Includes Teacher's Notes and Typical Experiment Results
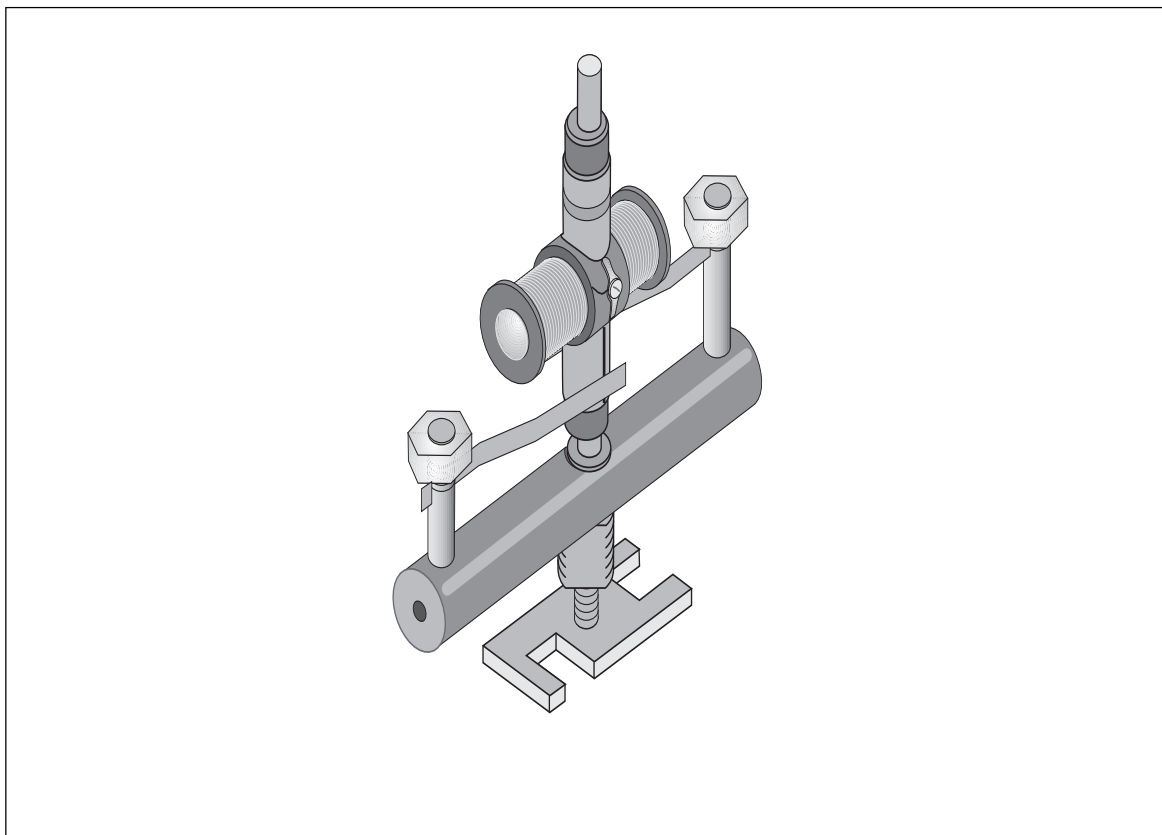
Instruction Manual and Experiment Guide for the PASCO scientific Model SE-8657

MOTOR ACCESSORY

$7.50

PASCO ®
s c i e n t i f i c

better
ways to
teach science

Table of Contents

Copyright, Warranty and Equipment Return

Please—Feel free to duplicate this manual
subject to the copyright restrictions below.

Copyright Notice

Limited Warranty

Credits

Author: Jim Housley
Editor: Sunny Bishop

Equipment Return

Should the product have to be returned to PASCO
scientific for any reason, notify PASCO scientific by
letter, phone, or fax BEFORE returning the product.
Upon notification, the return authorization and
shipping instructions will be promptly issued.

➤ **NOTE:** NO EQUIPMENT WILL BE
ACCEPTED FOR RETURN WITHOUT AN
AUTHORIZATION FROM PASCO.

When returning equipment for repair, the units
must be packed properly. Carriers will not accept
responsibility for damage caused by improper
packing. To be certain the unit will not be
damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the
item shipped.

② Make certain there are at least two inches of
packing material between any point on the
apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift
in the box or become compressed, allowing the
instrument come in contact with the packing
carton.

Address: PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100

Phone: (916) 786-3800
FAX: (916) 786-3292
email: techsupp@pasco.com
web: www.pasco.com

Introduction

The PASCO SE-8657 Motor Accessory transforms the PASCO EM-8641 Variable Gap Magnet into a motor that can operate on alternating or direct current, as well as a generator that can produce alternating or direct current. The Motor Accessory also transforms the PASCO SF-8616 Coils and Cores Set into a universal motor.   Combined with an AC/DC power supply and sensors for voltage, current, and rotational speed, these motors allow students to discover key concepts and relationships concerning motors and electric current.   Students can also explore properties of AC and DC generators with this apparatus.

Equipment

The Motor Accessory includes

- armature with split commutator at one end and a dual slip-ring commutator at the other

- brush holder

- shaft

- wrench/retaining nut

- maintenance items

- manual

- ceramic magnet

Additional Equipment Required:

- Variable Gap Magnet (EM-8641) or

- Coils and Cores Set (SF-8616)
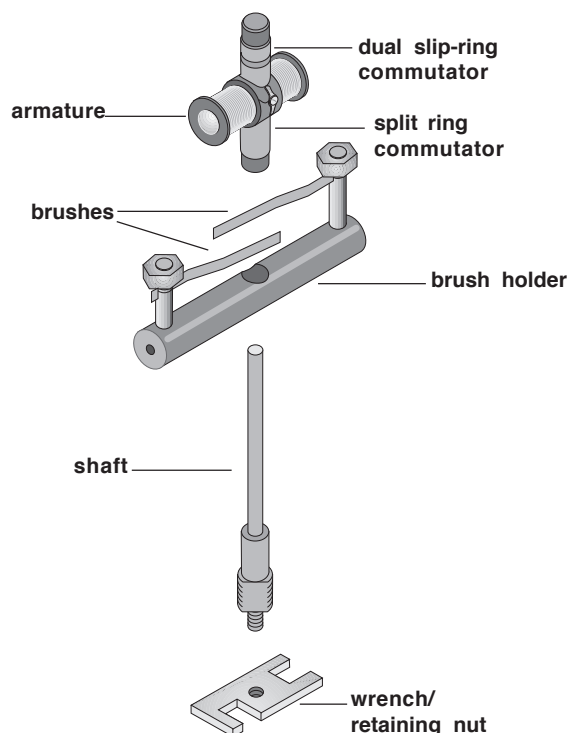
➤ Safety precautions

- Always wear safety goggles when in a room where the Motor Accessory is being used.
- Keep fingers and other objects away from the spinning armature.
- Choose power sources that limit current to not more than one ampere (1.0 A). The motor may overheat if this current is exceeded or if power is applied continuously, especially if the armature is not rotating. The motor is intended only for intermittent operation.
- Disconnect any power source whenever the motor is to be left unattended.

> ➤ **NOTE**: Although the instructions for experiments in this manual are for mechanical setups with specific PASCO equipment, the experiments in this manual may be set up in a variety of ways, depending upon the equipment you have available. They can all be done with or without the PASCO *Science Workshop* computer interface. Table 1 lists the equipment suggested for optional experimental setups. You may be able to substitute other equipment for the PASCO models listed in this table.

Table 1. Equipment Options for Experiments 1 - 4

Equipment Options for Experimental Setups with the PASCO SE-8657 Motor Accessory

Experiment Options	Motor Accessory (SE-8657)	Variable Gap Magnet (EM-8641)	Coils and Cores Set (SF-8616)	Low Voltage DC Power Supply (SE-9720) (SE-9712) or similar*	Low Voltage AC/DC Power Supply (SF-9584) *	Power Amplifier (CI-6550A) (CI-6552A)	Digital Function Generator/Amplifier (PI-9587)	Multimeter (e.g. SB-9623) or Ammeter (SF-9569)	Galvanometer (SF-9500) or Multimeter (SB-9623)	Voltage Sensor (CI-6503)	Science Workshop 300 or 500 Interface	Science Workshop 700 or 6500 Interface	Digital Photogate Timer (SF-9215A)	Digital Stroboscope (SF-9211)
Experiment 1: DC Motor														
no computer interface	X	X			X									
no computer interface	X	X		X	X									
computer interface	X	X				X		X		X		X		
computer interface	X	X				X					X	X		
Experiment 2: AC/DC Generator														
no computer interface	X	X							X					
computer interface	X	X								X	X	X		
Experiment 3: Synchronous AC Motor														
no computer interface	X	X			X								X	X
computer interface	X	X				X				X		X		X
computer interface	X	X				X					X	X		X
Experiment 4: Universal Motor														
no computer interface	X		X		X									
computer interface	X		X			X				X		X		
computer interface	X		X			X					X	X		

(Where two adjacent X's appear under the two power-supply columns or the two Science Workshop Interface columns, the entry reads "X OR X"; likewise "X OR X" appears between the Digital Photogate Timer and Digital Stroboscope columns in Experiment 3.)

*If your power supply does not have the capability to quantify output current, you will need to measure it using an ammeter, or preferably, by calculating it from the voltage drop across a small value series resistor. (This option avoids the potential for damage to a sensitive ammeter.) ***It is important to limit the current to a maximum of 1 A to avoid damaging the armature.***

Operation

Options for electrical connections

- Banana-style plugs may be inserted into openings in the ends of the black plastic brush holder.

- Large alligator clips may be attached to the brass posts that hold the brushes.

- Small alligator clips may be attached directly to the ends of the brushes where they protrude from the slits in the brass posts.

Options for Power Sources

It is important to limit the current of the power source to 1.0 A to avoid damaging the coils of the armature. Either choose a power supply that can be set to deliver a maximum current of 1.0 A, or use your power source connected in series with a multimeter or ammeter to monitor the output current. (Alternatively, to avoid possible damage to a sensitive ammeter, you can measure the voltage drop across a low-value series resistor, such as a 0.51 ohm, 1 watt resistor, and calculate the output current.) You will also need to adjust and measure the output voltage, so if your power supply does not have this capability, you will need a multimeter or voltmeter. (See Table 1 for specific suggestions for power sources.)

Starting the motor

- The motor is not self-starting. Immediately after you apply the power, start the motor manually by grasping the black plastic bushing at the top of the armature assembly between your thumb and forefinger and spinning the armature.

- With the Motor Accessory configured as either a DC or universal motor, almost any attempt you make at spinning the armature will result in successfully starting the motor; only the direction of the spin is important.

- When configured in an AC synchronous mode, the motor must be spun at a speed that approximately matches the frequency of the power source. This is impractical at frequencies much above 30 Hz, and some students may require assistance even a lower frequencies.

Maintenance and Storage

- A small box is provided for storing the parts of the motor not installed on either the Variable Gap Magnet or Coils and Cores Set.

