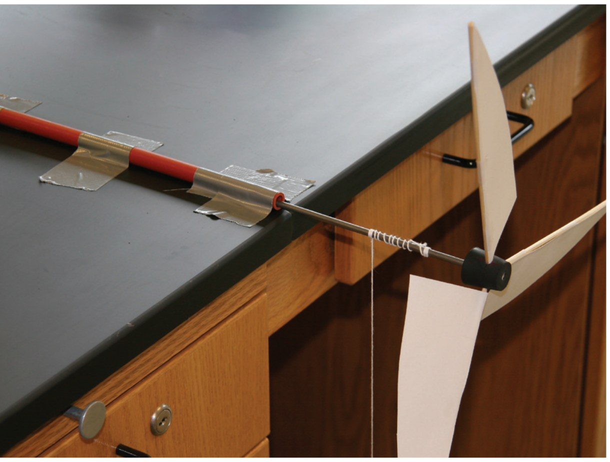
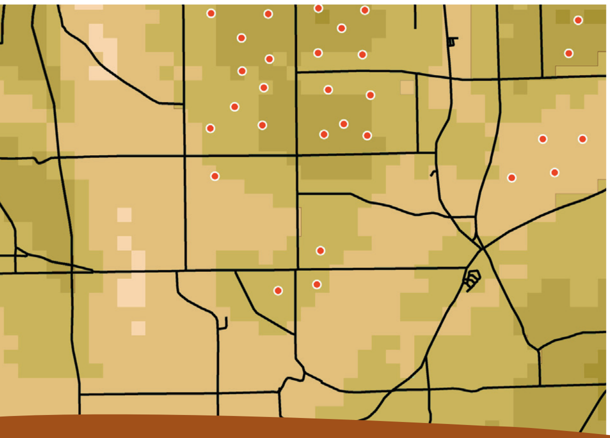
WindWise Education

Transforming the Energy of Wind into Powerful Minds

A Curriculum for Grades 6-12





windwise education

www.WindWiseEducation.org

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funding from the New York State Energy
Research & Development Authority.

V1.0

LESSON 7

HOW DOES A GENERATOR WORK?

KEY CONCEPT

Students will learn how electricity is generated and how design variables affect electricity production.

TIME REQUIRED

1 – 2 class periods

GRADES

6 – 8
9 – 12

SUBJECTS

Technology/Engineering
Physical Science

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BACKGROUND

All wind turbines contain generators that transform the energy of the wind into electricity. Engineers are constantly trying to improve the performance of these generators, allowing the turbines to transform more energy of the wind into electricity. This lesson explores the physics of how generators work and some variables to improve performance.

OBJECTIVES

At the end of this lesson students will

- Understand the main parts of an electrical generator and their relationships
- Be able to construct a simple generator
- Understand how electricity is generated
- Be able to use a digital multimeter to record voltage and amperage output

METHOD

Using simple materials, student groups will construct a simple generator to try to light a small bulb. Each group's generator will have a different number of windings and types and numbers of magnets so that the class can collect and compare data on the variables that affect electricity production.

MATERIALS

You will need one set of the following materials for each group:

- ❑ 2 pieces of coroplast (8 cm x 30.4 cm)
- ❑ 4 ceramic magnets (1 x 2 x 5 cm)
- ❑ 1 spool of 28 gauge magnet wire
- ❑ 1 nail
- ❑ 2 bulbs (1 small 1.5 v incandescent bulb and 1 bicolor LED)
- ❑ Simple digital multimeter
- ❑ Rectifier
- ❑ Construction plans for each group (provided)
- ❑ Student worksheets (provided)

Classroom materials to share:

- ❑ Drill
- ❑ Craft knife or scissors
- ❑ Paper towel stand
- ❑ Electrical tape or duct tape
- ❑ Rare earth magnets (strong type)
- ❑ Windmill from Lesson #6 (optional)

Optional items that teachers might already have in class or can track down:

- ❑ Examples of small/medium generators or DC motors
- ❑ Hand crank generators that can light a bulb or run a motor. An example is the Genecon made by NADA Scientific. There are a number of hand cranked flashlights available now.

MOTORS & GENERATORS: WHAT IS THE DIFFERENCE?

If you can find them, it is great to provide students some examples of commercially made generators or DC motors, so they can see what is on the inside. You can usually find these at local electronic or appliance repair shops for very little money—they don't even have to work. The "guts" of these devices have a number of similar components to the generator we are going to build.

