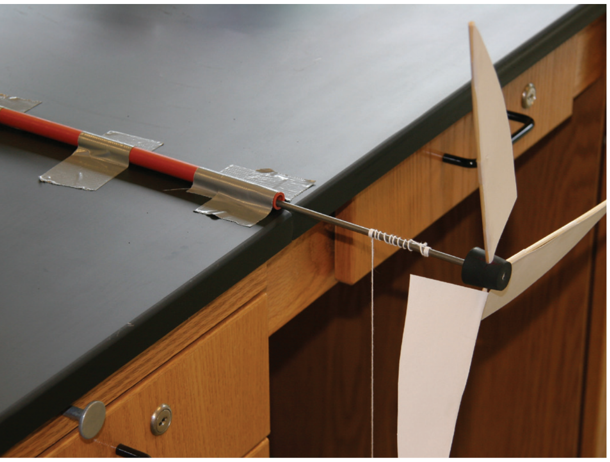
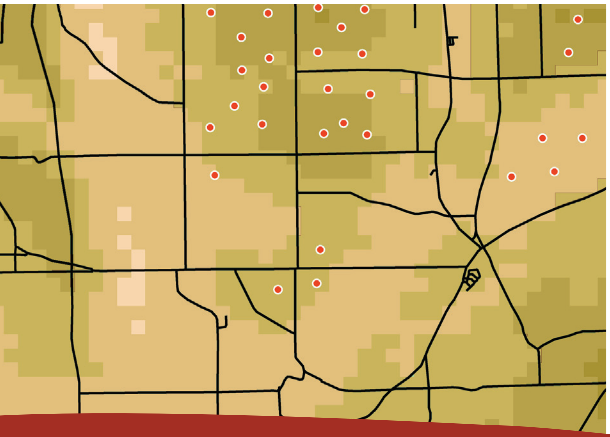
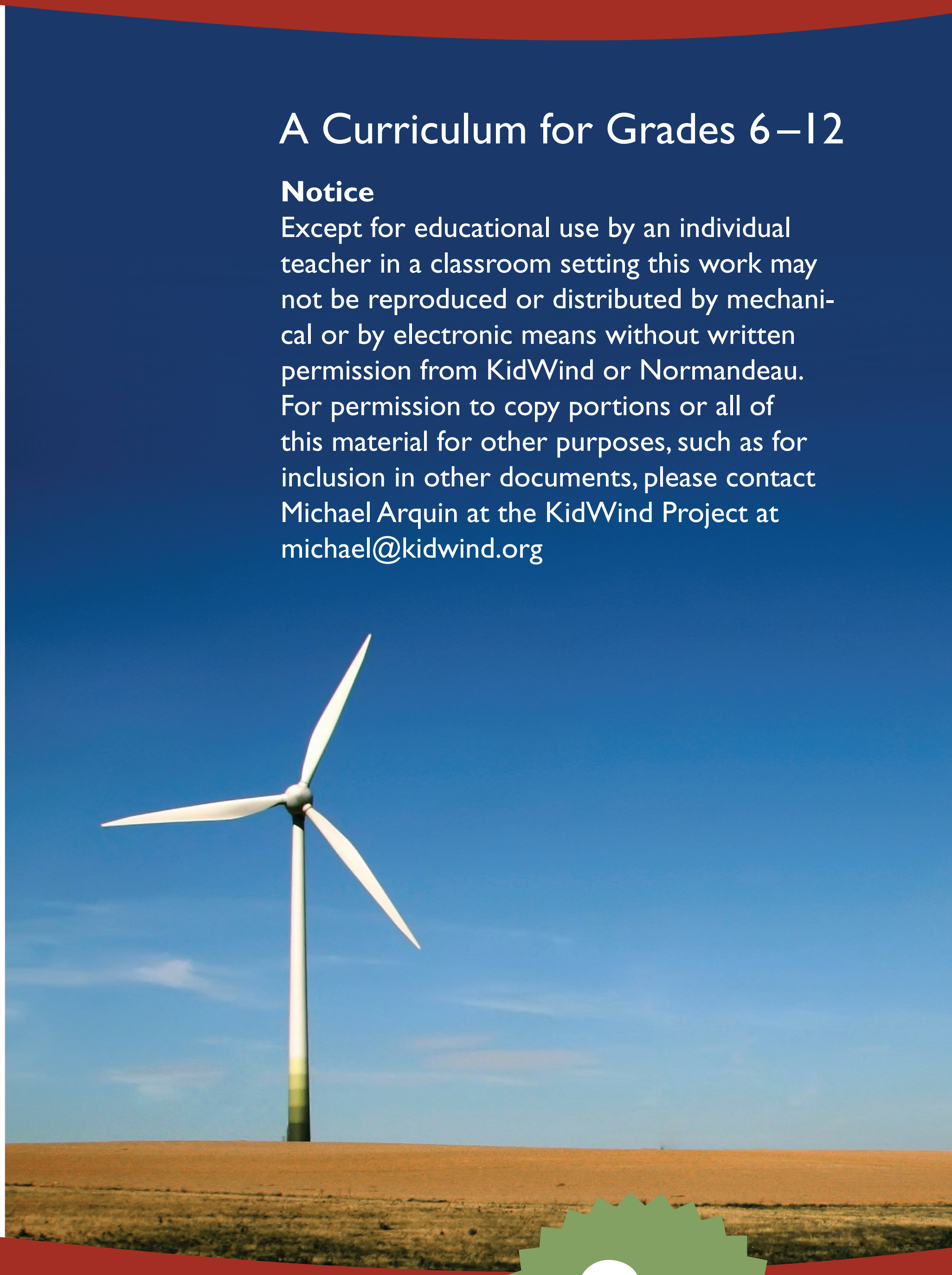
WindWise Education

