Subject Area(s) physics

Associated Unit

Associated Lesson

Activity Title **Levitating Magnets**

Header

Image 1

ADA Description: Blurred photograph of a passenger train moving through a tunnel

Caption: Levitating Magnets

Image file: mag-lev_image1.jpg

Source/Rights:

Grade Level **12 (11-12)**

Activity Dependency

Time Required **135 minutes (one 45 minute class period for lecture and demonstration, one for second demonstration and activity, and one for wrap-up)**

Group Size **3**

Expendable Cost per Group **US$0 (All materials might not be available in the classroom, but once purchased, they can be used for many years; suggested sources for materials are provided in the "Materials List" section below.)**

Summary

The overall aims for this lesson can be divided into two parts. The first is to expose students to the oft overlooked phenomenon of diamagnetism; the second is to give students a feel for ferromagnetic levitation.

Engineering Connection

Magnetism is a more complex phenomenon than what one might expect from looking at refrigerator magnets. Engineers take advantage of different types of magnetism to learn more about the natural world, develop new technologies. Mechanical and electrical engineers must be mindful of the dynamic interactions of electrical and magnetic fields, because the motion of a magnetic field near a conductor can have unexpected behaviors. Such is the case with eddy currents—not only can these induced currents slow down a moving conductor, they can generate unwanted levels of heating. Engineers, however, have even found ways to use seeming disadvantages for useful purposes, like stopping trains and cooking dinner.

In this activity, students act like engineers by building a spinning magnet toy and thinking critically about why it behaves as it does.

Engineering Category = **#1**

Keywords

diamagnetism, eddy current, ferromagnetism, induction, magnet, magnetic levitation

Educational Standards

- ITEEA, Standard 16, Grades 9-12, J. Energy cannot be created nor destroyed; however, it can be converted from one form to another.
- ITEEA, Standard 16, Grades 9-12, K. Energy can be grouped into major forms: thermal, radiant, electrical, mechanical, chemical, nuclear, and others.
- Texas Essential Knowledge and Skills (TEKS) §112.39. Physics, Beginning with School Year 2010-2011… (c) (5) (D) "Science concepts. The student knows the nature of forces in the physical world. The student is expected to… identify examples of electric and magnetic forces in everyday life;"

Pre-Requisite Knowledge

Understanding of atomic nature of solids. Basic knowledge of electricity and magnetism. Basic knowledge of calculus.

Learning Objectives

After this activity, students should be able to:

- Explain the physical origins of magnetism and eddy currents
- Understand the differences between dia- and ferro- magnetism
- Identify examples of magnetic levitation
- List Maxwell's equations and understand the meaning of each term
- Identify practical uses of eddy currents

Materials List

Demonstration One

Instructor needs:

- one Styrofoam block roughly 10cm on a side
- a large diameter Phillips head screwdriver
- one glass vial
- one large plastic container 30cm square and 20cm deep (large enough for the Styrofoam block to freely move around)
- enough water to completely fill the vial and fill the plastic container to a depth of ~8cm (deep enough so that the Styrofoam plus water-filled vial can float)
- one very strong magnet, such as a Neodymium Iron Boron grade N42 axially polarized cylinder 19mmOD x 38.1mm thick (3/4"x1.5")

Note: this demonstration is based on a diamagnetism detector presented by YouTube user NurdRage (http://www.youtube.com/watch?v=jyqOTJOJSoU&feature=related)

Note: magnets can be purchased online from K & J Magnetics. As of 28 April 2012, they are $17.93 and can be found at http://www.kjmagnetics.com/proddetail.asp?prod=DCX8

Note: a YouTube clip can be substituted for this demonstration (see "Procedure"-> "With the Students"->"*Day One*" below)

Demonstration Two

Instructor needs:

- Levitron

Note: Levitron can be found in select toy-stores and at various online retailers. One source is Innova Toys where the "Levitron® Omega" sells for $35.99 at http://www.innovatoys.com/c/LEV as of 30 April 2012

Note: a YouTube clip can be substituted for a real Levitron (see "Procedure"-> "With the Students"->"*Day Two*" below)

Activity

Each group of three needs:

- two ring magnets: 25.4mm OD x ~7.5mm ID x 6.35mm thick (1"x5/16"x1/4"), axially magnetized
- four disc magnets: 25.4mm OD x 3.18mm thick (1"x1/8"); axially magnetized
- one standard size pencil (~7.5mm diameter; round or hexagonal), sharpened
- one cardboard strip (~120mm x 50mm); white is preferable as students can more easily see the pencil marks; cardboard strips may be reused by subsequent groups if students are diligent about erasing pencil marks
- one thick (~10mm) rubber rectangle (150mm x 75mm) with three 50mm wide cuts
  - one at 20mm
  - one at 65mm
  - one at 125mm
- electrical or masking tape (may be necessary if magnets do not fit pencil snugly)
- one "Spinner" handout

Note: this activity is adapted from the work of Shibika Chowdhary and Arvind Gupta Toys team (http://www.arvindguptatoys.com/toys.html)

Note: a mouse pad or flip-flop are good sources for the "thick rubber rectangle"

Note: an X-Acto knife or box cutter work well for making the cuts

Note: magnets can be purchased online from K & J Magnetics. As of 28 April 2012, the ring magnets are less than $5.40 each and can be found at http://www.kjmagnetics.com/proddetail.asp?prod=RX054 ; the disc magnets are less than $4.23 each and can be found at http://www.kjmagnetics.com/proddetail.asp?prod=DX02-N52 .

Introduction / Motivation

We often consider levitation, or objects floating in air, to be a magical phenomenon—something limited to science fiction and fantasy stories. Consider the Wingardium Leviosa charm from *Harry Potter and the Sorcerer's Stone* by J. K. Rowling. [Clips from the Warner Bros. movie are available on YouTube in a 38 second and 92 second version at http://www.youtube.com/watch?v=rb6X6mg2qAo and http://www.youtube.com/watch?v=nAQBzjE-kvI, respectively; alternatively, the instructor could read this from the novel: this part of the movie is based on a passage near the middle of Chapter 10: Halloween]. Is it really possible to cause feathers to float by pointing a wand at them? Perhaps in the future it may be. Physicists and engineers in the Netherlands have released some surprising images of levitating frogs and grasshoppers. [Clips are available on YouTube at http://www.youtube.com/watch?v=m-xw_fmB2KA (10sec, frog), http://www.youtube.com/watch?v=iVmpOH1jzO4&NR=1 (5sec, grasshopper), http://www.youtube.com/watch?v=m-Al7GAnH8Q&feature=related (52sec, medley)]. No special incantations or magic wands were necessary! Magnetism is actually behind this strange levitation. Technically speaking, diamagnetism is the only known way for scientists to achieve true levitation, meaning that "no energy input is required and the levitation can last forever" [High Field Magnet Laboratory home page]. The impressive levitations in the preceding clips were assisted by powerful electromagnets, but a highly diamagnetic material (such as graphite or pyrolytic carbon) can levitate over strong permanent ferromagnets.

Sometimes it is difficult to predict which forces of nature are significant in a given situation. Magnetic effects, aside from posting notices on the home refrigerator, go largely unnoticed by the general public. The interaction of magnetic and electric fields, however, is critical in electric motors, magnetometers (metal detectors), mag-lev transportation, and more exotic applications. The motion of a magnet near an electrical conductor can produce unanticipated effects.

The lecture, activity, and (optional) demonstrations below introduce and explore different types of magnetic levitation.

Vocabulary / Definitions

Word	Definition
degaussing	Process of decreasing a magnetic field, typically by using a coil with an opposing magnetic field.
diamagnetism	Property of certain materials that have an electronic configuration which generates a magnetic field in opposition to an externally applied field
eddy	A current (either fluid or electrical) whose flow direction differs from that of the general flow
ferromagnetism	Property of certain materials that have an electronic configuration which supports a net total magnetic dipole moment even when the magnetizing field is removed.
permeability	Degree of magnetization a material will experience when exposed to a magnetic field.
precession	The motion (or change in orientation) of the rotational axis of a rigid body

Procedure

Background

1. Though we generally think of "ferromagnetic" materials and their behavior, all materials are influenced to a greater or lesser degree by the presence of a magnetic field. Physicists and engineers work with many different classes of magnetic materials—ferromagnetic, antiferromagnetic, ferrimagnetic, paramagnetic, diamagnetic… just to name a few!