- The commutators and brushes will experience wear, oxidation, and pitting and will require attention from time to time. Rotate the armature slowly by hand and monitor current flow or sense the force developed to determine whether proper contact is occurring between brushes and commutator. To restore proper operation, clean the contacts with emery paper or shift the brushes somewhat to expose new surfaces.

- Careless installation of the armature onto the shaft might bend the brushes. You can easily bend them back into their original shape with finger pressure.

> ➤ **NOTE:** If you are using a PASCO CI-6502A Power Amplifier (for the CI-6500 Interface System), the distorted waveform light will turn on during operation of the motor, but no damage is being done to the Power Amplifier; you can ignore the light.

Assembly

Motor Accessory onto the Variable Gap Magnet

① Be sure you have the flat iron pole pieces placed on the two neodymium magnets of the Variable Gap Magnet. The larger threaded portion of the *shaft* screws easily, without tools, into the threaded hole in the magnet base. Insert the threaded end of the shaft from above, screwing it in until 1 mm, or slightly less, of the threaded portion remains above the upper surface of the base.

② Turn the magnet over and screw the *retaining nut* onto the smaller diameter threaded portion of the
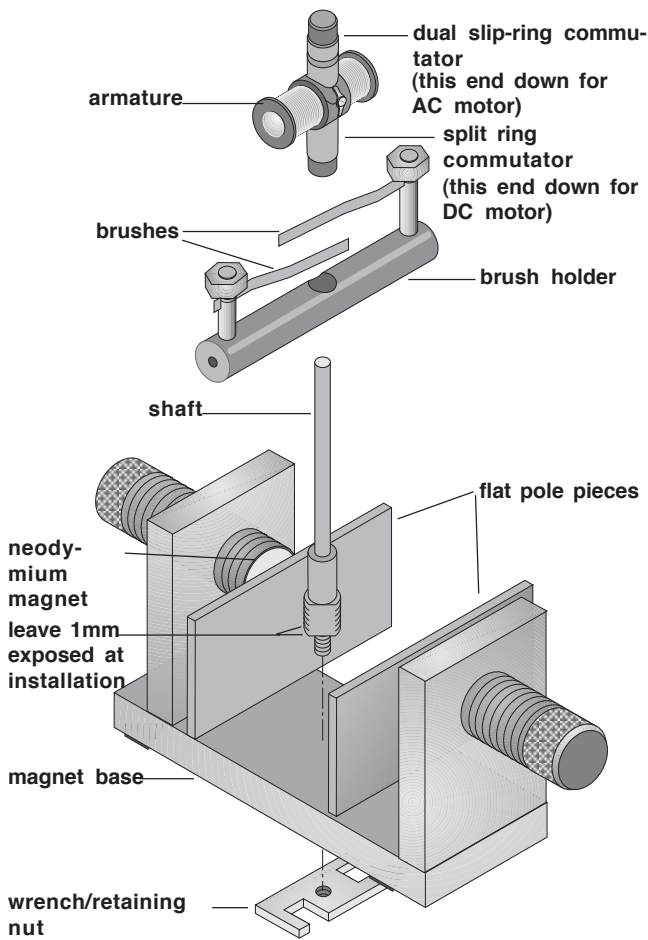
shaft that protrudes through the bottom of the magnet base. (Note that the retaining nut has a metric thread, size M6-1.0.) Use firm finger pressure. If this should prove inadequate, tighten the nut somewhat more with a wrench. If an appropriate wrench is not at hand, use a heavy metal object to tighten the nut by tapping the edge of the nut. Do not use a pole piece of the magnet to tighten the nut because that might mar the finish of the pole piece. Do not over tighten.

③ Working from above, press the *brush holder* onto the smooth, enlarged portion of the shaft. Apply increasingly firm pressure equally to each side of the brush holder while rotating the brush holder back and forth. If this action loosens the retaining nut, tighten it more tightly, as described in step 2. Check to be sure the brush assembly is seated as far down on the shaft as it will go.

④ Gently lower the *armature* onto the shaft. To make a DC motor, the split ring commutator should be down; for an AC motor, the *dual slip-ring commutator* should be down. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between them. If necessary, insert a pencil or similar object down between the brushes. Use only the most delicate force to avoid bending the brushes and necessitating adjustments or repairs.

⑤ Adjust the gap of the Variable Gap Magnet so there is approximately 1 mm of clearance between the pole pieces and the armature when it is rotated by hand.

⑥ Refer to the instructions included in experiments 1-4 for details of the electrical connections.

armature

dual slip-ring commutator (this end down for AC motor)

split ring commutator (this end down for DC motor)

brushes

brush holder

shaft

flat pole pieces

neodymium magnet

leave 1mm exposed at installation

magnet base

wrench/retaining nut

Motor Accessory—Variable Gap Magnet Assembly

**PASCO** scientific

Motor Accessory onto the Coils and Cores Set

① Begin with the U-shaped core, with the coils and any other parts removed. The smaller threaded portion of the *shaft* screws easily into the threaded hole in the core so the shaft is between the poles of the core. Use the *wrench* provided to tighten the shaft by gripping the flats on the larger threaded portion. The small wrench limits the torque that can be applied. If an ordinary wrench is used, be careful not to over tighten.

> ➤ **Note:** Do not discard the small wrench; it is essential as a retaining nut when the Motor Accessory is used with the Variable Gap Magnet.

② Working from above, press the *brush holder* onto the smooth, enlarged portion of the shaft. Apply increasingly firm pressure equally to each side of the brush holder while rotating the brush holder back and forth. If this action loosens the shaft, tighten it as described in step 1. Check to be sure the brush assembly is seated as far down on the shaft as it will go. Orient the brush holder perpendicular to the base of the Coils and Cores apparatus.

③ Place the two 400-turn coils from the Coils and Cores Set onto the poles of the core.

④ Gently lower the *armature* onto the shaft. The *split ring commutator* should be down for use as a universal motor. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between them. If necessary, insert a pencil or similar object between the brushes to separate them. Use only the most delicate force to avoid bending the brushes and necessitating adjustment or repairs.
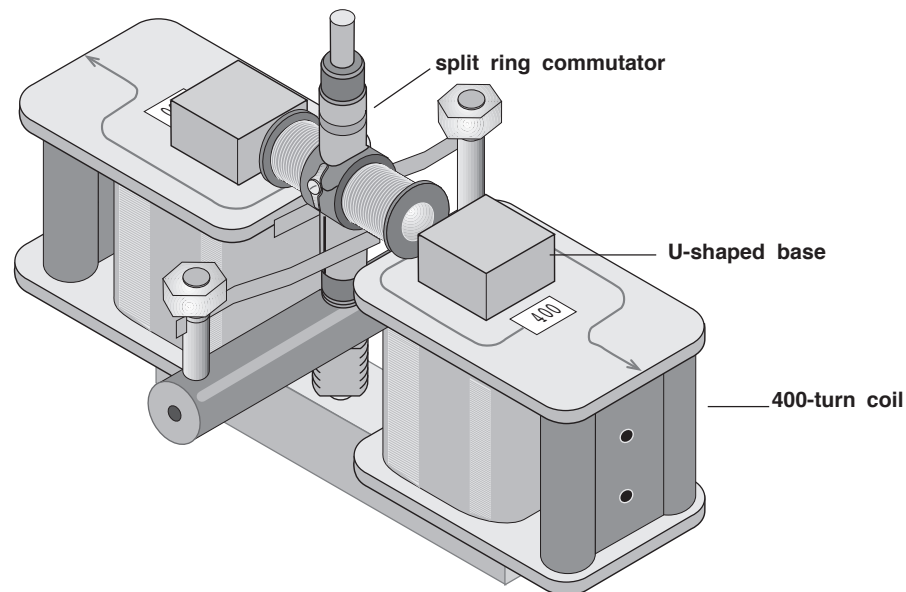
Motor Accessory—Coils and Cores Assembly

Suggested Uses

Operation as a DC motor

The Motor Accessory can be used with the Variable Gap Magnet to demonstrate the operation of a DC motor (Experiment 1). Students can explore relationships between motor speed and voltage, as well as between direction of armature rotation and polarity, developing key concepts including: action of the split ring commutator, dependence of speed on voltage, dependence of direction of rotation on polarity, right-hand rule, and direction of current flow from positive to negative poles.

Action of AC and DC generators

Spinning the armature by hand while it is connected to a sensitive DC meter or to the Signal Interface II shows the action of an AC generator, as well as the rectifying action of the commutator in a DC generator (Experiment 2).

Operation of a synchronous AC motor

Coupled with an AC signal supplied by the PASCO PI-9587C Digital Function Generator/Amplifier or similar function generator, the Motor Accessory-Variable Gap Magnet assemblies will operate in sync with 15 and 30 Hz (and often wider range) signals (Experiment 3). Students can explore the relationship between AC voltage and motor speed, as well as between AC current frequency and motor speed. They can conduct detailed explorations of the precision of synchronism of AC current and motor speed with a PASCO SF-9211 Digital Stroboscope or PASCO ME-9215A Digital Photogate or by observing the stroboscopic effect of an ordinary fluorescent lamp at selected motor speeds. As a result, they develop key concepts, including the independence of AC motor speed and voltage, dependence of AC motor speed on current frequency, and action of a dual slip-ring commutator.

Operation as a universal motor

The Motor Accessory-Coils and Cores assembly functions as a universal motor, operating on both AC and DC power supplies (Experiment 4). Students can explore the relationships of current direction and direction of the magnetic field, the effect of changes in voltage and AC current frequency on motor speed, and the effect of changes in DC voltage on motor speed.

Additional possibilities

The Motor Accessory–Variable Gap Magnet assembly can be used to determine the speeds of maximum power and maximum efficiency of a DC motor by varying the load while simultaneously measuring the speed, torque, and armature current. In this experiment, you can measure the motor's speed with a photogate or stroboscope.

The Motor Accessory–Coils and Cores assembly also can be used to demonstrate series-wound, shunt-wound, and hysteresis-synchronous motor setups.

Experiment 1: Operation of the DC Motor

EQUIPMENT NEEDED:	
• Motor Accessory	• multimeter
• Variable Gap Magnet	• patch cords
• low voltage DC power supply, limited to 1 A	• small piece of masking tape

Purpose

The purpose of this experiment is to demonstrate the operation of the DC motor in terms of basic concepts of electromagnetism.

Theory

The Variable Gap Magnet is a permanent magnet possessing a north pole and a south pole that interact with the north and south poles of the armature (an electromagnet when connected to an electric current). Like poles repel, while unlike poles attract. The armature rotates until its north pole is as close as possible to the south pole of the permanent magnet (and also as far as possible from the north pole). Instead, if the rotational speed of the armature matches the frequency of the alternating current, the direction of current in the armature will reverse at that instant, so that the torque continues to act in the original direction.