Transforming the Energy of Wind into Powerful Minds







A Curriculum for Grades 6–12

2nd edition

windwise education

www.WindWiseEducation.org

NYSERDA
New York State
Energy Research and
Development Authority

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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V2.0

LESSON 9

HOW DOES A GENERATOR WORK?

KEY CONCEPT

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

TIME REQUIRED

1–2 class periods

GRADES

6–8
9–12

SUBJECTS

Physical Science

windwise education

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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 to build one generator:

- ❑ 1 rectangular white box
- ❑ 4 ceramic magnets (1 × 2 × 5 cm)
- ❑ 1 magnet holder (orange)
- ❑ ½ spool of 28 gauge magnet wire
- ❑ 1 hex driveshaft (4" long)
- ❑ 1 bicolor or red LED
- ❑ Simple digital multimeter
- ❑ Construction plans for each group (provided)
- ❑ Student worksheets (provided)

Classroom materials to share:

- ❑ Drill
- ❑ Craft knife or scissors
- ❑ Electrical tape or duct tape
- ❑ Windmill from Lesson 8 (optional)

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

- ❑ Examples of small or medium generators or DC motors
- ❑ KidWind Hubs from Lesson 10 or 11

MOTORS & GENERATORS: WHAT IS THE DIFFERENCE?

It is great to provide students examples of commercially made generators or DC motors, so they can see what is 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 components similar to those in the generator we are building.

Keep in mind that at the scale at which 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 mechanical energy into electrical energy and it becomes a generator. When you put electricity into a motor-generator, it spins and becomes a motor.

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 copies of 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) Track down some sample DC motors and/or DC or AC generators to use as 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 electricity?
- What is a generator?
- What parts make up a basic electrical generator?
- How do we generate electricity (Lessons 2)?
- 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

Ask students to 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 two to three students each. Distribute a few magnets to the student groups. Ask the students what they notice about the magnets. Discuss repelling and attracting 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 students 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 observations 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 and wire
Discuss with students how the magnetic fields (flux) might impact the wire or what the wire is composed of. This discussion 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 from the other groups so that the class can collect and compare data for the different designs.

