



## Level A Investigations

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### A-1 Magnets

*What happens when you put two magnets next to each other?*

Students observe attractive and repulsive forces between a pair of magnets. They discover that opposite poles attract and like poles repel. Next, they measure the distance over which a magnetic force can occur.

### A-2 Magnetic Materials

*What kinds of things are affected by magnets?*

Students experiment with different objects to identify the difference between magnetic and non-magnetic materials. They compare the relative sizes of the forces of attraction by measuring the distance a magnet can move various objects.

### A-3 How a Motor Works

*How does a motor work?*

Students learn about the parts of an electric motor. In particular they learn how permanent magnets and an electromagnet work together to cause a motor to spin. They learn that they can control the direction of spin by changing the orientation of the magnets.

### A-4 Designing Motors

*How do you design a motor?*

Students apply what they have learned about how a motor works to design different motors. They must determine the best placement of magnets to make the motor run for each of the commutator disks. More than one design works for each disk, so they must decide which design works best.

### A-4 Measuring Current and Voltage

*How do you use a digital multimeter to measure current and voltage in the electric motor?*

Students measure the current and voltage used by the motor. Next, they use the generator coil and the hand crank to produce electricity. Finally, students measure the voltage produced by the generator.

## Level B Investigations

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### B-1 Permanent Magnets

*What effects do magnets have?*

In this Investigation, students explore how magnets affect each other and discover which materials are attracted to magnets. They also learn about precision in making measurements and calculating averages.

## **B-2 Electromagnets**

*Can electric current create a magnet?*

Students learn about and build a simple electromagnet using wire and a nail. They locate the north and south poles as a function of the direction of current flowing in the electromagnet. Next, they measure the strength of the electromagnet with different amounts of current.

## **B-3 The Electric Motor**

*How does an electric motor work?*

Students learn how reversing magnets causes an electric motor to turn. They build an electric motor and measure its speed, and then design and test several different motors using the switching disks. The speed of the motor as measured in revolutions per minute (rpm) is introduced as a way to gauge the quality of the motor.

## **B-4 Current, Voltage, and Power**

*How much electricity does the motor use?*

Students measure the current and voltage used by the motor when it is spinning and when it is held in place. They construct several different motor designs with varying numbers of permanent magnets. The power consumed by the motor for each design is calculated and compared.

## **B-5 Generators**

*How does a generator work?*

Students learn how moving magnets can be used to create electricity as they build and test an electric generator. The generator coil and crank attachments on the electric motor are used as the components of the generator. By changing the design and speed of the generator, students discover the principle of electromagnetic induction. The amount of electricity generated is proportional to the speed at which the magnets alternate back and forth from north to south.

## **Level C Investigations**

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### **C-1 Introduction to the Electric Motor**

*How much electricity does the motor use?*

Students measure the current and voltage used by the motor when it is spinning and when it is held in place. They construct several different motor designs with varying numbers of permanent magnets and electromagnets. The power consumed by the motor for each design is calculated and compared.

### **C-2 Optimal Performance**

*How can the performance of the motor be optimized?*

In this Investigation, the students experiment with different alignments of the disk to optimize the motor's performance. They will also add a second electromagnet and compare the motor's speed with one electromagnet to its speed with two.

### **C-3 Generators and Faraday's Law of Induction**

*How does a generator use induction to produce voltage?*

Students learn how moving magnets can be used to create electricity as they build and test an electric generator. By changing the design and speed of the generator, students discover the principle of electromagnetic induction. They apply Faraday's law of induction to explain the voltage generated.



Question: How does an electric motor work?

In this Investigation, you will:

1. Build an electric motor and measure its speed.
2. Design different electric motors and evaluate them for speed and electric power.