A better explanation involves an understanding of fields. The variable gap magnet produces a magnetic field that passes through the gap between the pole pieces. When current passes through the turns of the armature in the presence of the field, forces act to cause a torque that rotates the armature. Inertia carries the armature past the position of no torque to the point where the torque would force the armature back in the other direction. However, at that point the commutator reverses the direction of current in the armature so the torque continues to act in the original direction.

Setup

① Be sure you have the flat iron pole pieces placed on the two neodymium magnets of the Variable Gap Magnet. (The iron pole pieces spread the magnetic field over a wider area.) Screw the larger threaded portion of the *shaft* into the threaded hole in the magnet base. Insert the threaded end of the shaft from above, screwing it in until 1 mm, or slightly less, of the threaded portion remains above the upper surface of the base.

② Turn the magnet over and screw the *retaining nut* onto the smaller diameter threaded portion of the shaft that protrudes through the bottom of the magnet base. Use firm finger pressure. ***Do not over tighten.***

③ Working from above, press the *brush holder* onto the smooth, enlarged portion of the shaft. Apply increasingly firm pressure equally to each side of the brush holder while rotating the brush holder back and forth. If this action loosens the retaining nut, tighten it more tightly, as described in step 2.

> Check to be sure the brush assembly is seated as far down on the shaft as it will go.

④ Gently lower the *armature* onto the shaft with the *split ring commutator* down. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between them. If necessary, insert a pencil or similar object down between the brushes. Use only the most delicate force to avoid bending the brushes and necessitating adjustments or repairs.

⑤ Adjust the gap of the Variable Gap Magnet so there is approximately 1 mm of clearance between the flat pole pieces and the armature when it is rotated by hand.

⑥ Connect the positive terminal of the DC power supply to one end of the brush holder with a red patch cord by plugging the banana terminals into each.

⑦ Connect the negative terminal of the DC power supply to the other end of the brush holder with a black patch cord.
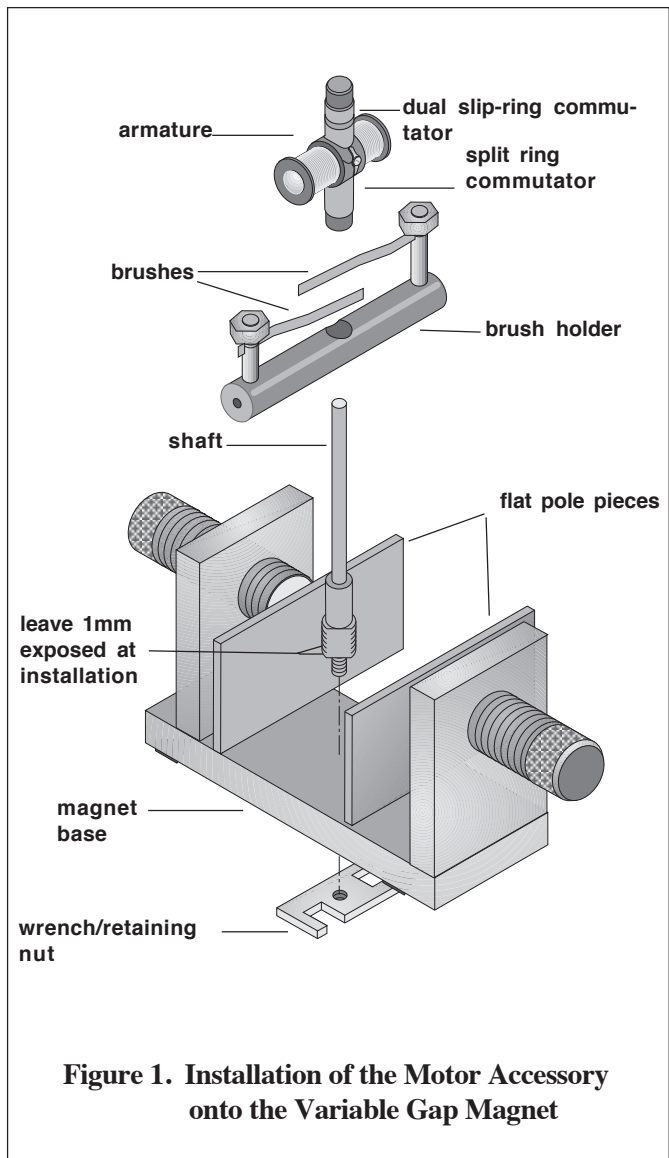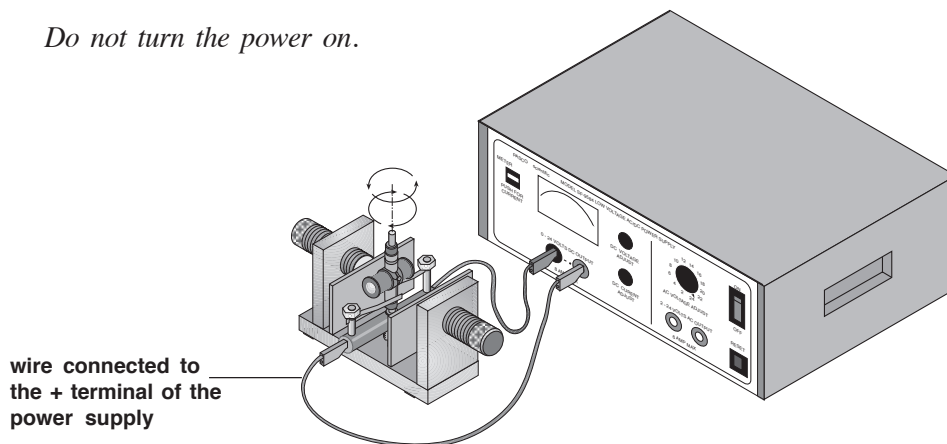
Do not turn the power on.

Figure 1. Installation of the Motor Accessory onto the Variable Gap Magnet

Figure 2. Experimental Setup

Procedure—Part A

① Rotate the armature and observe how the segments of the split ring commutator contact the brushes as the armature turns.

② Remove the armature from the shaft by grasping it between your thumb and forefinger and rotating it back and forth while lifting gently. If necessary, insert a pencil between the brushes to gently separate them to remove the armature.

③ Examine the armature closely and imagine current entering one of the split rings from a brush. Trace the path of the current through the wire to the coil, through the coil, through the wire to the coil on the opposite side of the armature, through that coil, and through the wire to the other split ring and into the second brush. By carefully examining the part of the coils where the wire emerges from the coil, you can determine the direction in which the wire is wound on the coil (see Figure 3).
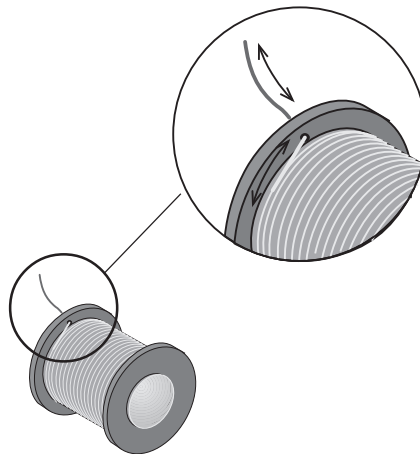

Figure 3. Direction of the Wire Winding on the Coil

④ Holding the armature in one hand, imagine that the brush from the + lead is touching one of the split rings of the commutator. Follow the wire from the split ring to the right coil of the armature and note the direction the wire is wound in the coil. Note where the wire enters the coil and where it exits.

⑤ Use the right-hand rule to determine the direction the magnetic field will flow when you turn on the power: Grasp the coil with your fingers wrapped around the coil in the direction of the current (Figure 4). (Current direction is described by convention as being from the positive to the negative lead. Note that this is opposite of the direction of electron movement—see note on page 10) . Your thumb will point in the direction of the field — that is, toward the north pole of the coil). Put a small piece of tape on the end of the armature that will be its north pole when you turn on the power.

⑥ Follow the wire over to the left coil. Use the right hand rule to find the direction of the north pole.

Record your observations on Figure 4.

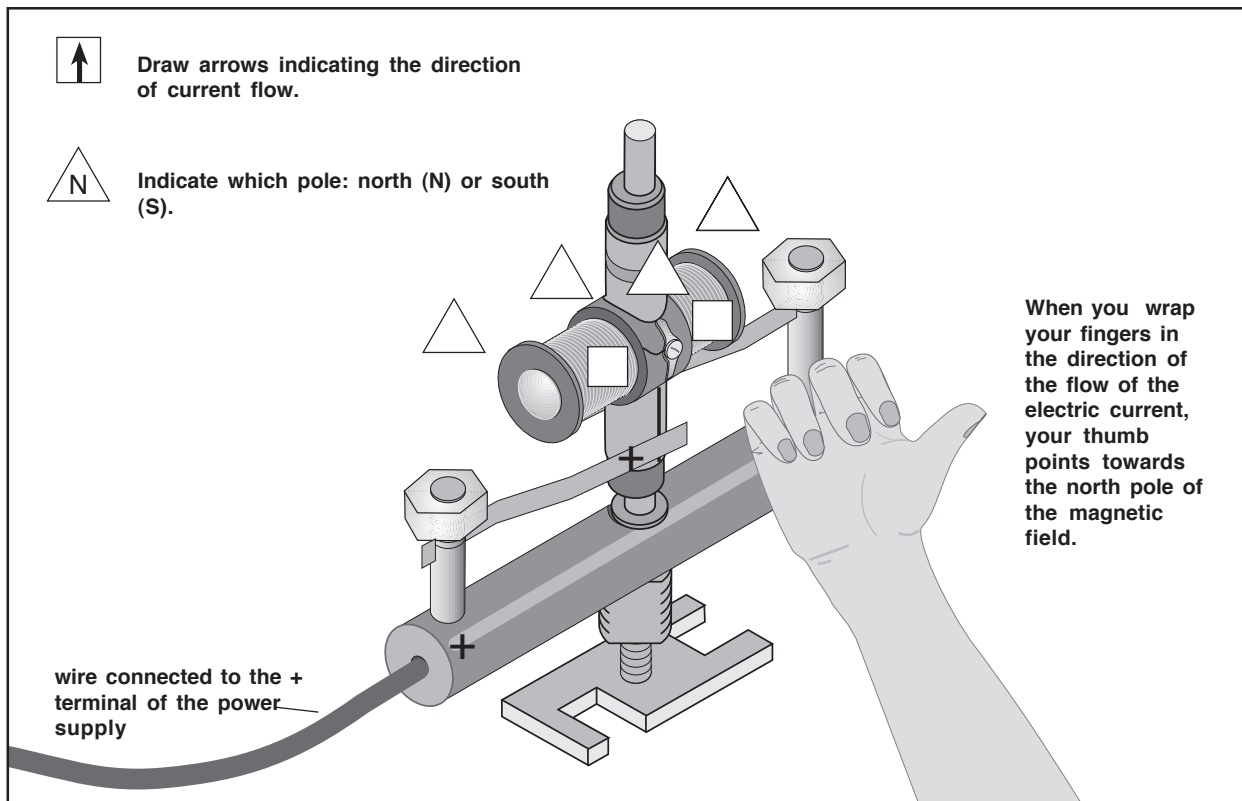a) In this situation, is the direction of the north pole the same for the right and left coils?