Keep in mind that at the scale we are working, a motor and a generator can be the exact same object, just used in different ways. When you spin a motor-generator it converts

continued on facing page

GETTING READY

- Before working with students, it is recommended that you build a few of the generators (with different numbers of windings and numbers and types of magnets) to help show variability in the device. This will also help if you have groups that do not build quality generators that can be used for testing and collecting data.
- Make copies of the worksheets for each student and the construction plans for each group.
- As a time-saving alternative for this lesson, have a variety of generators (with different numbers of windings and numbers and types of magnets) pre-constructed from which students can collect data. You can also save generators from the first year for use in later years or activities.
- Separate the materials to pass out to each group or put them in a central location for the student groups to collect.
- (Optional) Try to track down some samples of DC motors and/or DC or AC generators to use as demonstration examples of how these are constructed.

ACTIVITY

Step 1: Beginning Questions for Students

Start a discussion to assess how much your students understand about generators. This is a great time to share any hand crank generators or other demonstration items you have available. Some questions for discussion include:

- What is a generator?
- What parts make up a basic electrical generator?
- How do we generate electricity (Lessons 1&2)?
- What is electricity?
- What do we need to generate electricity?
- Has anyone ever seen a generator?
- Where do you find generators?
- What is the difference between a motor and a generator?

Step 2: Similarities of Generators

Have students examine some of the generators that you have previously constructed for this lesson and any other examples you have. What do these generators have in common? Students may respond that some of the parts are similar (i.e., magnets, wires, and coils) or that the generators all operate in a similar fashion (i.e., they all spin).

Step 3: Examining Magnets

Divide the class into groups of 2 to 3 students each. Distribute a few magnets to the student groups. What do they notice about the magnets? Discuss repelling and attraction and north and south poles. Draw a magnet and the magnetic fields on the board. Discuss the importance of the fields (flux) and how they can be of different strength depending on the type of magnets. You can also show them some stronger magnets (use care with stronger magnets, as they can snap together with a great deal of force).

Step 4: Examining Magnet Wire
Distribute magnet wire to the student groups. Is there anything they notice about this wire? How is it different from other wire they may have seen? The answer is a very thin layer of insulation. What do they notice about the orientation of the wire in the generator examples you have provided? Answers may include that there is a lot of wire, that the wire is in straight lines, and that the wires are packed very close together.

Draw a coil of wire next to the magnets you have drawn on the board. This is also a good time to talk about wire sizes (gauge). The larger the gauge number, the smaller the wire: 0 gauge wire is 8.25 mm in diameter; 26 gauge wire is 0.40 mm in diameter.

Step 5: Magnetic Fields & Wire
Have a discussion on how the magnetic fields (flux) might impact the wire or what the wire is composed of. This can refer to any lessons you may have given about induction.

Step 6: Building the Generator
Distribute the construction plans, worksheets, and materials. Have each group construct one generator with a different number of windings (from 100 to 400) and different numbers and types of magnets so that the class can collect and compare data for the different designs.

To ensure that students are doing a good job building their generators, you can grade their construction (see rubric, page 12). The construction plans cover a number of points where quality is important.

As students are building the generators, draw a data chart (similar to the one on their student worksheets) on the board to collect class data.

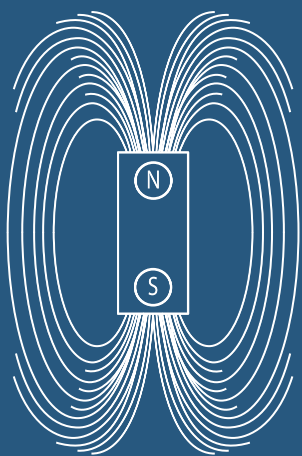
Step 7: Collecting Generator Output Data
Have each group hook their generator up to the LED and low voltage bulbs to see if it will light up the bulbs. Generators with less than 200 windings will probably not light the bulbs. Poorly made generators with a great deal of friction or misplaced magnets will not work well.

To spin the generators, have students first use their hands and record the AC voltage that is created at low speed. Then have students hook the generators up to a drill and record the AC voltage that is created at high speed. Have students record the data on their worksheets. After each group has collected their data, record the class data on the board and have students record it on their worksheets so they can make a graph of the data.

mechanical energy into electrical energy and it becomes a generator. When you put electricity into a motor-generator it spins and becomes a motor.