2. The observed differences in magnetic behavior are dependent upon the atomic structure and electron configuration of the material. Generally, these characteristics can be captured by the relative permeability, a measure that is analogous to the dielectric constant. The relative permeability (κ_m) is formed by taking the ratio of the permeability of the material (μ) to the permeability of free space (μ_0); the permeability refers to the amount of magnetization a material will experience when introduced to a magnetic field.
    a. ferromagnetic materials: κ_m significantly greater than unity
    b. paramagnetic materials: κ_m slightly greater than unity
    c. diamagnetic materials: κ_m slightly less than unity
3. Sources of magnetization are the electrons' orbital angular motion around the nucleus and the electrons' intrinsic magnetic moment. Orbiting electrons can be thought of as extremely small current loops, so that the circulating electrons give rise to an orbital magnetic dipole moment. If one considers the spin of an electron to be an infinitesimal current loop, one sees that the spinning electron also forms an intrinsic magnetic dipole moment. The vector sum of the orbital and intrinsic moments gives the total magnetic moment.
4. In most materials, the electrons are arranged such that their magnetic moments (both orbital and intrinsic) cancel out—these materials include diamagnetic materials. Paramagnetic and ferromagnetic materials, however, either spontaneously, or owing to an applied external magnetic field, will have electron magnetic moments that tend to align parallel to the magnetic field, thereby minimizing each moment's potential energy (the alignment is imperfect due to random motions associated with temperature).
5. Diamagnetic materials, like those shown in the Introduction clips (http://www.youtube.com/watch?v=m-xw_fmB2KA, http://www.youtube.com/watch?v=iVmpOH1jzO4&NR=1, and http://www.youtube.com/watch?v=m-Al7GAnH8Q&feature=related), are capable of generating a magnetic field in opposition to an applied magnetic field. However, they are unable to retain their magnetization after the external field is removed.

6. The Introductory clips were filmed in "the 32mm vertical bore of a Bitter solenoid in a magnetic field of about 16 Tesla at the Nijmegen High Field Magnet Laboratory in the Netherlands".
7. For ferromagnetic materials, a net magnetic dipole moment can persist after removal of the external field. If this is true a permanent magnet has been made. The term "permanent" is a bit misleading, however, because the magnetic dipoles can be re-randomized by increasing the material's temperature, mechanically impacting the material, or subjecting the material to a strong opposing magnetic field (degaussing).
8. Maxwell's equations
    a. Gauss' law for electricity: $\nabla \cdot E = \frac{\rho}{\varepsilon_0}$ (The electric flux through any closed surface is proportional to the enclosed electric charge: ε_0 is the electric constant)
    b. Gauss' law for magnetism: $\nabla \cdot B = 0$ (the magnetic field B has divergence equal to zero, in other words, that it is a solenoidal vector field. It is equivalent to the statement that magnetic monopoles do not exist)
    c. Maxwell–Faraday equation (Faraday's law of induction): $\nabla \times E = -\frac{\partial B}{\partial t}$ (electromotive force generated is proportional to the time rate of change of the magnetic flux)

d. Ampère's circuital law (with Maxwell's correction): $\nabla \times H = J_f + \frac{\partial D}{\partial t}$ (relates the integrated magnetic field around a closed loop to the electric current passing through the loop)

9. Looking at the Maxwell-Faraday equation above, we see that moving and/or temporally varying magnetic fields (or more specifically, magnetic flux densities $\boldsymbol{B}$) can generate electromotive force (EMF). The equation also indicates that stronger applied magnetic fields, lower resistivity conductors, and greater variation in the applied field (either due to faster relative motion or more rapid change in time) will all result in higher EMF.
10. The induced EMF can cause electrons to move in a conductor, resulting in "eddy" (or Foucault) currents. The circulating eddies of current, in turn, induce magnetic fields that lead to repulsive, attractive, propulsive, or drag effects.
11. The electromagnetic energy associated with the eddy currents is eventually converted to thermal energy, which can lead to a significant (and frequently undesirable) temperature rise in the conductor.
12. Eddy currents can be problematic in transformers, where they contribute to power loss.
13. Though eddy currents can cause significant heating of a conductor, scientists, engineers, and technologists have come to harvest this often undesirable side effect to great advantage in induction heaters and forges. These apparatuses generate very high, yet very localized, "hot spots" in a material. Induction cook tops can be found in many homes. Eddy currents are setup in the metal pots and pans placed on the range by passing time-varying currents through flat coils of wire underneath the cook top. These cook tops heat food quickly without the gas-powered range's open flames and do not retain heat the way conventional resistively heated burners do.