Figure 4. Determining the Direction of the Magnetic Field of the Coil Using the Right-Hand Rule

➤ **Note:** Here's why the direction of conventional current is opposite to that of the direction of electron flow: In the mid-eighteenth century, Benjamin Franklin suggested the terms *positive* and *negative*, and conjectured that electrical current was the movement of positive "fluid" from positive to negative regions. Although he understood that it was equally possible that a negative fluid moves from negative to positive, for more than a century there was no way to resolve the issue. By *convention*, scientists agreed to describe the direction of current as being from positive to negative. Not until 1879 did Edwin H. Hall show that in metals the current was a negative "fluid"; it remained for J. J. Thompson, R. A. Millikan, and others to demonstrate the existence of electrons, which are the charge carriers of this "fluid". This might seem an argument for changing the convention. But current doesn't always travel in metals. In gasses, current consists of electrons traveling in one direction while positive ions move simultaneously in the opposite direction. In solutions, current consists of oppositely charged ions traveling in opposing directions. And in certain semiconductors, it is most useful to think of positive "holes" as being the charge carriers.

Considering this complexity, scientists have found it most useful to continue the convention begun by Franklin: the "direction" of current is from positive to negative.

b) Both coils surround a single iron core on the armature, and each coil is capable of temporarily magnetizing the core when electric current is running through it. Do the actions of the two coils add to create a greater effect or cancel to create a reduced effect? (Consider your answer to 6a above.)

⑦ Turn the armature over 180° and imagine that the brush attached to the + lead is contacting the other split ring of the commutator. Note the path of the wire from where it is attached to the split ring to where it enters and exits from the coil on the right side of the armature. Imagine a current running through the wire and use the right-hand rule to determine the direction the magnetic field would flow. Is the north pole on the same end of the coil as it was in step 5?

⑧ Follow the wire over to the left coil. Use the right hand rule to find the direction of the north pole.

a) In this situation, is the direction of the north pole the same for the right and left coils?

b) True or False? When the electric current is on, the two coils become electromagnets with magnetic fields oriented in the same direction, which turns the armature into a single electromagnet with its force oriented towards that same direction.

c) True or False: In the DC motor, you cannot determine the direction of the magnetic field of the armature by determining the direction of the north pole of either of the two coils.

d) What happens to the location of the armature's north pole as the brush attached to the + lead touches the different sides of the split ring commutator?

e) Can you explain why the current in the armature is alternating, despite the fact that the motor is supplied with direct current. (Hint: think about your answer to 8d.)

⑨ Gently replace the armature onto the shaft with the split ring commutator down. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between them. If necessary, insert a pencil or similar object between the brushes to separate them. Use only the most delicate force to avoid bending the brushes and necessitating adjustment or repairs.

Procedure—Part B

① Turn on the power. Adjust the output voltage to 6 volts.

② Use the small cylindrical ceramic magnet to check your predictions from steps 5 and 6

above. The painted face of the magnet is its North Pole (north-seeking pole). [You can verify this by hanging the magnet from a thread and observing that the painted face points toward the North (toward the earth's north magnetic pole, located in northern Canada).] With the armature and power supply leads oriented as in Figure 2 and the power turned on, hold the ceramic magnet near the ends of the armature. If both poles of the ceramic magnet attract the armature, the pole with the stronger attraction will be the opposite pole.

a) Does the result of this test agree with your predictions in steps 5 and 6?

b) Label each end of the armature in Figure 2 according to whether it is the north or south pole of the electromagnet.

c) Determine the polarity of the Variable Gap Magnet in the same way. Label its poles "N" and "S" in Figure 2.

③ Predict the direction the armature will rotate when you release it from the position of Figure 2.

Will the motor rotate clockwise or counter-clockwise?

If the motor does not start up immediately, try turning it by hand in the predicted direction. If that fails, try turning it in the opposite direction.

➤ If the motor does not start in either direction, turn off the power and ask your teacher for help.

④ Turn off the power and reverse the positive and negative leads to the motor. Before turning the power on, predict the direction of rotation.

a) Will the motor rotate clockwise or counter-clockwise?

Turn the power back on and immediately try spinning the motor to start it. If it doesn't start, try spinning it in the other direction.

b) Explain why the armature turns when you turn on the power.

⑤ While the motor is running, raise the voltage to approximately 8 volts.

a) What happens to the motor's rotational speed when you raise the voltage?

b) Is the relationship of the motor's rotational speed and voltage of the DC current dependent or independent?

Experiment 2: Operation of AC and DC Generators

EQUIPMENT NEEDED	OPTIONAL EQUIPMENT
• Motor Accessory	• Voltage Sensor
• Variable Gap Magnet	• computer interface
• multimeter or galvanometer	
• patch cords	
• small strips of masking tape	

Purpose

The purpose of this experiment is to detail the operation of an AC generator and a DC generator in terms of basic concepts of electromagnetism.

Theory

Motors and generators may be regarded as devices that convert energy from one form to another. A motor converts electrical energy into mechanical energy. Many designs of motors work as generators as well: when mechanical energy is input by spinning the shaft, electrical energy is produced.   More than one line of reasoning may be used to predict the magnitude and direction of the electrical current that is produced. At the most fundamental level, electrical charges moving across a magnetic field experience a force that is at right angles to both the direction of motion and the direction of the magnetic field, according to the vector equation:

$$\mathbf{F} = q\mathbf{V} \times \mathbf{B}$$

Conductors, of course, contain charges, and moving a conductor sideways across a magnetic field causes a force on the charges that may make the charges flow the length of the conductor if it is part of a circuit. The force on the charges can be seen from the equation to be proportional to both the speed and the strength of the magnetic field.

From this reasoning you can derive Faraday's law of electromagnetic induction, which states that a change in the magnetic flux linking a closed circuit will result in an electromotive force (or electric current) in the circuit that is instantaneously proportional to the time rate of change of the linking flux; however, it is easier to understand Faraday's law by observing the action of a generator. In a generator, an electromotive force (emf) that is proportional to the rate of change is induced in a loop of wire that is in a field of changing magnetic flux. (The coils of the armature may thought of as many loops connected in series.)

Surprisingly, the direction of induced current can be determined from the law of conservation of energy. Due simply to friction, work must be done to rotate a generator. If the generator is connected to a load and producing electric current, the law of conservation of energy dictates that additional work must be done to turn the shaft. This is an example of the reasoning that led to Lenz's law: the induced current is in such a direction as to produce a magnetic field that opposes the original magnetic field.

You can demonstrate Lenz's law to yourself by determining the direction of the magnetic field of the Variable Gap Magnet and by detecting the direction of the induced electric current with a galvanometer (or multimeter) as you move the armature through the magnetic field.

Setup

voltmeter or galvanometer
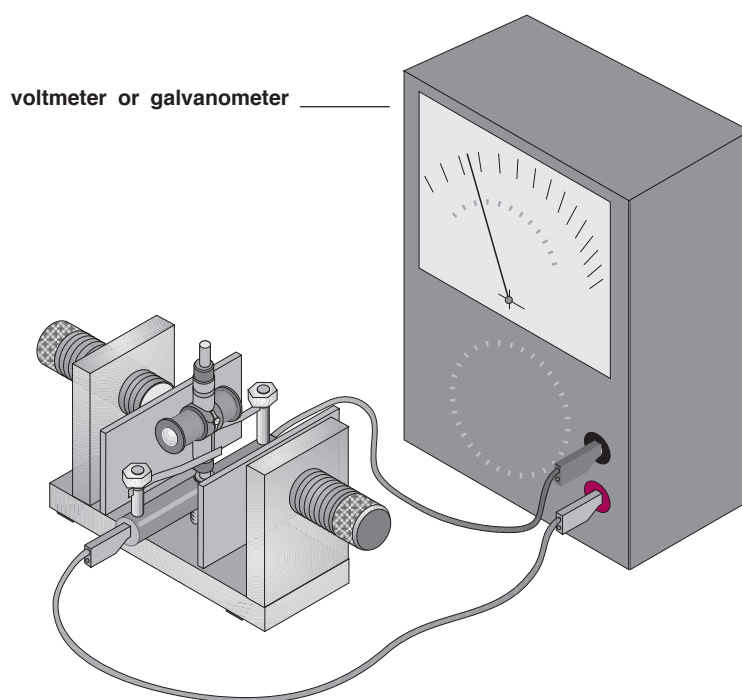
Figure 1. Experimental Setup

① Be sure you have the flat iron pole pieces placed on the two neodymium magnets of the Variable Gap Magnet. (The iron pole pieces spread the magnetic field over a wider area.) Screw the larger threaded portion of the *shaft* into the threaded hole in the magnet base. Insert the threaded end of the shaft from above, screwing it in until 1 mm, or slightly less, of the threaded portion remains above the upper surface of the base.

② Turn the magnet over and screw the *retaining nut* onto the smaller diameter threaded portion of the shaft that protrudes through the bottom of the magnet base. Use firm finger pressure. Do not over tighten.

③ Working from above, press the *brush holder* onto the smooth, enlarged portion of the shaft. Apply increasingly firm pressure equally to each side of the brush holder while rotating the brush holder back and forth. If this action loosens the retaining nut, tighten it more tightly, as described in step 2.

> ➤ Check to be sure the brush assembly is seated as far down on the shaft as it will go.

④ Gently lower the *armature* onto the shaft with the *dual slip-ring commutator* down. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between them. If necessary, insert a pencil or similar object down between the brushes. Use only the most delicate force to avoid bending the brushes and necessitating adjustments or repairs.

⑤ Adjust the gap of the Variable Gap Magnet so there is approximately 1 mm of clearance between the flat pole pieces and the armature when it is rotated by hand.

Procedure

Part A: AC Generator

① During the first part of this experiment, the dual slip-ring commutator should be down, between the brushes. If it is not, remove the armature from the shaft by grasping it between the thumb and forefinger and rotating it back and forth while lifting gently. Sometimes it may be necessary to insert a pencil between the brushes to gently separate them so that they don't prevent removal of the armature.

② The cylindrical ceramic magnet may be used to determine the polarity of other magnets. The painted face of the magnet is its North Pole (north-seeking pole). [You can verify this by hanging the magnet from a thread and observing that the painted face points toward the North (toward the earth's north magnetic pole, located in northern Canada).] Determine the polarity of the variable gap magnet by holding the ceramic magnet near its rectangular pole pieces. In the event that both poles of the ceramic magnet attract a pole piece, the stronger attraction occurs when opposite poles are together. Label the pole pieces N and S using small strips of tape.

③ Examine the armature closely, and imagine current entering one of the two slip rings from a brush. Trace the path of the current through the wire to the coil, through the coil, through the wire to the coil on the opposite side of the armature, through that coil, and through the wire to the other split ring and into the second brush. By carefully examining the part of the coils where the leads emerge from the coil, it should be possible to determine the direction in which the wire is wound on the coil. Can you verify that the current maintains its same direction of rotation as it leaves one coil and enters the other? This means that the two coils of the armature act as a single coil. Ask for help if you cannot.