Cover the topics listed below before students build their generators:

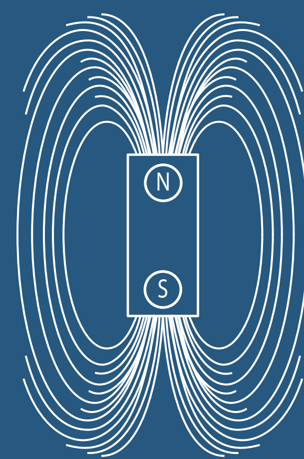
- Windings: be sure to show students a few generator windings in commercially made generators or in your homemade ones. Students should notice how straight the magnet wire is lined up as it is coiled. They should try to duplicate this in their generators.
- Driveshaft: students should make sure they do not put wires over the holes in the box where the driveshaft will be placed as this can cause friction or break the wire.
- Stripping magnet wires: before students connect their wires to the multimeter or LED bulb, they must make sure that the wires have been stripped using sandpaper or the sharp edge of a scissors. It is a good idea to secure the wires to the box once you have them stripped so they do not get tangled.

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

Step 7: Collecting generator output data
Ask each group to hook its generator up to the LED and low-voltage bulbs to see if the generator will light up the bulbs. Generators with less than 100 windings will probably not light the bulbs.

To spin the generators, tell students to first use their hands and record the AC voltage that is created at low speed. Then direct students to hook the

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.

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 ask students to record it on their worksheets so they can make a graph of the data.

Step 8: Wrap up

Some questions for class discussion include:

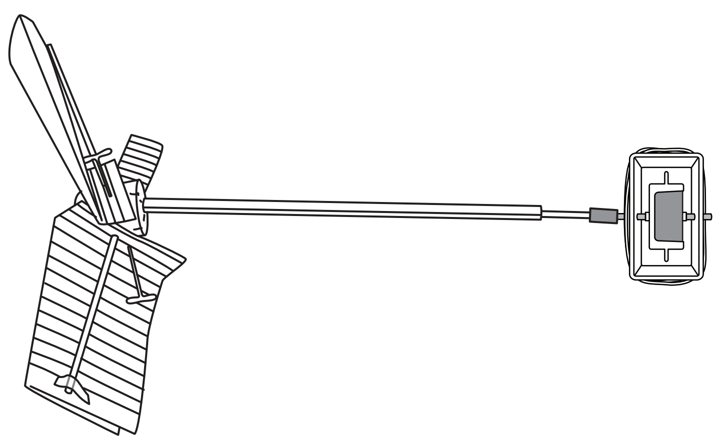
- What were some of the problems in building the device?
- How are these problems solved on the commercial generators that have been examined?
- How could your team have improved the design of this generator?
- What generator made the most voltage?
- Why do you think that occurred?
- What was the minimum number of wire turns needed to light a bulb?
- If you had smaller diameter wire, how might it affect your output?
- 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

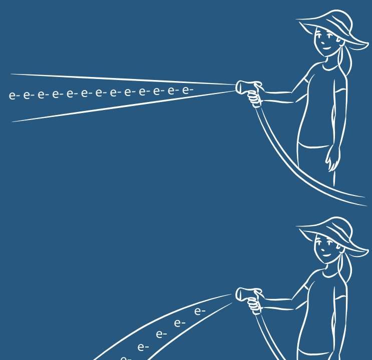
Extension Activity 1

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. Students can also use KidWind Hubs that are found in many KidWind kits. These hubs attach to the green quick connect at one end of your driveshaft. You can then attach blades to the hub and see how well the generator will run using wind power.

For example:



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.

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 contain coils 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.

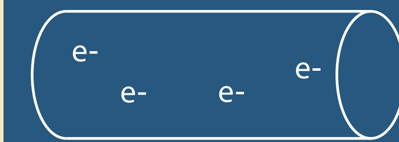
electrical generator – A device that converts mechanical energy to electrical energy.

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

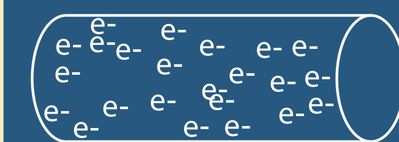
electromagnetic induction – Moving magnets near wires will create electric voltage in the wires. The amount of voltage depends on how quickly you move the magnets past the wires or vice versa. The more wire that interacts with the magnetic flux, the higher the voltage and subsequent current generated.

magnetic field (flux) – The space around a magnet where its 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.

