



Electricity and Magnetism

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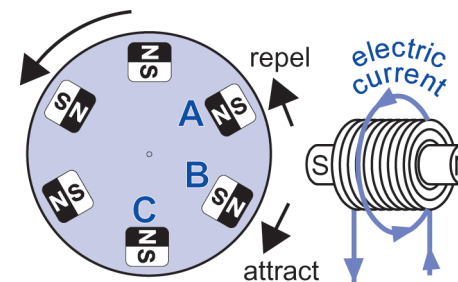
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B-3 The Electric Motor

Key Question: How does an electric motor work?

In this Investigation, 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 (a.k.a. commutator 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.



Preparation

Students need to understand how permanent magnets and electromagnets work in order to successfully complete this activity. Students can gain this knowledge by completing Investigations *B-1 Permanent Magnets* and *B-2 Electromagnets*.

Extra batteries are needed for this Investigation because when the motor is constantly running, the batteries will drain in about 15 minutes. The run button disconnects the power supply as soon as it is released. This is to conserve batteries.

Setup and Materials

Students work in groups of four at tables.


Each group should have:

- Electric motor kit with all commutator disks (yellow, orange, pink, green, and blue), permanent magnets, and a battery pack
- Timer with one photogate

The teacher should have on hand:

- Extra D-cell batteries

The Investigation

Time  One or two class periods

Leading Questions

- How does an electric motor work?
- What is the purpose of an electromagnet in an electric motor?
- What is the purpose of permanent magnets in an electric motor?
- How can you design a motor for optimum performance?

Learning Goals

In this Investigation, students will:

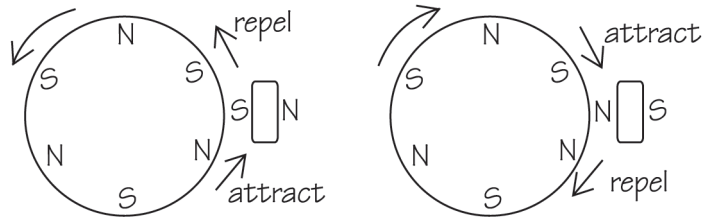
- Build a working electric motor and measure its speed.
- Demonstrate how electromagnets and permanent magnets interact to make an electric motor work.
- Design different motors and evaluate them for speed.

Key Vocabulary

motor, permanent magnet, electromagnet, alternating current, commutator, frequency, revolutions per minute (rpm)

1

- 1a. You need to reverse the magnet at the same time each magnet in the rotor passes by.
- 1b. If you start with the opposite pole facing the rotor the motor will go the opposite way.

**2**

There are no questions to answer in Part 2.

B-3**The Electric Motor**

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.

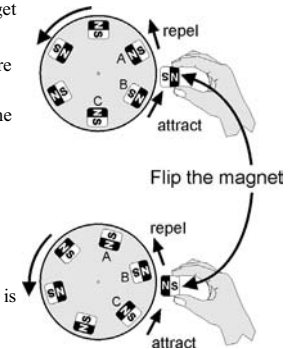
1**Getting the rotor to spin**

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

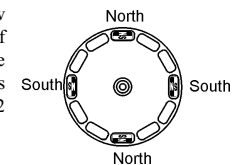
1. Take the motor apart, and put 6 magnets in the rotor so they are evenly spaced and alternate north-south facing outwards.
2. Bring a stack of two or three magnets close and try to repel one of the magnets in the rotor. The rotor should spin a little.
3. As soon as you move one magnet, reverse the 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?

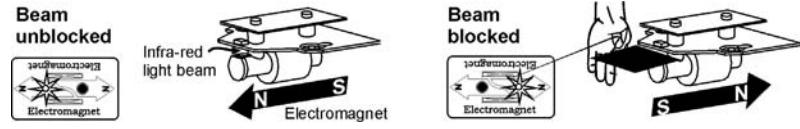
**2****Making a 4-pole electric motor**

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.