④ Label the end of the armature that connects to the upper slip ring with a small piece of tape.

⑤ Gently replace the armature onto the shaft. The dual slip-ring commutator should be down. Carefully rotating the armature back and forth will often separate the brushes and allow the commutator to slip down between them. Otherwise, inserting a pencil or similar object between the brushes to separate them may be necessary. Only the most delicate force should be used to avoid bending the brushes and necessitating adjustments or repairs.

⑥ Adjust the gap of the Variable Gap Magnet so that there is approximately 1 mm of clearance between the pole pieces and the armature when it is rotated by hand.

⑦ Position the armature so that it is at right angles to the N-S orientation of the Variable Gap Magnet. Then rotate it by hand 90 degrees until the end of the armature marked with tape is near the north pole of the magnet. The magnetic field of the magnet may be envisioned as arrows passing out of the north pole piece and into the south pole piece.

(a) What happens to the amount of this magnetic field that passes through the loops of the coils during your 90-degree rotation above? If the amount changed, did it increase or decrease?

(b) What does Faraday's induction law say about this situation?

⑧ Continue rotating the armature another 90 degrees.

(a) What happens to the amount of this magnetic field that passes through the loops of the coils during your 90-degree rotation above? If the amount changed, did it increase or decrease?

(b) What does Faraday's induction law say about this situation?

(c) How would the induced emf be different during the rotation of step 7, compared to step 8?

⑨ The forces due to Lenz's' law in this equipment are much less than other effects and are not readily noticeable. Nonetheless, the reasoning involving Lenz's law allows you to predict the direction of current. Consider the 180 degree rotation you performed above:

(a) To oppose the motion during the first 90 degrees of rotation, what pole (N or S) would the taped end of the armature need to be?

(b) To oppose the motion during the second 90 degrees of rotation, what pole (N or S) would the taped end of the armature need to be?

⑩ In order to cause the armature to act as you stated in step 9 above, what direction would the induced current need to move?

➤ To answer this, you will need the "right hand rule", which can be used to predict the direction of the magnetic field of a coil. Grasp the coil with the fingers wrapped around the coil in the direction of the current. The thumb will point in the direction of the field. (i.e., toward the north pole of the coil.) Current direction here is described as being from the positive to the negative (conventional current). Note that this is opposite of the direction of electron movement.

(a) Must conventional current enter the coil, or leave the coil, from the upper brush, in order to make the armature act as you described in 9 (a) above?

(b) Must conventional current enter the coil, or leave the coil, from the upper brush, in order to make the armature act as you described in 9 (b) above?

⑪ Use a sensitive galvanometer or a digital multimeter set on a DC millivolt range to test your predictions. When conventional current enters the positive terminal of a meter, the needle of a traditional meter will move to the right, and the number displayed by a digital meter will be positive (or no sign will be displayed). If conventional current enters the negative terminal, the needle will swing left (unless prevented by a peg in the meter) and, in a digital meter a negative result will be displayed.

   a) Test your predictions to 10 (a) and (b) above: After connecting the meter to the brushes, repeat the two 90-degree rotations, taking about one-half second for each. Comment on your findings.

⑫ Using the same reasoning as before, predict the direction(s) of the current during the next 180-degree rotation following the one you just made.

   (b) Test your predictions with the meter and comment.

   (c) What is different if the armature is rotated in the opposite direction?

⑬ As the armature rotated, the current changed both in magnitude and direction. This is called alternating current. If this generator were rotated at 3600 revolutions per minute, what would the frequency of the alternating current be?

Part B: DC Generator

① Review steps 1 and 5. Then remove the armature and install it with the split ring commutator down between the brushes.

② Connect the meter and rotate the armature slowly, at a rate of about one complete revolution in two seconds.

   (a) How does the meter respond?

   (b) How does the meter respond when the armature is rotated in the opposite direction?

(c) What does the split ring commutator do to explain the difference in results from those with the dual slip rings?

(d) Which of the following describes the results? (a) AC   (b) pulsating DC (c) steady DC

③ Spin the armature several more times, more rapidly each time. Stop if this causes you to exceed the range of the meter. (a) What is the effect of greater rotational speeds?

(b) This result may be explained in terms of the ideas discussed above. Try to explain the effect of greater speeds.

④ If you have a PASCO computer interface and Voltage Sensor, try this: (a) predict how a voltage vs time graph would look if you put the dual slip rings down and spun the armature rapidly and let it slow to a stop.

(b) What if the split rings were down?

(c) What if the split rings were down, but you spun it in the opposite direction.

(d) Test these predictions if the proper equipment is available.

Experiment 3: Operation of an AC Synchronous Motor

EQUIPMENT NEEDED	
• Motor Accessory	• multimeter
• Variable Gap Magnet	• patch cords
• Digital Stroboscope or Digital Photogate Timer	• power source that will deliver both DC and AC current limited to 1.0 A
	• corrugated cardboard

Purpose

The purpose of this experiment is to demonstrate the operation of an AC synchronous motor in terms of basic concepts of electromagnetism.

Theory

The Variable Gap Magnet (a permanent magnet) may be thought of as possessing a north pole and a south pole that interact with the north and south poles of the armature (an electromagnet). Like poles repel, while unlike poles attract. The armature rotates until its north pole is as close as possible to the south pole of the permanent magnet (and also as far as possible from the north pole). At that moment, the alternating current reverses its direction in the armature. The poles likewise reverse, promoting another half-turn of the armature.

A better explanation involves an understanding of fields. The variable gap magnet produces a magnetic field that passes through the gap between the pole pieces. When current passes through the turns of the armature in the presence of the field, forces act to cause a torque that rotates the armature. Inertia carries the armature past the position of no torque to the point where the torque would force the armature back in the other direction. Instead, if the rotational speed of the armature matches the frequency of the alternating current, the direction of current in the armature will reverse at that instant, so that the torque continues to act in the original direction.

Setup

① Be sure you have the flat iron pole pieces placed on the two neodymium magnets of the Variable Gap Magnet. (The iron pole pieces spread the magnetic field over a wider area.) Screw the larger threaded portion of the shaft into the threaded hole in the magnet base. Insert the threaded end of the shaft from above, screwing it in until 1 mm, or slightly less, of the threaded portion remains above the upper surface of the base.

② Turn the magnet over and screw the retaining nut onto the smaller diameter threaded portion of the shaft that protrudes through the bottom of the magnet base. Use firm finger pressure. ***Do not over tighten.***

③ Working from above, press the brush holder onto the smooth, enlarged portion of the shaft. Apply increasingly firm pressure equally to each side of the brush holder while rotating the brush holder back and forth. If this action loosens the retaining nut, tighten it more tightly, as described in step 2.

> Check to be sure the brush assembly is seated as far down on the shaft as it will go.

④ Gently lower the armature onto the shaft with the dual slip- ring commutator down. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between them. If necessary, insert a pencil or similar object down between the brushes. Use only the most delicate force to avoid bending the brushes and necessitating adjustments or repairs.

⑤ Adjust the gap of the Variable Gap Magnet so there is approximately 1 mm of clearance between the flat pole pieces and the armature when it is rotated by hand.

Figure 1. Installation of the Motor Accessory onto the Variable Gap Magnet

armature — dual slip-ring commutator

brushes

brush holder

shaft

flat pole pieces

leave 1mm exposed at installation

magnet base

wrench/ retaining nut
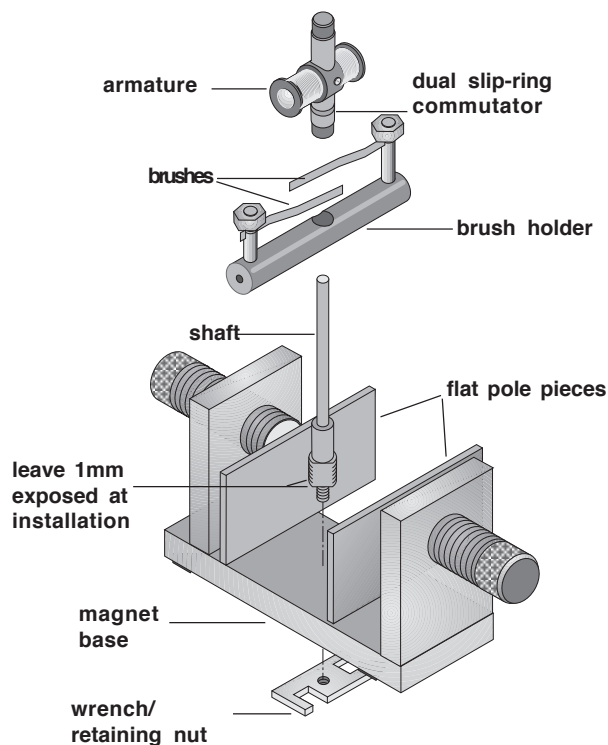
Procedure—Part A

① Remove the armature from the shaft by grasping it between your thumb and forefinger and rotating it back and forth while lifting gently. If necessary, insert a pencil between the brushes to gently separate them so they don't prevent removal of the armature.

② Examine the armature closely and imagine current entering one of the two slip rings from a brush. Trace the path of the current through the wire to the coil, through the coil, through the wire to the coil on the opposite side of the armature, through that coil, and through the wire to the other slip ring and into the second brush. By carefully examining the part of the coils where the leads emerge from the coil, you should be able to determine the direction in which the wire is wound on the coil.

③ Holding the armature in one hand, follow the wire from the slip ring to the left coil of the armature and note the direction the wire is wound in the coil. Note where the wire enters and exits the coil.

④ Imagine that the AC current is in the positive half of the waveform. This means that conventional current comes out of the terminal marked positive of the power supply and enters the terminal marked negative. Use the right-hand rule to determine the direction the magnetic field will flow at that instant: Grasp the coil with your fingers wrapped around the coil in the direction of the current. (Current direction is described by convention as being from the positive to the negative. Note that this is opposite of the direction of electron movement.) Your thumb will point in the direction of the field (that is, toward the north pole of the coil). Put a small piece of tape on the end of the coil that would be its north pole at that instant.

⑤ Follow the wire over to the right coil. Use the right hand rule to find the direction of the north pole.

   a) In this situation, is the direction of the north pole the same for the right and left coils?

   b) In that case, can you say that, in this situation, the north pole of either the coils is in the same direction as the north pole of the armature?   Explain why.

   c) True or False: In this AC motor, we can determine the direction of the magnetic field of the armature at any instant by determining the direction of the north pole of either of the two coils.

⑥ Imagine that the AC current is in the negative half of the wave form. This means that conventional current comes out of the terminal marked negative of the power supply and enters the terminal marked positive. Repeat step 5 to determine which end of the armature would be its north pole at that instant.

   Is the north in this case on the same or opposite end of the armature as in step 5?

⑦ Turn the armature over 180° and imagine that the AC current is in the positive half of the waveform. Note the path of the wire from where it is attached to the slip ring to where it enters and exits from the coil on the left side of the armature.

