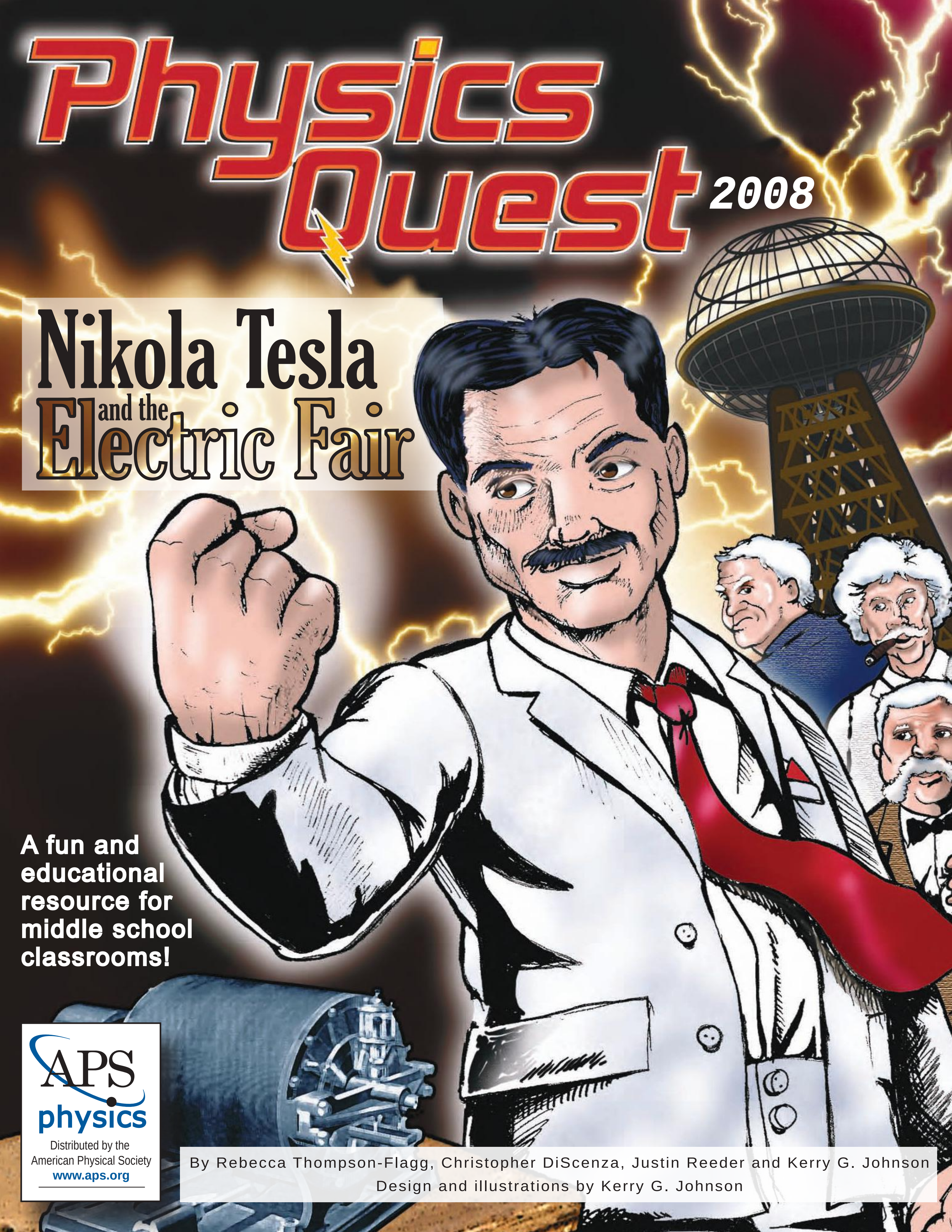
Physics Quest 2008



Nikola Tesla and the Electric Fair

A fun and educational resource for middle school classrooms!

APS physics
Distributed by the American Physical Society
www.aps.org

By Rebecca Thompson-Flagg, Christopher DiScenza, Justin Reeder and Kerry G. Johnson
Design and illustrations by Kerry G. Johnson

PhysicsQuest: An Overview

PhysicsQuest is a set of four activities designed to engage students in scientific inquiry. The 2008-2009 activities are linked together via a storyline and comic book that follow Nikola Tesla from his home in Croatia to his interactions with Thomas Alva Edison and finally to his winning the right to light the World's Columbian Exposition in Chicago in 1893. It was at this point that alternating current (AC) power beat Edison's direct power (DC) power in the great "War of the Currents."

PhysicsQuest is designed with flexibility in mind – it can be done in one continuous session or split up over a number of weeks. The activities can be conducted in the classroom or as an extra credit or science club activity. The challenges can be completed in any order, but to get the correct final result all of the challenges must be completed correctly.

The PhysicsQuest Competition

APS sponsors an optional Physics Quest competition designed to encourage students to invest in the project. If you chose to participate in the competition, your class must complete the four activities and you must submit their answers online by **May 8, 2009.** All classes that submit answers online will receive a certificate of completion and those that complete the activities correctly will be entered into a prize drawing. Details on the prizes will be posted on the PhysicsQuest web site as they become available.

The online results submission form requires the answers to all of the questions on the Final Report. Each step must be correct in order for classes to qualify for prizes. Each class can only submit one entry form, so class discussions of results are encouraged.

Answers can be submitted online through the PhysicsQuest web site beginning
January 5, 2009

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Physics Quest 2008

Nikola Tesla *and the* Electric Fair

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APS physics

www.aps.org

Welcome to PhysicsQuest 2008

History of the PhysicsQuest Program

Kerry G. Johnson / APS

As part of the World Year of Physics 2005 celebration, the American Physical Society (APS) produced *PhysicsQuest: The Search for Albert Einstein's Hidden Treasure.* Designed as a resource for middle school science classrooms and clubs, the quest was received enthusiastically by nearly 10,000 classes during the course of 2005. Feedback indicated that this activity met a need within the middle school science community for fun and accessible physics material, so the American Physical Society (APS) has decided to continue this program. APS is pleased to present this fourth kit, *PhysicsQuest 2008: Nikola Tesla and the Electric City.*

Each PhysicsQuest kit follows a mystery-based storyline and requires students to correctly complete four activities in order to solve the mystery and be eligible for a prize drawing. We hope this goal will entice students to actively participate — and that once students begin participating they find that physics is interesting and fun!

American Physical Society (APS)

APS is the professional society for physicists in the United States. APS works to advance and disseminate the knowledge of physics through its journals, meetings, public affairs efforts, and educational programs. Information about APS and its services can be found at **www.aps.org.**

Physics Central

APS also runs PhysicsCentral, a web site aimed at communicating the excitement and importance of physics to the general public. At this site, **www.physicscentral.com**, you can find out about APS educational programs, current physics research, people in physics and more.

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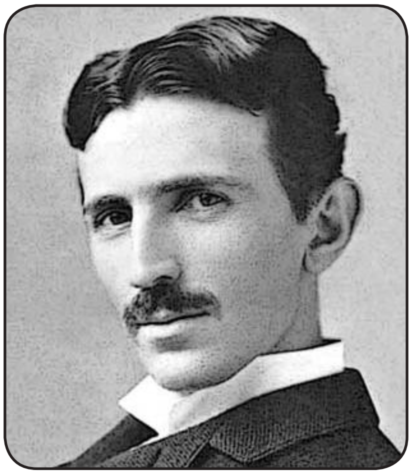
About Nikola Tesla

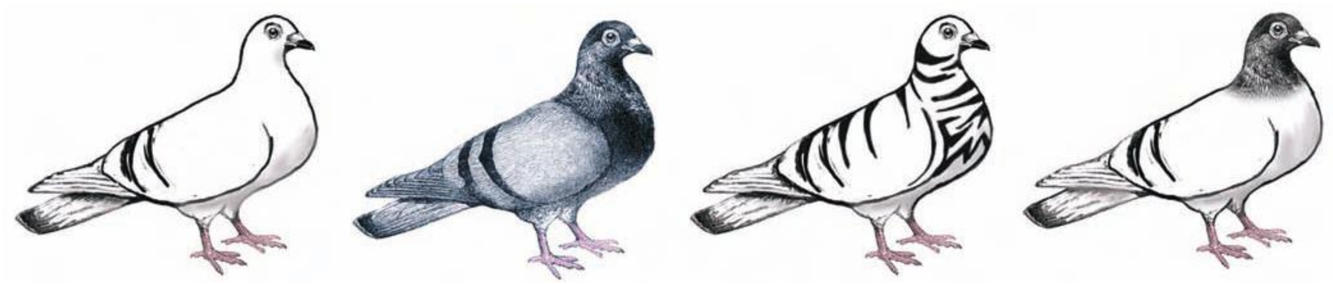


Born in 1856 in Smiljan Croatia of Serbian heritage, Nikola Tesla was a true genius. As a child, he was fascinated with physics and mathematics. This fascination transformed into an obsession with electricity. He studied Electrical Engineering at the Austrian Polytechnic in Graz and the Charles Ferdinand University in Prague. Then in 1881, he worked in Budapest and Paris on the new telephone and electrical systems. At that time, all electrical motors were powered by direct current (DC) with brushes that transferred the electrical current to the rotating shaft. These primitive motors had many problems. The brushes created friction in the motor and DC was an inefficient means of transporting electricity. However, Tesla conceived of a brushless motor that used alternating current (AC). He was walking with a friend through a park when the concept of the rotating magnetic field flashed through his mind. He stopped and sketched a diagram in the sand with a stick while explaining the principle to his friend. This vision was to lead him to many great inventions and success later in his life.

In 1884, he arrived in America looking to develop his ideas with the successful inventor Thomas Alva Edison. Tesla handed Edison a recommendation letter from his former supervisor, Charles Batchelor. The letter said: "I know two great men and you are one of them; the other is this young man." Edison hired Tesla immediately to work for his *Edison Machine Works*. Tesla made significant improvements to Edison's power generator designs. However, Tesla fought with Edison over the use of AC in the electrical systems. Edison had invested too much time and money into his DC system. Tesla knew that AC was more efficient and it would allow for more electrical innovation in the future. Switching to Tesla's AC system would be too expensive in the short term and it would also cost Edison his pride. Tesla left Edison's workshop to work for one of Edison's rivals, George Westinghouse Jr. Thus began a personal as well as scientific battle between Tesla and Edison over Alternating Current AC versus Direct Current DC. This conflict was known as the "War of the Currents."

The battle quickly shifted onto the political stage. It involved public events and demonstrations with the media. Edison was a successful businessman and a celebrity. He would publicly demonstrate the harmful effects of AC on livestock. To further his political war, he attempted to coin the phrase for electrocution as "getting Westinghoused". These cruel demonstrations were intended to frighten the public and have shivers run down their spine upon hearing the words "Alternating Current." Ironically today, Edison's Direct Current is generally considered more dangerous because electricity can remain stored long after the power has been shut off.

The Chicago World's Fair of 1893 was the symbolic end to the "War of the Currents". The fair resembled a great white city that was designed to glow with electric light. Tesla and Edison competed for the chance to provide electrical power for the first time to such an event. Edison's inefficient DC design required a heavy price compared to Westinghouse and Tesla's AC generators. The winning design would light the white city.



The Physics Quest Challenge

Nikola Tesla was a close friend of author Mark Twain and a bitter rival of Thomas Alva Edison, he invented such things as the remote control and the alternating current generator. In 1893, he was charged with lighting the Chicago World's Fair, the first electric fair in the world.

As you move through the PhysicsQuest activities you will follow Tesla on his journey from Croatia to New York to Pittsburgh and finally to Chicago and the fair. You will follow along as Tesla, battles with the reigning king of electric current, Edison.

You will be Tesla's sidekick (or "hero support") as he battles Edison in the great "War of the Currents." To be a successful sidekick you will have to learn about light, magnets and electricity.

Unfortunately, pigeons have stolen Tesla's tools! So he runs into problems as he tries to light the fair and he needs your help to make this important event happen.

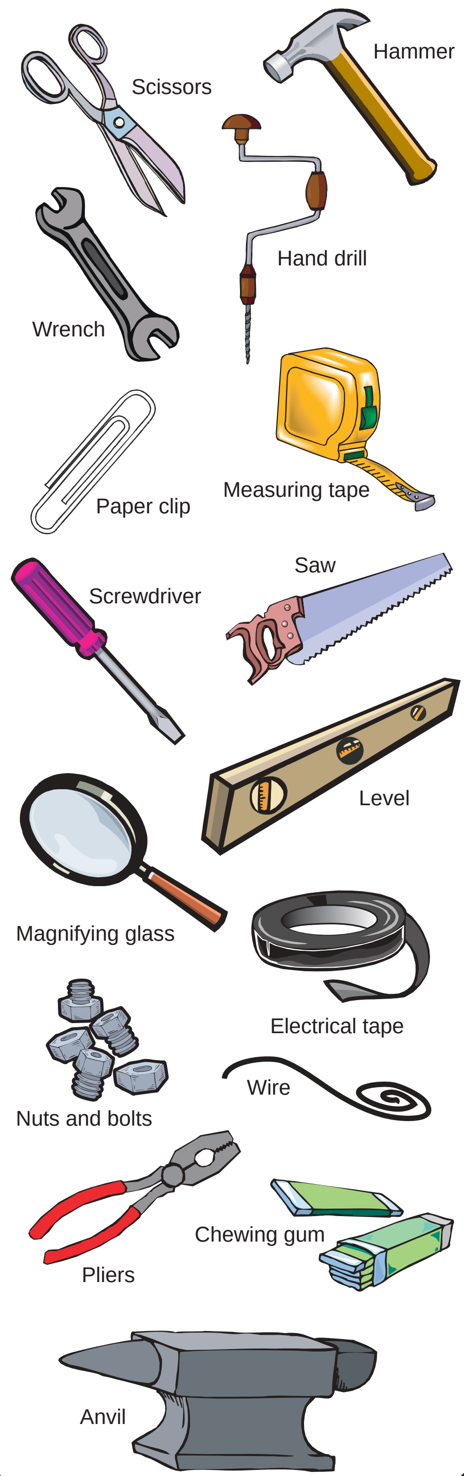
You must hunt through the comic book pages and find all of Nikola's tools before it's too late. At the end of each PhysicsQuest activity you will be asked to look through the comic book pages that precede the activity to find a particular pigeon. That pigeon is holding one of Tesla's important tools and just like many superheroes, he might need things that don't look like your traditional tools.