CURRENT



Less Current



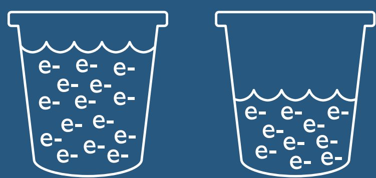
More Current

Current is the flow of electric charge in a conductor.

We can think of this as the amount of water flowing in a tube. The higher the current, the more water 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).

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.

RELATED ACTIVITIES

- Lesson 8: How Does a Windmill Work?

ADDITIONAL RESOURCES

BILL BEATY—http://kwind.me/o8g—Lots of great information about magnetism, electricity and other subjects from the generator designer, Bill Beaty.

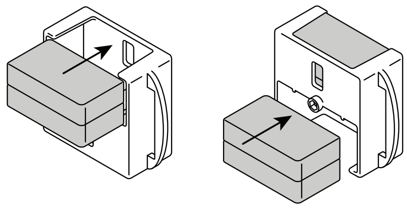
KIDWIND PROJECT—http://kwind.me/x3r—Multimeter Tutorials: KidWind has a number of video tutorials on using a multimeter

MAG LAB U—http://kwind.me/u8v—Java applet on how electromagnetic induction works.

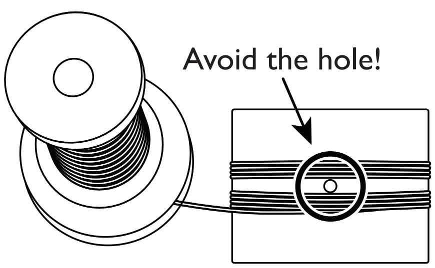
MAG LAB U—http://kwind.me/u5c—Java applet on how a DC motor works.

OTHERPOWER.COM— http://kwind.me/t6v—See plans for building a small, home-built wind generator. The links for the stator and magnet rotors are interesting and applicable.

HOW TO BUILD A SIMPLEGEN

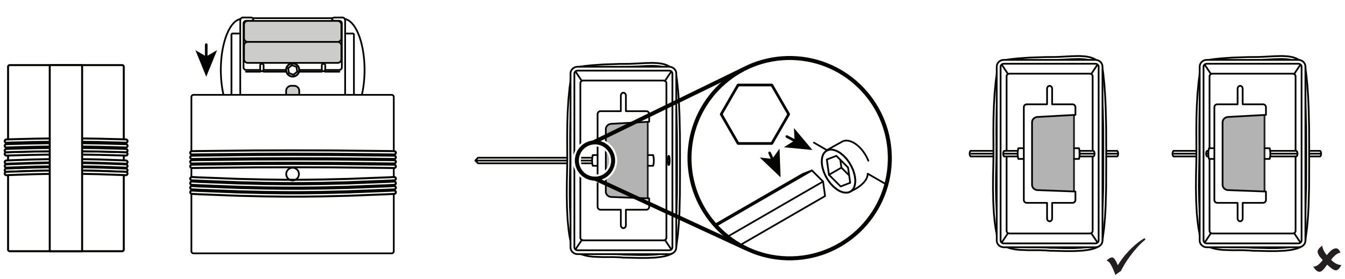


Step 1. Magnets
Insert magnets into the magnet holder. You will want to use *two magnets* on each side. In order for the generator to work properly you need to make sure you have opposite fields facing outwards, north on one side, south on the other. An easy way to test is to take one magnet and place it near each side of the holder after the magnets are inserted. One side should attract and the other should repel the testing magnet.



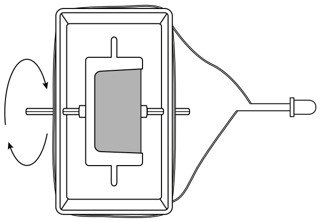
Step 2. Wire
Determine how many turns of wire you will wrap around your generator box. Each turn will use approximately 28 cm of wire. Wrap the wires neatly around the top and bottom of the hole where the drivetrain will be located. *Do not* cover up the drivetrain hole. *Do not* cut the wire in between the top and bottom coil. Wrap the top and bottom coil in the *same direction.* When you have finished wrapping, you can tape your coils in place. Make sure to leave leads extended from the box.