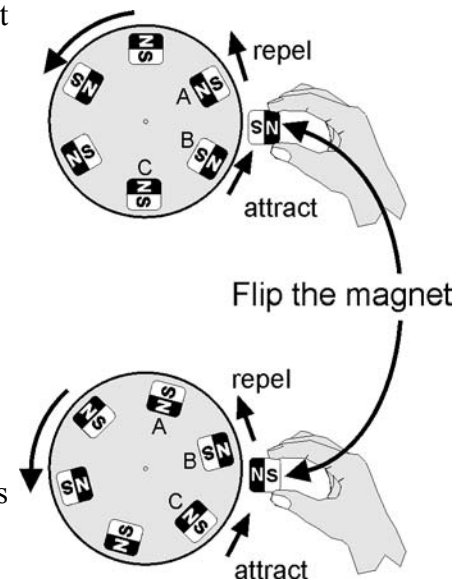
Electric motors are everywhere. You find them in locomotives, washing machines, cars, tools, spacecraft, and anywhere else that we use powered machines. All electric motors use one or both of the two kinds of magnets we just explored, permanent magnets and electromagnets. Permanent magnets are useful because they create the magnetic field without needing any electricity. We will discover that electromagnets are necessary because the north and south poles can be reversed.

## 1 Getting the rotor to spin

Electric motors spin because of the action of magnetism. Try to get the rotor to spin by manipulating magnets.

1. Take the motor apart, and put 6 magnets in the rotor so they are evenly spaced and alternate north-south facing outwards.
2. Bring a stack of two or three magnets close and try to repel one of the magnets in the rotor. The rotor should spin a little.
3. As soon as you move one magnet, reverse the magnet in your fingers to attract and then repel the next magnet on the rotor.
4. By sequentially reversing the magnet in your fingers, try to push and pull on the magnets in the rotor to get the motor to spin.

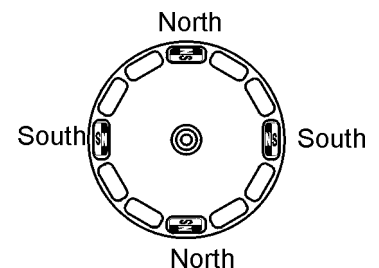
You will see that reversing the poles of the magnet in your fingers is the key to making the rotor spin.



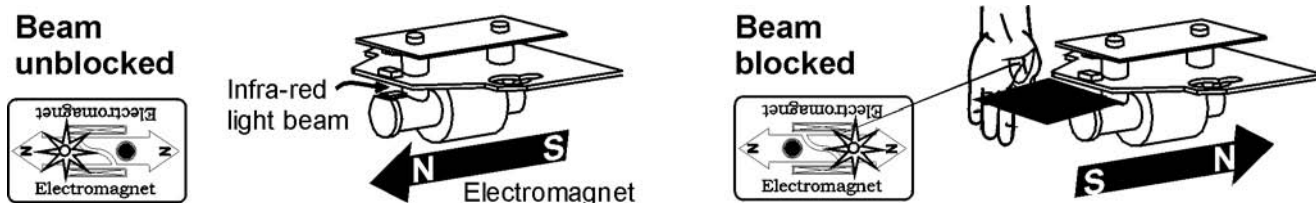
- a. When is the right time to reverse the magnet in your fingers? Think about where the magnets are in the rotor.
- b. How could you make the rotor spin the other way?

## 2 Making a 4-pole electric motor

The key to understanding how electric motors work is learning how electromagnets are used to alternately attract and repel other magnets. If we arrange the electromagnets and permanent magnets just right, the rotor will turn when electricity is connected. The first motor to build is called a 4-pole motor because you are going to use 4 magnets to make 2 north poles and 2 south poles in the rotor.