One example of this is the motor-generator that is used in electric vehicles. When the vehicle is accelerated, the batteries supply power to the motor-generator and it acts as a motor, making the wheels spin and the car move forward. When the brake is pressed, the motor-generator uses the vehicle's inertia to spin and to generate electricity. Some of this energy is stored in the car batteries.

MAGNETIC FIELD



Magnetic fields of flux surround magnetic objects. This field can be felt when you get two magnets near each other or put magnets near other metal objects. The strength of these fields depends on the size, type, shape, and orientation of the magnets. The poles of magnets are often labeled North and South.

Step 8: Wrap Up

Some questions for class discussion include:

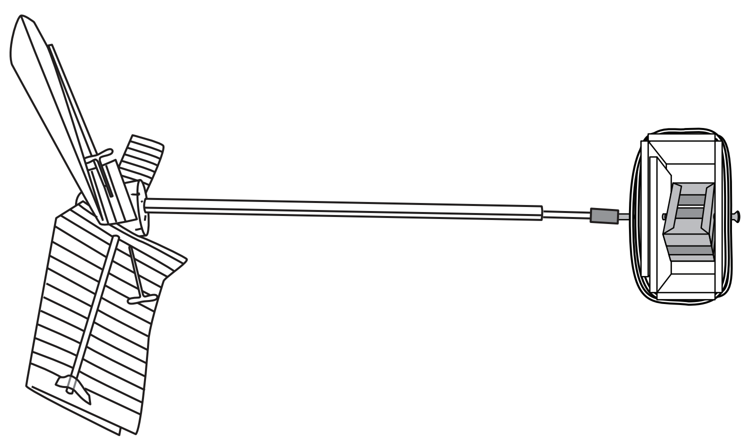
- What were some of the problems building the device?
- How do they solve these problems on the commercial generators that you examined?
- How could your team have improved the design of this generator?
- What generator made the most voltage?
- Why do you think that occurred?
- What was the minimum number of wire turns needed to light a bulb?
- How might it affect your output if you had smaller diameter wire?
- How did stronger magnets affect the output of the generator?
- How did the rate of spin affect the output?
- When you attached the bulb, was it harder to spin?
- If you got the bulb to light, why did it flicker?

EXTENSION

Extension Activity 1

Students can attempt to connect the windmill they constructed in Lesson 6 to the generator they built in this activity. By attempting this additional activity, students can further explore energy transformations that start with wind energy as the energy source.

For example:



Extension Activity 2

Students can spend time improving the efficiency or output of the generator by changing the wire size, the number of windings, or the number and strength of magnets they are using. They can also explore ways to reduce the friction and increase the spin rate.

Let students use neodymium magnets, which are very strong and have a larger magnetic field (flux). Use care with these magnets. They can be very strong and snap together with a great deal of force.

Use smaller magnet wire (32-40 gauge) and let students try to wind 1,000 turns of wire in the same amount of space.

Use a faster drill or build some gearing mechanisms on your driveshaft to increase your spin rate.

VOCABULARY

Alternating Current (AC) – Electric current that flows in two directions – back and forth over and over again. The polarity (+/-) at the generator is constantly reversed by alternating the magnetic poles past the coils. Most household outlets have AC current.

Coil – A winding of magnet wire. All generators and motors have coils in them that vary in size, number, shape and orientation.

Direct Current (DC) – Current that flows in one direction. A battery, capacitor, or spinning DC motor all provide DC current.

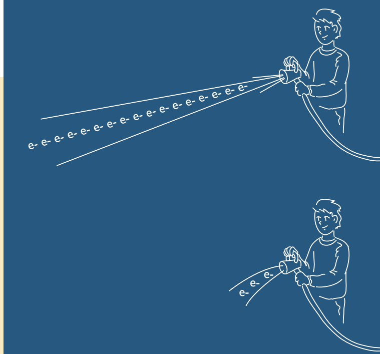
Electrical Generator – A device that converts mechanical energy to electrical energy.

Electromagnet – By putting current through a wire, you can make a wire magnetic.

Electromagnetic Induction – Moving magnets near wires will create electric voltage in the wires. The amount of voltage depends on how quickly you move the magnets past the wires or vice versa. The more wire that interacts with the magnetic flux, the higher the voltage and subsequent current generated.

Magnetic Field (Flux) – The space around a magnet where the force is exerted. This force is stronger the closer you get to the magnet and can be stronger or weaker depending on the type of magnet. Different areas of the magnet have opposite or opposing forces. We typically label these areas the north and south poles.