   Use the right-hand rule to determine the direction the magnetic field would flow.

   Is the north pole on the same arm of the armature as in step 5?

⑧ Imagine that the AC current is in the negative half of the waveform. Use the right hand rule to find the armature's north pole.

   a) What can you say about the location of the armature's north pole as the AC waveform alternates from positive to negative?

   b) What is the function of the slip-ring commutator?

⑨ Gently replace the armature onto the shaft. The dual slip-ring commutator should be down. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between the brushes.

PASCO
scientific

Procedure—Part B

① Adjust the gap of the Variable Gap Magnet so there is approximately 1 mm of clearance between the pole pieces and the armature when it is rotated by hand.

Connect the motor to the power source by one of these methods (See Figure 2):

- Insert banana plugs into the openings in the ends of the plastic brush holder; or

- Grip the brass posts of the brush holder with large alligator clips; or

- Attach small alligator clips to the ends of the brass strips that serve as brushes.

Adjust the power source to deliver 6 volts of DC current limited to 1.0 amp. (Have your teacher show you how if you don't know.)

② Hold the armature in a position like that shown in Figure 2. Hold the ceramic magnet near the ends of the armature in order to establish which end is a north pole and which is a south pole. The painted face of the magnet is its North Pole (north-seeking pole). [You can verify this by hanging the magnet from a thread and observing that the painted face points toward the North (toward the earth's north magnetic pole, located in northern Canada).] If both poles of the ceramic magnet attract the armature, the pole with the stronger attraction will be the opposite pole. Verify that the result of the tests agree with your results from step 3. Determine the polarity of the Variable Gap Magnet in the same way.

③ Now set the power source to furnish to the brushes with alternating current with a sinusoidal

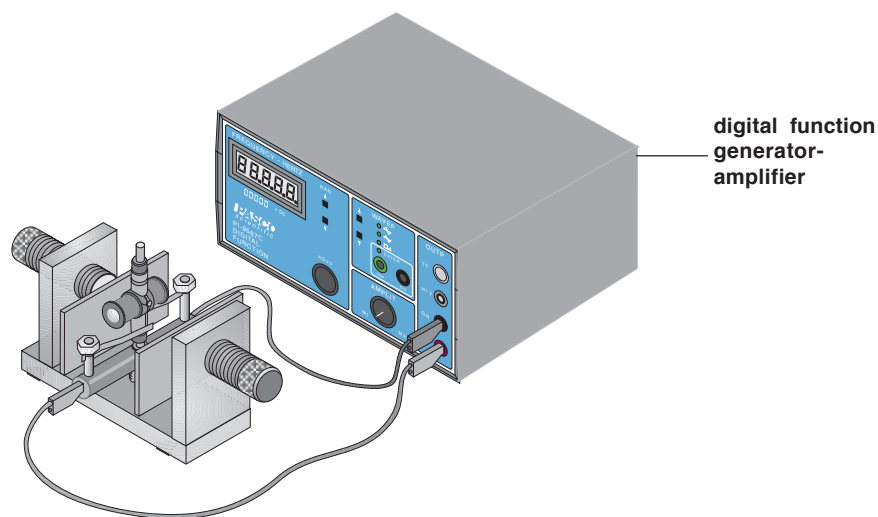digital function generator-amplifier

Figure 2. Experimental Set up

waveform at a frequency of about 30 Hz and voltage of about 6 volts. Rotate the armature by hand slowly through one complete revolution.

a) Describe the sensation you feel.

b) Explain why this happens.

④ Repeat this with 30 Hz and 4 volts.

a) Does this feel different? How?

b) Explain why.

⑤ Repeat with 15 Hz and 6 volts.

a) Does this feel different? How?

b) Explain why.

> ➤ Troubleshooting: If there was no vibrating sensation in the previous step, the brushes were not contacting the slip rings, there was no AC voltage present at the brushes, or some other defect existed. Recheck the connections and gently bend the brushes inward to make better contact. If neither of these corrects the problem, get assistance. If there was a vibrating sensation during only part of the rotation, turn off the power, remove the armature, and examine both the split rings and brushes for corrosion and pitting. Cleaning these with very fine (600 grit) emery paper will usually correct the problem and result in better operation.

⑥ Turn the power off.

⑦ Set up the photogate or stroboscope to measure the speed of rotation of the motor, following your teacher's instructions.

If you are using a photogate, construct a "chopper" of a 3-inch piece of card stock to interrupt the beam of light from the photogate as follows:

Cut a 3 cm square from corrugated cardboard and punch a hole that is 1 cm in diameter in the center (a #4 cork boring tool works well). If the square slips, you may need to secure it with tape. Slip the square part way down the split ring commutator so you can grip the plastic bushing to spin the armature. Position the photogate so the corners of the square interrupt the photogate's beam 4 times per revolution.

> ➤ Notice that the motor is not self-starting. Immediately after you apply the AC power, start the motor manually by grasping the black plastic bushing at the top of the armature assembly between thumb and forefinger and spinning the armature. It may take several attempts to successfully start the motor because you must spin the armature at a speed that approximately matches the frequency of the power source.

⑧ Set the voltage to 8 volts and the frequency of the alternating current to 16 Hz. Start the motor and use the stroboscope or photogate to determine the rotational speed of the motor. What is the rotational speed of the armature?   If the result is not already expressed in revolutions per second, convert it to these units.

⑨ While the motor is running, lower the voltage to 6 volts. Does the rotational speed of the

armature change when you change the voltage?

> ➤ Note: with the PASCO 6500 Series Power Amplifier, the motor may stop and
> need to be restarted manually.

⑩ Return the voltage to 8 volts and change the frequency of the alternating current to 20 Hz,
and then 24 Hz, determining the rotational speed each time. (Manually restart the motor
each time if needed.)

Does the rotational speed of the armature change when you change the current frequency?

⑪ If the room is lit with fluorescent lights, you can also see the effect changing the current
frequency on the motor's speed. Fluorescent lamps flash twice during each cycle of the AC
power that supplies them. When the motor operates at a submultiple of this rate, multiple
images will appear to be stationary, so the armature will appear to be not moving. Observe
the armature at current frequencies of 15, 20, 24, and 30 Hz (or at 16.67, 20, and 25 Hz in
locations with 50 Hz AC power).

Experiment 4: Operation of the Universal Motor

Equipment needed:	
• Motor Accessory	• multimeter
• Coils and Cores Set	• patch cords
• power source that will deliver both DC and AC current at 1.0 A	

Purpose

The purpose of this experiment is to demonstrate the operation of the universal motor in terms of basic concepts of electromagnetism.

Theory

When current passes through the coils mounted on the U-shaped core of the Coils and Cores apparatus, the core may be thought of as an electromagnet possessing north and south poles that interact with the north and south poles of the armature (another electro-magnet). Like poles repel, while unlike poles attract. The armature rotates until its north pole is as close as possible to the south pole of the permanent magnet (and also as far as possible from the north pole) At that moment, the action of the split ring commutator reverses the direction of current in the armature, which reverses the poles of the armature, promoting another half-turn.

When the coils on the U-shaped core are in series with the coils of the armature, the configuration is called a "universal motor." The term comes from the fact that it will operate on either DC or AC current. With alternating current, the changes in direction of the current cause reversals in both the poles of the U-shaped core and the armature, so attraction or repulsion between poles is the same as with direct current. In terms of the magnetic fields, with direct current, the magnetic field of the armature reverses every half turn and the magnetic field of the coils does not. With alternating current, the opposite happens. Either way, the armature keeps turning.

Setup

① Begin with the U-shaped core, with the coils and any other parts removed. The smaller threaded portion of the *shaft* screws easily into the threaded hole in the core so the shaft is between the poles of the core. Use the *wrench* provided to tighten the shaft by gripping the flats on the larger threaded portion. The small wrench limits the torque that can be applied. If an ordinary wrench is used, be careful not to over tighten. Do not discard the small wrench; it is essential as a retaining nut when the Motor Accessory is used with the Variable Gap Magnet.

② Working from above, press the *brush holder* onto the smooth, enlarged portion of the shaft. Apply increasingly firm pressure equally to each side of the brush holder while rotating the brush holder back and forth. If this action loosens the shaft, tighten it as described in step 1.
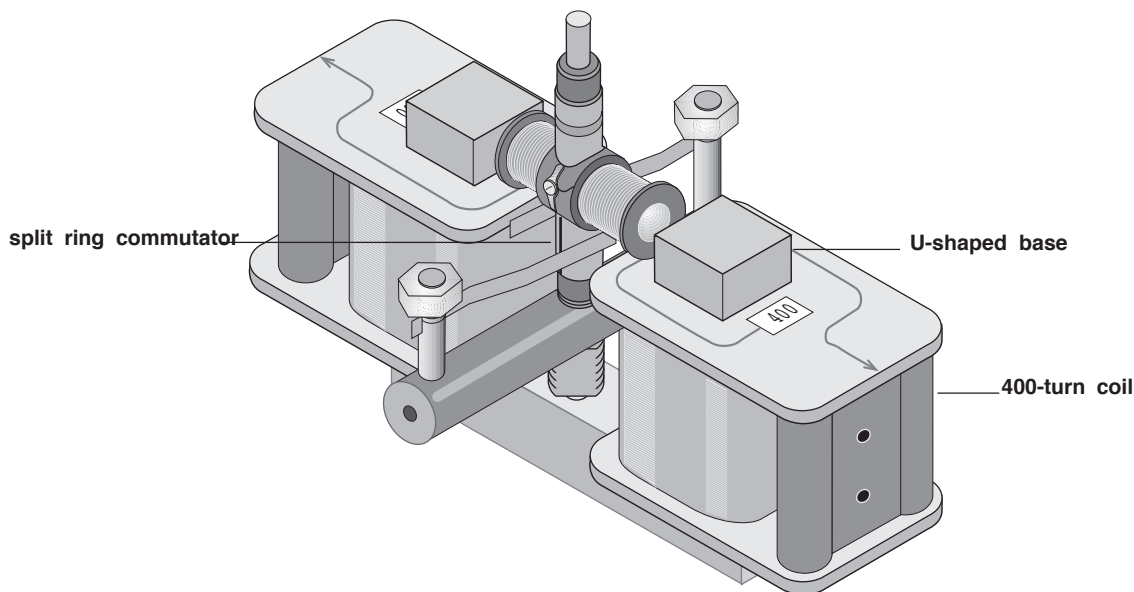
Figure 1. Motor Accessory Installed on the Coils and Cores Set

➤ Check to be sure the brush assembly is seated as far down on the shaft as it will go.

③ Orient the brush holder perpendicular to the base of the Coils and Cores apparatus. Place the two 400-turn coils from the Coils and Cores Set onto the poles of the core.

④ Gently lower the *armature* onto the shaft. The *split ring commutator* should be down. Carefully rotate the armature back and forth to separate the brushes and allow the commutator to slip down between them. If necessary, insert a pencil or similar object between the brushes to separate them. Use only the most delicate force to avoid bending the brushes and necessitating adjustment or repairs.