So look hard, they are tricky little birds! But with your help our hero, Nikola Tesla will become a legend!

Good luck!

The PhysicsQuest 2008 Team

Tesla's missing tools (16 items)



PhysicsQuest 2008 Materials

The PhysicsQuest kit includes this manual and most of the hardware your students need to complete the activities. There is also a corresponding web site, **www.physicscentral.com/physicsquest,** which has supplemental material such as extension activities.

■ Comic Book

Each activity will be preceded by several pages of a comic book that will follow the life of Nikola Tesla. Through these pages the students will learn about the life of Tesla and follow him from his birthplace of Croatia, through his battles with Thomas Edison and finally his triumph in the "Great War of the Currents."

■ The Teacher's Guide

The Teacher's Guide for each activity includes:

- ***Key question***
This question highlights the goal of the activity.

- ***Key terms***
This section lists terms related to the activity that the students will encounter in the Student's Guide.

- ***Before the activity***
Students should be familiar with these concepts and skills before tackling the activity.

- ***After the activity***
By participating in the activity, students are practicing the skills and studying the concepts listed in this section.

- ***The science behind***
This section includes the science behind the activity and some historical background. The Student's Guide does not include most of this information; it is left to you to decide what to discuss with your students.

- ***Safety***
This section highlights potential hazards and safety precautions.

- ***Materials***
This section lists the materials needed for the activity. Materials that are provided in the kit are in **BOLD** type; you will need to provide the other items.

- ***Extension activities***
Extension activities related to each activity can be found on the PhysicsQuest web site This section gives a brief description of those related to the activity.

- ***Bibliography and suggested resources***
This section lists the books and other resources used to create this activity and recommended resources for more information on the topics covered.

■ The Student's Guide

Each activity has a Student's Guide that you will need to copy and hand out to all of the students. In addition, you will need to copy the comic book pages and hand them to your students when you first start the PhysicsQuest activities.

The Student Guide's includes:

- ***Key question***
  This question highlights the goal of the activity.

- ***Materials***
  This section lists the materials students will need for the activity.

- ***Getting started***
  This section includes discussion questions designed to get students thinking about the key question, why it's important, and how they might find an answer.

- ***The experiment***
  This section leads students step-by-step through the set-up and data collection process.

- ***Analyzing your results***
  This section leads students through data analysis and has questions for them to answer based on their results.

■ PhysicsQuest Challenge / Final report

The PhysicsQuest Challenge introduces students to the project and their mission. Students should fill out the opposite side of this handout, the final report, as they complete each activity. Although groups may fill out the form independently, each class can only submit one answer to the online competition.

■ Activity hardware

The hardware included in the kit is listed on page 8. For specific information on these items and where they can be purchased, see the materials list on the PhysicsQuest web site.
NOTE: Please note that the "Disappearing Crystals" activity requires advanced set-up.

■ PhysicsQuest web site

www.physicscentral.com/physicsquest, has supplemental material for teachers, such as extension activities. Also, periodic updates on the program will also be posted on this site**.**

Materials list

Included in this kit
If your kit is missing any of these materials, please contact the kit vendor according to the directions on the PhysicsQuest web site.

- PhysicsQuest manual
- Splenda® Brand Sweetener packets (21)
- Water gel crystals
- Stiff steel wire (12 inches)
- Compasses (4)
- Battery holder
- AA batteries (6)
- C battery
- Coil of magnet wire
- Disk magnets (4)
- Red LED (light-emitting-diode)
- Green LED (light-emitting-diode)
- Steel slug
- Cardboard tube
- Insulated wire (8 inches)
- Nail
- Pinwheel top

Not included in this kit
For more information on these items and where they can be purchased, please visit the PhysicsQuest web site.

- Transparent cups (5)
- Water
- Masking tape
- Calculator
- Permanent marker

Nikola Tesla, with Ruder Boskovic's book *Theoria Philosophiae Naturalis,* sits in front of the spiral coil of his high-frequency transformer at East Houston St., NY. (Public domain image)

About the comic book

Before writing the comic book section, the PhysicsQuest team did extensive research into the life and inventions of Nikola Tesla. Though much of the comic is historically accurate to the best of our knowledge, parts of it needed to be fictionalized for a middle school audience and suited to fit within the PhysicsQuest mystery. We hope that no one is upset with our additions. We are also well aware that Tesla did much more than what is presented on the pages of the comic book. We would have loved to create a more extensive history of his life, but we were limited by space.

This program is created for a younger audience, so we glossed over some of the more "colorful" aspects of Tesla's life. We hope that the large contingent of Tesla fans enjoys the pigeon references. The PhysicsQuest team has great respect for Nikola Tesla's life and accomplishments and we hope that you find this to be a fitting tribute to his life.

Comic bibliography

Cheney, Margaret, *Tesla: Man out of Time.* Simon and Shuster NY, NY, 2001

Tesla, Nikola, *My Inventions: The Autobiography of Nikola Tesla*, bnpublishing.net, 2008

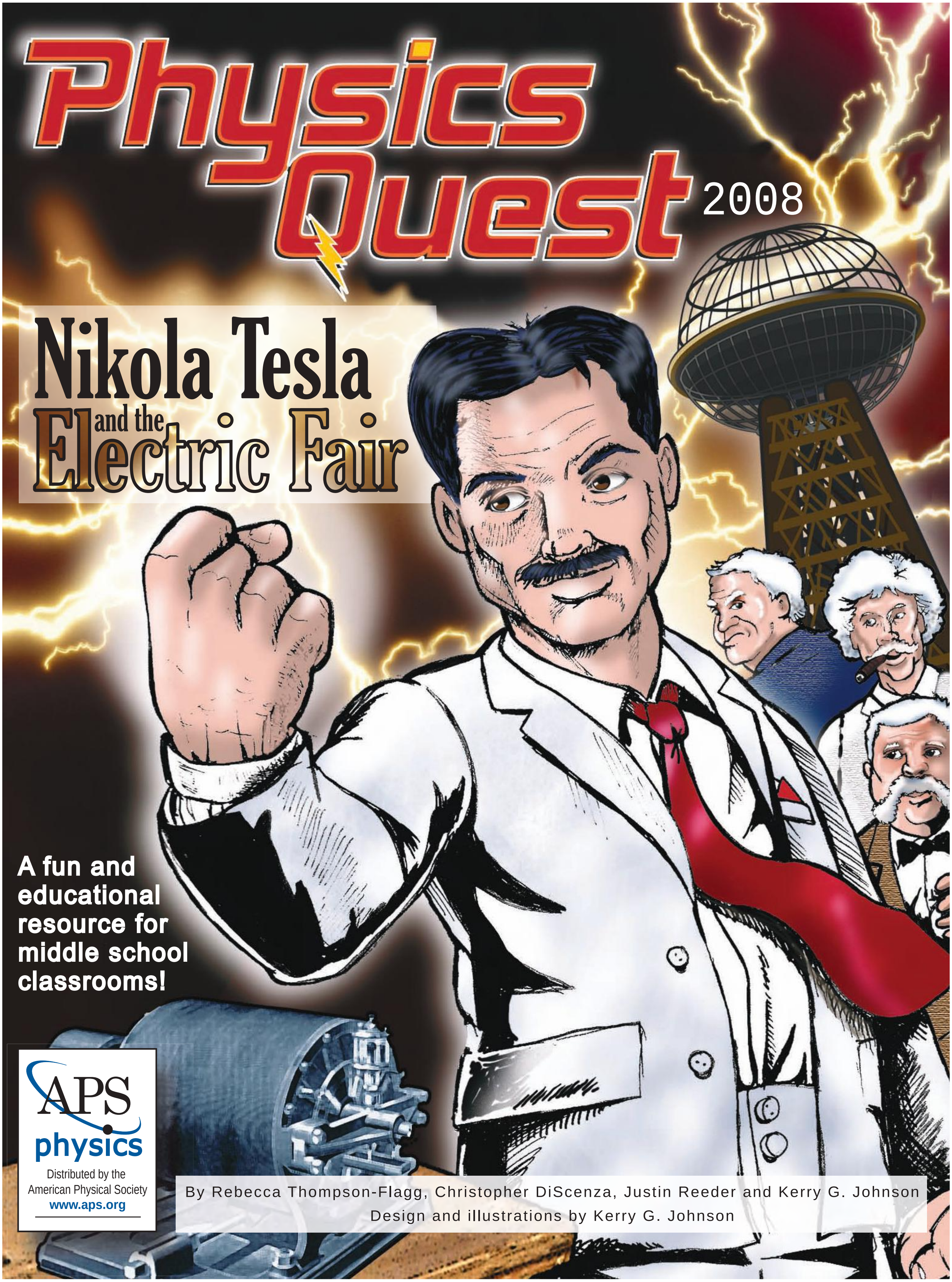
Uth, Robert, *Tesla: Master of Lightning*, New Voyage Communications and PBS Home video, 2000

Tesla Memorial Society of New York, www.teslasociety.com

The Tesla Foundation of North America, www.tesla.org

New Tesla Society, www.ucsofa.com/newtesla.htm

The PhysicsQuest 2008 Team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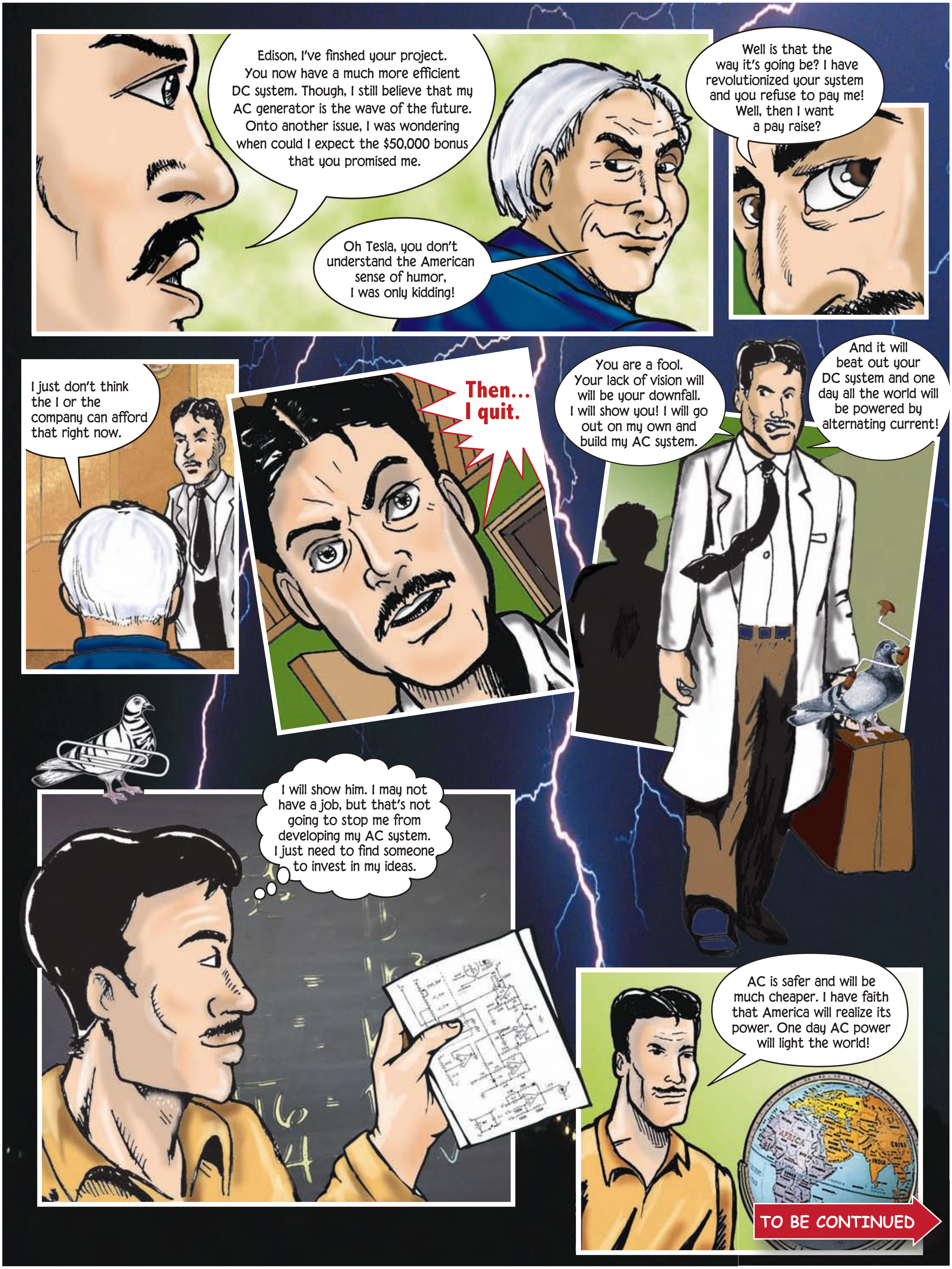
Traveling from his homeland, young Nikola Tesla arrives in New York City.
I've made it to America, the land of opportunity. I have always wanted to come here and work for Thomas Edison, the greatest inventor of our time.
Thomas Alva Edison
Tesla searches throughout the city and finally locates the address of Thomas Edison.
Tesla arranges a meeting with Edison and ...
... presents Edison a note from a friend of them both.
"Dear Mr. Edison, I know two great men and you are one of them; the other is this young man standing before you."
Well that certainly is one heck of a recommendation from Charles W. Batchelor*, you're hired!
Welcome to the Edison Machine Works team.
* Charles W. Batchelor was an inventor and close associate of Thomas Edison. He was involved in some of the greatest inventions and technological developments in history.
Tesla was soon hard at work.
He began first by solving some simple electrical engineering problems but his brilliance was quickly realized and he moved up to being Edison's right-hand man.
Tesla my boy, you are amazing. For a long time I've wanted to redesign my direct current system to make it more efficient. This has been a difficult task so I need my best man on the project.
As an extra incentive I will give you a bonus of $50,000 if you complete the job!
Tesla was excited about the challenge and worked very hard to impress Edison and earn the $50,000.
He worked night and day to increase the efficiency of Edison's direct current system. While doing so, he won several profitable patents for Edison's company. Finally the more efficient system was completed.
Continued on page 13


Edison, I've finshed your project. You now have a much more efficient DC system. Though, I still believe that my AC generator is the wave of the future. Onto another issue, I was wondering when could I expect the $50,000 bonus that you promised me.
Oh Tesla, you don't understand the American sense of humor, I was only kidding!
Well is that the way it's going be? I have revolutionized your system and you refuse to pay me! Well, then I want a pay raise?
I just don't think the I or the company can afford that right now.
Then… I quit.
You are a fool. Your lack of vision will will be your downfall. I will show you! I will go out on my own and build my AC system.
And it will beat out your DC system and one day all the world will be powered by alternating current!
I will show him. I may not have a job, but that's not going to stop me from developing my AC system. I just need to find someone to invest in my ideas.
AC is safer and will be much cheaper. I have faith that America will realize its power. One day AC power will light the world!
TO BE CONTINUED

Teacher's Guide

ACTIVITY 1:

Disappearing crystals

Intro

In this activity students will use crystals to determine the concentration of Splenda® in 4 different cups of water. Dry water gel crystals are put into water where they will quickly absorb hundreds of times their weight in water. They will be invisible in plain water but if Splend® a is added they will begin to appear. Students will use this property to determine how much Splenda® is in 4 different cups of water.