VOLTAGE

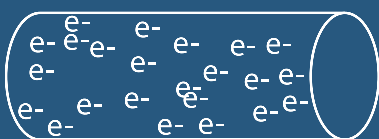


A negative charge will attract a positive charge. Invisible fields of voltage exist between the charges—kind of like magnetic fields. Voltage causes the attraction between opposite charges. We can quantify this attraction with a simple multimeter.

Using water as an analogy, we can also think of voltage like water pressure. Low voltage would be water under low pressure. High voltage would be water under high pressure. The amount of water is not so important—it is the pressure of the water that matters.

CURRENT

Less Current



More Current

Current is the flow of electric charge in a conductor.

Using water we can think of this as the amount of water flowing in a tube. The higher the current, the more water that is moving in the tube. Low current would be similar to less water flowing in the same size tube.

Current is measured in Amperes (A).

RELATED ACTIVITIES

- How Does a Windmill Work?

ADDITIONAL RESOURCES

WEBSITE OF BILL BEATY—http://amasci.com/amateur/coilgen.html —Lots of great information about magnetism, electricity and other subjects from the generator designer, Bill Beaty.

OTHERPOWER.COM—http://www.otherpower.com/turbineplans.shtml —See plans for building a small, home-built wind generator. The links for the stator and magnet rotors are interesting and applicable.

MAG LAB U—http://www.magnet.fsu.edu/education/tutorials/java/electromagneticinduction/index.html —Java applet on how electromagnetic induction works.

MAG LAB U—http://www.magnet.fsu.edu/education/tutorials/java/dcmotor/index.html —Java applet on how a DC motor works.

NY STATE STANDARDS

Intermediate Level Science–Standard 4: The Physical Setting
Key Idea 5
Energy and matter interact through forces that result in changes in motion.

Major Understandings:
5.2b Electric currents and magnets can exert a force on each other.

5.2c Machines transfer mechanical energy from one object to another.

Intermediate Level Science–Standard 1: Analysis, Inquiry and Design
Scientific Inquiry

Key Idea 2:
Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

Intermediate Level Science–Standard 1: Analysis, Inquiry and Design
Technology Standards

Key Idea 1:
Engineering design is an iterative process involving modeling and optimization finding the best solution within given constraints which is used to develop technological solutions to problems within given constraints.

Mathematics–Standard 3
Key Idea 5:
Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data.

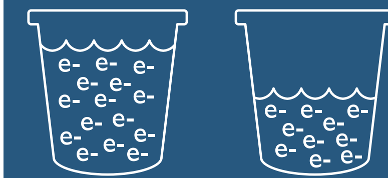
Intermediate Level Science–Standard 4: The Physical Setting
Key Idea 4:
Energy exists in many forms and when these forms change energy is conserved.

Major Understandings:
4.1b Solar energy, wind, moving water, and biomass are some examples of renewable energy resources.

4.1c Most activities in everyday life involve one form of energy being transformed into another.

4.4d Electrical energy can be produced from a variety of energy sources and can be transformed into almost any other form of energy.

ENERGY



Energy is something that can do work.

In our water analogy this would be equivalent to a bucket of water. It is a quantity of energy that can do a certain amount of work. If we had a lot of pressure (voltage) and a lot of water (current) moving through a hose we could fill up the bucket very fast. In electrical terms a bucket of energy is kind of like a battery.

4.4e Electrical circuits provide a means of transferring electrical energy.

4.4g Without direct contact, a magnet attracts certain materials and either attracts or repels other magnets. The attractive force of a magnet is greatest at its poles.

Physical Setting–Physics (High School)
Key Idea 4:
Energy exists in many forms and when these forms change energy is conserved.

Major Understandings:
4.1b Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms.

4.1j Energy may be stored in electric or magnetic fields. This energy may be transferred through conductors or space and may be converted to other forms of energy.

4.1k Moving electric charges produce magnetic fields. The relative motion between a conductor and a magnetic field may produce a potential difference in the conductor.

