero
Transition/Critical Temperature
Cooper Pairs
Levitation
Meissner Effect
Quantum Locking
Thin Film Materials
Fluxons

Materials:

- Ceramic magnets with attached Velcro
- Adjustable hover board blank
- Premade adjustable track
- Force meter (spring scale)
- Assortment of 1-5 gram masses
- Scale (triple beam balance)
- High temperature superconductive discs
- Neodymium magnet
- Liquid nitrogen
- Styrofoam container or Petri dish
- Multimeter or voltmeter capable of measuring millivolts
- Thermocouple

Description:

This module will introduce students to the concept of superconductivity. It is to be used after students have covered electricity. It also expected that before this unit students will have an understanding of magnet basics (polarity, field lines, magnetic domains, etc.). Following a discussion of the discovery of low temp and high temp superconductors and the mechanism for superconductivity in these materials, students will take on a design challenge in a lab using magnetic levitation. Stable levitation using a superconductor will then be observed in a separate experiment where student will determine the critical temp of the superconductive disk. Students will compare and contrast simple magnetic levitation and superconductive levitation. The theory of quantum locking in a superconductor will be demonstrated (via video clip) and discussed along with students ideas for the application of quantum locking.

Science Content for the Teacher:

Magnetism

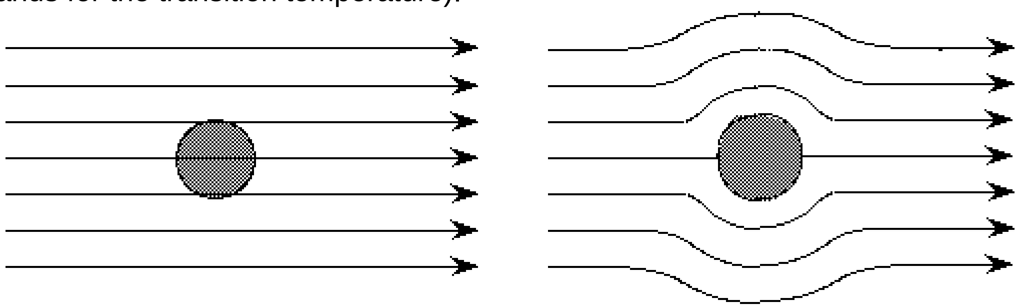
- The lines of magnetic field from a bar magnet form closed lines. By convention, the field direction is taken to be outward from the North pole and in to the South pole of the magnet. Permanent magnets can be made from ferromagnetic materials.
- A magnetic field may be represented by a mathematical description of the magnetic influence of electric currents and magnetic materials. The magnetic field at any given point is specified by both a direction and a magnitude (or strength); as such it is a vector field.
- Diamagnetism is the property of an object which causes it to create a magnetic field in opposition to an externally applied magnetic field, thus causing a repulsive effect. Specifically, an external magnetic field alters the orbital velocity of electrons around their nuclei, thus changing the magnetic dipole moment.
- According to Lenz's law, this opposes the external field. Diamagnets are materials with a magnetic permeability less than μ_0 (a relative permeability less than 1). Consequently, diamagnetism is a form of magnetism that is only exhibited by a substance in the presence of an externally applied magnetic field. It is generally quite a weak effect in most materials, although superconductors exhibit a strong effect.
- Diamagnetic materials cause lines of magnetic flux to curve away from the material, and superconductors can exclude them completely (except for a very thin layer at the surface).

Superconductivity

- Superconductivity is a phenomenon observed in several metals and ceramic materials. When these materials are cooled to temperatures ranging from near absolute zero (0 degrees Kelvin, -273 degrees Celsius) to liquid nitrogen temperatures (77 K, -196 C), their electrical resistance drops with a jump down to zero.
- In the early 1900’s, Kammerlingh Onnes, an experimental physicist, was studying the low temperature behavior of conductors. It was well known by this time that the
- In 1911, he found that mercury losses ALL its resistance abruptly as the temperature is lowered to a critical value of 4.1 K! Detailed measurements of a superconducting

ring with an induced current showed that after a year, no observable decrease in current could be detected.

