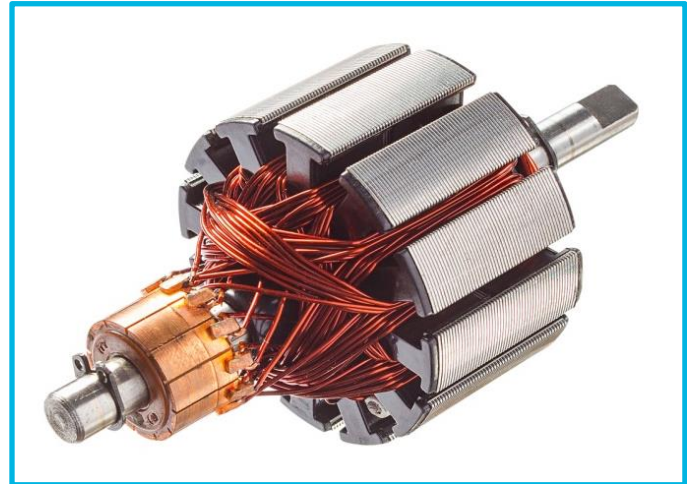


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Lesson Focus

The general field of electric motors is unusually wide, covering as it does both direct current (DC) and alternating (AC) machines. While DC motors are comparatively simple, AC motors are more complex and cover a much wider range of alternatives. They are therefore more suited to an older group of students. With this in mind, we cover this topic in two separate lessons. This present lesson covers DC motors and generators only and is suited for students in the 10 to 14 age bracket. AC motors are covered in the lesson entitled "Basic



Alternating Current Motors" to be found elsewhere in this general series. Since this lesson is intended for the younger students, the tone of the writing is deliberately light hearted.

The existence of electricity has been known to mankind almost from the beginning of time, notably in the form of lightning. Two of the early experimenters in this field were Ben Franklin (1706 – 1790) and Luigi Galvani of Italy (1737 – 1798). Franklin, is of course, generally known for his experiment of flying a kite into a thunder cloud and obtaining a spark from a key attached to the end of the kite string. (Old Ben was not foolish and knew what he was doing. He attached the string to an iron rod set deep in the ground, and stood on a wooden box to insulate himself). The iron rod would today be known as a ground rod and is a safety requirement in all electrical installations. Furthermore, he flew his kite close to, but not into the storm cloud. (Note also that thunder clouds contain hundreds of thousands of Volts). Galvani is best known for his accidental discovery in 1780 that when he was dissecting a frog's leg, it twitched when touched with a scalpel which had become electrically charged after being wiped on a clean dry cloth. It is worth noting that today we use the expression that "...he was suddenly galvanized into action....."

Magnets have been known to mankind for many centuries, in the form of compasses used by seafarers. But the needles in these compasses were generally formed from naturally occurring materials, or by stroking a piece of iron with another piece which was already magnetized. It was only within the last 200 years or so that it was discovered that magnets could also be made by passing an electric current through a coil of wire and placing pieces of iron inside the coil.

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Lesson Synopsis

The lesson begins by outlining the work of some of the early experimenters and the sequence which eventually led to the realization of how a changeable electro-magnetic field could be harnessed to other purposes. From there the lesson goes on to demonstrate how electric currents, magnetic fields and electro-magnetic fields are so closely related. A simple hands-on activity is provided at the end of the lesson.

The lesson ends with a section in which the students are invited to discuss with the teacher, various ways in which they think these demonstrations could be improved.

Age Levels

10 - 14

Objectives

Students will:

- ◆ Gain a useful initial acquaintance with the most common elements of electricity and electrical equipment.
- ◆ Learn about how a rotating magnetic field, when interacting with suitably arranged coils of wire, can be made to produce a rotating mechanical force, i.e. an electric motor.
- ◆ Learn that a rotating magnetic field, when driven by a mechanical force, can produce an electric voltage, i.e. a generator.
- ◆ Learn that these two effects are generally speaking, equal and reversible.
- ◆ Learn about how these two phenomena can be conveniently and safely controlled.
- ◆ Learn about the importance of discipline and team work.

Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- ◆ Basic direct current generators and motors
- ◆ engineering history
- ◆ problem solving
- ◆ teamwork

Lesson Activities

- ◆ It is suggested that the students assist the teacher in obtaining the simple materials –basically, some a small “button type” magnets, and fiber discs and some 30 awg magnet wire (see Figs. 27-29) and assemble them together to demonstrate how an electric motor works. The cost of these materials is negligible – probably less than \$10.00 per “motor” and can be re-used many times.

Resources/Materials

- ◆ Teacher Resource Documents (attached).
- ◆ Student Resource Sheets (attached)

Alignment to Curriculum Frameworks

- ◆ See attached curriculum alignment sheet.

Internet Connections

- ◆ TryEngineering (www.tryengineering.org)

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Recommended Reading

- ◆ Wikipedia "How Electric Motors are made".

Optional Writing Activity

- ◆ Having discussed the obvious limitations of this very simple demonstration unit, students should be asked to set out ways in which they think it could be improved.

Materials and Costs

To all intents and purposes, the material costs for the demonstrations in this lesson are very modest, perhaps \$10, and can be used over and over again. (See end of this lesson.). There is a list of materials contained in the hands on section.

Safety Note

Although the subject matter of this lesson is essentially harmless, it is suggested that the hands-on section be carried out under adult supervision.

Time Needed

It is suggested that, for the younger students, aged between 10 and 14, three sessions of 45 minutes each should be sufficient. For older students, two such sessions should be enough.

Source

- ◆ This lesson contributed to TryEngineering by Dave Hepburn, IEEE Canada.