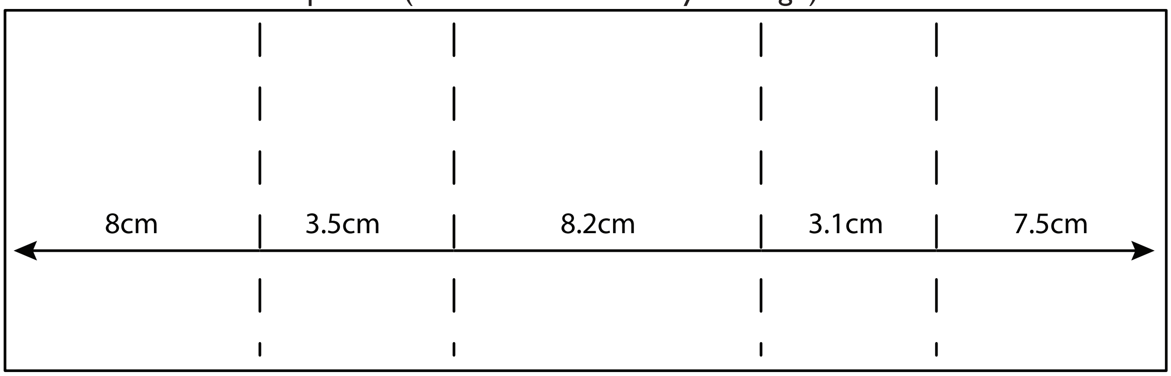
4.1l All materials display a range of conductivity.

4.1m The factors affecting resistance in a conductor are length, cross-sectional area, temperature, and resistivity.

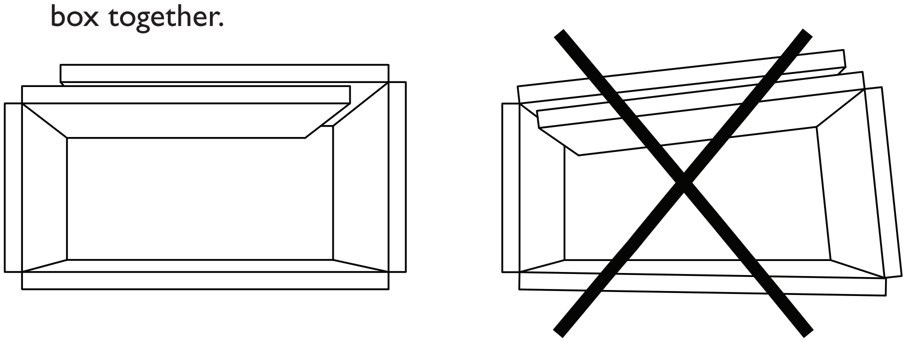
4.1p Electrical power and energy can be determined for electric circuits.

CONSTRUCTION PLANS – HOW TO BUILD THE GENERATOR

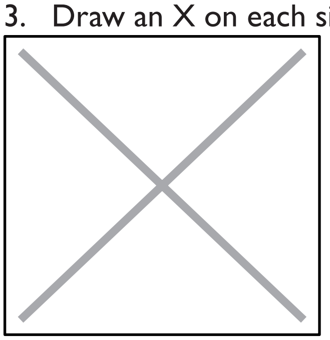
1. Measure these dimensions on your piece of coroplast or cardboard. At each of the marks, score the material with a sharp knife (do not cut all the way through).