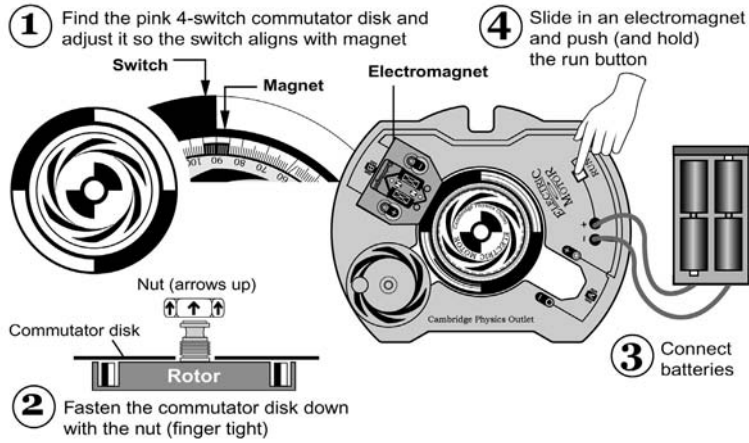
B-3

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.



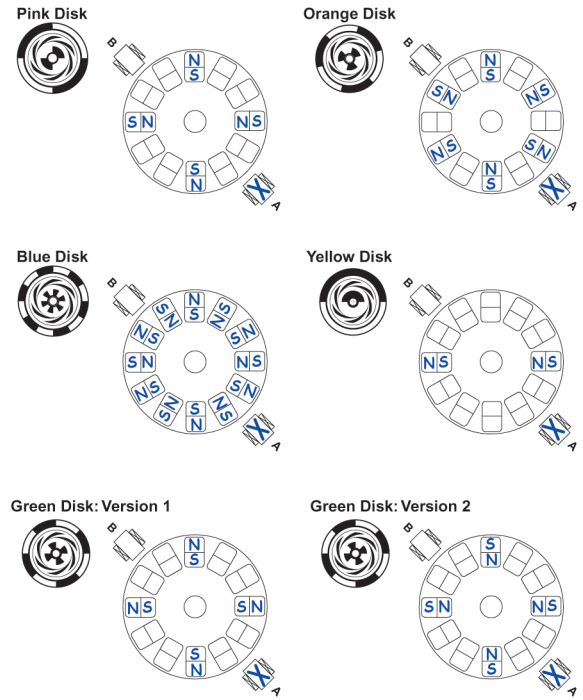
1. Find the pink four-pole commutator disk shown in the picture.
2. Arrange 4 magnets so the north or south poles alternate.
3. Be sure the disk is aligned so the border between clear and black is centered on each of the four magnets. The border is where the electromagnet will switch from north to south.
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.

2

3 Shown on the next page

Teaching Note:

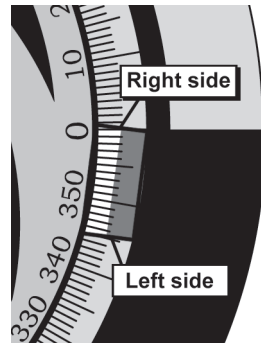
The electromagnet can be placed at either position A or B.



4 Shown on the next page

Teaching Note:

You will find that your students will be able to come up with a number of ways to design the motor to get top speeds. The following designs are only a few of many different ways to set up the motor to get high speeds—other designs are possible. If you have time, allow your students to explore what is possible with the electric motor for this part of the Investigation.



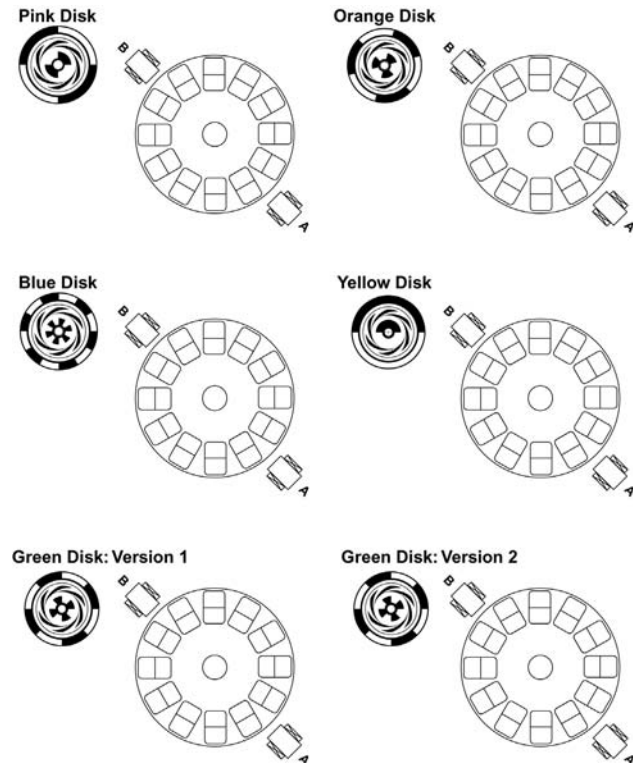
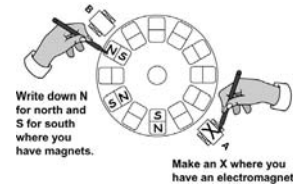
Disk	Highest frequency (# of times light beam is broken/sec.) and description	Rotation speed (rpm)
blue	59.6 w/ 12 alternating magnets and the electromagnet switch is to the right edge of the magnets	596
pink	21.0 w/ 4 alternating magnets and switch to the left of the magnets	630
orange	38.9 w/6 alternating magnets and switch to the right of the magnets	778
yellow	4.4 w/2 alternating magnets and switch to the left of the magnets	264
green, v. 1	29.7 w/ 4 magnets all south poles facing inward	445.5
green, v. 2	26.9 w/ 4 magnets all north poles facing inward	403.5