**For Teachers:
Teacher Resource**

THE BASIC BASICS.

The companion lesson plan, “**Basic Electricity and Magnetism**” covers this material in some detail. However a brief summary may be useful here.

Lines of a Magnetic “Field” (Or Magnetic Flux)

Unfortunately magnetism cannot be seen, although it can certainly be measured. Figure 1 illustrates the general concept of what are known as “lines of magnetic force”. Lay one of your bar magnets flat on the table and cover it with a sheet of newspaper. Sprinkle some of your iron filings on the paper. You will find that they form a pattern like that shown in the figure, with the filings bunched together at the ends, and curving away towards the other end, where they bunch up again.

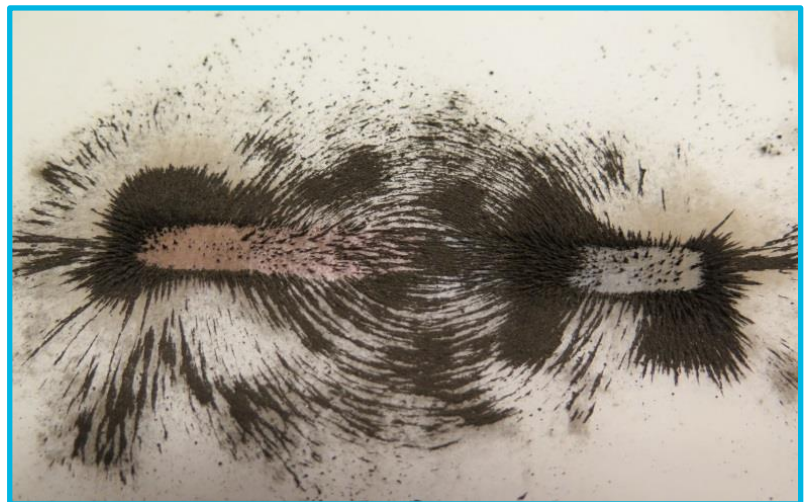


Fig. 1

Furthermore, if you take a reasonably strong bar magnet and suspend it horizontally by a piece of string, it will be found that gradually, it will swing around so that one end points roughly north and the other roughly south. These are therefore known as a “North-Seeking” and “South-Seeking” poles respectively, but are usually shortened to “North” and “South”.

Flux Density

A related concept is that of “Flux Density”. In other words, the more closely the lines are bunched together (notably close to the two ends of the magnet), represents a higher flux density. These densities can actually be measured and calculated, but require sensitive instruments, and we will skip that here. The unit of flux density is measured in “lines per square cm” (or square inch). For many years the unit of flux density was known as a **Gauss**, after the early German experimenter, Carl Friedrich Gauss, 1777 - 1855. However in 1960, the international unit for flux density became the **Tesla, or T**, after the famous pioneer, Nicola Tesla (1856 - 1943) and is equivalent to 10,000 Gauss.

Electromagnets

It was during the experiments made by Gauss, Oersted, Faraday et al, that it was discovered that the passage of an electric current through a wire (probably copper or soft iron in those days.) produced a small magnetic field around itself. Figure 2. It was further discovered that this magnet field could very much intensified if the wire was wound up into a cylindrical coil. (See Figure 3 below, and note the similarity to the flux around a bar magnet shown in Figure 1). This was a useful discovery for certain applications, because as we have seen above, as soon as the electric current is cut off, the magnetism around the coil collapses again to zero.

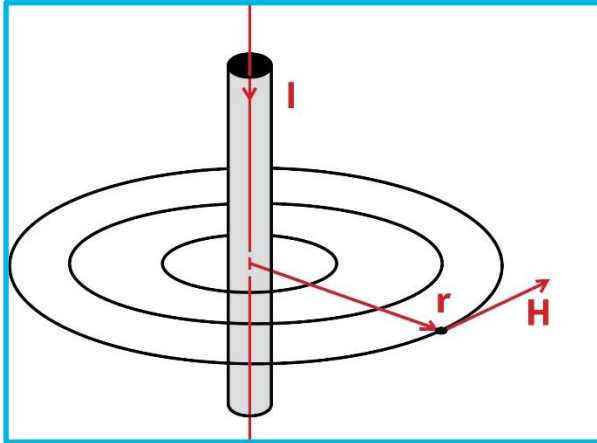


Fig. 2

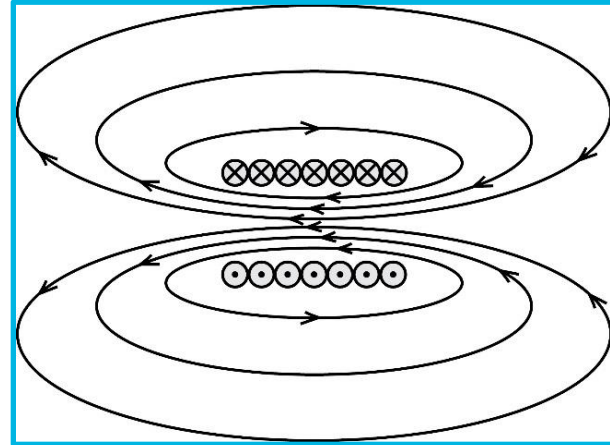


Fig. 3

The Fundamental Relationship between Electric Currents and Magnetism

The above text will hopefully have explained that electric currents and magnetism are fundamentally inter-related. By this we mean that an electric current in a wire (or a coil of wire) will induce a corresponding magnetic field having a certain polarity. If the direction of the current in the coil is reversed, the polarity of magnetic field is reversed.