Key Question

How does adding Splenda® to water change the index of refraction?

Key Terms

Refraction: When light travels from one material to another it changes direction, or refracts.

Index of refraction: A number that describes how the speed of light in a material compares to the speed of light in vacuum. It also tells how much light changes direction when it moves from one material to another, as well as how much light will be reflected when light hits the surface.

Transparent: Most light is transmitted, a little bit is reflected

Translucent: Some light is transmitted, some will be reflected

Opaque: All light it reflected or absorbed, none is transmitted.

Materials

- **Water gel grystals**
- **21 Splenda® Brand Sweetner packets**
- Water
- 4 clear plastic or glass cups labeled A, B, C, D
- 1 clear plastic or glass cups, unlabeled.
- Spoon

NOTE TO TEACHERS: This activity must be set up beforehand. It takes several hours to grow the water gel crystals. The students will be guessing the contents of 4 "mystery cups" so cups must be prepared by the instructor before the students begin the activity.

Fill all cups with ½ cups of water. Then add Splenda® as follows:

Cup A: 3 packets
Cup B: 12 packets
Cup C: 0 packets
Cup D: 6 packets

Make sure all of the Splenda® has dissolved completely before starting the activity.

The unlabeled cup will be used to grow the crystals. Fill the cup with water and place about 10 water gel crystals in the cup and wait several hours. The cup will be full of gel crystals but you will not be able to see them when they are still in the cup of water.

Before the activity students should know that …

Light travels in a straight line

When light goes from one material to another it changes its path

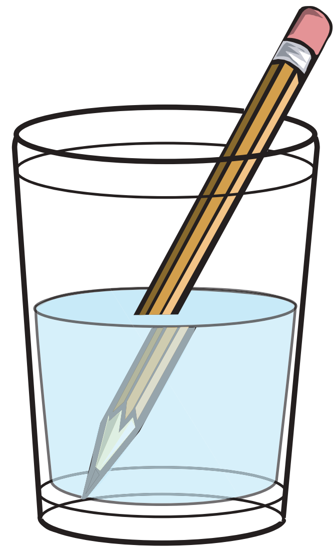
After the activity students should be able to …

Explain why we can see materials that are transparent even though light passes through them.

ACTIVITY 1: Disappearing crystals

Explain why we cannot see the water gel crystals when they are submerged in water but we can see them when they are in air.

Explain "index of refraction" and understand that larger indices of refraction make light change direction more.



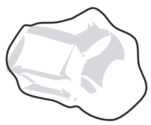
The science behind refraction
Light travels in a straight line. If it weren't for this property of light there wouldn't be shadows or laser pointers. This rule however isn't completely true. When light moves from one material to another it changes its path. Some of the light changes it direction by reflecting and some changes direction by refracting. When a light ray goes from one transparent or translucent material to another it continues to move through the material but not in the same direction. This change in direction is called refraction.

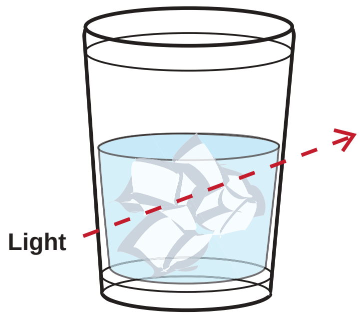
In the year 984 Ibn Sahl noticed that light did this when it moved through a lens and he wondered if there was a rule that said how much light changed direction. He found that as light moved from air to the glass of the lens that the amount it refracted depended on the angle at which the light hit as well as the type of glass he used. He realized that the light was also changing speed. In 1621 Willebrord Snellius and Renee Decartes both found an equation that tells how much of a light ray will reflect and how much will refract when the light hits a surface. Both of these depend on a number called the index of refraction, or "n". The larger the index of refraction of a material the more light it will reflect and the more it will bend the light that is transmitted. The index of refraction also tells how fast light travels in the new material.

Light is fastest when it is moving in a vacuum. No, not a Hoover, in this case "moving in a vacuum" means that light is moving through nothing, no matter at all, not even air. Outer space is an example of a vacuum. In a vacuum light travels at 300,000,000 meters per second but that's as fast as it can go. If it travels in any type of matter, even air, it slows down a little bit. As it slows down it changes directions. Because the index of refraction tells how fast light goes in a particular material it can also say how much light changes direction as it moves from one material to another. It can also tell us how much light will be reflected. The speed of light in a material is related to the index of refraction by the formula: $n=c/v$ where c is the speed of light in a vacuum and v is the speed of light in a material.

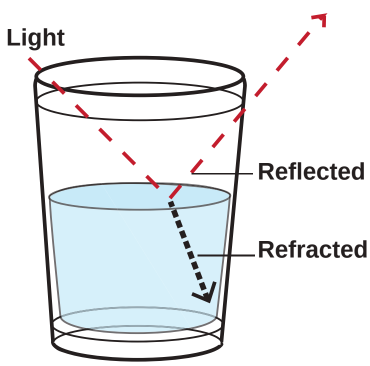
The index of refraction depends on many things. Mostly it depends on the type of material. Water has an index of refraction of 1.3 while diamond has an index of refraction of 2.4. This means that diamond reflects more light than water and that light goes 2.4 times slower in diamond than it does in a vacuum. Index of refraction can also depend on temperature. The index of refraction of cooler air is 1.0003 but when the air is heated by 100 degrees C it changes to 1.0002. This may not seem like much but it bends light enough to cause the wavy appearance seen on top of roads and the hood of your car on hot days.

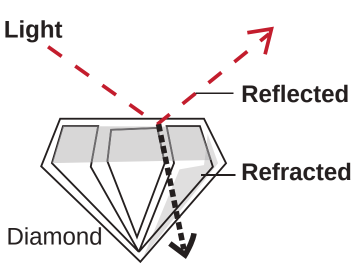
Water gel crystal





Light is not bent or reflected going from water to crystal





When we look at an object through a transparent material, such as water, we can see that the light is bending because it looks like the object has shifted a bit. Try this with a glass of water and a pencil. When you put the pencil in the water it looks like the part that is in the water is disjointed from the part that is still in air. This is because of refraction. But what happens when two different materials have the same index of refraction? Could we see them?

We can see transparent materials because of the reflections and in some cases because objects seen through these materials seem distorted by refraction. The index of refraction is different from that of air. But what would happen if two objects had the same index of refraction? Would we be able to distinguish between the two? Would one seem to disappear? That is what the students will be investigating with this experiment. The gel crystals are grown in water and because the final crystal is 99% water it has the same index of refraction as water. While in water, it seems to disappear but in air it is clearly visible. But is it possible to change the index of refraction of water to make the crystals visible? Yes, by adding Splenda®. Water with Splenda® in it has a different index of refraction than plain water. The more Splenda® dissolved in the water, the greater the difference in the index of refraction. When you place a crystal that is grown in water in Splenda® water, it will be visible. The more Splenda® in the water, the easier it will be to see the crystal. There are machines that cost hundreds of thousands of dollars that use this fact to determine the amount of sugar in a liquid, but your students can do the same thing for pennies with the amazing water gel crystals.

Safety

For water gel crystal safety see the Material Safety Data Sheet on page 48.

Corresponding extension activities

1. **Jello lensing:** Watch as light bends on its way through Jell-o.
2. **Spear fishing:** Learn how light bends in water by trying to spear Swedish Fish.
3. **Tabletop sunset:** Create a beautiful sunset using milk and a flashlight.

Bibliography/suggested resources

The Arizona Collaborative for Excellence in Preparation of Teachers. *The Refraction of Light. http://acept.asu.edu/PiN/rdg/refraction/refraction.shtml*

Robin Wood. *Refraction Index of Various Substances for 3D modelers. http://www.robinwood.com/Catalog/Technical/Gen3DTuts/Gen3DPages/RefractionIndexList.html*

Kwan, A., Dudley, J., and Lantz, E. (2002). "Who really discovered Snell's law?". *Physics World* **15** (4): 64

Cobb, Vicki, and Cobb, Josh, *Light Action!*. New York: Harper Collins, 1993

Student's Guide

ACTIVITY 1: Disappearing crystals

Intro

You have been cast in the role of Nikola Tesla's sidekick, or "hero support," as he battles Edison and lights the Chicago World's Fair. After each activity you will have to track a pigeon throughout the comic book pages you read. The pigeons have stolen Tesla's tools and it's up to you to get them all back. Before you begin this epic quest, you must first learn about light itself. Then you will begin to learn about exactly how Tesla used magnets and electricity to power the light bulbs he used to illuminate the fair.

Key Question

How does adding Splenda® to water change the index of refraction?

Getting Started

Why can we see clear objects such as glass or clear plastic?

What happens to light when it moves from air to water?

Does light always travel in straight lines?

How might you change the direction in which light travels?

When light interacts with an object it is absorbed, reflected or refracted. If the object is opaque all of the light will be reflected or absorbed. If the material is transparent, such as glass or water, some of the light is reflected but much of the light goes through the material and is refracted or bent. Both the amount of light that is reflected and the amount the light is bent depends on a number called the index of refraction. Most of the time different materials will have different indices of refraction which is why we can see them. This activity will show you what happens when two materials have the same index of refraction. You will then use the fact that Splenda® Brand Sweetener can change the index of refraction of water to determine the concentration of Splenda® in a glass of water.

Materials

- **Water gel crystal**s
- 4 clear plastic or glass cups labeled A, B, C, D
- 1 unlabeled cup full of what looks like water

Setting up the experiment

Before you began, your teacher mixed different amounts of Splenda® into 4 cups. Unfortunately your teacher promptly forgot how much Splenda® was in each cup (Note to Teacher: just play along). Your job is to figure out how much Splenda® is in each cup, but remember, just like all good scientists, you cannot taste anything in the lab. To accomplish your task you will have to use your knowledge of light and its properties.

ACTIVITY 1: Disappearing crystals

Please write in your answers

Your water gel crystals are in a cup filled with water.

Are you able to see them in the water?

____

____

____

____

Are you able to see them in the air?

____

____

____

____

How do you think the index of refraction of the crystals compares to that of water? Air?

____

____

____

Collecting data

1. Place three large crystals in each of the four cups.
2. Have each person in the group arrange the cups so that the cup in which the crystals are least visible is ranked “1” and the most visible is ranked “4.”
3. Record your results.
4. As a group determine an order for the cups.

Why do the crystals disappear some times, but not at other times?

____

____

____

____

ACTIVITY 1: Disappearing crystals

Analyzing your results

In the box below, draw an illustration of your 4 cups in order.

Why do you think you can see the crystals in some cups but not others?

How does the index of refraction of the water depend on the amount of Splenda® dissolved in the water?

Which cup do you think has the most Splenda®?

What are some practical ways you might use what you just learned about how index of refraction depends on what is dissolved in water?

Lets say you wanted to make an invisibility cloak just like Harry Potter's. How might you use what you learned about index of refraction to do that? Write your answers below:

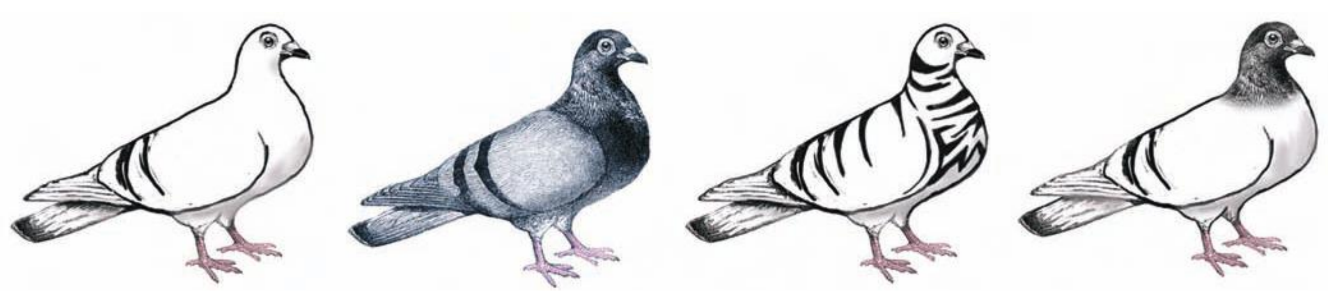
ACTIVITY 1: Disappearing crystals

You can use the relationship between index of refraction and speed of light to find the speed of light in a particular material. N = c/v where c is the speed of light (300,000,000) and v is the speed of light in the material. Here is a list of the index of refraction of some other materials. What is the speed of light in these materials?

Material	**Index of refraction**	**Speed of light**
Water	1.33	____________________
Window glass	1.52	____________________
Diamond	2.42	____________________
Pyrex	1.47	____________________
Cubic zirconia	2.17	____________________
Cranberry juice	1.35	____________________

Using your results to help Tesla light the Chicago's World Fair

It's time to chase your first pigeon! Hurry, they can be fast and Nikola Tesla needs your assistance to accomplish his goal. Rank the cups from most amount of Splenda® to the least amount of Splenda® Where did you put cup D?