4a. The orange disk with 6 magnets alternating poles was the fastest. I believe this disk was the fastest because the number of “pushes” from the electromagnet was optimal for the mass of the rotor. The blue disk was not the fastest because the mass of the magnets added too much rotational inertia to the rotor.

3 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.

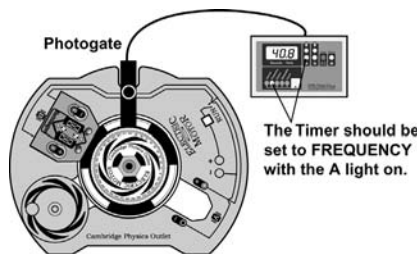


4 Testing for performance



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.

4 continued

Teaching Note:

The new version of the electric motor has been designed so that the weight of the rotor is minimized. This means that the mass of the magnets are now a factor in how the rotor spins. In other words, as the number of magnets increases, the extra mass causes the rotor to slow down due to rotational inertia. However, the added number of poles does mean that the rotor will experience extra “pushes.” Thus, the optimal design, the orange disk as described in the table, strikes a balance between these two competing factors.

- 4b. The commutator disks themselves are a factor that influences speed. They indicate how many times the electromagnet will be switched during a rotation. Another variable is changing the angle of the switching. This factor, when set just right, is timed perfectly to work with the switching of the electromagnet due to the disk black/clear boundaries. The angle of the boundaries relative to the magnets takes into consideration that there is a time delay from the time that the switch occurs until when the poles on the electromagnet are switched. For example, if we start switching a little before the magnet gets there, the motor goes faster. This is because it takes a little time for the electromagnet to complete the change from north to south. Additionally, the number of permanent magnets used and their orientation are important factors that are related to the speed of the motor. The orientation of the permanent magnets is crucial to the electromagnet being able to attract and repel the magnets and push/pull the rotor around.
- 4c. If the batteries were being drained we might not know if slower results were caused by changing the angle or because the batteries were used up. The loss of power from the batteries is an additional variable to be concerned about in the experiment.
- 4d. We could use a meter and measure the voltage of the batteries during every test. If the voltage stayed the same we would know the batteries were OK. We could also repeat a control experiment between trials. If the results of the control experiment stayed the same we would know the batteries were not changing during the day. A control experiment might be to test the motor with the blue disk with the switch exactly centered on the magnet.

1. No, a motor would not work with an entirely clear disk. The electromagnet would not switch polarity, and it would get stuck on a magnet to which it is attracted.
2. The electromagnet must switch polarity so it will first attract and then repel each magnet as it passes by. The switching of the electromagnet is crucial for the rotor to spin.
3. No, the motor would not spin. The magnets are all facing the same direction, so the electromagnet would either attract or repel both of the magnets near it at the same time.
- 4.



5. It will spin with 12 or 4 evenly spaced, alternating polarity magnets. It will also spin with 10, 8, 6, or 2 magnets as long as the polarity of the magnets alternates and if the magnets are not evenly spaced around the rotor. For 10, 8, 6 or 2 magnets, it is more challenging to find the right placement of the magnets to get the rotor to spin.

6. The blue disk works with six, three, or two. The orange disk works with three. The pink works with two. The yellow disk will not work with one magnet with one electromagnet because it is not strong enough to keep it spinning. However, if you set up the motor to have the generator be a second electromagnet, it will spin. See Investigation C-2 to set up the generator as an electromagnet. The generator will have to be connected to the electromagnet with the wires not crossed.

Curriculum Resource Guide: Electric Motor

Credits

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