Some Basic Conventions

At the outset, it should be clearly understood that these “conventions” are just that and no more. Some were established 150 years ago, when measuring instruments were in their infancy. Subsequent improvements have shown one or two were in fact of the wrong polarity. But the basis of these conventions is still valid inasmuch that if one element is reversed, all other related elements will also reverse. Consider the following:-

Current Flow from a Battery.

The convention is that current from a battery flows OUT from the so called “Positive” terminal, through the circuit and then back INTO the “Negative” terminal of the battery. All batteries have a “+” and a “-” to indicate the correct polarity. However, subsequent research has shown that the electrons actually flow the other way. But so long as you follow the conventional rules (assumptions) everything else will fall into place and “north seeking poles” will continue to seek the geographic North Pole, and motors will continue to rotate in the desired direction. And then, of course, if you want to reverse the motor, all you have to do is reverse either the connection to the battery, or reverse to polarity of the field. So just hold on while we outline the other conventions, and you will see what we mean.

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Current Flow in a Conductor.

- If you see a circle with a dot in it, the convention is that the current is flowing **OUT** of the paper, towards you.
- If you see a circle with an X in it, the convention is that the current is flowing **INTO** the paper, and away from you.
- In other words, visualize a dart. If the point is towards you, the current is also flowing towards you. If you see an X, which looks like the tail feathers of a dart, the current is flowing away from you.

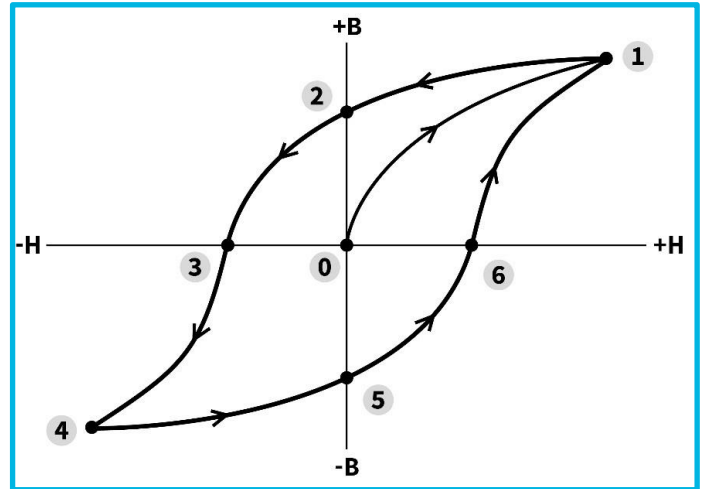


Fig. 4

Magnetic Field produced by Current Flow and Movement.

See Figures 2, 3, & 4.

- In Figure 2, the current is assumed to be flowing downwards through a single straight conductor. This will create a magnetic flux with a “North seeking pole” as shown. A handy way to visualize this is to think of a corkscrew, which if you turn it clockwise, will produce a North pole in the direction shown.
- Figure 3 represents a coil of wire, in which the current in the upper side is flowing **into** the paper, and is flowing **OUT** of the paper along the lower side. Again, if you visualize a corkscrew, turning it **clockwise when looking on the right hand end**, will (by convention) produce a North seeking pole over in the left side.

Electromotive Force, or EMF.

An EMF can in fact be created in any one of three ways – (a) from a battery, (b) by moving a wire through a magnetic field, or (c) by heating two wires of different materials which are solidly connected together. An EMF is therefore analogous to a voltage and/or a current flow.

Fleming’s Right-Hand and Left-Hand Rules.

John Ambrose Fleming (1849 – 1945) was an English Engineer and Physicist who pioneered many new developments including the thermionic tube (radio tube) in 1904. One of his earlier developments was a simple way of figuring out which way the current would flow in a DC generator (his right-hand rule) and which way a DC motor would turn (his left-hand rule). Figure 5 shows both of Flemings’ rules. His right-hand rule for generators, and his Left hand rule is for motors. And remember that generators can be made to motor simply by applying an EMF from an external source, and motors can be made to generate, this memory helper can be useful in both cases.

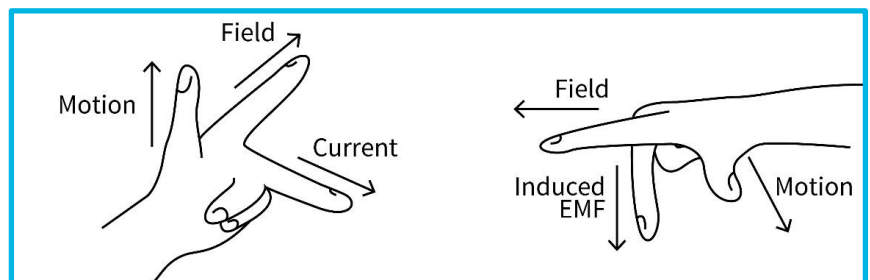


Fig. 5

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Consider the following:

Generators

- ◆ The **F**irst finger represents the magnetic **F**ield. Note here that the convention is that the field is understood to be the North polarity.
- ◆ The thu**M**b represents the direction of **M**otion.
- ◆ The se**C**ond finger represents the polarity of the induced EMF, which is analogous to the direction of **C**urrent flow.

Motors.

The same memory helper with regard to the thumb and fingers applies to motors as well. But remember, that it represents the other hand, so some of the directions are reversed.

So, how does a DC Generator Work?