2. Fold to make a box. There is a right way and a wrong way! Once you are satisfied, you can tape your box together.

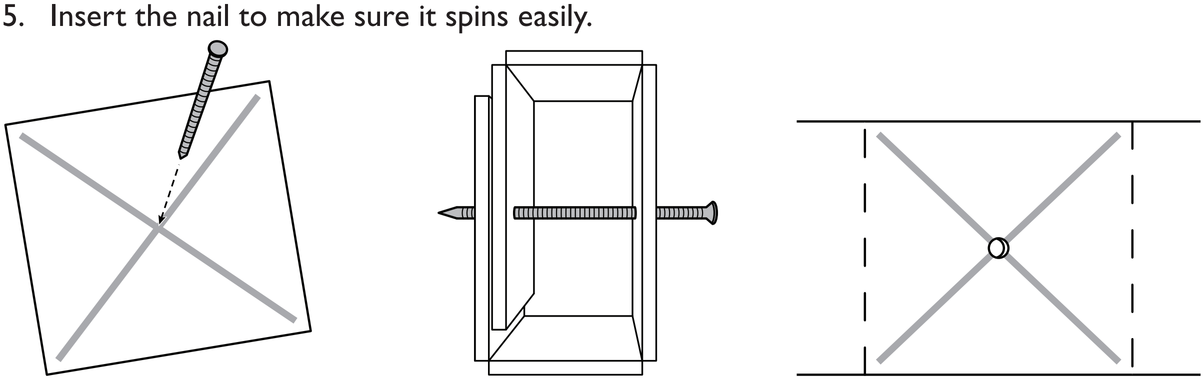


3. Draw an X on each side to find the middle of the box.

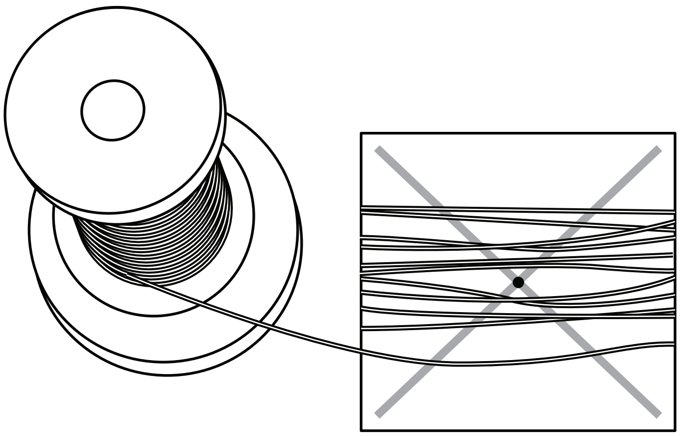


4. Poke a hole with a nail through the center of the X. It is important to make this hole bigger than the nail as it can cause a great deal of friction.

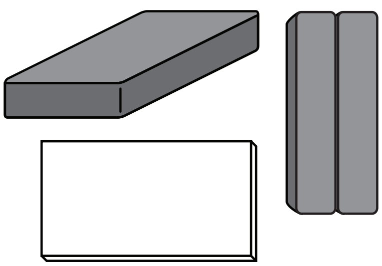
5. Insert the nail to make sure it spins easily.

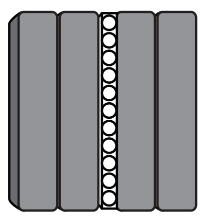


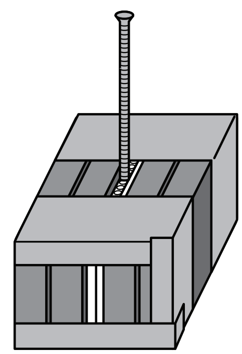
6. Wind magnet wire around generator counting each turn of wire. It is important to try and keep the wire in the middle of the generator and make your lines tight and straight. Once you have wound your coils, you can tape them in place. We are using 28 gauge on our generator but you can vary your size to experiment.



7. Build the magnet assembly by sandwiching a piece of coroplast between magnets; tape to make the assembly secure. We have two ceramic magnets stacked on each side to provide more magnetic flux. You can also try just using one magnet on each side or using neodymium (strong) magnets.

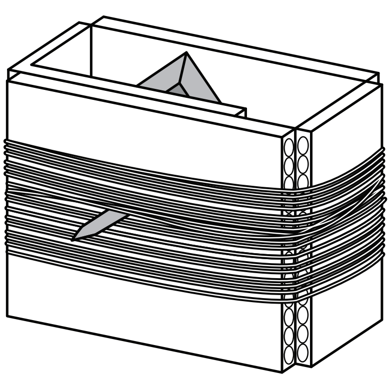


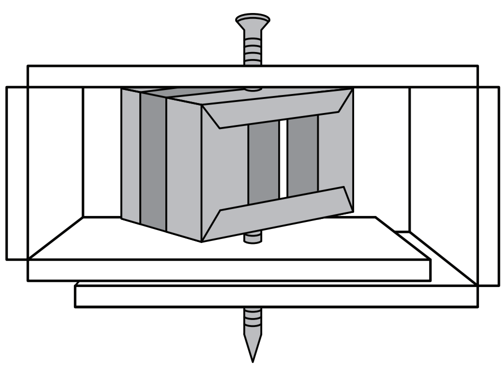




8. Push your nail through the coroplast. This will be hard as it is very tight, but this is good as it will provide a friction fit and not slip on the shaft when you spin the magnets.

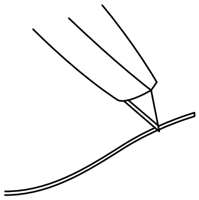
9. Put your magnets in your box and push the nail through the holes you made. It will take some care to line up and push through. You can do it!