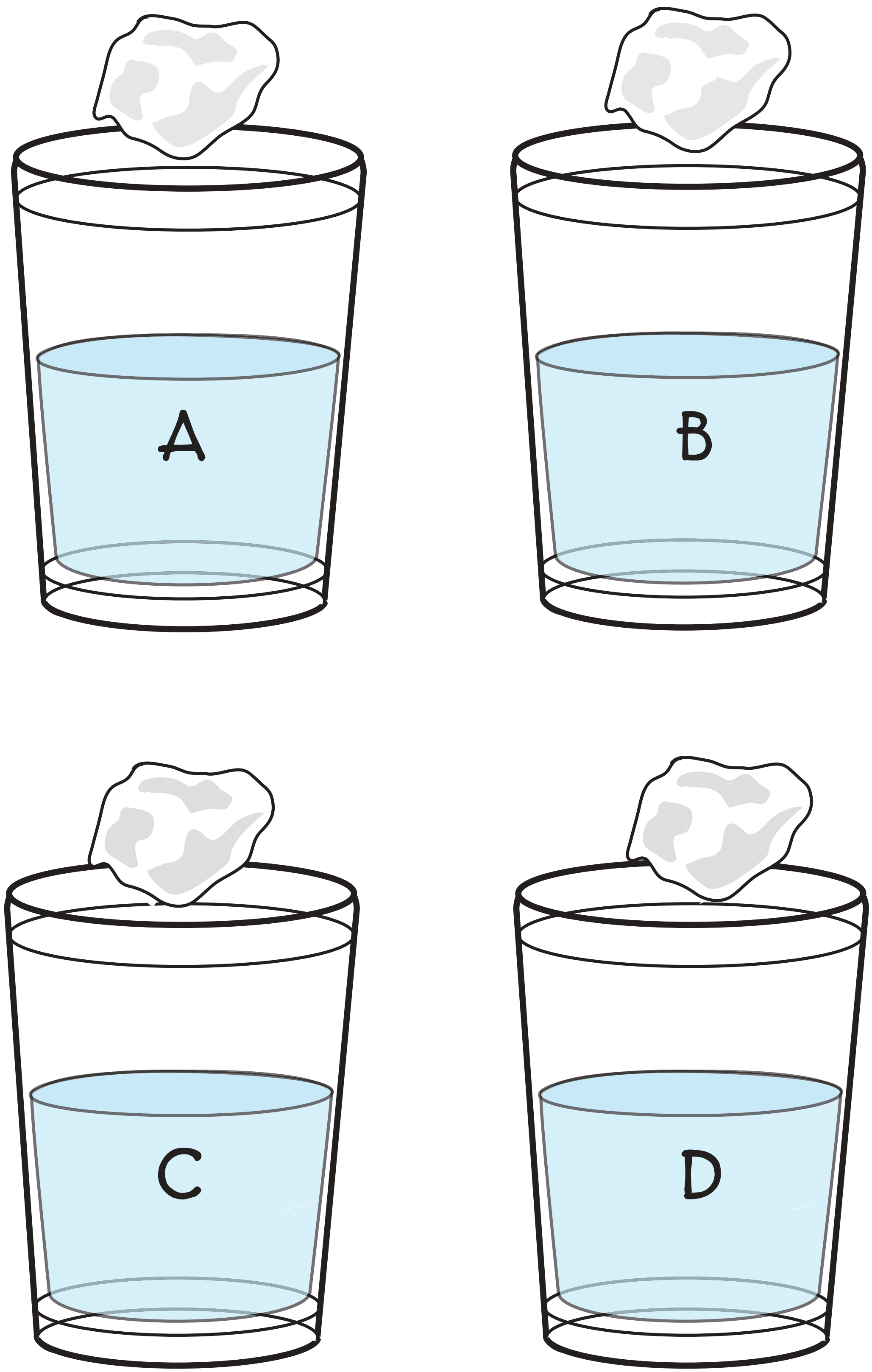
First
Chase the white pigeon

Second
Chase the gray pigeon

Third
Chase the pigeon with stripes

Fourth
Chase the pigeon with the gray head and white body

ACTIVITY 1: Disappearing crystals



CONTINUED ON PAGE 23

* George Westinghouse Jr. was an American entrepreneur and engineer who invented the railroad air brake and was a pioneer of the electrical industry. Westinghouse was one of Thomas Edison's main rivals.

Teacher's Guide

ACTIVITY 2:

Dancing compasses

Intro

Electricity and magnetism are often thought of as two separate topics but they are actually intertwined. When electric charges move, they create a magnetic field and conversely when a magnetic field changes it can make charges move. This experiment uses compasses to show that current, which is moving electric charges, creates a magnetic field.

Materials

- **12-inch stiff wire**
- **Battery holder**
- **6 AA batteries**
- **8-inch insulated wire**
- **4 small compasses**
- **PhysicsQuest cardboard box**
- **Tape**

Key Question

How do nearby compasses react when current flows through a wire?

Key Terms

Electromagnetism: Electricity and magnetism are not separate. Electro-magnetism is the study of how they are combined.

Current: Current is the flow of positive charges

Magnetic Pole: All magnets have a north and a south pole. Compasses have a small magnet inside them that turns to align with a magnetic field.

Before the activity students should know that …

The earth has a magnetic field.

Compasses are made of tiny magnets that can rotate and align themselves with a magnetic field.

Like electric charges repel; positive repels positive and negative repels negative.

When a wire is connected to a battery a circuit is formed and current flows.

The direction that current flows is the direction of the motion of positive charges.

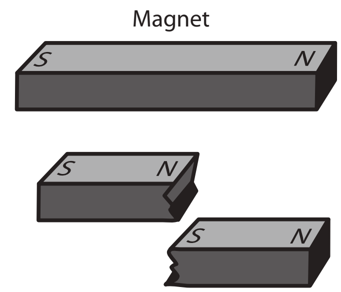
After the activity students should be able to …

When current flows through a wire, a magnetic field is created around the wire.

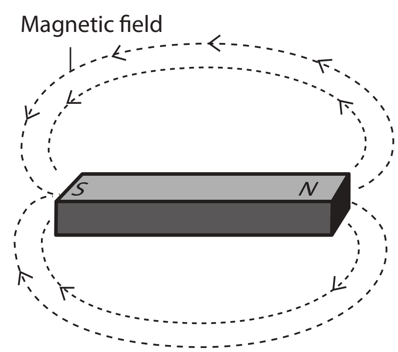
Changing the direction of the flow of current changes the direction of the magnetic field that is produced.

ACTIVITY 2: Dancing compasses

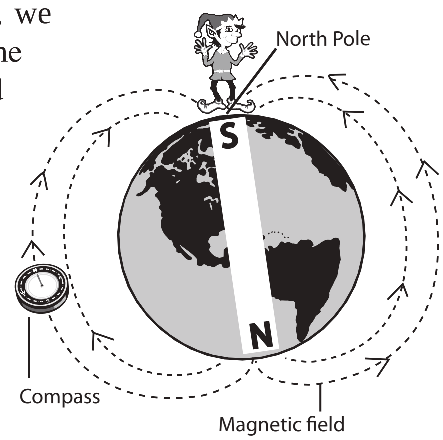
The science behind …



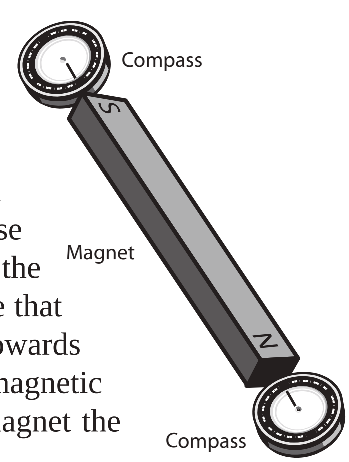
Though often thought of as two separate topics, magnetism and electricity are closely linked. Whenever a charge moves a magnetic field is created. In fact, the only way to create a magnetic field is to have moving charges. Even the magnetic field of permanent magnets is created by the movement of the electrons in the atoms. Magnets have a north pole and a south pole just like electricity which has positive and negative charges.



However, with electric charges you can have just a positive charge, like a proton, or just a negative charge, like an electron. You can't do that with magnets, north will always be attached to a south and south will always attached to a north. Even if you break a permanent magnet in half both of the pieces will again have a north and a south. You can keep splitting the magnet, but it will always be a magnet with a north and a south. With electrical charges, like charges repel and opposite charges attract. It is the same with the magnetic poles. The north end of one magnet will be attracted to the south end of another.

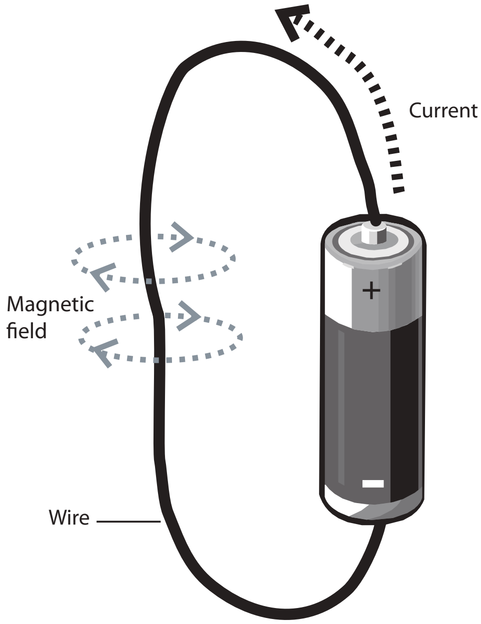


A magnetic field is called a field because at any point it has both a strength and a direction. If it had only a direction, we would know if it would push or pull on another magnet, but not how hard. If it had only a strength, we wouldn't know if it would be pushing or pulling. An electric field has the same properties except it acts on electric charges while a magnetic field only affects magnets. The unit for magnetic field strength is named after our hero, Nikola Tesla. A very strong refrigerator magnet has a magnetic field strength of about 0.1 Tesla. When drawing a magnetic field it is important to include arrows to show the direction of the field. The arrows always point away from the magnet's north pole and towards the magnet's south pole.



In this activity you will use a compass to determine the direction of a magnetic field produced when current flows through a wire. A compass needle is just a tiny magnet that is allowed to move around. It has both a north end and a south end. Normally, when it is not near other magnets, it will align itself along the magnetic field created by the earth. This means that the north pole of the compass needle is attracted to the south pole of the earth's magnet. Now here's where it gets a bit tricky. Earth has a geographic North Pole. This is the place that kids send letters to Santa and elves happily make toys. However the magnetic south pole of the Earth is close to the geographic North Pole. So Santa, his elves, and Rudolph live above the south end of earth's magnet. The compasses used for this activity have a face that spins so the "N" points toward the geographic North Pole, or in other words, towards Santa. In actuality, the end of the compass face marked "N" is attracted to magnetic south. So if you were to bring a compass close to the south end of a bar magnet the magnet would attract the "N" of the compass needle. Opposite poles attract.

ACTIVITY 2: Dancing compasses



Because compass are just small magnets they can be used to do more than find your way in the woods, they can show the direction of any magnetic field. We can use them to show what the field around a current carrying wire looks like. Because of a convention set by Ben Franklin the direction of current is the direction positive charges would move. Later physicists learned that current was actually caused by negative charges flowing, but Ben Franklin's convention stuck and now even physicists pretend that it is the positive charges that flow. If a wire is hooked to a battery, the flow of current is away from the positive end of the battery. If the battery is turned around, the current changes direction. The direction of the magnetic field around the wire depends on the direction of the current. Because moving charges create magnetic fields and current is just moving positive charges, the current will create a magnet field. By placing compasses around the wire and then connecting the wire to the battery, it is possible to see the direction of the magnetic field.

Even though we have said that current will produced a magnetic field, we haven't said which direction the magnetic field will go. This experiment will give you the answer!

Safety

Any time you are working with electricity you must be very careful. If the stiff wire is left connected to the battery the wire will get very hot. Be sure to just quickly touch the battery lead to the wire. The stiff wire is quite sharp. Eye protection should be worn during this activity.

Corresponding extension activities

Galvanometer: Build a super sensitive device to test for current.
3-D compass: Make a compass needle that can move in three directions instead of just two.
Jumping Wire: Make a wire "jump" with just a magnet and a battery.

Bibliography/Suggested resources

Exploratorium Science Snacks. *Circles of Magnetism*
http://www.exploratorium.edu/snacks/circles_magnetism_I/index.html

Reuben, Gabriel. Electricity Experiments for Children. London: Sterling Publishing, 1960

Robinson, Tom. *The Everything Kids' Science Experiments Book.* Avon, MA: Adam's Media, 2001

Walter Fendt. *Magnetic Field of a Straight Current-Carrying Wire*
http://www.walter-fendt.de/ph11e/mfwire.htm

Student's Guide

ACTIVITY 2: Dancing compasses

Intro

Now that you have learned about light itself, your next step is to learn about how current and magnetic fields are related. Tesla used the relationship to create his famed AC generator which lit the fair. You are a brave sidekick! Now you must complete this activity to find the next sneaky pigeon and get one step closer to finding all our hero's tools.

When a wire is hooked up to a battery, current flows through the wire. This current can do lots of things like light light bulbs and power your radio. But is that all that is happening? When a battery produces a current, is that all that is produced? In this experiment you will use magnetic compasses to find out what else happens when current flows.

Materials

- **12-inch stiff wire**
- **Battery holder**
- **6 AA batteries**
- **8-inch insulated wire**
- **4 small compasses**
- **PhysicsQuest cardboard box**
- Tape

Key Question

When current flows through a wire, what happens to magnetic compasses placed around the wire?

Getting started

What things around you are magnetic?

What do you think makes them magnetic?

Look at the compasses, why do you think the "N" always points north? Can you think of other uses for compasses besides find your way in the woods?