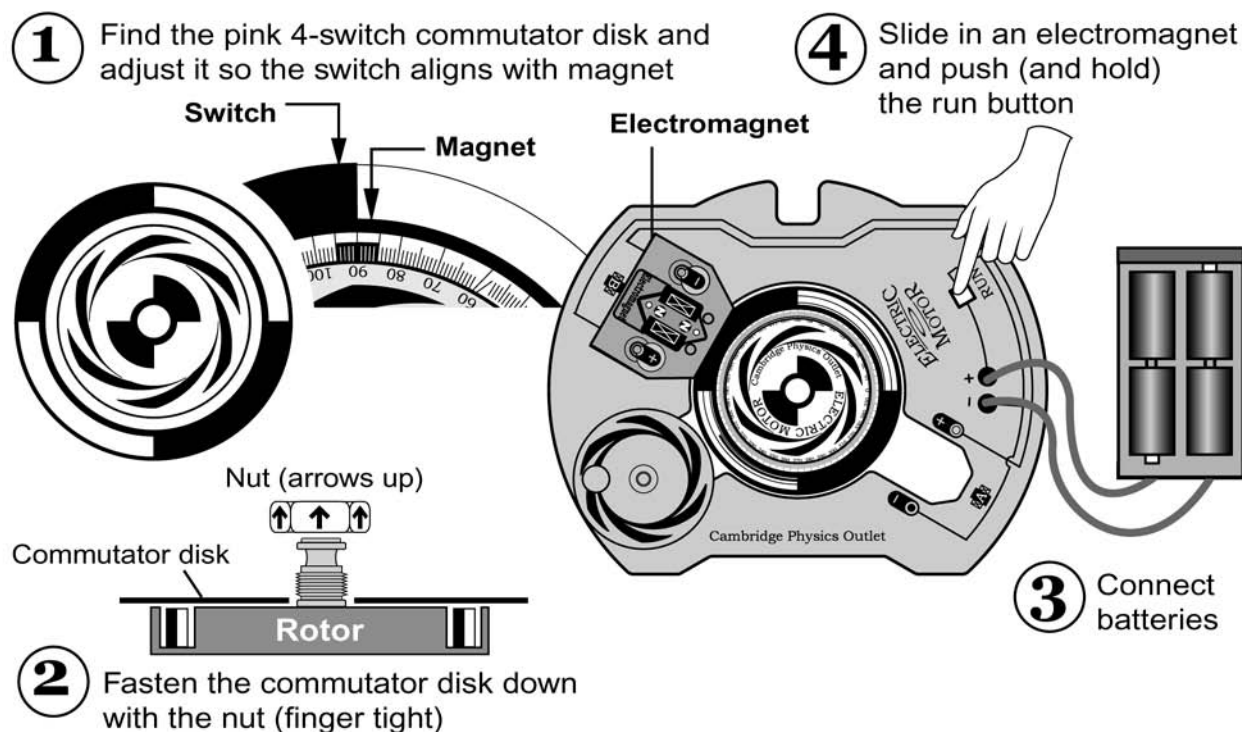


All electric motors use some kind of switch to change the orientation of the poles of the electromagnet at the right time. The device called a **commutator** is used to switch the orientation of the north and south poles of the electromagnet. In the electric motor you are building is a plastic disk (the commutator) and it switches the electromagnets using light.



When the light is not blocked (see diagram above) the current flows in a direction to make the north pole at the front of the electromagnet. Blocking the beam causes the current to reverse, making a north pole at the back, and a south pole at the front. Two green lights indicate where the north pole is.

The commutator (or switching) disks have alternating black and clear sections around the edge that switch the electromagnets by blocking the light beam. Aligning the clear/black edges with the centers of the magnets ensures that the switching happens in the right place.

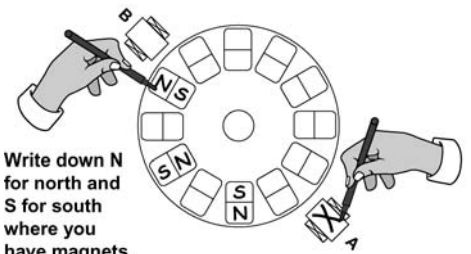


1. Find the pink four-pole commutator disk shown in the picture.
2. Arrange 4 magnets so the north or south poles alternate.
3. Be sure the disk is aligned so the border between clear and black is centered on each of the four magnets. The border is where the electromagnet will switch from north to south.
4. Finger tighten the big nut to secure the disk once you have it aligned with the magnets.
5. Attach the electromagnet to position A or B. To make the electrical connections the electromagnet should be pushed forward and the thumb-nuts gently tightened. Don't over-tighten the thumb nuts.
6. Push and hold the RUN button. You may need to give the motor a small push to start it.