Consider first, there are four main components as in Figure 6:

1. Two fixed (non-rotating) magnets. For the moment, let us assume they are "permanent" magnets. They are shaped into a "semi-tubular" configuration, but with opposite polarities. (Remember that opposite polarities attract, and like polarities repel each other). With the arrangement shown, the two magnets will both have a common magnetic field with the two "Norths" pointing towards the left. (There is nothing magic about which way they point, as long as they both point in the same direction).
2. A coil of wire, which rotates about an axis (the bearings are not shown). This is known as the rotor. Remembering what we have learned in the lesson on "Basic Electricity", you will recall that while mild steel is very easy to magnetize, air is extremely difficult – by a ratio of about 15,000:1 in fact. Therefore in the design of motors and generators, it is important to arrange things so that the two sides of the coil are as close to the face of the magnets as possible. (Hence two good strong bearings are necessary).
3. Each of the two ends of the coil are brought out to substantial copper connectors, which are together known as segments of the commutator. The outer surfaces are also curved to form part of a circle. Only 2 shown, but actually there always enough to form a full circle.
4. Two brushes. These press up against the outer surfaces of the commutator segments. These brushes are usually made of carbon, which is (a) a good

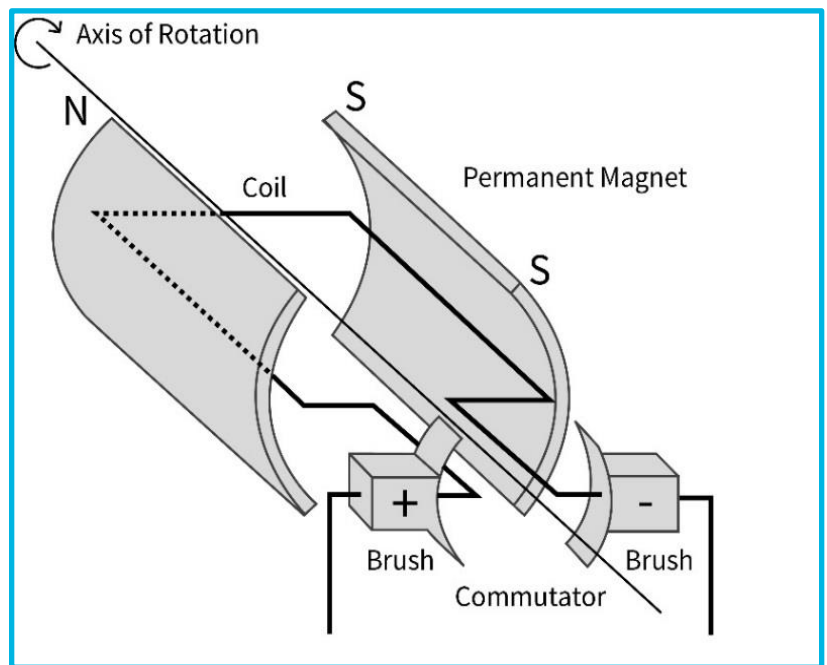


Fig. 6

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conductor of electricity, and (b) very smooth and with good lubricating properties. This is important because the copper segments of the commutator are quite soft and would soon wear down if the brushes were abrasive.

5. Class Note: The carbon from which brush gear are made is quite similar to the lead in a wooden pencil.

So what happens next?

Assuming all components have been suitably designed, if we rotate the coil at a steady speed about its' axis as shown, the two sides of the coil which run parallel to and are very close to, the inside faces of the two magnets, there will be a change of "Flux-Turn Linkages" (See companion lesson "Basic Electricity"), and an EMF induced in the coil. This in turn will appear as a voltage across the two brushes. If we connect a battery, to the two brushes shown in Figure 6, current will flow and the battery will begin to charge.

Polarity and direction of current flow

If for some reason, the direction of the current flow into the battery is in the wrong direction, it can be easily corrected by doing one of two things:

- Reverse the connections to the battery, or,
- Reverse the rotation of the coil.

Voltage control of a DC Generator

In the generator as shown in Figure 6, there is only one way of regulating the voltage it produces, and that is by changing the speed of rotation. It should be obvious that the faster the speed, the greater the rate of "Flux-turn linkages" and consequently the voltage produced.

However, there is better way to do this, as shown in Figure 7. In this diagram, the two permanent magnet "field poles" shown in Figure 6, have been replaced by a pair of electro-magnets. These two coils can be connected to the brushes as shown. Then, as soon as the rotor begins to turn, the magnetism in the poles (and there is always some very small residual magnetism, no matter how small) will begin to produce an EMF.

This will begin to build up (boot strap itself) almost instantaneously. The variable resistor shown can then be used to regulate the amount of current in the field and hence the voltage produced.