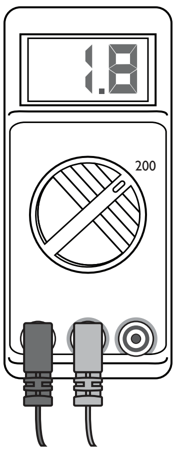


10. Once assembled spin to test for balance and friction.

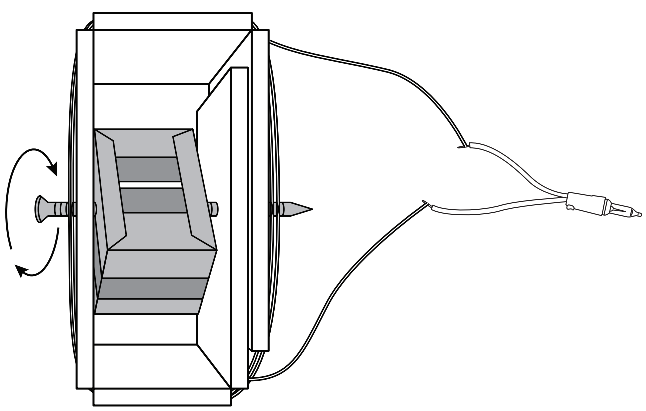
11. Strip the enamel off the ends of your magnet wires for a good connection to the multimeters or LED.



12. Set your meter to measure AC.



13. Attach your bulb or meter and spin.



14. You can spin the generator with your hand or a drill.

15. A well-built generator with around 150-200 turns of wire should definitely light a bulb with hand spinning or by using a drill. We have had simple generators like this make 2-4 volts by hand spinning and even more if we use a drill.

Common problems:

- Make sure you have made your holes large enough to reduce friction.
- Make sure you have really cleaned the enamel off the ends of the wires or you will not conduct any electricity.
- Make sure that you have wound enough coils; less than 100 turns will not light a bulb.
- Make sure your coils are straight, tight and neat.
- Make sure your magnets are not slipping.

Generator Grading Rubric

GENERATOR PARTS	BOX CONSTRUCTION	WINDING	MAGNETS	OVERALL
Excellent	Box is square and solid. Driveshaft is properly centered and can spin easily as the holes it sets in have been widened. Frame has tape neatly applied.	Windings are tightly wound, straight and neat around the driveshaft area. Wires are stripped at the ends and attached to frame securely.	Magnets are secured to the driveshaft very well and do not slip when you spin the driveshaft. They are centered and do not hit the sides of the generator frame when spun.	This generator is very solid, neat and spins well. If it has enough windings it can easily light a bulb by hand spinning.
Good	Box is a little off square and not so neat. Driveshaft can spin but could be improved with more friction reduction.	Windings are wound properly but may not be straight or neat. May be wound a little too tight. Wires may not be centered around the driveshaft. Wire ends are stripped.	Magnets are secured but may slip sometimes. Centered well but may hit sides of the frame.	If it has enough windings the generator works sometimes by hand spinning or the drill. The frame and windings are solid but could be more square and carefully constructed.
Poor	Box is not square and feels fragile. Driveshaft cannot spin easily and does not seem to be centered properly. Does not have a neat appearance. Mistakes in construction are covered up with duct tape.	Windings are loose, tangled and not secured to the frame. Wire ends are not properly stripped. Wires are spread all over and not concentrated near the driveshaft area.	Magnets are not centered and slip when spun. They tend to move around and hit the frame when you spin them.	Generator looks sloppy, is not square and does not spin well. Magnets may be hitting sides of generator. It will not light a bulb even if spun with the drill and despite having enough windings.

Name______________________________________ Date________________ Class_________

HOW TO BUILD A GENERATOR

Understanding Generators

1. Draw a magnet. Label the poles and field lines. Next to your magnet, draw a simple wire coil.

2. How might the magnetic fields (flux) interact with the wire?

3. Which is larger: 20 gauge or 30 gauge wire? _______________

Building & Testing Your Generator

Build your generator using the construction plans and materials provided.

1. How many times did you wind the wire on your generator? _______________

2. What size is the wire? _______________

Voltage Output:

NUMBER OF MAGNETS AND TYPE	VOLTAGE OUTPUT (HAND)	VOLTAGE OUTPUT (DRILL)	DID IT LIGHT A BULB?

Name_______________________________________ Date________________ Class_________

Once you have collected your own data, share it with others and put it on the board.

3. Draw a picture of the generator your team built and label the coils, magnets, and driveshaft.

4. Where do you think the magnetic fields are affecting the wires the most?

5. How does your generator compare to the commercial generators where you were able to see the insides? How were they different or similar? (Optional, depending on materials)

6. What parts of the generator had a great deal of friction? How could you improve the design and performance?

Analyzing Generator Performance

Graph the class data. Show the number of windings versus AC voltage at low speed (hand) and at high speed (drill).