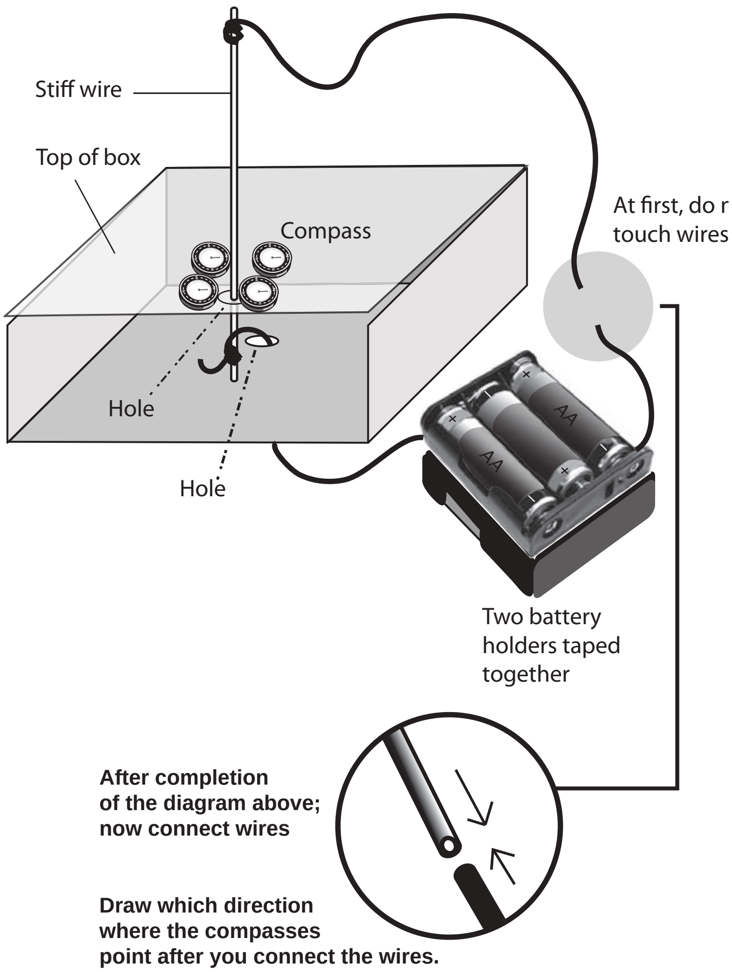
Find items in the room that might be magnetic and bring a compass near them. Does the compass change direction?

How do you think electricity and magnetism are related?

Setting up the experiment

1. Poke a hole in the PhysicsQuest box top and one right under it in the PhysicsQuest box bottom.
2. Place the 6 batteries in the battery holder.
3. Put the box on its side and put the black lead of the battery holder through the hole in the bottom of the box. This lead is connected to the negative end of the battery.
4. Open your PhysicsQuest box and put the stiff wire through the hole in the top.
5. Carefully wrap the black battery lead around the end of the stiff wire. Make sure it is secure; the metal of the lead should be in good contact with the wire. Tape them together if necessary.

ACTIVITY 2:: Dancing compasses



6. Close the box and tape the stiff wire so that it is sticking straight up out of the box. Be sure that the black lead is still securely wrapped around the bottom of the wire.
7. Wrap one end of the 8” insulated wire around the top of the stiff wire making sure the two are in good contact.
8. Place the four compasses on top of the box surrounding the wire.

Collecting data
Draw a picture of your compasses. Make sure you indicate which direction they are pointing.

Touch the free end of the insulated wire to the red battery lead and hold it for 1 second. Notice what happens to the compasses.

Describe what happened to the compasses when the wires were connected and draw a picture. Make sure you indicated the direction the compasses were pointing.

Now you will flip the battery leads, which will change the direction of the current flow.

Detach the black lead from the bottom of the stiff wire and attach the red lead in its place.

Touch the black lead to the insulated wire for 1 second and again draw your results. What was different?

Troubleshooting
If the compasses did not move it is because current is not flowing through the stiff wire. For current to flow there must be good connections and good batteries. First, make sure that all the wires are securely connected. Second, make sure the batteries are not dead.

Write your answers below:

____

____

____

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ACTIVITY 2:: Dancing compasses

Analyzing your results

When both leads of the battery were connected to the stiff wire, current is flowing. Current flows from the red lead of the battery to the black lead. On each of the pictures you have drawn draw and arrow on the wire to show which direction current is flowing.

When the wire was connected to the battery what happened to the compasses?

What makes the compasses move? Is it the electricity in the wire or is the electricity producing something else to make the compasses move?

As you found out as you were exploring your room with the compasses, the compass needle will align itself along a magnetic field. Magnetic fields go in a specific direction. The direction of the field is shown by the direction of the compass needles. Does the direction of the current affect the direction of the magnetic field?

If you had a wire that had a current and a compass, could you tell which way current was flowing, even if you couldn't see a battery? How?

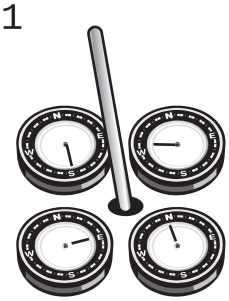
When current is flowing through a wire, is the space around the wire empty? There is no right or wrong answer to this question. Discuss and then decided on an answer as a group and justify your answer to the class.

Write your answers:

Using your results to help Tesla light the fair.

You caught your first pigeon and found the first tool stolen from Tesla. Yet again, you must be on the move and chase away. When the red lead from the battery was connected to the top of the stiff wire, which direction did your compasses point?

1



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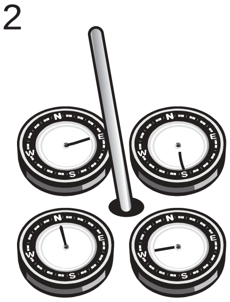

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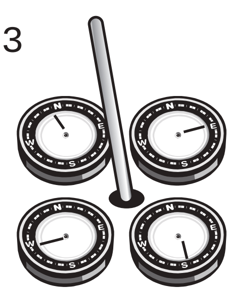

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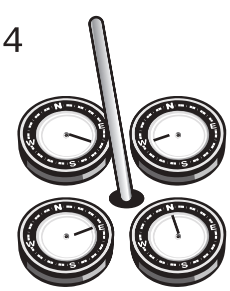
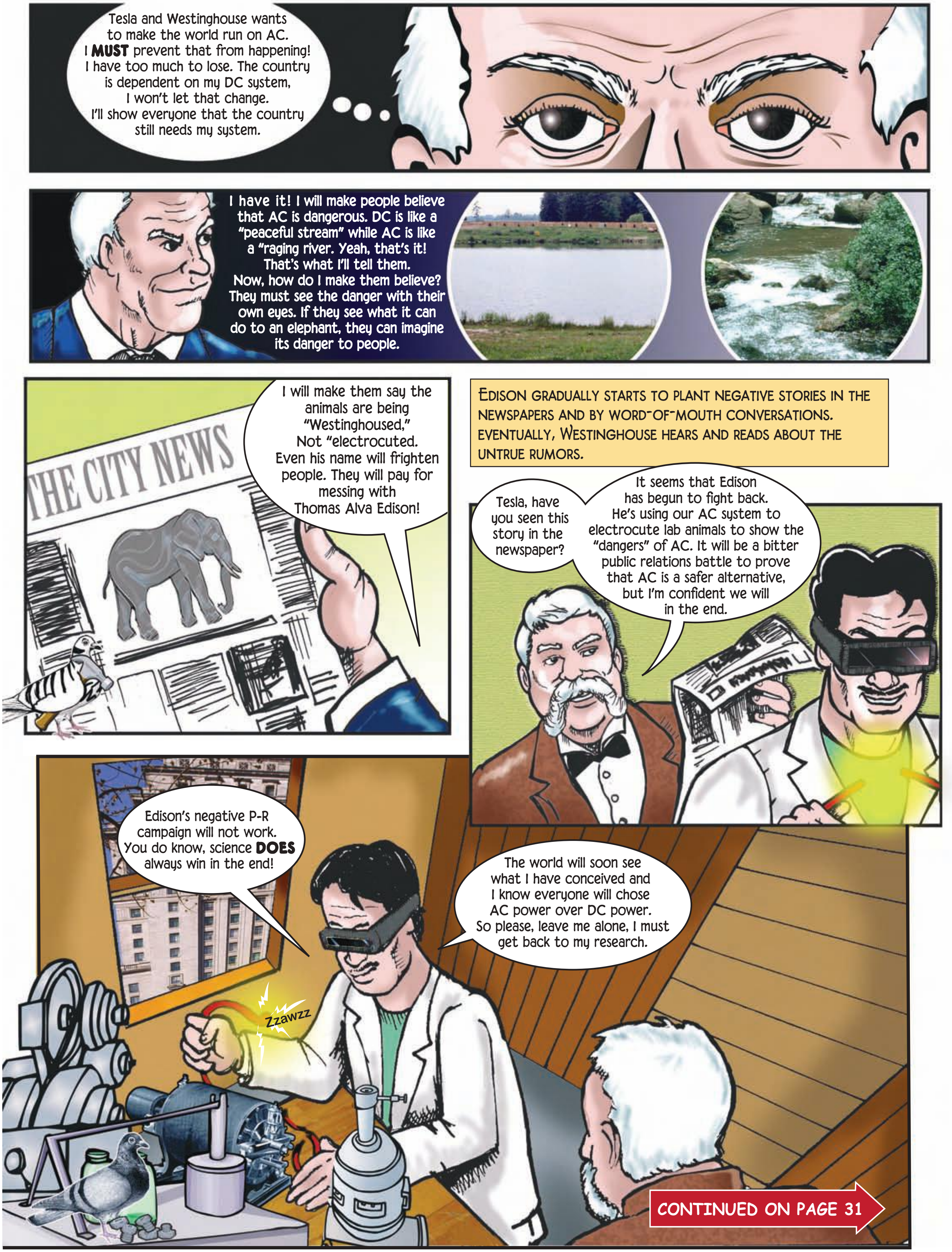


Picture 1	Chase the white pigeon
Picture 2	Chase the gray pigeon
Picture 3	Chase the pigeon with stripes
Picture 4	Chase the pigeon with a gray head and white body



CONTINUED ON PAGE 31


THE WORLD'S FAIR WAS HELD IN CHICAGO IN 1893. IT WAS THE FIRST WORLD'S FAIR TO USE ELECTRICITY. DURING THE LATE 1800S, IT WAS A COMING-OF-AGE ERA FOR THE ARTS AND ARCHITECTURE OF THE "AMERICAN RENAISSANCE". AT THAT TIME, MOST OF THE DOWNTOWN BUILDINGS IN THE CITY WERE BASED ON NEOCLASSICAL ARCHITECTURE AND MADE OF WHITE STUCCO, THIS GAVE CHICAGO THE NICKNAME "THE WHITE CITY."
TESLA AND WESTINGHOUSE LEARNED ABOUT AN ENGINEERING COMPETITION TO "LIGHT UP THE CHICAGO'S WORLD FAIR". THEY KNEW IF THEY GOT TO DO THE HIGH PROFILE PROJECT, IT WOULD GO FAR AT SHOWING THE PUBLIC THE IMPORTANCE OF THEIR ALTERNATING CURRENT SYSTEM.
EDISON ALSO BIDS FOR THE LUCRATIVE AND IMPORTANT CONTRACT.
I can light the fair with my DC system and my light bulbs. My name will be in lights! My price is $1,000,000, let's see Westinghouse beat that price!
NEWS ABOUT EDISON'S MILLION DOLLAR BID GOT BACK TO WESTINGHOUSE AND TESLA.
Edison is a powerful man. It will be difficult to compete with his bid to light the World's Fair.
Westinghouse, my dear fellow, don't panic. You must have faith in my vision.
So, what are you thinking?
With your assistance, we **WILL** light up Chicago.
Westinghouse, look here.
My alternating current system is much more efficient than Edison's direct current system. Alternating current is always changing. It flows to each light bulb without losing power.
Edison's direct current floods the wires with electricity that nearly melts the wires. Also, his whole system is made from expensive copper.
Tesla, your calculations are amazing!
And Westinghouse, since my AC system is more efficient, we will only charge $500,000.
Great! That's half of what Edison's charging for his system! We will surely win the contract to light the World's Fair.
ON THE OTHER SIDE OF TOWN, EDISON'S LEARNS ABOUT WESTINGHOUSE AND TESLA'S BEING AWARDED THE CONTRACT TO LIGHT THE WORLD'S FAIR.
HE WAS ANGRY THAT HIS BID WAS NOT ACCEPTED, SO HE TOLD THE FAIR OFFICIALS ...
"Since my DC system will not illuminate the World's Fair, then neither will my bulbs!"
Edison has pulled his light bulbs out of the fair. How are we going to light the fair without his light bulbs?
No worries, I'll just have to make a little light of my own.
TO BE CONTINUED

Teacher's Guide

ACTIVITY 3:

Shake it up!

Intro

In Activity 2 students learned that moving charges in the form of current create a magnetic field. In this activity students will learn that a moving magnet will cause charges to move. They will also learn that the direction in which the charges move depends on the direction in which the magnet is dropped. These two activities together do a good job illustrating the connections between electricity and magnetism.

Key Question

When a magnet is dropped through a coil of wire what happens in the wire? Does it depend on the direction and speed of the magnet?

Key Terms

Magnetic field: A field that is produced by either moving charges or a permanent magnet.

Current: Movement of positive charges

Diode: A diode only allows current to flow in one direction. It's like a one way street for current.

LED: *Light Emitting Diode*. This is a type of diode that lights up when current goes through it.

Induction: When current is created from a changing magnetic field it is an induced current. The process of changing the magnetic field to create the current is called induction.

Direct Current (DC): In this type of power the current never changes direction. Batteries have this type of power. Edison's power system was DC.

Alternating Current (AC): In this type of power, current constantly changes direction, like water in a washing machine. Wall sockets give this type of power. Tesla invented a way to power cities, including Chicago, with this type of power.

Materials

- **Cardboard tube**
- **Long copper wire**
- **Green LED**
- **Red LED**
- **4 disk neodymium magnets**
- **Steel slug**
- Scissors
- Tape
- Ruler
- Permanent marker

Before the activity students should know …

For current to flow, there must be a source of electrical energy, like a battery or a wall socket.

For a light to light, there must be current.

Magnets have a north and a south pole.

After the activity students should know…

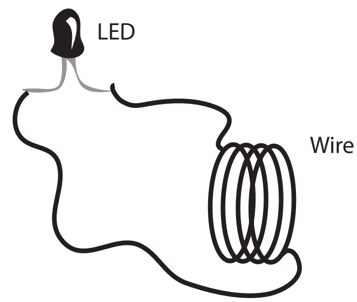
Moving a magnet through a coil of wire quickly enough will cause a current to flow.

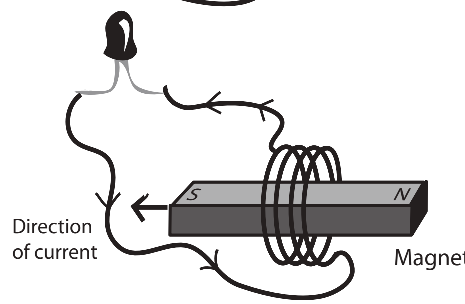
The direction of the current depends on which pole of the magnet goes through the coil first.