Step 3. & 4. Spin
Insert the magnet holder with magnets into the generator box. Align the hex driveshaft with the magnet holder center hole and insert. When spinning make sure that the magnet holder is centered in the generator box.



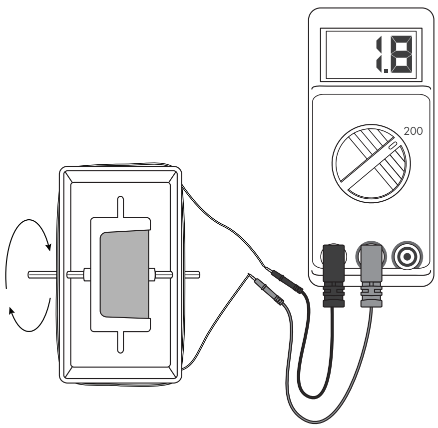
SIMPLEGEN TESTING

To collect output on how well your generator is performing you, can attach an LED bulb or use a digital multimeter.



LED

Depending on how many turns of wire or the size of the wire used, you may be able to light up an LED as you spin the generator. You can get a rough idea of how much current or voltage you are generating if the LED lights up at all or how brightly it glows.



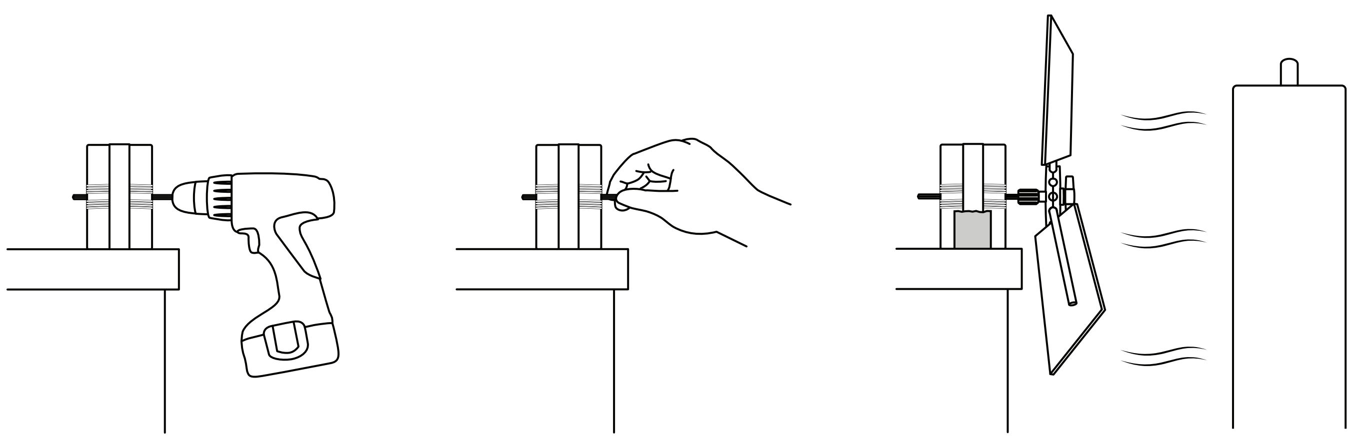
Multimeter

Using a simple multimeter set to measure AC voltage you can collect data on the output of your generator as you conduct comparative experiments.

Spinning your generator

You can use your hands or a drill to spin your generator. For experimental purposes it is better to use a drill as you can maintain a constant speed over a longer time.

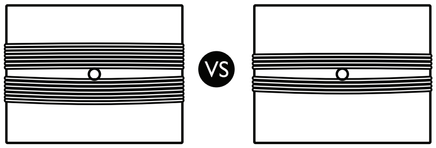
You can also turn your generator into a wind turbine by attaching a KidWind hub the drive train, making some blades and placing the turbine in front of a fan or out in the wind. For more details on making wind turbine blades, see WindWise lessons 10 and 11.



Common problems:

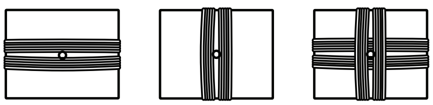
- Make sure you have really cleaned the enamel off the ends of the wires or you will not conduct any electricity.
- Make sure that you have wound enough coils; less than 100 turns will not light a bulb.
- Make sure your coils are straight, tight and neat.