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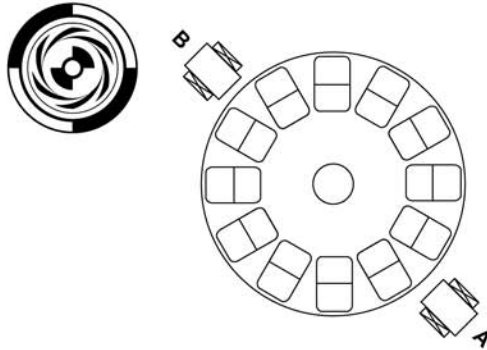
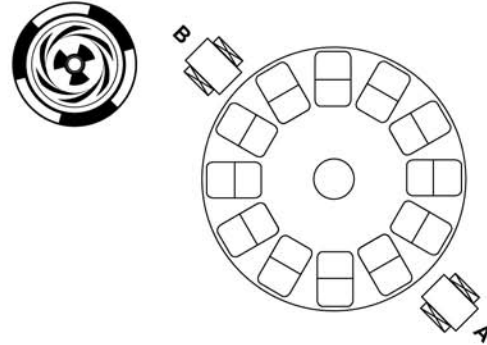
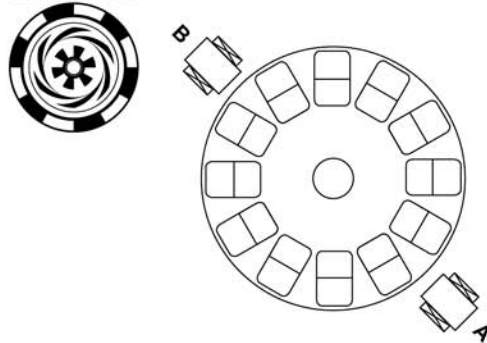
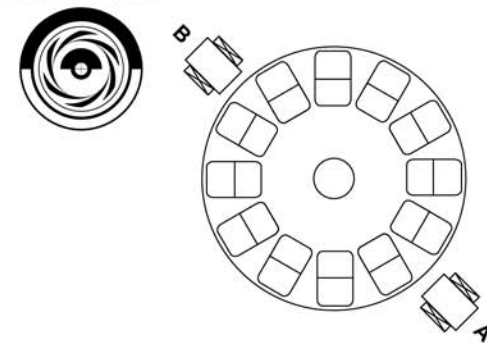
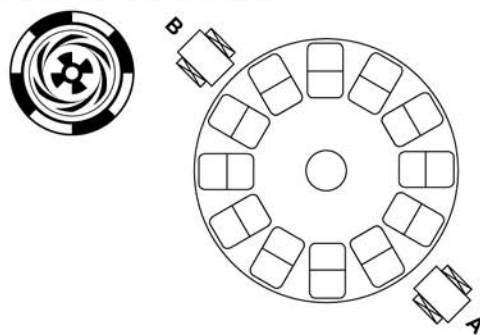
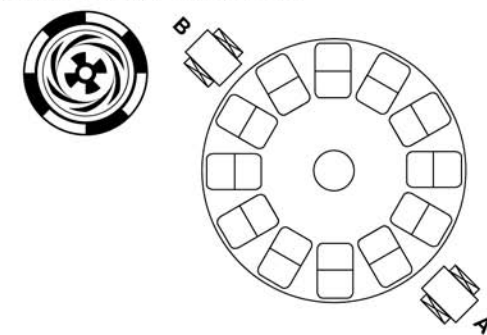
## Designing and testing different electric motors

Design and test a working electric motor for each of the commutator disks. Use the design charts to record your design, including the direction (north and south) and position of all magnets. Put an X where you placed the electromagnet. Record only designs that work. Keep changing things until you get a design that works for each commutator disk.



Write down N for north and S for south where you have magnets.

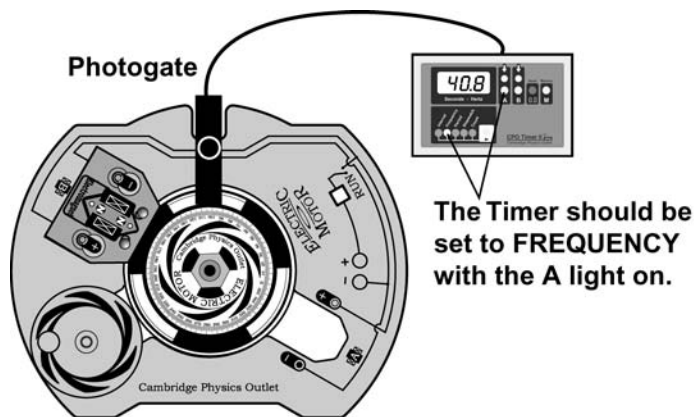
Make an X where you have an electromagnet.