Image 2 [left justified]

Image 2

ADA Description: Photograph of the surface of an induction cook top set into a kitchen countertop

Caption: The cooking surface of an induction cook top looks smooth and glassy

Image file: mag-lev_image2.jpg

Source/Rights: Copyright © Erik1980, Wikimedia Commons http://en.wikipedia.org/wiki/File:Kookplaat_inductie.JPG

Image 3 [right justified]

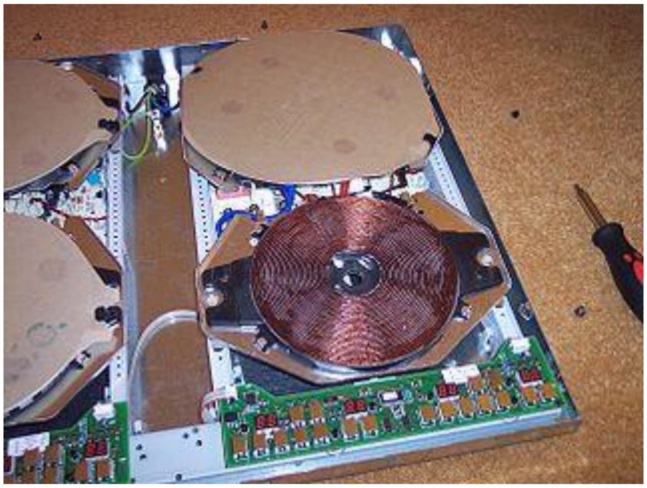
Image 3

ADA Description: Photograph of the underside of the induction cook top shown in Image2. Three of the four heating coils are covered, but the fourth is exposed. The electronic connections are also visible

Caption: Behind the smooth top cover, the heating coils are visible, as are the electronic controls and connections

Image file: falling_magnets_image3.jpg

Source/Rights: Copyright © Twostaricebox, Wikimedia Commons http://en.wikipedia.org/wiki/File:Induction_Cooker.JPG



14. A couple of short videos showing industrial inductive heating are available at:
    a. http://www.youtube.com/watch?v=d7DBS2Is0ws
    b. http://www.youtube.com/watch?v=NofJswNBDBs&NR=1&feature=fvwp
15. Eddy currents can be used to provide non-contact braking. A conductor in the form of a rotating disc or translating bar is allowed to move freely past a series of electromagnets. When the magnets are not energized, the moving conductor feels no effects. However, when the electromagnets are turned on, eddy currents are generated within the conductor that tend to oppose the motion of the conductor. Thus the interaction of the magnetic forces causes the conductor to slow down. The deceleration is dependent upon the electromagnet's strength and the speed of the conductor. The type of brake can be used as an emergency stopping mechanism for trains and rotating machinery. Because no physical contact is made, these brakes tend to be gentler on the mechanical system, offering longer life with less wear.
16. Induced EMF generated by sliding a magnet through a coil of wire can be harnessed to light an LED. This idea has been combined with rechargeable batteries (and a bit of circuitry) to make shake flashlights. The flashlight is an example of energy inter-conversion. The chemical energy liberated from metabolism of nutrients by cells allows a person to impart kinetic energy to a magnet. The motion of the magnet leads to eddy currents (electromagnetic energy) that can be converted to both thermal energy and radiant energy in a light emitting diode.
17. Directions for making a homemade shake light can be found by following the link to the K & J Magnetics blog in the "Activity Extension" and "Additional Multimedia Support" sections below.

Before the Activity

1. Assemble Diamagnetism Observation Apparatus
    a. Using the screwdriver, carefully make a hole in the Styrofoam block that extends about half the length of the vial
    b. Gently press the vial into the hole and fill with water
    c. Fill the plastic container with water and float the Styrofoam-vial unit
    d. During demonstration, keep the apparatus away from drafts and vibrations as these may obscure the weak diamagnetic interaction
2. Practice with the Levitron
3. Gather materials for Activity, cut cardboard strips and mouse-pads, and sharpen pencils