Procedure

① Connect the motor the power source as shown in Figure 2. All connections may be made by inserting banana plugs into the openings in the ends of the plastic brush holder and the external coil forms. *Do not turn on the power source yet*.

② Rotate the armature and observe how the segments of the split ring commutator contact different brushes as the armature turns.

③ Remove the armature from the shaft by grasping it between your thumb and forefinger and rotating it back and forth while lifting gently. If necessary, insert a pencil between the brushes to gently separate them so they don't prevent removal of the armature.

④ Examine the armature closely and imagine current entering one of the split rings from a brush. Trace the path of the current through the wire to the coil, through the coil, through the

wire to the coil on the opposite side of the armature, through that coil, and through the wire
to the other split ring and into the second brush. By carefully examining the part of the
coils where the leads emerge from the coil, you can determine the direction in which the
wire is wound on the coil. [Current direction is described as being from the positive to the
negative (conventional current). Note that this is opposite of the direction of electron
movement.] Draw arrows on Figure 2 showing the direction of current at various points in
the motor, armature, and wire.

⑤ You can use the "right-hand rule" to predict the direction of the magnetic field of a coil.
Grasp the coil with your fingers wrapped around the coil in the direction of the current.
Your thumb will point in the direction of the field (that is, toward the north pole of the
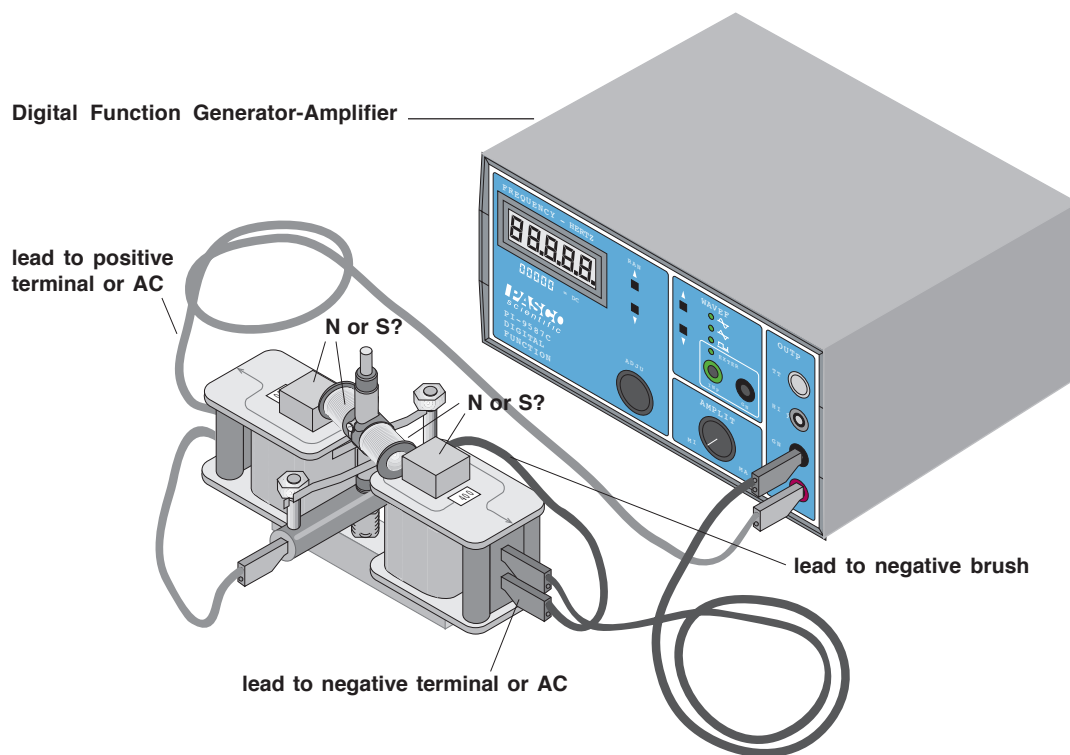coil). Label the ends of the coil N and S in Figure 2.

Figure 2. Experimental Setup

⑥ Gently replace the armature onto the shaft. The split ring commutator should be down.
Carefully rotate the armature back and forth to separate the brushes and allow the commu-
tator to slip down between them. If necessary, insert a pencil or similar object between the
brushes to separate them. Use only the most delicate force to avoid bending the brushes
and necessitating adjustments or repairs.

⑦ Use the right-hand rule to establish the location of the north and south poles of the U-
shaped core. Arrows molded into the plastic coil forms show the direction of the winding
in the coils. Label the poles on Figure 2.

⑧ Turn on the power supply (10 volts DC) for the next step.

> ➤ Do not leave the power connected to the motor for extended periods, particularly with the armature not rotating, because the windings may overheat.
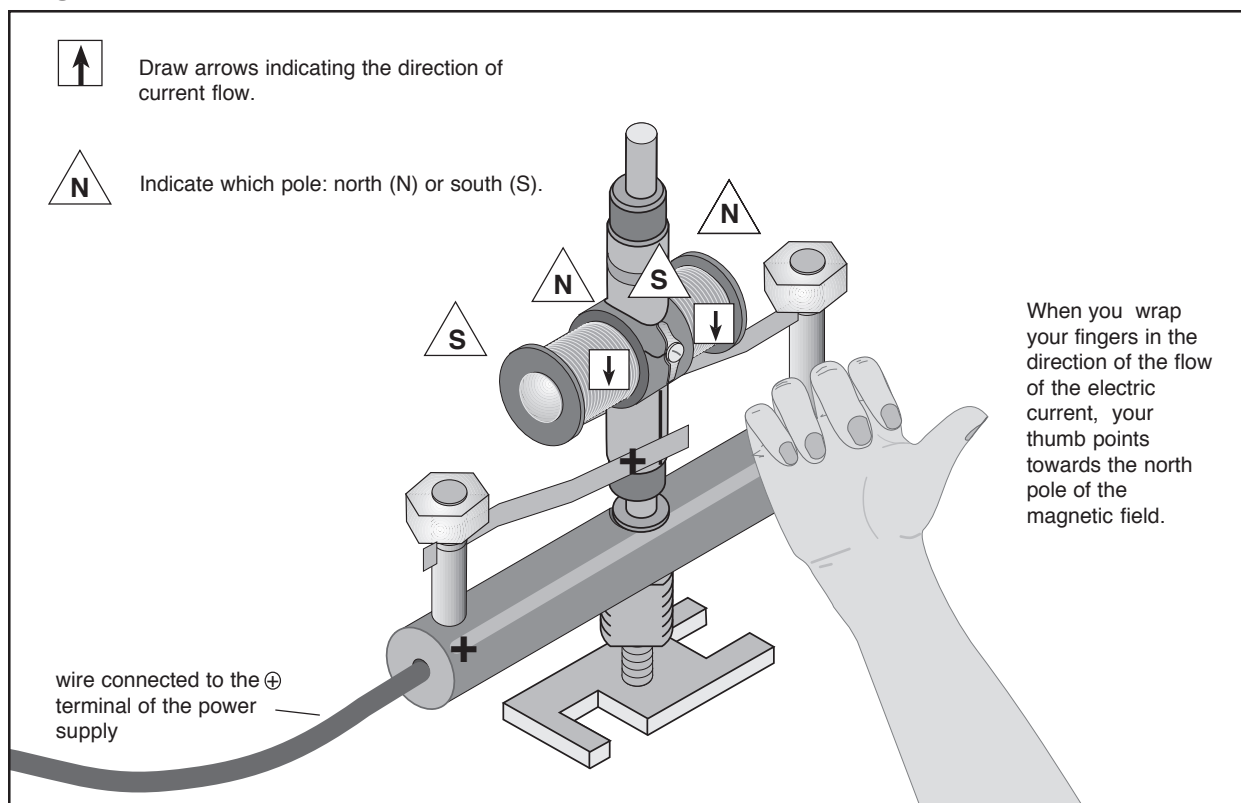
⑨ Use the small cylindrical ceramic magnet to check your predictions from steps 5 and 7 above. The painted face of the magnet is its North Pole (north-seeking pole). [You can verify this by hanging the magnet from a thread and observing that the painted face points toward the North (toward the earth's north magnetic pole, located in northern Canada).] With the armature and power supply leads oriented as in Figure 2, hold the ceramic magnet near the ends of the armature. If both poles of the ceramic magnet attract the armature, the pole with the stronger attraction will be the opposite pole. Verify that the result of the tests agree with your labeling of the figure. Determine the polarity of the U-shaped core in the same way. Label its poles N and S in Figure 2.

⑩ Predict the direction the armature will rotate when you release it from the position shown in Figure 2. If the motor does not start up immediately, try turning it by hand in the opposite direction.

⑪ Turn off the power and reverse the leads to the brushes. Before turning the power on, predict the direction of rotation. Turn the power back on and immediately try spinning the motor to start it. If it doesn't start, try spinning it in the other direction.

⑫ Predict the effect on the motor's speed of decreasing the voltage to 8 volts.

⑬ Predict the effect of replacing the direct current with alternating current of 10 volts at 12 Hz. Also predict the effect of then reducing the voltage to 8 volts. Test these predictions.

⑭ Predict the effect of raising the frequency to higher values such as 15, 20, 25, and 30 Hz. Test this prediction. Try to explain the result. (The explanation involves the concept of inductive reactance.)

Teacher's Guide

Experiment 1:

➤ Remind students not to prolong situations when the armature is not spinning and the power is connected—the coils will overheat.

Figure 4, labeled

Draw arrows indicating the direction of current flow.

Indicate which pole: north (N) or south (S).

When you wrap your fingers in the direction of the flow of the electric current, your thumb points towards the north pole of the magnetic field.

wire connected to the ⊕ terminal of the power supply

Questions:

Part A

⑥ a) Yes.
  b) They add together to create a greater effect.

⑦ No.

⑧ a) Yes.
  b) True.
  c) False.
  d) The location of the armature's north pole alternates between ends of the armature as the + lead touches the alternate sides of the split ring commutator.
  e) The current is alternating in the coils because one side of the split ring commutator sends the current in one direction in the wire, while the other side sends it in the opposite direction in the wire.

Part B

③ Results of the test should agree with predictions.

④ Clockwise, if the leads are connected exactly as shown in Figure 2 and the north pole of the Variable Gap Magnet is on the left.

⑤ a) It should rotate in the counter-clockwise direction.

b) Answers will vary. If students explain using the concept of "opposite magnetic poles attract and same poles repel," they will say something like, "As the opposite sides of the split-ring commutator come in contact with the + lead of the DC power supply, the location of the north pole of the electromagnet alternates, causing it to seek alternating poles on the permanent magnet."

If student responds using the concept of torque they might say, "The flux lines of the permanent magnet extend from its north to south pole and interact with the flux lines of the electromagnet, producing a torque that spins the armature. Inertia carries the armature past the position of no torque to the point where the torque would force the armature back in the other direction. However, at that point the commutator reverses the direction of current in the armature so the torque continues to act in the original direction."