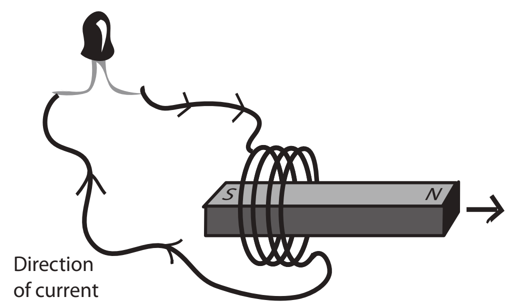
The amount of current depends on how fast the magnet falls.

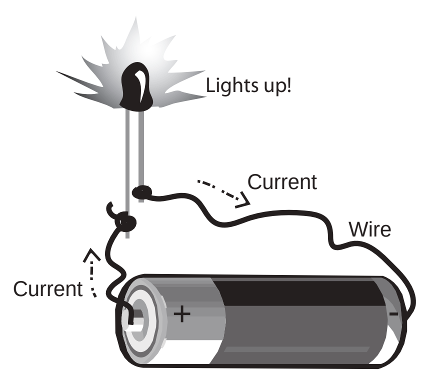
ACTIVITY 3: Shake it up!

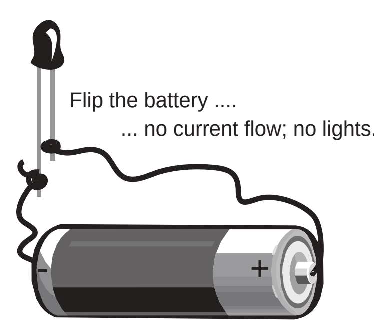
The science behind induction











Usually we think of a battery or wall power as the only way to make current flow. Just connecting wire to a light bulb won't cause it to light up; there must be a power source, something to push the charges. It turns out that batteries and sockets are not the only way to push positive charges and create a current. When a magnet is moved through a loop of wire the magnetic field the wire sees is changing and this change causes the charges to move. This is a fantastic and rare example of energy of motion, moving the magnet, being changed into electrical energy. When current is created by moving a magnet through a coil it is said to be an "induced current." Faraday's Law is also called the law of induction.

This phenomenon was discovered by both Michael Faraday and Joseph Henry in 1831 but is called Faraday's Law because Faraday published his work first. In science it is important to quickly publish your discoveries! Faraday also discovered that the direction in which the magnet is moved will change the direction of the current. So if you drop a magnet south end first through a coil the direction of the current will be different than if you dropped in north end first.

Another important point is that the amount of current depends on how fast the magnetic field is changing. If the field is changing quickly the current will be stronger than if the field is changing more slowly. For this experiment it is the moving magnet that makes the magnetic field near the wire change so if the magnet is dropped quickly there is a bigger current than if it is dropped slowly. The LED must have a minimum current to make it light up. Even if there is some current produced from a slowly falling magnet it may not be enough for the LED to light. Your students will investigate this and find that the magnet must be dropped straight through the coil and not slid down the side of the tube to make the LED light up.

If changing the direction of the magnet changes the direction of the current, what happens if you shake the magnet back and forth through the coil of wire? The current will

ACTIVITY 3: Shake it up!

be changing direction constantly like a washing machine. This type of current is called alternating current, or AC. This is the type of current that comes from our wall sockets. Tesla designed a type of generator that moves magnets through coils of wire to create current and because it was so efficient, this is the type of power we use.

DC, or direct current is the type of current that comes from a battery. The current is always flowing in the same direction, like a stream. Edison designed all his systems based on this type of current even though it was less efficient than an AC system and in the end it was beaten by Tesla's AC system. Interestingly, though AC comes into our homes, most of our electronics are designed to run on DC power. This first thing the current passes through is a device that converts the AC power to DC power.

It is possible to see Faraday's law of induction using a very strong magnet, a coil of wire and two LEDs. LED stands for "Light Emitting Diode." When current tries to flow in one direction it will pass through the diode and make it light up. However, if it tries to pass through in the other direction it gets blocked and the light won't light. By attaching 2 LEDs to a coil of wire it is possible to drop a magnet through the coil and watch the LED light up. If the LEDs are attached so that one lets current through in one direction while one lets current through in the other it is possible to see which direction the current is flowing. Manufacturers of LEDs let us know which way current can flow by making one leg of the LED longer than the other. Current is allowed to flow from the long leg, through the LED and then through the short leg. It is not allowed to flow from the short leg to the long leg. Remember, current flows from positive to negative so if the long leg of the LED were put against the positive end of the battery and the short leg against the negative end, current would flow and the LED would light. However, if the LED were flipped, with the short leg on the positive end, current would not flow and the LED would not light.

Safety

The magnets used are quite strong. It is very important to be careful when handling them. If two are brought close together and part of a finger is in the way it will be pinched. Do not swallow the magnets. Do not bring them near cell phones, computers, iPods or credit cards.

Corresponding extension activities

- **Homemade battery –** Use common household products to build a battery
- **Mechanical flashlight—** Use mechanical energy to light a flashlight
- **Wearable LED –** Make a little light for your shirt or backpack.

ACTIVITY 3: Shake it up!

Bibliography/Suggested resources
National Academy of Sciences. *Joseph Henry*
http://www.nationalacademies.org/history/members/henry.html

University of Colorado at Boulder. *PhET program*
http://phet.colorado.edu/simulations/sims.php?sim=Faradays_Electromagnetic_Lab

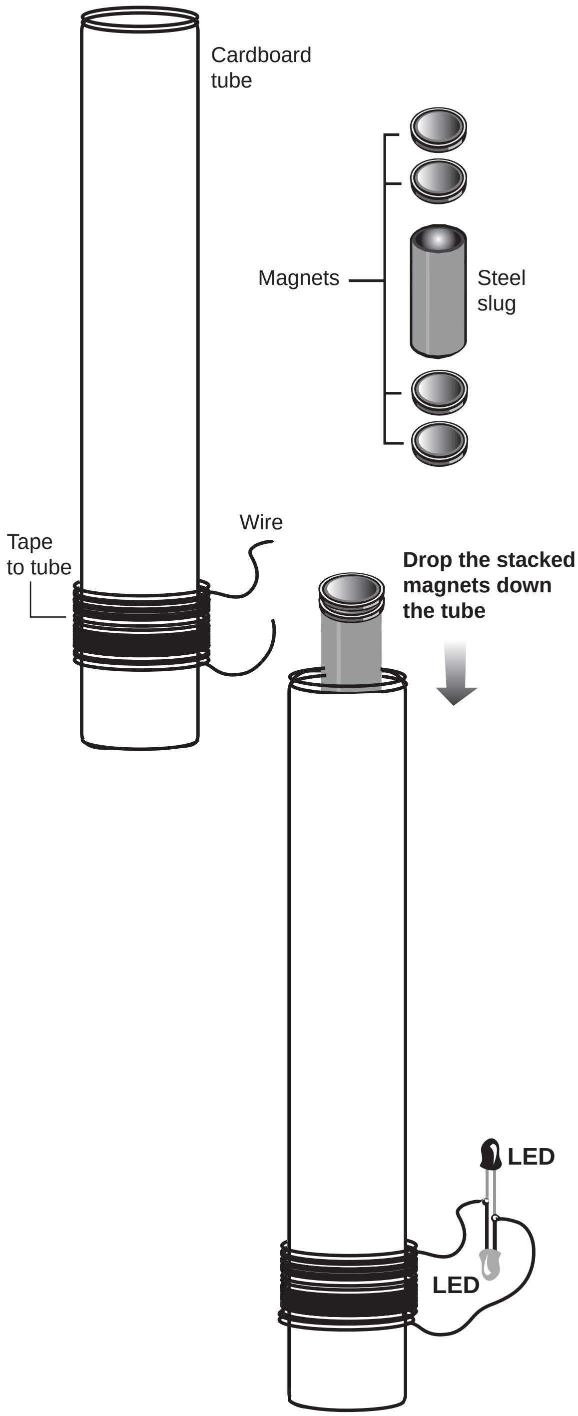
Wolfram Research. *Faraday, Michael*
http://scienceworld.wolfram.com/biography/Faraday.html

University of Virginia Physics Department. *LED coil*
http://demolab.phys.virginia.edu/demos/demos.asp?Demos=K&Subject=5&Demo=5K10.81#subtopic

Key Question
When a magnet is dropped through a coil of wire what happens in the wire? Does it depend on the direction and speed of the magnet?

Student's Guide

ACTIVITY 3: Shake it up!



Intro

You've seen that current can create a magnetic field but is there a way that a magnetic field can create current? In fact there is! It is this idea that is the basis for Tesla's powerful AC generators.

Materials

- Cardboard tube
- Long copper wire
- Green LED
- Red LED
- 4 disk neodymium magnets
- Steel slug
- Compass
- Scissors
- Tape (electrical)
- Ruler
- Permanent marker

Getting started

What is a "complete circuit"? ______________________________

____

What type of things can make current flow in a circuit?

____

____

How might you be able to tell if current is flowing?

____

____

Can you think of a way you could tell which direction current is flowing? ____

____

Setting up the experiment

1. Use the scissors to scrape the coating off of each end of the copper wire.
2. Put a piece of tape 0.5-inch from one end of the tube.
3. Tape one end of your wire 1.5-inch from the same end of the tube. Leave the scraped off end free from the tape.
4. Wrap the rest of the wire around the tube making sure to keep your coils between the two tape marks.

ACTIVITY 3: Shake it up!

5. Use tape to secure the coil.
6. Twist the longer leg of the red LED around the shorter leg of the green LED and mark this side with a permanent marker.
7. Now twist the short leg of the red LED around the long leg of the green LED and leave unmarked.
8. Twist the end of the copper wire that is taped to the tube around the marked end of your LED set up.
9. Twist the unmarked end around the other end of the copper wire.
10. Put two magnets on either end of the steel slug (you need all four magnets)
11. Use your compass to figure out which end of the magnet and slug combination is north and mark it with an "N". Mark the other end with an "S" for south.

Collecting data

Hold the tube at a 45 degree angle and slide the magnet down the tube north end first.
What happened to the LEDs?

Now hold the tube at a 70 degree angle and slide the magnet down the tube north end first. What happened to the LEDs?

Now hold the tube completely vertical and drop the magnet north end first down the tube. What happened to the LEDs?

Repeat these three steps but this time drop the magnet south end first.

What happened to the LEDs at each step?

____

____

____

Trial	**Red lit**	**Green lit**
45 degrees, north first	________	________
70 degrees, north first	________	________
Vertical, north first	________	________
45 degrees, south first	________	________
70 degrees, south first	________	________
Vertical, south first	________	________

ACTIVITY 3: Shake it up!

Analyzing your results
What types of energy do you see in each step of the experiment?

____

____

How is energy being changed from one form to another? ______________________________

____

Sometimes the green LED lit up, sometimes the red LED lit up and sometimes neither did. What is the pattern you saw? ____

When did the red LED light and when did the green LED light? ______________________

____

What is flowing in the wire? Can you tell the direction? ___________________________

____-

What things do you need to make the LEDs light up? _____________________________

____

Could you ever make them light at the same time? ________________________________

____

How would the current behave if you dropped a magnet north end first and then very quickly dropped a magnet south end first? ____

____

____

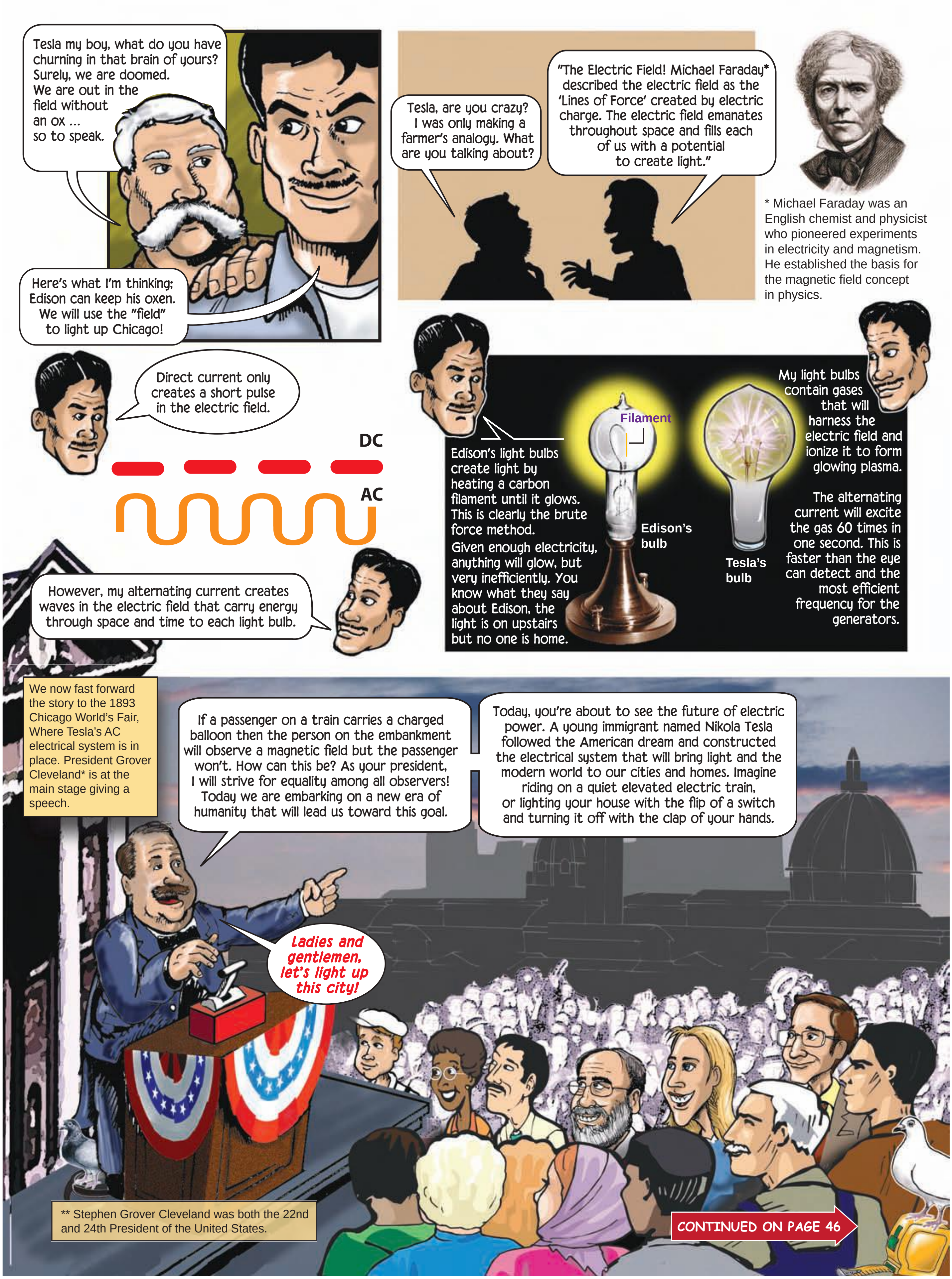
Using your results to help Tesla
You have almost done it faithful sidekick. You have found 2 of Tesla's tools and you are about to chase yet another pigeon to find the third Those pigeons are fast, but you are faster. Now you need to find which one has Tesla's tool. When you dropped the magnet north side first when the tube was held vertically, which LED lit up?

