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!

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.

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.

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.

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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.

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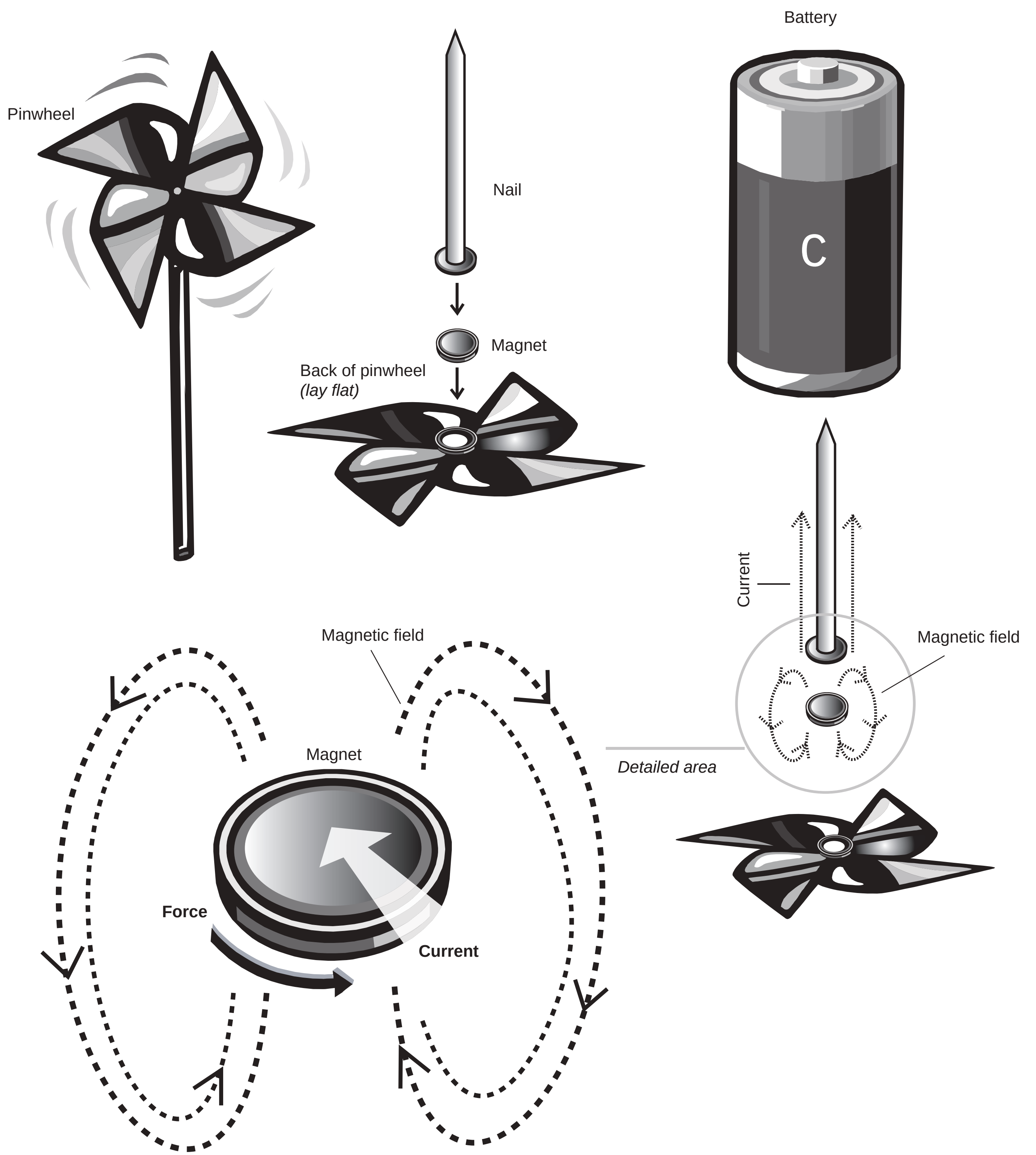

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Safety

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.

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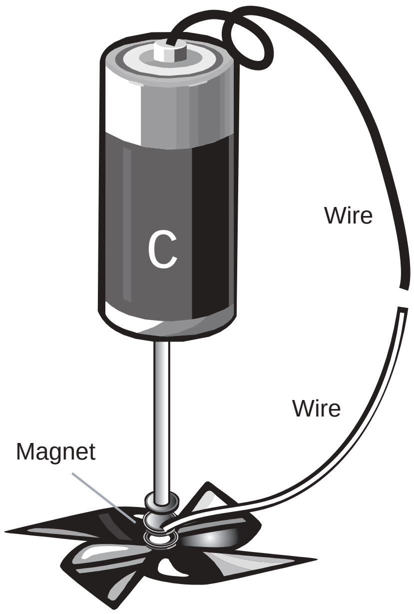


Collecting data

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? ______________________________

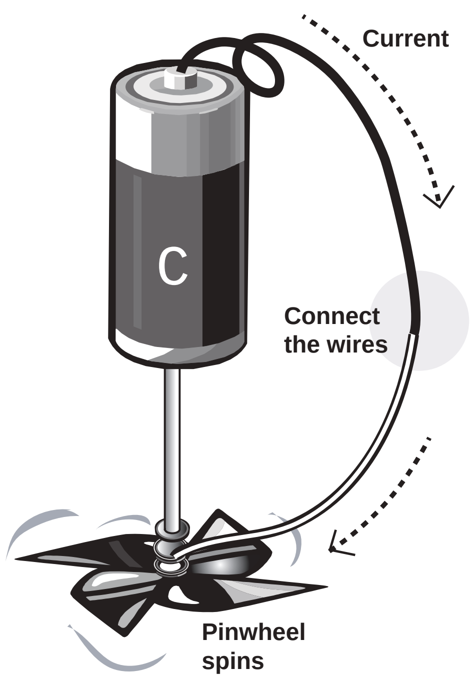
Now hang the magnet and nail from the positive end of the battery and touch the wire to the negative end and the magnet.

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 **–**	________	________

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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? ____

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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