With the Students

Day One

1. Present Introduction/Motivation material detailed in the section above
2. Ask the students whether they think water is magnetic?
3. Reveal the Set-up for Demonstration One (Diamagnetism Observation Apparatus) (or show the YouTube clip http://www.youtube.com/watch?v=jyqOTJOJSoU&feature=related)
4. Perform the demonstration
    a. keep the apparatus away from drafts and vibrations as these may obscure the weak diamagnetic interaction
    b. hold magnet near (but not touching) the water filled vial
    c. watch vial drift away from magnet
    d. if students ask whether vial is responsible for the motion (and not water inside), empty the water and repeat
    e. if students ask whether impurities in water are responsible for motion, explain that most impurities would tend to be ferro- or para-magnetic and thus tend to be attracted to the magnet rather than repelled
5. Invite students to move the magnet
6. Discuss the origins of magnetism and explain the differences between diamagnetism and ferromagnetism
7. Ask students to recall levitating frog and grasshopper clips (show again, if desired)
8. Ask students how this was accomplished
    a. organisms are water-based
    b. very-strong electromagnet used
9. Introduce the work at the High Field Magnet Laboratory (http://www.ru.nl/hfml/research/research_program/)
    a. describe Bitter magnet
        i. named for Francis Bitter (American physicist) who devised using circular plates interleaved with insulating spacer to form a helical structure
        ii. the Bitter plates are better able to withstand the large Lorentz forces which tend to create an outward pressure on the material (and would cause a wire to burn out)—force increases with the square of the magnetic field strength
        iii. the plates also have holes allow cooling water to circulate—heat dissipation increases with the square of the magnetic field strength
        iv. Bitter magnets can easily generate fields of more than 20 Tesla—this is nearly a million times stronger than Earth's magnetic field
    b. HFML uses magnetism to perform molecular manipulations

Image 4 [centered]

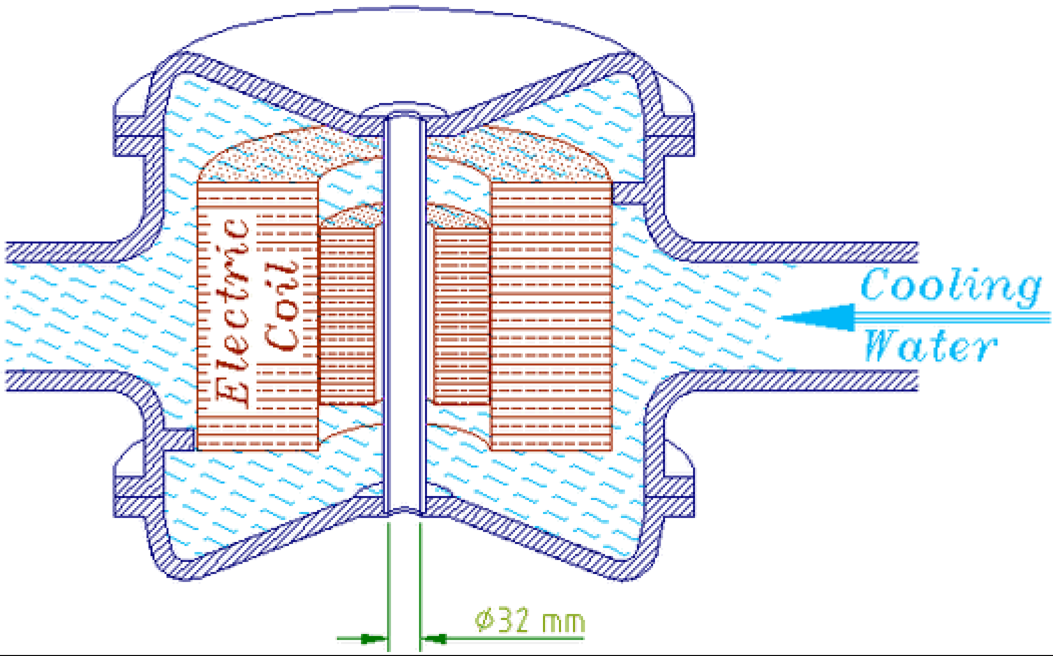


Image 4

ADA Description: Schematic of a Bitter magnet showing a cross section of the magnet with the sample core surrounded by Bitter coils and cooling water

Caption: Cross-section of the Bitter magnet used at HFML to make the introductory levitation clips