Green Chase the white pigeon

Red Chase the gray pigeon

Both Chase the pigeon with stripes

Neither Chase the pigeon with a white body and gray head


Tesla my boy, what do you have churning in that brain of yours? Surely, we are doomed. We are out in the field without an ox ... so to speak.
Here's what I'm thinking; Edison can keep his oxen. We will use the "field" to light up Chicago!
Tesla, are you crazy? I was only making a farmer's analogy. What are you talking about?
"The Electric Field! Michael Faraday* described the electric field as the 'Lines of Force' created by electric charge. The electric field emanates throughout space and fills each of us with a potential to create light."
* Michael Faraday was an English chemist and physicist who pioneered experiments in electricity and magnetism. He established the basis for the magnetic field concept in physics.
Direct current only creates a short pulse in the electric field.
DC
AC
However, my alternating current creates waves in the electric field that carry energy through space and time to each light bulb.
Edison's light bulbs create light by heating a carbon filament until it glows. This is clearly the brute force method.
Given enough electricity, anything will glow, but very inefficiently. You know what they say about Edison, the light is on upstairs but no one is home.
Filament
Edison's bulb
Tesla's bulb
My light bulbs contain gases that will harness the electric field and ionize it to form glowing plasma.
The alternating current will excite the gas 60 times in one second. This is faster than the eye can detect and the most efficient frequency for the generators.
We now fast forward the story to the 1893 Chicago World's Fair, Where Tesla's AC electrical system is in place. President Grover Cleveland* is at the main stage giving a speech.
If a passenger on a train carries a charged balloon then the person on the embankment will observe a magnetic field but the passenger won't. How can this be? As your president, I will strive for equality among all observers! Today we are embarking on a new era of humanity that will lead us toward this goal.
Today, you're about to see the future of electric power. A young immigrant named Nikola Tesla followed the American dream and constructed the electrical system that will bring light and the modern world to our cities and homes. Imagine riding on a quiet elevated electric train, or lighting your house with the flip of a switch and turning it off with the clap of your hands.
Ladies and gentlemen, let's light up this city!
** Stephen Grover Cleveland was both the 22nd and 24th President of the United States.
CONTINUED ON PAGE 46

Teacher's Guide

ACTIVITY 4:

Magnet powered pinwheel

Intro

In activity 3 the students saw that a moving magnet will make charges move and cause a current, which lights a light bulb. In this activity students will see that current moving through a magnet will cause the magnet to turn. Magnetic motion creates current, and then current creates magnetic motion. There is nothing like using advanced physics to spin a pinwheel!

Key Question

How can you make a pinwheel turn using a magnet and a battery?

Key Terms

Permanent magnet: A substance such as iron that produces a magnetic field. A refrigerator magnet is a good example of this type of magnet.

Current: Flow of positive charges. When a complete circuit is created with a battery, current flows.

Magnetic field: A field produced by either a permanent magnet or a current. At every point it has both a strength and a direction.

Force: Objects move only when a force is applied to them.

Radius: Line from the center of a circle to the outer edge of the circle.

Materials

- **C battery**
- **Nail**
- **Pinwheel top**
- **Magnet**
- **Insulated wire**
- Tape (electrical)

Before the activity students should know …

When materials such as iron come in contact with a strong magnet they also become magnets.

When things move it is because they feel a force.

Current is the motion of positive charges.

After the activity students should know…

When charges move in a magnetic field they feel a force

The direction of the force they feel is related to the direction of the magnetic field and the direction in which the charges are moving.

The science behind the simple motor

In experiment 3 the students learned that when magnets move they can create a current. In this experiment, just the opposite happens. Here, current is going to flow through a magnet and now the moving charges that make up the current will feel a force which makes the magnet turn.

Current is moving charges. Because of Ben Franklin's convention we always assume it is positive charges moving, even though we really now know it is negatively charged electrons. From now on we are just going to assume that the positive charges are moving, thank you Ben.

ACTIVITY 4: Magnet powered pinwheel

The tricky thing about electromagnetism is that when charges are sitting still they don't interact with a magnetic field that is constant. So an electron could happily sit next to a refrigerator magnet forever and feel nothing at all. But electricity starts affecting magnetism and vice versa as soon as one starts changing. In experiment 3 you saw what happened when it was the magnet that moved. It made the positive charges in the wire coil move and current flowed which made the diode light up. This activity will look at what happens when charges move through a magnetic field that isn't changing.

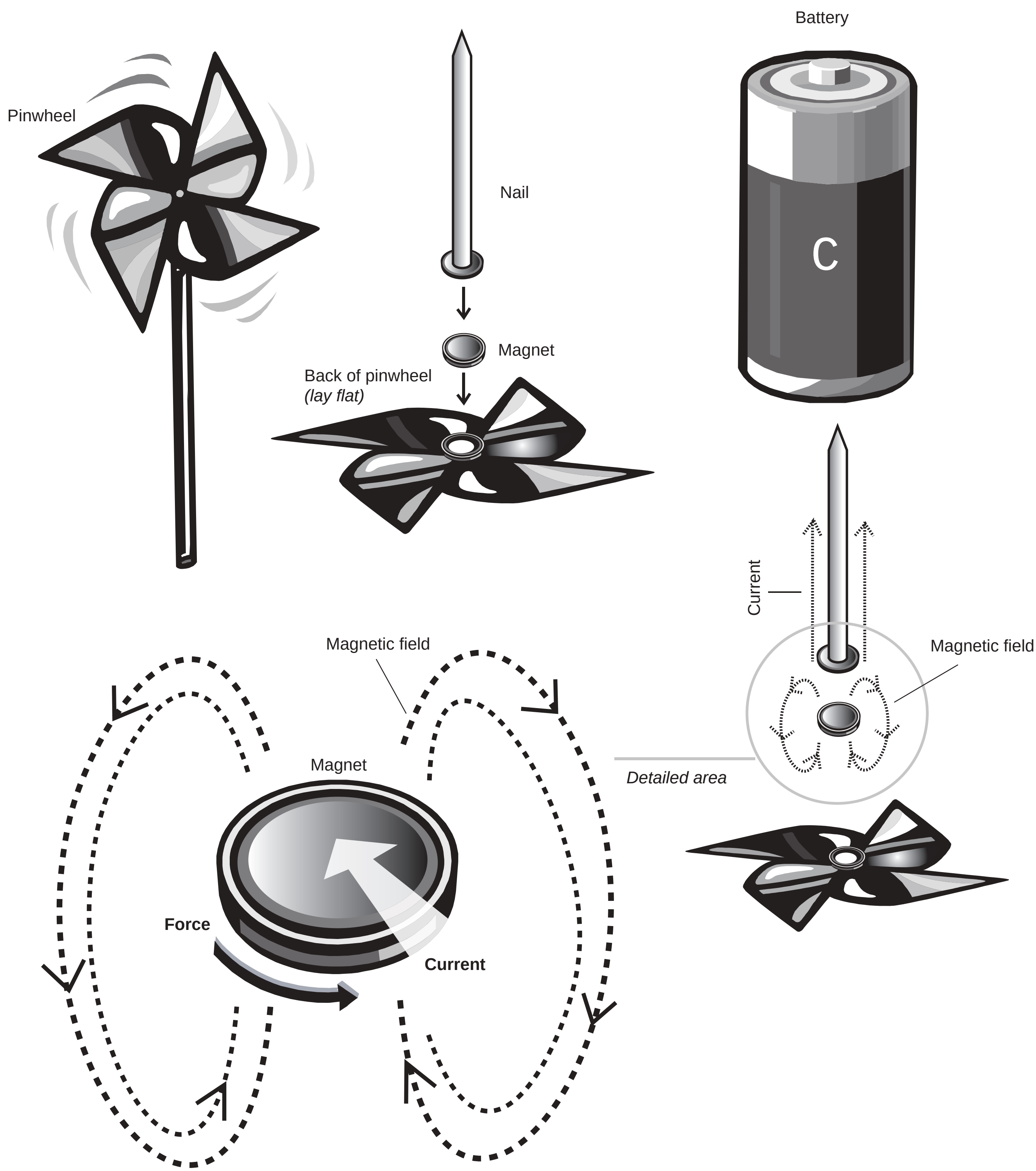
This time the magnetic field is produced by the neodymium magnet so it won't be changing, but current will be flowing so charges are moving. If charges sit very still, a magnetic field won't affect them, but if the charges begin to move they feel a force from the magnetic field. The direction of the force depends on which way the charge is moving and which way the magnetic field is going. The interesting thing is that the force the positive charge feels is not in the direction of the magnetic field or of its motion, it is perpendicular to both. This force is called the Lorenz force after Hendrik Lorentz who discovered it in 1892.

When the motor is connected and current is flowing there are positive charges flowing through the magnet. During the activity the direction of current will change, sometimes it will be flowing down the nail, through the magnet and to the outside edge of the magnet. Sometime it will flow from the outside edge through to the middle and back up the nail. ither way the direction of the current flow will be along the radius of the magnet. The magnetic field points from one flat side of the magnet to the other.

The only direction that is perpendicular to both the magnetic field and the direction of the current is the direction that would cause the pinwheel to spin. This force on the charges moving through the magnet is so strong that is causes the magnet and therefore pinwheel, to turn. The force is always in a direction that causes the magnet to turn, but it doesn't always turn in the same direction. During this activity the students will set up the motor in various configurations and see which way the magnet turns. At the end of this activity your students are asked to find a rule to predict which way the force will point for a given magnetic field direction and current direction. This is no easy task and they may be a bit stumped but it is a good exercise for them to think through. If they cannot agree on an answer, they will still be able to find the correct answer to the PhysicsQuest mystery. An explanation of the rule your students are asked to find is given in the first reference in the bibliography.

Apart from the main physics in this activity there is a little extra piece shown when the nail is hung from the battery. When a strong magnet is attached to certain metals it makes the metal object magnetic as well. In this case the neodymium magnet is attached to the head of a nail and then the nail itself becomes magnetic. Your students have probably stumbled across this before with paper clips. If paper clips are touching a magnet, they also become magnets and can pick up more paper clips. Because the end of a battery is made of steel, which will allow magnets to stick, when the magnet is attached to the head of the nail and nail becomes a magnet it can hang from the end of the battery.

ACTIVITY 4: Magnet powered pinwheel



ACTIVITY 4: Magnet powered pinwheel

Safety

Just as in activity two, if the wire is held for too long it may get hot. Only touch the wire to the magnet long enough to observe the direction of the spinning pinwheel.

Corresponding extension activities

- **Steamroller motor:** Spin a battery like a mini steamroller
- **Electric whirl pool:** Watch water swirl using electricity
- **Electric train:** Magnetic wheels propel down an electric track

Bibliography/Suggested resources

Chiaverina, Christopher, *The Simplest Motor?*, The Physics Teacher **42** 553 (2004)

Peter L. Vogel *Magnet-nail Motor* Physics On-Line
http://www.ndrs.org/physicsonline/motor/index.htm

Hendrik A. Lorentz Nobelprize.org
http://nobelprize.org/nobel_prizes/physics/laureates/1902/lorentz-bio.html

Ron Kurtus *Magnetism and the Lorentz Force.* School for Champions
http://www.school-for-champions.com/science/magnetism_lorentz.htm

Student's Guide

ACTIVITY 4: Magnet powered pinwheel

Intro

This is your last task before Tesla can light the fair. You, trusty sidekick, have come a long way. You have learned about light, magnetism and electricity. Now, you will pull together everything you have learned to create a motor to turn a pinwheel. If you are up to the challenge you will track down the last pigeon and help Tesla save the day and illuminate the greatest world's fair in history. It is up to you, don't let your hero down!

In activities two and three you saw that current creates a magnetic field and that a changing magnetic field creates a current. In this activity you get to find out what happens when charges move through a magnetic field. Shocking!

Materials

- **C cell battery**
- **Nail**
- **Pinwheel top**
- **Magnet**
- **Insulated wire**
- Tape

Key Question

How can you make a pinwheel turn using a magnet and a battery?

Getting Started

Why do things move? What is a force?

What direction of force would cause something to spin?

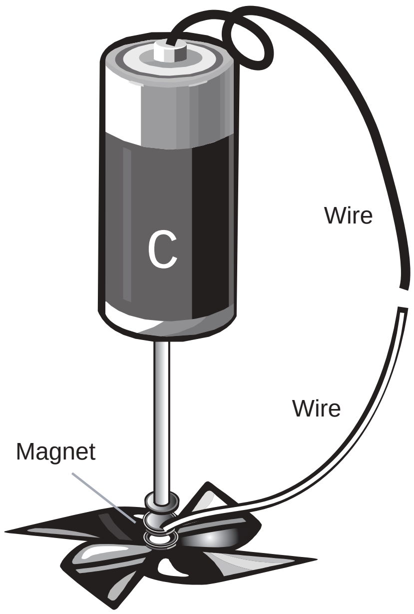
What types of motors can you think of? What do they have in common?

Do you think a magnetic field can affect positive charges if they are sitting still? What if they are moving?

Setting up the Experiment

1. Use your compass to figure out which end of the flat neodymium magnet is north and which is south. Use a permanent marker and put an S on the south end and an N on the north end.
2. Put the magnet on the head of the nail with the "N" side against the head.
3. Tape the pinwheel top to the other side of the magnet.
4. The nail will now be magnetic thanks to the magnet. Hang the nail by its point from the negative side of the battery.
5. Hold the battery so the nail is hanging and free to move.

ACTIVITY 4: Magnet powered pinwheel



Collecting data

Draw your set up, indicating where the north and south ends of the magnet are as well as the positive and negative ends of the battery.

Now touch the wire to both the positive end of the battery and the magnet.