**Pink Disk**

**Orange Disk**

**Blue Disk**

**Yellow Disk**

**Green Disk: Version 1**

**Green Disk: Version 2**


## Testing for performance

Engineers usually want to build the best possible machine. In the process of design, it is important to define what ‘best’ means. The word ‘best’ might mean fastest, least expensive, lightest, strongest, most shock resistant, or most attractive. It is usually impossible to be best in all categories. The engineer chooses which categories to be best in depending on the machine’s function. The speed of the rotor is one way to evaluate the electric motor. We can choose the best design as the one that goes fastest.

1. Set up the timer with one photogate attached to the motor. When the photogate is all the way in the slot, the black and clear segments of the disk break the beam as the motor spins.
2. Set the timer to measure FREQUENCY. When measuring frequency, the timer counts the number of times the beam is broken in one second. As the motor speeds up, the light beam is broken more times per second.



$$\text{Rotation speed (rpm)} = \frac{\text{frequency}}{\text{Number of black segments}} \times 60 \frac{\text{sec}}{\text{min}}$$

We want to calculate the speed in revolutions per minute (rpm). The equation above shows you how to calculate the speed if you know how many times the light beam gets broken for each turn of the disk.

Now, you will work some more with the blue, pink, orange, and yellow commutator disks. Adjust the motor design for each of these disks until you have reached the highest speed you can get. The variables that you can adjust to get the highest speeds for each disk are: (1) the number of magnets, (2) the orientation of the magnets, and (3) the placement of the disk relative to the magnets. Record the top speeds for each motor design and a description of the optimal design in the table below.

Disk	Description of motor design	Highest frequency (# of times beam is broken/second)	Rotation speed (rpm)
blue			
pink			
orange			
yellow			
green, v. 1			
green, v. 2			

- a. Which motor design gave you the highest speed and why do you think it was higher than the others? Your answer should identify the commutator disk and number of magnets you used.
- b. Give an explanation for why each of variable you could adjust has an affect on speed.
- c. What would happen to your speed comparisons if the batteries lost their power during the experiment?
- d. Write a procedure for checking the batteries to see that they stay the same throughout the experiment.

Name:

**B-3**

## The Electric Motor



Question: How does an electric motor work?

### **1** Getting the rotor to spin

- a. When is the right time to reverse the magnet in your fingers? Think about where the magnets are in the rotor.

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- b. How could you make the rotor spin the other way?

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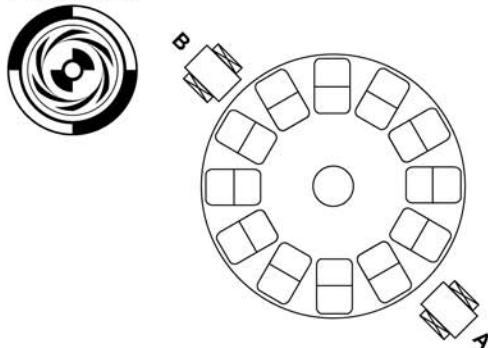
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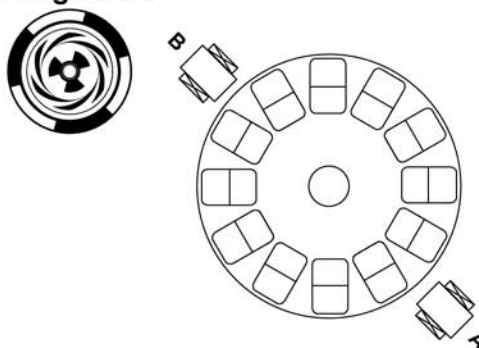
### **2** Making a 4-pole electric motor

There are no questions to answer in Part 2.