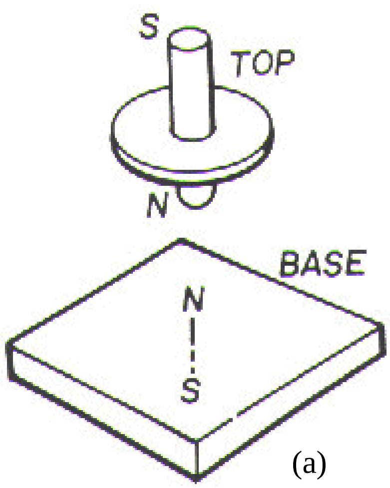
Image file: mag-lev_image4.png

Day Two

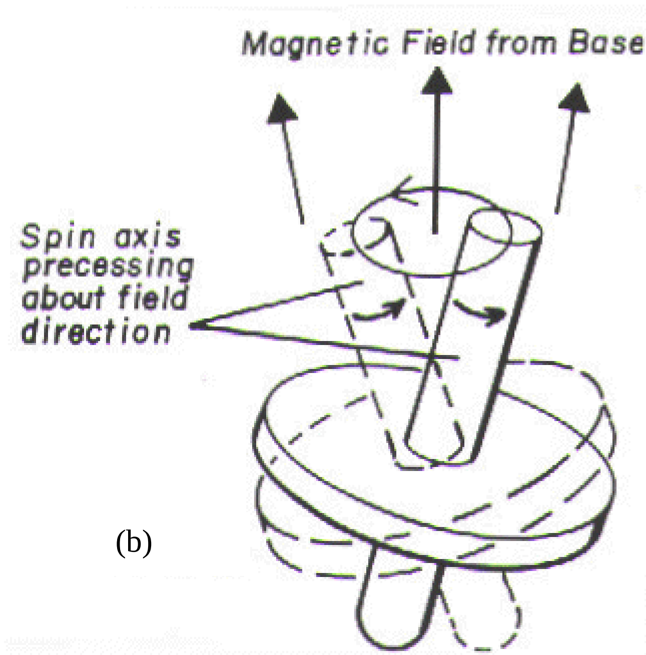
1. Recap demonstration and lecture from *Day One*
2. Inform students that these clips used strong electromagnets, but that diamagnetic materials can be passively levitated (in fact, diamagnetic levitation is science's only know form of true levitation—no external energy source is necessary to maintain levitation)
3. Remind students that clips from *Day One* were obtained using powerful electromagnets
4. Show students a clip of graphite (pencil lead) levitating over strong rare-earth magnets (http://www.youtube.com/watch?v=-08BAmpFDig)
    a. it is possible to use the class-set of disc magnets from the Spinner Activity to do an in-class demonstration of this video
    b. great care should be used, however, as these powerful magnets can easily pinch fingers and are very difficult to separate
5. Show students that it is not possible to get one of the rare-earth magnets to levitate over another (or others)
6. Invite students to try (or make suggestions for the instructor to try)

7. Remind students that graphite levitated due to diamagnetism but that the rare-earth magnets are ferromagnetic
8. Introduce the students to Earnshaw's Theorem
9. Explain Earnshaw's theorem to students
   a. "a collection of [magnetic dipoles] cannot be maintained in a stable stationary equilibrium configuration solely by the [ferromagnetic] interaction of the [dipoles] in of permanent [ferromagnets] and paramagnetic materials or any combination" (adapted from Wikipedia)
   b. Explain that without eddy currents or motion of magnets, levitation cannot be maintained
10. Explain what Levitron is
11. Show the students the Levitron demonstration (a YouTube video can be substituted if a Levitron is not available: one example is http://www.youtube.com/watch?v=iv8msBamA3M)
12. Ask students for ideas why Levitron works
13. Explain physics of the Levitron (summarized from http://www.levitron.com/physics.html)
    a. electromagnet in base opposes permanent magnet in the top—north-north interaction dominates because field strength drops with distance
    b. the top spins and precesses (or wobbles) which has a stabilizing effect and keeps the top from flipping over

Image 5 (a) and (b) [centered]



(a)



(b)

Image 5

ADA Description: (a) schematic indicating polarity of the top and base—north-north pole interaction dominates and (b) a schematic showing the top's precession (or "wobble")

Caption: Schematics indicating (a) polarity of top and base and (b) top's precession