STUDENT GROUP	# OF WINDINGS	# OF MAGNETS	MAGNET TYPE	AC VOLTAGE (HAND)	AC VOLTAGE (DRILL)	DID IT LIGHT A BULB?	DESIGN PROBLEMS

Name______________________________________ Date________________ Class_________

1. What are the independent and dependent variables?

Answer the following questions using the class data:

2. What generator made the most voltage?

3. What was the minimum number of wire turns needed to light a bulb? __________________________

4. How might smaller diameter wire affect the output?

5. How did stronger magnets affect the output of the generator (if used)?

6. How did the rate of spin affect the output?

7. When you attached the bulb, was it harder to spin?

8. If you got the bulb to light, why did it flicker?

1. Draw a magnet. Label the poles and field lines. Next to your magnet, draw a simple wire coil.

2. How might the magnetic fields (flux) interact with the wire?
   Students observations. Students might say the wire is attracted and repelled. It is doubtful that they will make the leap to electrons moving in the wires unless coached. The magnetic fields of force will cause the electrons in the wires to move. As the field switches from north to south as the magnets spin, the electrons will move back and forth.

3. Which is larger: 20 gauge or 30 gauge wire? *20 guage*

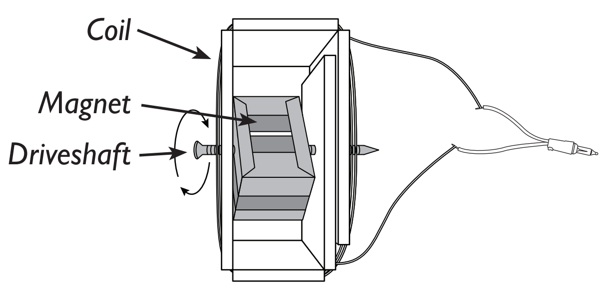
Building & Testing Your Generator

Build your generator using the construction plans and materials provided.

1. How many times did you wind the wire on your generator? *Student observation*

2. What size is the wire? *28 gauge (but teachers might have different sizes)*

3. Draw a picture of the generator your team built and label the coils, magnets, and driveshaft.



4. Where do you think the magnetic fields are affecting the wires the most?
   With the basic ceramic magnets the wires at the end of the generator are most impacted by the magnetic fields.

5. How does your generator compare to the commercial generators where you were able to see the insides? How were they different or similar? (Optional, depending on materials)
   Both devices will have coils of wire and magnets. On many of the motors and generators, the coils of wire will be the part that spins and the magnets are stationary.

6. What parts of the generator had a great deal of friction? How could you improve the design and performance?
   Where the nail touches the box can produce a great deal of friction. Making the hole larger or using a bushing can improve this. There might also be slipping of the magnets on the driveshaft as it spins; securing with tape or glue can solve this as well.

Analyzing Generator Performance

Graph the class data. Show the number of windings versus AC voltage at low speed (hand) and at high speed (drill).

If the generators are built with care then what you should see on the graphs is that more windings equals higher voltage. Also, faster spinning should increase voltage output.

1. What are the independent and dependent variables?
   The independent variable is the wire winding. The dependent variable is the voltage.

Answer the following questions using the class data:

2. What generator made the most voltage?
   Should be the generator with the most windings, but this can be greatly impacted by the quality of construction and the neatness of the wire windings.

3. What was the minimum number of wire turns needed to light a bulb? <u>*Student observations; around 150.*</u>

4. How might smaller diameter wire affect the output?
   Smaller wire would allow you to pack more windings in a smaller space. More windings will increase your voltage. But watch out! If the wire is too small, the resistance of the wire can impede the flow of electrons and start to heat up and become less efficient.

5. How did stronger magnets affect the output of the generator (if used)?
   Stronger magnets should increase voltage as they have more magnetic flux.

6. How did the rate of spin affect the output?
   Faster spin changes the magnetic field more quickly, which should increase voltage, but this depends on how well the device is wound.

7. When you attached the bulb, was it harder to spin?
   When you put a load (light bulb, motors) in the circuit, it should be harder to spin. This may be somewhat noticeable with your hand but probably not with the drill.

8. If you got the bulb to light, why did it flicker?
   The generator produces alternating current (AC) as the magnet spins around near the coils. If you wire the output to the red LED you will get a pulsed light (since LEDs only accept one direction of current flow). If you can count fast, you may be able to count the LED light pulses and figure the frequency of the AC being generated. Say it blinks 10 times/second; that would be 10Hz.