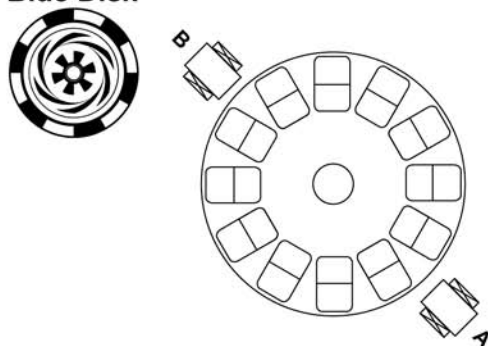
Pink Disk



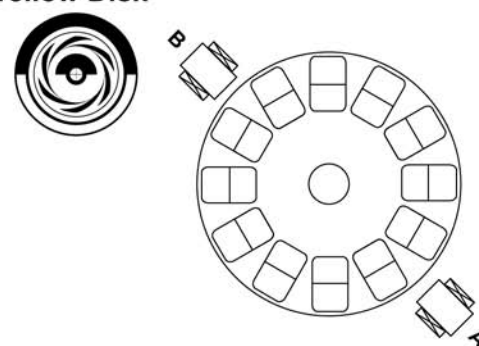
Orange Disk



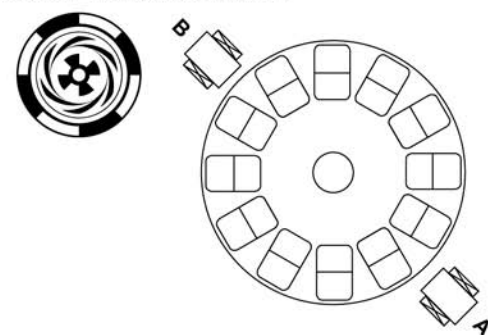
Blue Disk



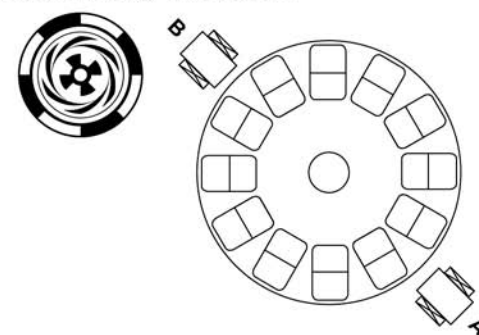
Yellow Disk



Green Disk: Version 1



Green Disk: Version 2



**4 Testing for performance**

Disk	Description of motor design	Highest frequency (# of times beam is broken/second)	Rotation speed (rpm)
blue			
pink			
orange			
yellow			
green, v. 1			
green, v. 2			

- a. Which motor design gave you the highest speed and why do you think it was higher than the others? Your answer should identify the commutator disk and number of magnets you used.
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- b. Give an explanation for why each of variable you could adjust has an affect on speed.
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- c. What would happen to your speed comparisons if the batteries lost their power during the experiment?
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- d. Write a procedure for checking the batteries to see that they stay the same throughout the experiment.
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# Questions

1. Would the motor work with a disk that was entirely clear? Why or why not?

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2. Why must the electromagnet reverse polarity in order to spin the rotor?

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3. Would the motor shown at right spin? Why or why not?

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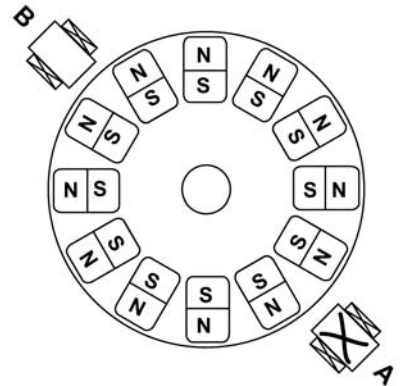
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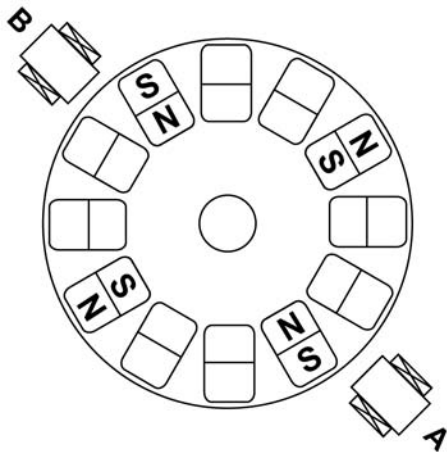
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4. Draw the disk you would use if the magnets were arranged as in the diagram below.



5. How many permanent magnets with alternating poles would you use to make the disk to the right spin? List all possible numbers of magnets.

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6. Most of your motor designs contain magnets with alternating poles facing outward. But the only way to make the green disk work is to face all of the magnets the same direction. Which of the other disks could you make spin with all of the magnets evenly spaced and facing the same way? How many magnets would you use?

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## Curriculum Resource Guide: Electric Motor

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