Image file: mag-lev_image5a.gif; mag-lev_image5b.gif

    c. the top spins and is thus able to dynamically respond to the field from the base, so Earnshaw's theorem is not violated
    d. the weight of the top is critical in determining the equilibrium position of the top
    e. the top slows down because of air resistance, and the angular velocity is no longer sufficient to stabilize the torque of the other non-dominant magnetic interactions
14. Tell students that a similar phenomenon has been used to study micro- and nano-scale particles
    a. optical tweezers
    b. neutron traps
15. Students follow the steps listed on the "Spinner" handout
    a. Remind students to be careful—magnets can pinch!
    b. Urge students to not let magnets fall to the floor or stick together
    c. Insert cardboard into rubber slot closest to edge of the rubber
    d. Slide the two ring magnets onto the pencil leaving about 6cm between them
        i. don't worry about the polarity
        ii. if the magnets are loose, wrap a few layers of electrical or masking tape around the pencil
        iii. if the magnets are too tight, use a knife to scrape away some wood
    e. Insert two disc magnets in the slot nearest the cardboard so that both attract the magnet closest to the point of the pencil
    f. Insert the remaining two disc magnets in the final slot so that both magnets repel the magnet at the far end of the pencil
    g. With the pencil tip just touching the cardboard, adjust the magnets on the pencil so that it hovers
    h. Gently twirl the end of the pencil and watch as it spins in mid-air
    i. Answer the questions on the handout if time permits, finish for homework

Day Three

1. Recap activity and discussions from *Day Two*
2. Remind students that changes in electrical fields can generate magnetic fields
    a. Introduce the students to linear motors and Mag-Lev trains
    b. A nice video presentation is available from Transrapid on YouTube at http://www.youtube.com/watch?v=weWmTldrOyo
    c. The K & J Magnetics blog has directions to build a toy mag-lev train: http://www.kjmagnetics.com/blog.asp?p=maglev-train
3. Present Maxwell's Equations
4. Remind students that moving magnetic fields can induce current flow in near-by conductors—so-called eddy or Foucault currents
5. Inform students that eddy currents can be sources of heating, but that engineers have been able to take advantage of this energy interconversion
6. Ask the students to name other major forms of energy; these include thermal, radiant, electromagnetic, mechanical, chemical, nuclear, and others. (ITEEA, Standard 16, Grades 9-12, K)

7. Discuss practical applications of eddy currents (Texas Essential Knowledge and Skills (TEKS) §112.39. Physics, Beginning with School Year 2010-2011… (c) (5) (D) "Science concepts. The student knows the nature of forces in the physical world. The student is expected to… identify examples of electric and magnetic forces in everyday life;")
    a. Induction heating—remind students that this is an example of energy conversion. The thermal energy may appear to be magically created, but it arises from the electromagnetic energy associated with the eddy currents in the conductor. (ITEEA, Standard 16, Grades 9-12, J)
    b. Eddy current brakes—illustrate conversion of kinetic energy into electromagnetic and thermal energies. (ITEEA, Standard 16, Grades 9-12, J)
    c. LED "shake" flashlights—illustrate conversion of kinetic to electromagnetic to radiant energy. (ITEEA, Standard 16, Grades 9-12, J)

Attachments

"Spinner" handout (docx)

"Spinner" handout (pdf)

Safety Issues

- Use caution around magnets to avoid pinching fingers
- Rare earth magnets are quite brittle and can be cracked, so care is warranted to keep magnet from directly impacting the tabletop or floor and shattering

Troubleshooting Tips

- Magnets are shipped with spacer materials. If these spacers are lost or discarded, magnets can stick together and become difficult to separate. A shearing motion (performed by strong fingers!) is most effective in separating magnets. Using sharp objects to pry magnets apart should be avoided, if possible, to avoid damaging the (nickel) coating.
- Styrofoam dinner plates can be cut into discs and used as spacers if original spacers have been lost or discarded
- To improve levitation during Spinner activity, magnets may need to be adjusted on pencil

Investigating Questions

Assessment

Pre-Activity Assessment

Baseline

Ask students about what "levitation" means

Ask students if they have ever heard of electromagnetic induction or eddy currents

Activity Embedded Assessment
Observation
Students observe pure ferromagnetic levitation is not possible
Students observe diamagnetic materials are repelled by strong magnetic fields

Post-Activity Assessment
Summarization
Students complete the questions on the Spinner handout

- Could you get one ring magnet to levitate over the other without any mechanical support? Why or why not?
- What is the purpose of the cardboard in the spinner setup?
- Could you get the pencil to hover over the spinner setup without spinning it? Why or why not?
- Sketch the pencil marks observed on the cardboard. Is there any pattern? If so, why do you think it occurs?
- Why does the pencil eventually stop levitating?
- Write one paragraph detailing a practical application of magnetic levitation.