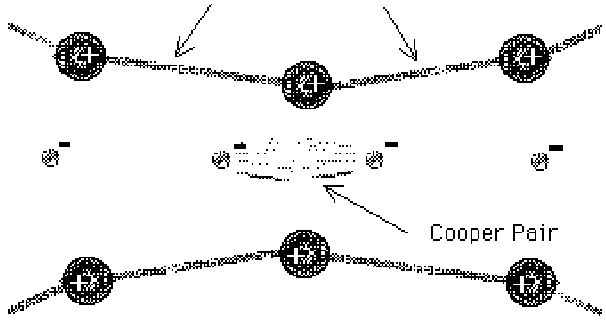
- Superconductors have zero resistance below a critical temperature. Superconductors have magnetic properties just as extraordinary as their electrical properties.
- The electric field inside a superconductor is exactly zero, and interestingly enough, the magnetic field inside is also zero. When a superconductor is placed inside a magnetic field, surface currents are produced in the superconductor. These currents produce a magnetic field which exactly cancels the external magnetic field.
- Below is a picture of what happens when a sample is placed in a magnetic field (T_c stands for the transition temperature).



$T > T_c$: Normal Metal
Magnetic Field Penetrates

$T < T_c$: Superconducting State
Magnetic Field Expelled

- In a normal metal, positive ions form a lattice, and mobile electrons are responsible for the current. As the electrons move, they collide with impurities or imperfections in the lattice.
- The lattice atoms vibrate, which causes scattering of the electrons, and thus resistance to current flow. This vibration decreases with decreasing temperature, but always exists at temperatures above 0 K.
- The sharp disappearance of resistance at a critical temperature suggests a transition to a completely different state of matter.
- In a superconductor below its transition temperature Tc, there is no resistance because these scattering mechanisms are unable to impede the motion of the current carriers.
- The current is carried in all known classes of superconductor by pairs of electrons known as Cooper pairs. The mechanism by which two negatively charged electrons are bound together is still controversial in "modern" superconducting systems such as the copper oxides or alkali metal fullerides, but well understood in conventional superconductors such as aluminium in terms of the mathematically complex BCS (Bardeen Cooper Schrieffer) theory.
- The Cooper pairs move smoothly through the superconductor and there is no dissipation of energy. As the superconductor is heated beyond the transition temperature, the lattice vibrations cause the Cooper pairs to break, thus destroying superconductivity.



The two electrons, called Cooper Pairs, become locked together and will travel through the lattice.

Meissner Effect

- When the temperature of a superconductor is lowered to below the critical temperature, (Tc), the superconductor will "push" the field out of itself.
- It does this by creating surface currents in itself which produces a magnetic field exactly countering the external field, producing a "magnetic mirror".
- The superconductor becomes perfectly diamagnetic, canceling all magnetic flux in its interior.
- This perfect diamagnetic property of superconductors is perhaps the most fundamental macroscopic property of a superconductor.
- When a material is superconducting the magnet will begin to float above the superconductor.
- If you monitor the temperature as the Meissner effect occurs you can obtain a good approximation of the critical temperature.

Classroom Procedure:

HoverBoard Activity:

Engage (Time: 10 min)

- Hands on activity with the Levitron, can anyone get stable levitation.
- Discuss how magnets interact through fields from magnetic poles.
- Lead in video clip from *Back to the Future II*. Marty on the his hoverboard.

Explore (Time: 40 min)

- Handout HoverBoard Activity Sheet and have students complete the pre-lab questions.
- Divide students into groups. Students should share pre-lab questions.
- Students begin work on the HoverBoard kit, inventory to make sure all kits are complete.
- As students are assembling their boards and tracks, go from group to group to ensure that directions are being followed and answer/redirect student questions.
- Students complete the assembly and collect data.

Explain (Time: 15 min)

- Each group reports out on the performance of their HoverBoards with the results from the analysis questions.

Expand (Time: 20 min)

- Students work individually on the discussion questions.
- Recombine with the group and share discussion questions.
- Class reforms and each group shares two major points that came out of the conversation of post lab questions.

Assessment:

The following rubric can be used to assess students during each part of the activity. The term “expectations” here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

1= exceeds expectations
2= meets expectations consistently
3= meets expectations occasionally
4= not meeting expectations

	Engage	Explore	Explain
1	Shows leadership in the discussion and an in depth understanding of chemical reactions and titration.	Completes work accurately while providing an explanation for what is observed. Works very will with partner.	Provides and in-depth explanation of findings. Fills out worksheet clearly.
2	Participates in the demo and shows an understanding of chemical reactions and titration.	Completes work accurately and works cooperatively with partner.	Provides clear explanation of findings. Fills out worksheet clearly.
3	Contributes to the discussion, but shows little understanding of reactions or titration.	Works cooperatively with partner, but makes some mistakes with the procedure.	Provides a limited explanation of findings. Fills out some of the worksheet.
4	Does not participate in discussion. Shows no understanding of reactions or titration.	Has trouble working with partner. Does little to complete the procedure.	Is not clear in explanation of findings. Does not fill out worksheet.

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