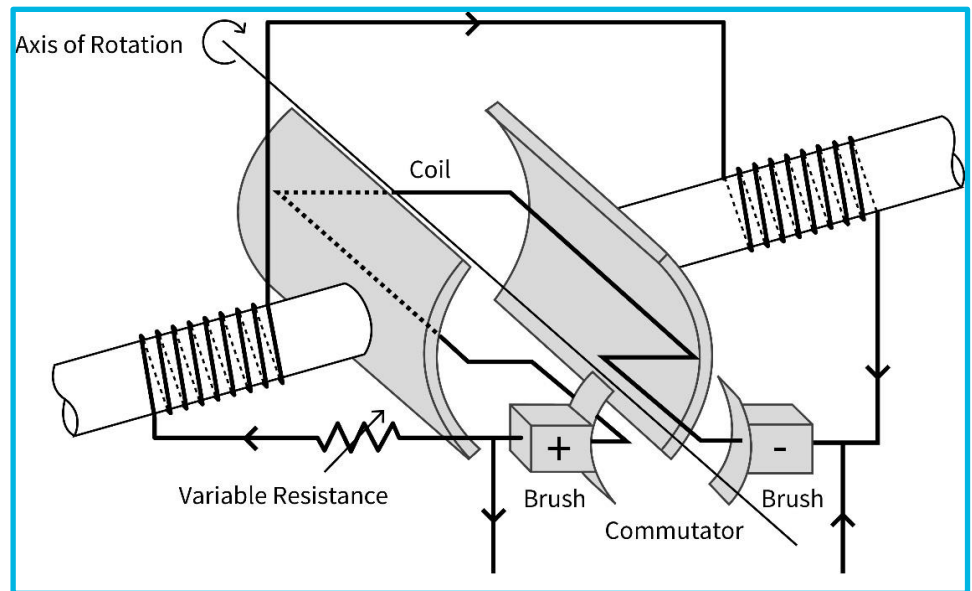


Fig. 7

The above is of course, a much simplified situation, inasmuch that the rotor only has one coil and two brushes. The next step would be to add a second pair of coils situated at right angles to the first pair. This would require 4 brushes, but would run much more smoothly. In real life even quite small rotors, such as that shown in Figure 8 has six, while larger units will have as many as 8 or 10 coils, and 16 or 20 commutator segments. Note that the segments have to go in pairs because each coil will have two "pig tails", a + end and a - end. If you want to see a really big commutator, turn to the associated lesson, Basic AC Motors and look at Figure 1.

What is the Difference Between a DC Generator and a DC Motor?

Very little. Referring again to Figure 7, and from what we know already about electricity and magnetism being closely inter-related, it should be readily obvious that if we remove whatever is driving the generator, and connect the two brushes to a source of DC voltage, the rotor will rotate, and will continue to rotate because each time it gets to about the 150° point, the commutator will reverse the polarity and keep the rotor turning.

Physical Construction.

1. Figure 8 shows a very small battery operated vacuum cleaner motor.
2. Figure 9 is an end view of the rotor shown in Figure 8, and shows how the coils of insulated copper wire are laid in each slot. These wires are insulated with varnish (magnet wire). Note that in this particular case there is a large amount of free space in each slot. This is because vacuum cleaner motors tend to run hot because of the way in which they are enclosed in a small and dusty environment.
3. Figure 10 shows the commutator end, with the individual segments being made of narrow copper sections. Note that there is a thin layer of insulating material between each segment to avoid short circuits between coils. There are the same number of commutator segments as there are coils.
4. The whole rotor assembly is comparatively complex and requires a good deal of hand work. All coils have to be carefully laid in their slots, and the tag ends soldered to the correct commutator segment. If this is done by machine, the machine to do all this will be expensive. If it is done by hand, the manual work will probably be even more expensive.



Fig. 8



Fig. 9



Fig. 10

5. The stator of this motor is shown in Figure 11 In this particular case, there are only two stator poles, and are molded permanent magnets for cheapness. On larger motors the stator coils would be wound with insulated copper wire.



Fig. 11



Fig. 12

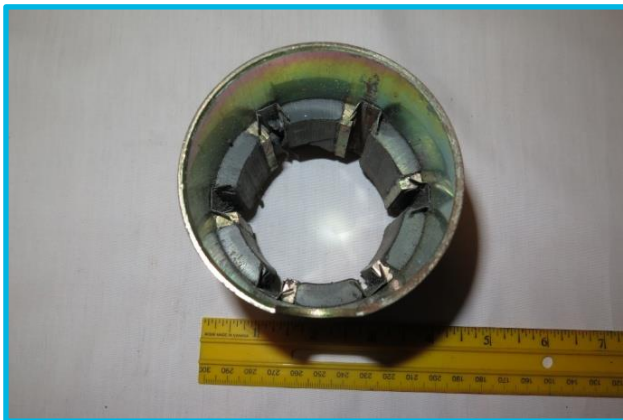


Fig. 13



Fig. 14

6. In order to illustrate other types, Figures 12 13 and 14 show a 12 Volt starter motor from an automobile. Starter motors require a specialized design, because, although they only run for a few seconds at a time, the shock impact when the spinning rotor meets the full weight of the stationary engine parts is very severe. Therefore the rotor has to be extremely robust. Note in this case how much thicker are the coils and how they are embedded solidly into the slots using epoxy resin. On the other hand, heating and efficiency are not important. Figure 14 shows the stator which has six poles.

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7. Figure 15 shows a set of brushes for the same machine. A medium hard grade of carbon is usual material for brushes. Carbon is a good conductor of electricity. Because of the high content of graphite, it also provides a smooth and non-abrasive rubbing surface as the copper commutator segments slide beneath it. All brushes are mounted in a spring loaded clip so that a constant contact pressure is maintained as the brushes gradually wear down.



Fig. 15

8. For good measure, Figure 16 shows the brush gear from the very small battery operated vacuum cleaner motor shown in Figures 8, 9 & 10. Although very small, the principle remains the same.

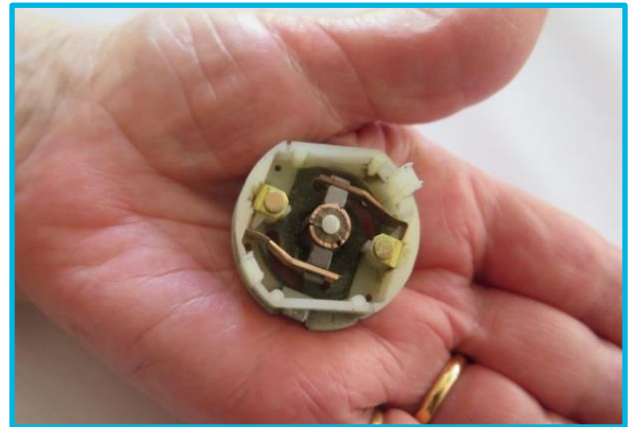


Fig. 16

An Exception to the above

It should be noted here that some very small commutator motors, such as those found in vacuum cleaners, will run acceptably well on an AC supply, although it may spark a little.