⑥ a) The motor speeds up.

b) The motor's speed is directly dependent on the voltage of the DC current.

Experiment 2

Questions:

Part A: AC Generator

⑦ (a) It increased.

(b) An emf (electromotive force or voltage) will be induced in the coil.

⑧ (a) It decreased.

(b) An emf will be induced.

(c) The emf will be opposite in sign (or direction) in the two steps because the change in flux within the turns is opposite in the two cases. (In one case it is increasing, in the other case, decreasing.)

⑨ (a) It should be a north pole, to repel the N pole of the Variable Gap Magnet and thus to oppose the motion.

(b) a south pole

⑩ (a) It must enter the coil from the upper brush.

(b) It must leave the coil and pass into the upper brush.

⑪ If the negative lead of the meter is connected to the upper brush and the positive lead is connected to the lower brush, then the meter will show positive (or move right) curing the first quarter turn, and negative (needle will move left) during the second quarter turn.

⑫ (a) During the 3rd quarter turn, the current will leave the coil and pass into the upper brush; during the 4th quarter turn, the current will enter the coil from the upper brush.

(b) Assuming as before that the negative lead of the meter is connected to the upper brush and the positive lead is connected to the lower brush, during the 3rd quarter turn, the meter will show negative (or move left); during the 4th quarter turn, the meter will show positive (or move right).

(c) Every result will be reversed.

⑬ 3600 cycles per minute, or 60 cycles per second, more properly termed 60 Hertz, or 60 Hz

Part B: DC Generator

① (a) The voltage and current produced is always in the same direction (direct current) but is pulsating, not steady. (The pulsating nature will be difficult to note with a digital meter.) Assuming as before that the negative lead of the meter is connected to the upper brush and the positive lead is connected to the lower brush, then if armature is rotated clockwise (as viewed from above) the meter will read positive.

(b) It responds similarly to *a* but in the opposite direction.

(c) Just as the current is about to reverse direction (as, for example, between steps 10 *a* and *b*), the commutator reverses the connections between the coil and the brushes in order to main the consistent direction of the current.

(d) pulsating DC

② (a) The effect would be greater voltage and current.

(b) Answers will vary. Two possible explanations include: (1) The free electrons present in the wire of the coil move through the wire as a current due to the force given by **F=qV x B**, where the force is seen as being proportional to the velocity of the wire, and thus the electrons contained in it. At greater rotational speeds, the velocity of the wire would be greater, and thus the force causing electron movement. (2) Faraday's law states that the emf induced is proportional to the *rate* at which the flux in the loops of the coils is changing. At higher rotational speeds, the rate of change to the flux is greater, and thus so is the emf.

③ (a) The voltage vs. time graph would be a "sine wave" whose amplitude *and* "wave-length", or period, is decreasing to zero.

(b) It would be the same as *a* except all portions that would be below the horizontal (time) axis are instead reflected above it.

(c) It would be the same as *b* except everything is below the axis.

Experiment 3

Notes concerning the setup:

• If the power source does not limit the current to 1 A, use an appropriate resistor in series to limit the current.

• If the AC power source does not quantify the current, use an appropriate ammeter, or measure the voltage drop across a resistor of 0.51 ohm, 1 watt wired in series and calculate the current.

• Remind students not to prolong situations when the armature is not spinning and the power is connected—the coils will overheat.

Questions

Part A

⑤ a) Yes.

b) Yes. Since the coils are wound such that the north poles of each are in the same direction, they work together to produce a net magnetic flux for the armature that is the sum of the magnetic flux of each of the coils.

c) True.

⑥ Opposite

⑦ Yes.

⑧ a) The armature's north pole alternates from end to end as the AC waveform alternates from positive to negative.

b) The slip-ring commutator connects the armature to the power source by way of the brushes and enables the current to travel in an unbroken stream from the positive to the negative terminals of the power supply.

Part B

③ a) The armature vibrates or pulses.

b) This happens because the alternating current causes the polarity of the armature to reverse with each AC cycle.

④ a) It vibrates or pulses at the same frequency, but with less force.
b) This happens because the rate at which the polarity reverses is the same, but the force of the induced magnetic flux of the armature decreases with the decreased voltage.

⑤ a) The rate of vibration is lessened, and the strength of the pulsation is increased.
b) The halving of the cycle rate of the AC results in halving the rate of reversal of polarity in the armature, while the increase in voltage results in the increase in strength of the pulsations.

⑨ The rotational speed of the armature does not change when you change the voltage.

⑩ The speed varies directly with the AC frequency.

Experiment 4

• Remind students not to prolong situations when the armature is not spinning and the power is connected—the coils will overheat.

• If the power source does not limit the current to 1 ampere, use an appropriate resistor (e.g. 0.51 ohm, 1 watt) in series to limit the current.

Questions

4, 7, and 9 (see diagram below)
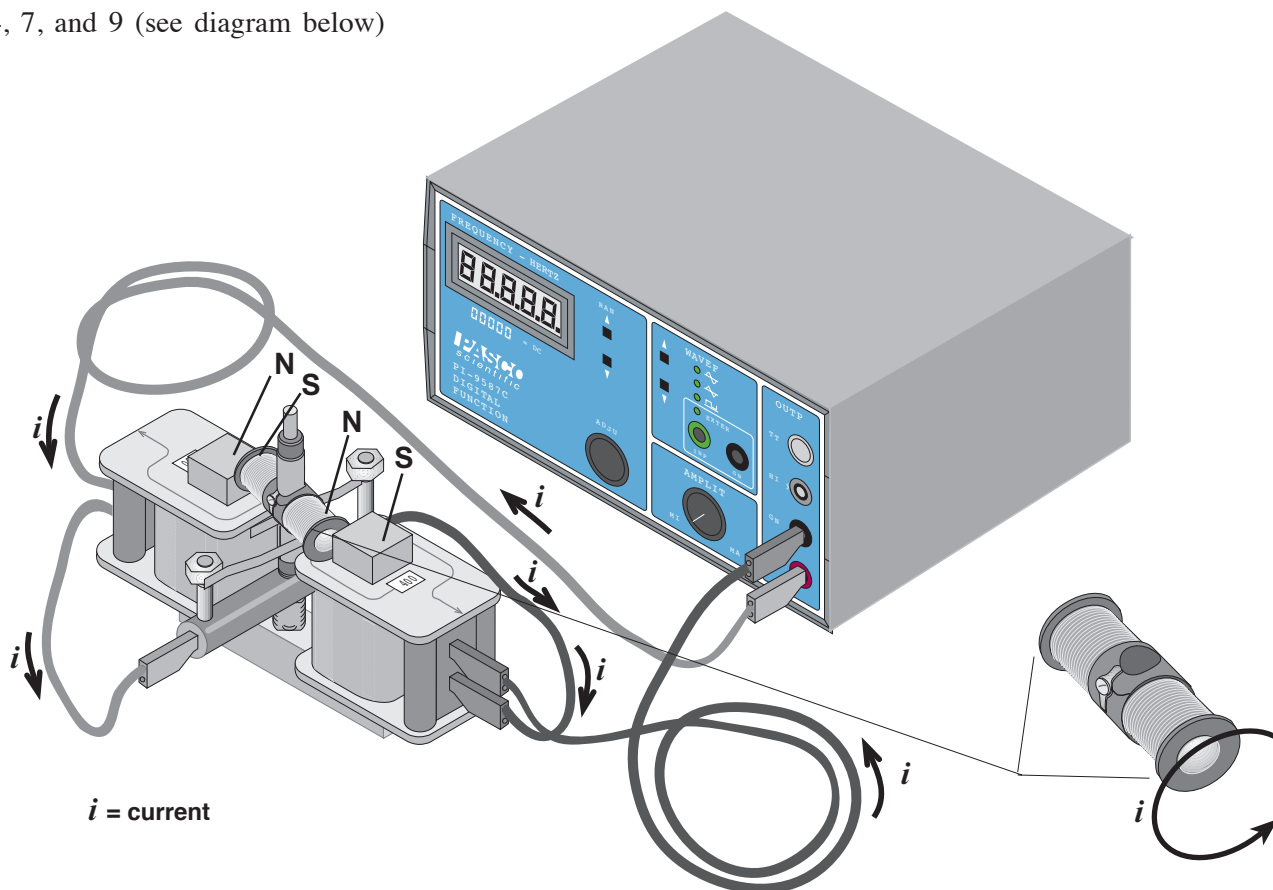
i = current

⑩ Counter-clockwise, as viewed from above.

⑪ The motor should turn clockwise.

⑫ The motor's speed will decrease.

⑬ The motor should operate at a high rate of speed, but not in synchronism with the alternating current source. Reversing the direction of current flow from the power supply has no effect on the motor's operation, because a reversal of polarity will occur in BOTH the armature and field coils simultaneously, and any attraction or repulsion between poles will be unaffected. The speed will be lower when the voltage is reduced.

⑭ The speed of the motor will decrease as the frequency is increased, clearly showing that it is not operating in synchronism with the alternating current source. Coils resist changes in current, and the greater the rate of change, the greater the "resistance". This resistance is properly termed *inductive reactance*. The inductive reactance of the coils is greater at higher frequencies; thus less current flows and there is less power.

• You can use this experimental setup to demonstrate a *hysteresis synchronous motor* by disconnecting the leads to the brushes and attaching them to each other. In this configuration, no current flows through the armature. Nonetheless, when 10 V, 12 Hz current is applied to the field coils and the armature spun, it will continue to rotate in sync with the applied current.

• You may want to challenge the students to predict and test what happen if DC is applied to the armature while AC is applied to the coils. You can use this experimental setup to demonstrate a *hysteresis synchronous motor* by disconnecting the leads to the brushes and attaching them to each other. In this configuration, no current flows through the armature. Nonetheless, when 10 V, 12 Hz current is applied to the field coils and the armature spun, it will continue to rotate in sync with the applied current.

• You may want to challenge the students to predict and test what happen if DC is applied to the armature while AC is applied to the coils.

Notes

Technical Support

Feedback

If you have any comments about the product or manual, please let us know. If you have any suggestions on alternate experiments or find a problem in the manual, please tell us. PASCO appreciates any customer feedback. Your input helps us evaluate and improve our product.

To Reach PASCO

For technical support, call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

fax: (916) 786-3292

e-mail: techsupp@PASCO.com

web: www.pasco.com

Contacting Technical Support

Before you call the PASCO Technical Support staff, it would be helpful to prepare the following information:

➤ If your problem is computer/software related, note:

- Title and revision date of software;

- Type of computer (make, model, speed);

- Type of external cables/peripherals.

➤ If your problem is with the PASCO apparatus, note:

- Title and model number (usually listed on the label);

- Approximate age of apparatus;

- A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.);

- If possible, have the apparatus within reach when calling to facilitate description of individual parts.

➤ If your problem relates to the instruction manual, note:

- Part number and revision (listed by month and year on the front cover);

- Have the manual at hand to discuss your questions.