What happens? ________________________________

Now hang the magnet and nail from the positive end of the battery and touch the wire to the negative end and the magnet.

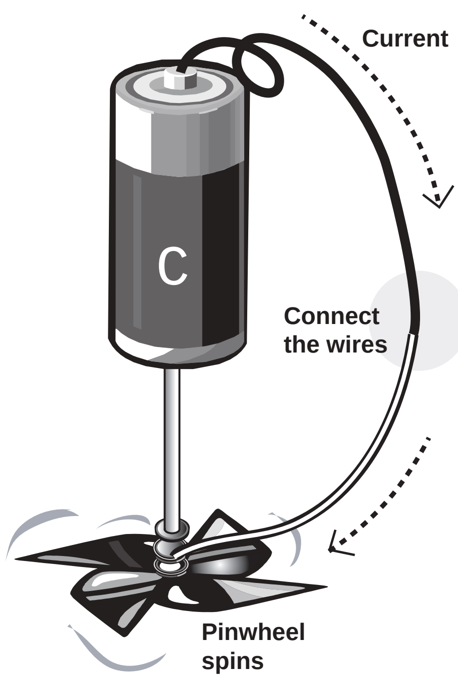
What happened? How does this compare to what happened before? ________________________________
____

You have changed the direction of the current flow through the magnet by putting the nail on the other side, besides changing the current, what else could you change in this experiment?

If you said the magnet, good job! If you didn't, good job! We are going to see what happens when the magnet is flipped, but if you came up with something else to change, great! Try it!

Pull the pinwheel top off the magnet and flip the magnet so the "S" is against the nail head, reattach the pinwheel, and repeat the experiment.

Record your results in the table. Next to each set up check either clockwise or counterclockwise to indicate which way the pinwheel turned. Assume you are looking down at the pinwheel.



Set-up	Clockwise	Counter-clockwise
1. "N" on nail head, nail on +	________	________
2. "N" on nail head, nail on –	________	________
3. "S" on nail head, nail on +	________	________
4. "S" on nail head, nail on –	________	________

ACTIVITY 4: Magnet powered pinwheel

Analyzing your results

Draw the two set ups that made the pinwheel turn clockwise. Make sure you include the direction of the current.

Draw the two set ups that made the pinwheel turn counterclockwise. Make sure you include the direction of the current.

What other things might you be able to spin with a set up like this?

____

When the current was flowing positive charges moved through the magnet. These charges felt a force from the magnet and caused the magnet to turn. In each case you investigated, which direction was the force? ________________________________

How does that compare to the direction of the current and magnetic field? ___________________________________

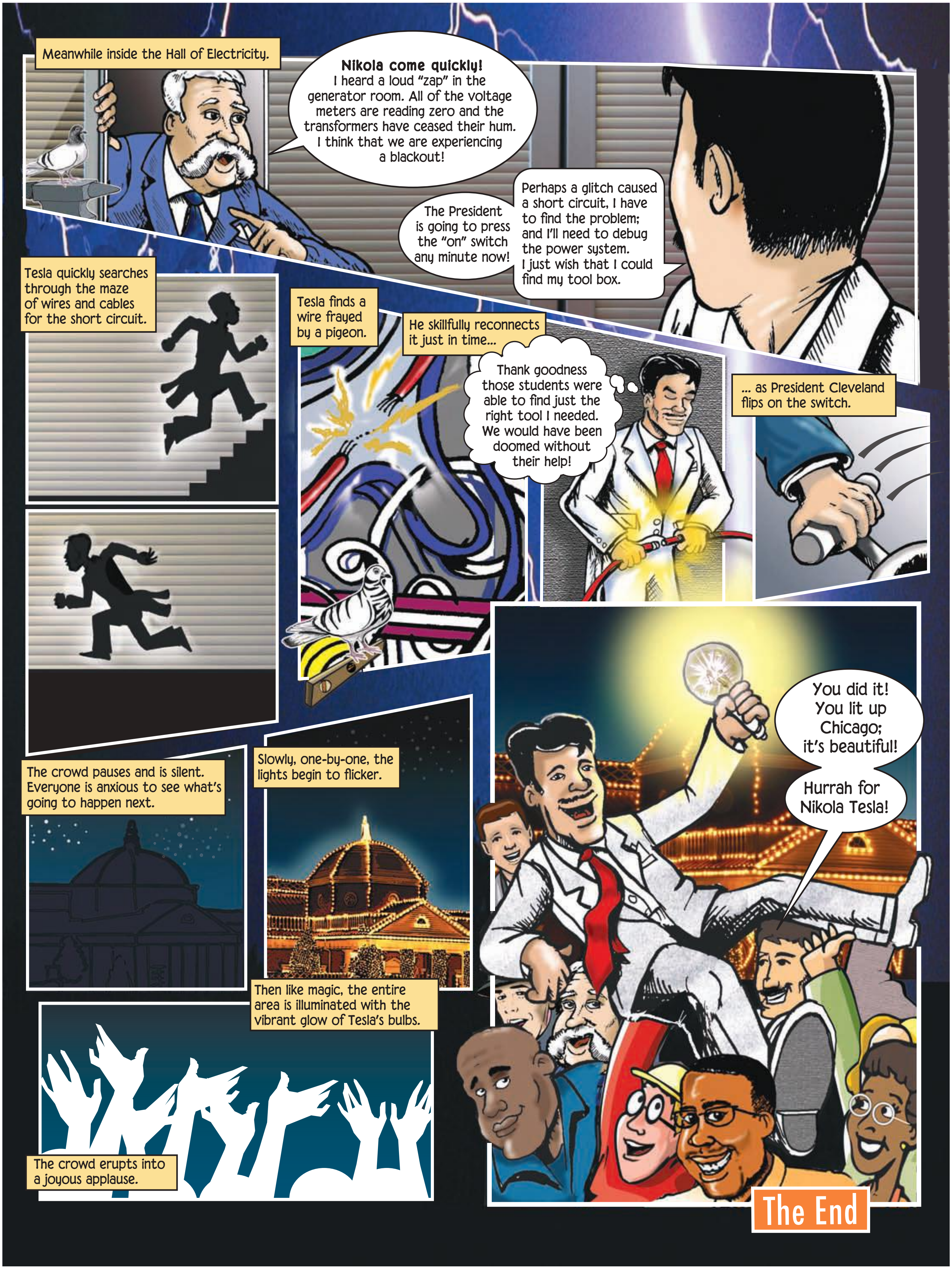
____

Can you come up with a way to predict the direction of force if you know the direction of the magnetic field and the direction of the current?

Using your results to help Tesla light the fair:

Congratulations! You have learned an amazing amount of physics. In fact, you have explored the physics that is the basis for our entire electric life. You created light with a moving magnet and moved a motor with a current and a magnet. You learned how light travels through materials and seen that current does more than just light light bulbs, it creates magnetic fields. You are a truly worthy sidekick and perhaps one day you will be a physics superhero with your own side kick! Tesla would be lost without your help. Now you have just one more pigeon to find. Which two set-ups made the pinwheel turn counterclockwise? Now go chase that pigeon! You have done it! Read on to find out what happens and if Tesla is saved!

First and fourth set-up	Chase the white pigeon
Second and third set-up	Chase the gray pigeon
First and third set-up	Chase the pigeon with stripes
Second and fourth set-up	Chase the pigeon with the gray head and white body


Meanwhile inside the Hall of Electricity.
Nikola come quickly! I heard a loud "zap" in the generator room. All of the voltage meters are reading zero and the transformers have ceased their hum. I think that we are experiencing a blackout!
The President is going to press the "on" switch any minute now!
Perhaps a glitch caused a short circuit, I have to find the problem; and I'll need to debug the power system. I just wish that I could find my tool box.
Tesla quickly searches through the maze of wires and cables for the short circuit.
Tesla finds a wire frayed by a pigeon.
He skillfully reconnects it just in time...
Thank goodness those students were able to find just the right tool I needed. We would have been doomed without their help!
... as President Cleveland flips on the switch.
The crowd pauses and is silent. Everyone is anxious to see what's going to happen next.
Slowly, one-by-one, the lights begin to flicker.
Then like magic, the entire area is illuminated with the vibrant glow of Tesla's bulbs.
The crowd erupts into a joyous applause.
You did it! You lit up Chicago; it's beautiful!
Hurrah for Nikola Tesla!
The End

Educational Innovations

MEMBER:

MSDS
MATERIAL SAFETY DATA SHEET

PRODUCT IDENTIFICATION	TRADEMARK	SOIL MOIST™	Water retention aid
	CAS#	71042-87-0	
	SYNONYMS	None	
	CHEMICAL FAMILY	Crosslinked modified acrylic polymer	
	MOLECULAR FORMULA	Polymer	
	MOLECULAR WGT.	Polymer	
WARNING	SPILLS ARE SLIPPERY WHEN WET		
INGREDIENTS	SOIL MOIST contains polymer. No permissible exposure limits have been established.		
HEALTH INFORMATION	SOIL MOIST is a chemically neutral material. Prevent dust excape in the air, DO NOT breathe dust. A NIOSH, approved respirator for nuisance dust should be worn. After use, in horticulture work, normal hygenic practice should be followed.		
FIRE AND EXPLOSION	FLASH POINT	Not Applicable	
HAZARD INFORMATION	FLAMMABLE LIMITS	Not Applicable	
	FIRE FIGHTING	Use water, carbon dioxide or dry chemicals to extinguish fires. Wear self-contained, positive pressure breathing apparatus and full fire fighting protective clothing. Dust may be explosive if mixed with air in critical proportions and in the presence of a source of ignition.	
REACTIVITY DATA	STABILITY CONDITIONS TO AVOID	Stable None Known	
	POLYMERIZATION CONDITIONS TO AVOID	Will Not Occur None Known	
	INCOMPATIBLE MATERIALS	Strong oxidizing agents	
	HAZARDOUS DECOMPOSITION PRODUCTS	Thermal decomposition or combustion may produce carbon monoxide and/or oxides of nitrogen	
PHYSICAL PROPERTIES	APPEARANCE AND ODOR	Granular free flowing white material with typical odor	
	BOILING POINT	Not Applicable	
	MELTING POINT	Not Applicable	
	VAPOR PRESSURE	Not Applicable	
	SPECIFIC GRAVITY	Not Applicable	
	VAPOR DENSITY	Not Applicable	
	% VOLATILES	Approx. 4-10 % (H^2O)	
	pH	Not Applicable	
	SOLUBILITY IN WATER	Swells (does not dissolve). pH of aqueous system approx. 6.4 - 7.0	
SPILL PROCEDURES	Spilled material is slippery when wet. Remove sources of ignition. Sweep up spills and place in a waste disposal container. Disposal must be made in accordance with applicable governmental regulations.		
SPECIAL PRECAUTIONS	Maintain good housekeeping to control dust accumulations. DO NOT ALLOW MATERIAL TO ENTER DRAINS.		

NOTE: This information is given without any warranty or representation. We do not assume any legal responsibility for same. It is offered solely for your consideration, investigation and verification. Before using any product read its label.

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Educational Innovations

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Using PhysicsQuest in the Classroom

The PhysicQuest activities directly corresponds to many of the National Science Education Standards. The standards addressed by each of the activities are listed below:

Activities 1-4
Grades K-12
K-12: Unifying concepts and processes: *Systems, order, and organization.* There are physical laws governing the behavior of nature that exemplify its order, predictability, and regularity.

K-12: Unifying concepts and processes: *Evidence, models, and explanation.* Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical

Grades 5-8
Science as inquiry: Use appropriate tools and techniques to gather, analyze, and interpret data. The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design.

5-8: Science as inquiry: *Think critically and logically to make the relationship between evidence and explanations.*

5-8: Science as inquiry: *Develop descriptions, explanations, predictions, and models using evidence.* Students should base their explanation on what they observed, and as they develop cognitive skills, they should be able to differentiate explanation from description.

5-8: Science in personal and social perspectives: *Science and technology in society.* Societal challenges often inspire questions for scientific research.

5-8: Science as inquiry: *Design and conduct a scientific investigation.* Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables.

5-8: History and nature of science: *Nature of science.* Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

ACTIVITIES
■ **Activity 1: Gel crystals**
K-12: Unifying concepts and processes: *Constancy, change, and measurement.* Knowledge of mathematics is essential for accurate and communicable measurement. Changes in systems can be quantified. Mathematics is essential for accurately measuring change.

K-12: Unifying concepts and processes: *Constancy, change, and measurement.* Knowledge of mathematics is essential for accurate and communicable measurement. Changes in systems can be quantified. Mathematics is essential for accurately measuring change.

5-8: Nature of science: Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

5-8: Science in personal and social perspectives: *Science and technology in society.* Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact.

5-8: Physical science: *Properties and changes of properties of matter.* A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample.

5-8: Physical science: *Transfer of energy.* Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection).

5-8: Science as inquiry: *Use mathematics in all aspects of scientific inquiry.* Mathematics can be used to ask questions; to gather, organize, and present data; and to structure convincing explanations.

■ **Activity 2: Magnetic field around wire with compasses**
K-12: Unifying concepts and processes: *Constancy, change and measurement.* Knowledge of mathematics is essential for accurate and communicable measurement. Changes in systems can be quantified. Mathematics is essential for accurately measuring change.

5-8: Science and technology: *Understandings about science and technology.* Science and Technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technology.

5-8: Science in personal and social perspectives: *Science and technology in society.* Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact.

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5-8: Physical science: *Transfer of energy.* Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.

■ **Activity 3: Lighting an LED by dropping a magnet through a coil**
K-12: Unifying concepts and processes: *Constancy, change, and measurement.* Knowledge of mathematics is essential for accurate and communicable measurement. Changes in systems can be quantified. Mathematics is essential for accurately measuring change.

5-8: Science and technology: *Understandings about science and technology*. Science and Technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technology.

5-8: Science in personal and social perspectives: *Science and technology in society.* Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact.

5-8: Physical science: *Transfer of energy.* Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

5-8: Physical science: *Transfer of energy*. Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.

■ **Activity 4: Simple pinwheel motor**
K-12: Unifying Concepts and Processes: Constancy, change and measurement. Knowledge of mathematics is essential for accurate and communicable measurement. Changes in systems can be quantified. Mathematics is essential for accurately measuring change.

5-8: Science and technology: *Understandings about science and technology.* Science and Technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technology.

5-8: Science in personal and social perspectives: *Science and technology in society.* Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact.

5-8: Physical science: *Transfer of energy.* Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

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