Speed control of a DC motor

Just as the output voltage of a generator can be smoothly regulated by a rheostat (a smoothly variable resistance) in the field (Figure 7), so it is equally possible to control the speed of a motor by the same process. There are, however, two important differences.

Two New Concepts

- ◆ **Motor starting inrush current.** Refer once again to Figure 6, but visualize it as a motor and not a generator. At the instant the current is switched on, the rotor is stationary, and with the full supply voltage applied to the resistance of the rotor, which is usually very low in order to keep the power losses down to a reasonable minimum, the so-called "inrush current" will be comparatively high. A typical figure is about five or six times full load current. However, this high current soon damps out, as explained in the next paragraph.
- ◆ **Back-EMF.** (Note: The concept of "Back-EMF" is really just that – a concept – which helps understand what goes on inside an electric motor). We have already noted that there is almost always a very small amount of residual magnetism in the steel of the field poles. Thus the "inrush" current explained above, will interact with this residual magnetism and cause the rotor to turn, even if only very slowly. But the moment it starts to turn, it will start to operate as a generator (yes, really, that's true) and the coil in the rotor will start to produce a very small voltage or EMF. Even a quite small EMF will tend to oppose the voltage of the power supply

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and thus reduce the starting current inrush. In reality these things happen very quickly, in just a few seconds in fact, and quite soon, as the rotor gains speed and the back-emf builds up, the inrush current will die down to almost nothing. The interesting thing to note here is that if you wish to speed up a DC motor, you reduce the field, and vice versa. But if the field strength is somehow lost altogether, the motor will in fact “run away” and speed up until it bursts. This is an important safety consideration.

Normal Operation



Fig.17



Fig. 18

Figures 17 and Figure 18 shows a pair of “real world” stator poles in which the coils have been wound with copper wire (with the leads brought out). Note that the pole pieces are just simple cast steel without laminations (for cheapness). This arrangement permits the field current (magnet strength) and speed to be varied at will. But of course, this is a little more expensive than the molded permanent magnet type seen previously. And don’t forget that if the field current is increased, the speed will go down, and vice versa. This may seem counterintuitive, but read the notes above.

Returning once again to Figure 7, it follows from the two paragraphs above that it is quite easy to regulate the current in the field coils. But at this point it is necessary to make sure we have fully understood the concept of a back-emf. In this case, it should be relatively easy to understand that the stronger the magnetic flux in the field poles, the stronger the back-emf, and hence the less current will flow in from the power supply. Thus in order to obtain maximum flux in the field poles, we need to have maximum current. In other words, if we want to keep the motor crawling at a very low speed, and drawing minimum current from the system, we need maximum field current. Then if we want to increase speed, we need to reduce the field current. This may seem counter-intuitive, but it is a fact of life. Carried to an extreme, as mentioned above, this situation can in fact be very destructive to the motor. If, for example, you got an open circuit in the field leads, the back-emf would collapse to zero, the current from the power supply would increase enormously and the motor speed would increase until it would probably burst. For that reason safety devices are required.

Internal Connections for DC motors

There are two basic means of making the internal connecting a DC motor.

Shunt Connection. This has already been shown in Figure 7, This is the most common for the smaller size of DC motors. Typically used for motors which run at comparatively high speed.

Series Connection. This is shown in Figure 19. In this arrangement, instead of having the field coils in parallel with the rotor, they are connected in series. This makes a fundamental difference because, as you will see, the current in the field is the same as in the rotor at all times. The prime feature here is that the starting current flowing through the field, produces a very strong field and consequent high torque. This type of connection is mostly used in cranes and what are known as traction motors – street cars, and diesel-electric locomotives etc. Visualize, for a moment what happens inside the traction motors of a locomotive when it first struggles to get a long train of cars moving. Even one locomotive alone can probably pull over 3,000 tons of wagons.

But the starting process is usually long, like 10 or 15 minutes, during which full starting current is flowing thru both the field and the rotor coils. Of course, such motors are heavily designed to take such conditions on a regular basis without overheating. But nevertheless it is a thought to be kept in mind and appreciated any time you see a so-called “unit train”, some of which are two miles (3 km) long and hauled by five or six locomotives, each of 2,000 hp.