Number of Coils



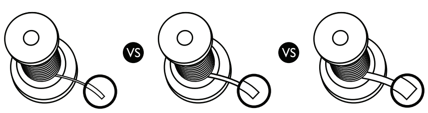
More coils Fewer coils

Orientation of Coils



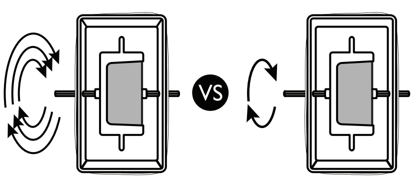
Horizontal coils | Vertical coils | Horizontal & vertical coils

Size of Wire



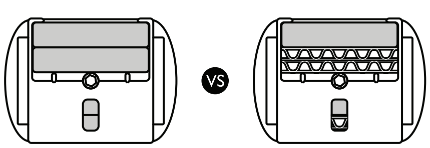
28 gauge wire | 22 gauge wire | 32 gauge wire

Speed of Spinning



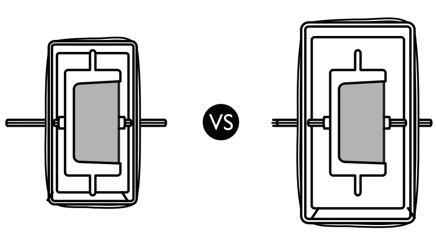
Faster Slower

Number of Magnets



Four magnets | Two magnets, two shims

Distance from Magnets to Coils



Smaller box Larger box

GENERATOR EXPERIMENTS

Coils

Number of turns, total number of coils, orientation of coils

How you wind your coils can affect how well a generator works. Try testing generators with different numbers of turns of wire, different orientation of coils, or different numbers of coils.

Size of wire

The size of the wire can affect how many turns of wire you can get close to the magnetic field. Try wrapping the same number of turns using different wire sizes. What happens to your voltage output?

Speed of spinning

How fast you spin your magnets can affect your voltage output. Try spinning your generator at different speeds and see what happens.

Number of magnets

On one generator, use only one magnet on each side of the magnet holder. You can do this by making a cardboard shim and substituting it for one of the magnets on each side. How does this affect your voltage output?

Strength of magnets (*safety issue*!)

You can buy larger neodymium magnets from a number of companies. Look for a size that will fit into the magnet holder. See what happens to your output when you use stronger magnets. Use caution because large neodymium magnets are *very* strong and can cause injury.

Distance from magnets to coils

We have provided a simple box to wind your coils. If you want to get creative, you could build your own box that tries to get the coils closer to the magnets. This can greatly improve your performance.

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?

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 that you were able to see inside? 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	NUMBER 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. If stronger magnets were used, how did they affect the output of the generator?

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

7. When you attached the bulb, was the generator 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 students 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 gauge*

Building & testing your generator

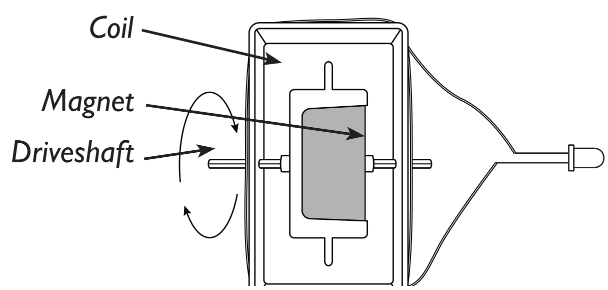
Build your generator using the construction plans and materials provided.

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 that you were able to look inside? 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?
   The place 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 them 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. Which generator made the most voltage?
   This 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? *Student observations; around 150.*
4. How might smaller diameter wire affect the output?
   Smaller wire would allow for packing more windings in a smaller space. More windings will increase 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. If stronger magnets were used, how did they affect the output of the generator?
   Stronger magnets should increase voltage because they have more magnetic flux.
6. How did the rate of spin affect the output?
   Faster spin charges 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 the generator harder to spin?
   When you put a load (light bulb, motors) in the circuit, the generator should be harder to spin. This may be somewhat noticeable with hand spinning 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 because 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.