Students write one paragraph describing eddy currents and electromagnetic induction and one paragraph describing everyday applications of electromagnetic induction (topics may include those mentioned during the lesson)

Activity Extensions

- Students can build their own toy mag-lev trains. The directions and material list are available at http://www.kjmagnetics.com/blog.asp?p=maglev-train . This activity could be used to address
    - ITEEA, Standard 8, Grades 9-12, J. The design needs to be continually checked and critiqued, and the ideas of the design must be redefined and improved.
    - ITEEA, Standard 11, Grades 9-12, Q. Develop and produce a product or system using a design process.
    - ITEEA, Standard 11, Grades 9-12, R. Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.
- Students can build their own LED shake flashlights. The directions and material list are available at http://www.kjmagnetics.com/blog.asp?p=shake-flashlight . This activity could be used to address
    - ITEEA, Standard 8, Grades 9-12, J. The design needs to be continually checked and critiqued, and the ideas of the design must be redefined and improved.
    - ITEEA, Standard 11, Grades 9-12, Q. Develop and produce a product or system using a design process.
    - ITEEA, Standard 11, Grades 9-12, R. Evaluate final solutions and communicate observation, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Activity Scaling

Additional Multimedia Support

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Other

Redirect URL

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Supporting Program

National Science Foundation AWARD # 0840889—New, GK-12 Program at the University of Houston: Innovations in Nanotechnology and Nanosciences using a Knowledge, Applications, Research, and Technology (KART) Approach—Pradeep Sharma, Ph.D., Principal Investigator

SPINNER

Adapted from work by Arvind Gupta Toys team (http://www.arvindguptatoys.com/toys.html)

Earnshaw's Theorem tells us that ferromagnetic materials cannot be stably levitated by stationary magnetic fields alone. By adding a mechanical stop and rotation to a group of magnets, however, we will be able make a pencil levitate and twirl for several seconds.

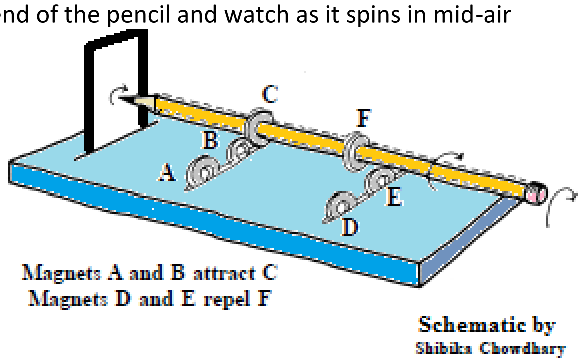
Be careful handling the magnets—they can deliver a hard pinch!
Do not let magnets fall onto the floor—they are very brittle and may shatter on impact!

Each group of three needs:

- two ring magnets
- four disc magnets
- one standard size pencil, sharpened
- one cardboard strip
- one rubber rectangle
- electrical or masking tape (may be necessary if magnets do not fit pencil snugly)

INSTRUCTIONS

1. Remind students to be careful—magnets can pinch!
2. Urge students to not let magnets fall to the floor or stick together
3. Insert cardboard into rubber slot closest to edge of the rubber
4. Slide the two ring magnets onto the pencil leaving about 6cm between them (no need to worry about the polarity)
   a. if the magnets are loose, wrap a few layers of electrical or masking tape around the pencil
   b. if the magnets are too tight, use a knife to scrape away some wood
5. Insert two disc magnets in the slot nearest the cardboard so that both **attract** the magnet closest to the point of the pencil
6. Insert the remaining two disc magnets in the final slot so that both magnets **repel** the magnet at the far end of the pencil
7. With the pencil tip just touching the cardboard, adjust the magnets on the pencil so that it hovers
8. Gently twirl the end of the pencil and watch as it spins in mid-air



HOMEWORK QUESTIONS

- Could you get one ring magnet to levitate over the other without any mechanical support? Why or why not?
- What is the purpose of the cardboard in the spinner setup?
- Could you get the pencil to hover over the spinner setup without spinning it? Why or why not?
- Sketch the pencil marks observed on the cardboard. Is there any pattern? If so, why do you think it occurs?
- Why does the pencil eventually stop levitating?
- Write one paragraph detailing a practical application of magnetic levitation.