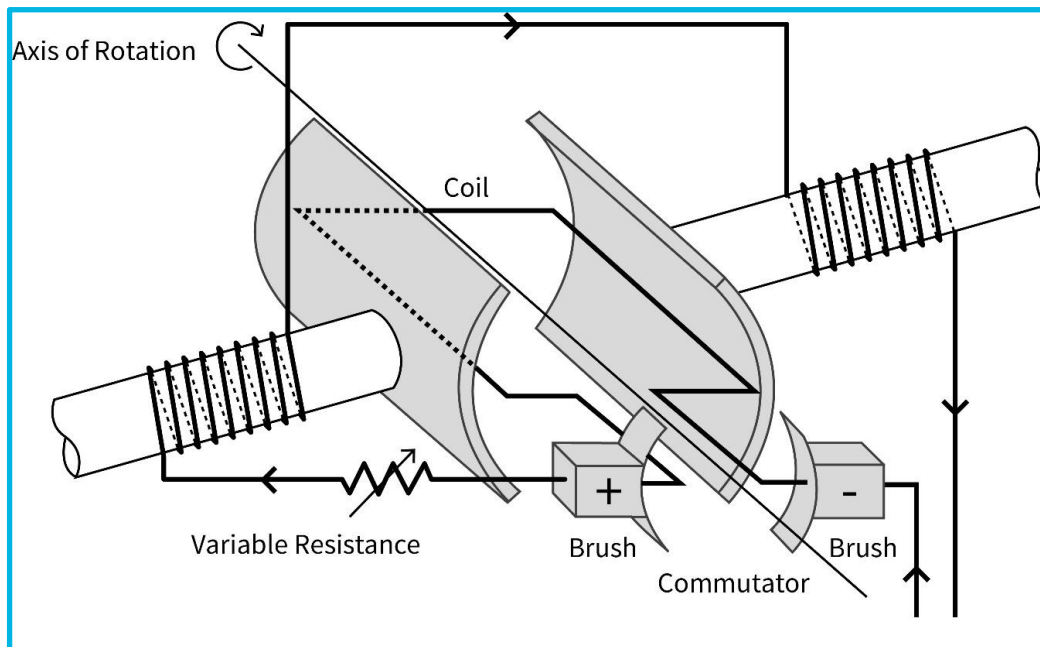


Fig. 19

For Teachers:
Teacher Resource - Hands On Activity

The Seventy Cent Electric Motor.



Fig. 20

Materials required: See Figure 20 above.

ITEM	COST	
One transparent plastic glass or mug.	\$1	
One D-size flashlight battery.	\$2	
Two rubber bands	\$.10	
Two button magnets ½" (1.5 cm) dia.	\$1.30 ea,	= \$2.60 total.
Four feet (1.5 m) of 20 awg insulated copper wire.	\$0.15 per ft.	= \$0.60 total.
12" (30 cm) of 18 awg bare aluminum wire.		= \$0.10 total.
Two pairs of crocodile clips.	\$2	
One felt marker pen. Permanent type.	\$2.	

Total cost about \$10

Note: The 20 awg insulated copper wire should be "single conductor". Stranded conductor will not be suitable because it may be too flexible.

Procedure.

- Figure 20 shows a bird's eye view of all the material you will need for this demonstration. Not so very much, is it?
- Slip the two rubber bands around the glass as shown in Figure 21.
- Take one button magnet and drop it into the bottom of the plastic glass. Put the other magnet on the outside of the bottom of the glass. The two will then hold tight to each other. See Figure 22. NOTE that the magnets are really strong and difficult to separate. Also if you are wearing a wristwatch, better to remove it because if you magnetize it, it probably won't work afterwards.
- Take the 12" (30 cm) aluminum wire and cut it into two pieces. Aluminum is very soft and can be cut with scissors. Copper wire will do equally well, provided it is not insulated. Wind one end around a pencil to form a loop as shown in Figures 23.
- Straighten out the two lengths of aluminum wire as best you can as shown in Figure 24.
- Slip the two pieces of wire under the rubber bands as shown in Figure 25.
- Strip about 2" (5 cm) of the insulation from both ends of the copper wire. Wind all the remainder firmly around the D-size battery as shown in Figure 26.
- Slip the coil off the battery and loop each tag end around the coil to secure as shown in Fig. 27.
- Lay the coil flat on a piece of paper and run the marker pen along one side of one tag end several times until the bare copper is well coated with ink. See Figure 28. Note that if some of the ink runs right around the other side of the bare copper, it can be scraped off. This is important because this is your commutator.
- Place the coil of wire carefully into the two loops of aluminum wire and adjust so that the lower part of the coil is level and turns just clear of the button magnet as shown in Figure 29. Using the alligator clips, connect the aluminum wire to the D Battery as shown also in Figure 29.
- Give the coil a gentle push and after a little adjustment, it will start to rotate all by itself, and will continue to do so as long as the battery is connected.
- It is important to do the best you can keep the two "tag ends" of the coil as straight as possible and to keep them as close as possible to the center of the coil. In other words, do the best you can to ensure that the coil is evenly balanced and rotates smoothly with a minimum of wobble.
- By way of a "sensitivity test", Figure 30 shows a coil with a much smaller diameter (but still with 4 ft of wire, so that the resistance is the same). It was found that this coil was much less satisfactory.



Fig. 21



Fig. 22



Fig. 23

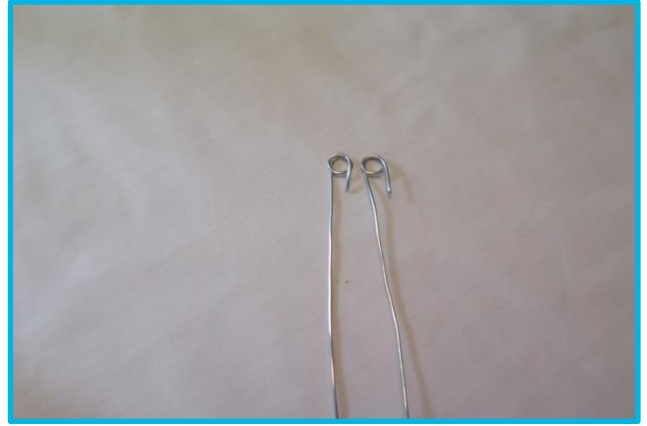


Fig. 24



Fig. 25



Fig. 26

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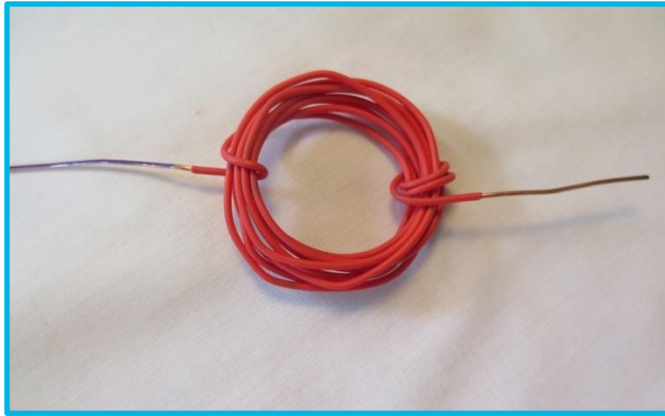


Fig. 27

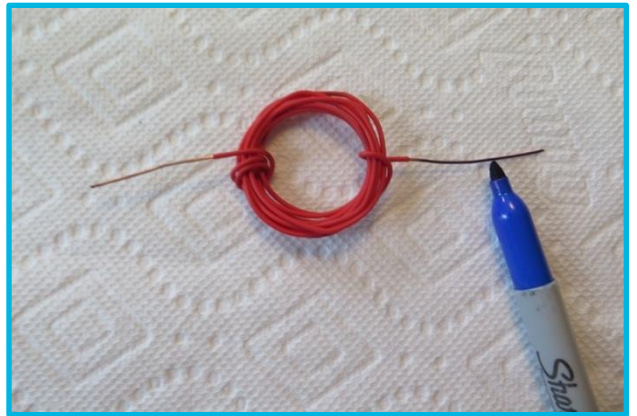


Fig. 28

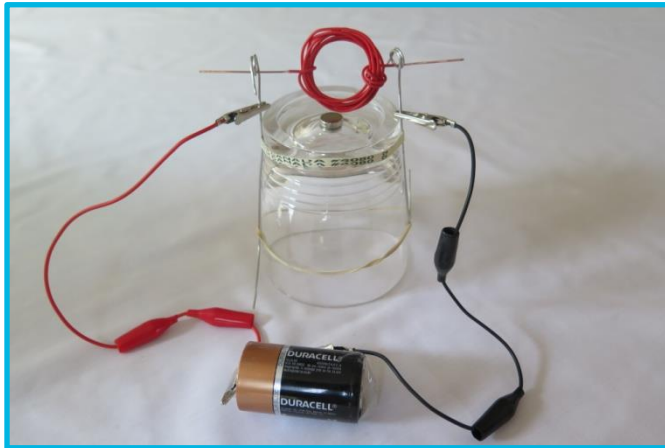


Fig. 29

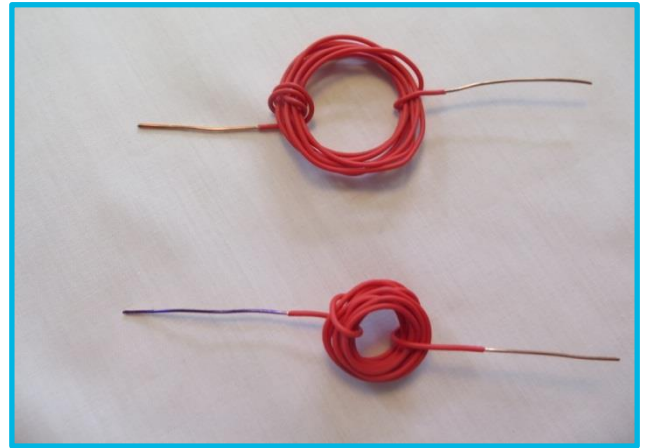


Fig. 30

Credit: There are numerous versions of this demonstration available on the net under the heading of "Very simple electric motors". The one above is loosely based on that suggested by "Howcast", but with certain alterations by the IEEE.

A Word of Caution. These small magnets are extremely powerful and should be kept well away from electronic equipment such as computers and digital cameras. Close proximity may cause malfunction.

Basic Direct Current Generators and Motors

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Student Worksheet:

Reflection

Complete the reflection questions below:

1. Which very famous man flew a kite up close, but not into a thunder cloud?
2. What attracts a North (seeking) pole like nothing else?
3. Can you explain Fleming's Right-Hand Rule?
4. What is the principal material in a commutator?
5. What is the difference between a "Series" connected DC motor and a "Shunt Connected" motor and what is a typical application for each?
6. What is the approximate efficiency of an electric motor?
7. In the hands-on exercise above, two coils of differing diameter but the same resistance, were tested. Why do you think the larger one was more effective?

For Teachers:

Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (<http://www.nextgenscience.org/>)
- International Technology Education Association's Standards for Technological Literacy (<http://www.iteea.org/TAA/PDFs/xstnd.pdf>)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (<http://www.nctm.org/standards/content.aspx?id=16909>)
- U.S. Common Core State Standards for Mathematics (<http://www.corestandards.org/Math>)
- Computer Science Teachers Association K-12 Computer Science Standards (<http://csta.acm.org/Curriculum/sub/K12Standards.html>)

◆ **National Science Education Standards Grades K-4 (ages 4 - 9)**

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ◆ Abilities necessary to do scientific inquiry
- ◆ Understanding about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of the activities, all students should develop an understanding of

- ◆ Light, heat, electricity, and magnetism

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ◆ Understanding about science and technology

◆ **National Science Education Standards Grades 5-8 (ages 10 - 14)**

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ◆ Motions and forces
- ◆ Transfer of energy

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ◆ Science and technology in society

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ◆ History of science

***For Teachers:
Alignment to Curriculum Frameworks***

◆Next Generation Science Standards Grades 3-5 (Ages 8-11)

Motion and Forces: Stability and Interaction

Students who demonstrate understanding can:

- ◆ 3-PS2-3. Ask questions to determine cause and effect relationships of electric or magnetic interactions between two objects not in contact with each other.
- ◆ 3-PS2-4. Define a simple design problem that can be solved by applying scientific ideas about magnets.

Energy

Students who demonstrate understanding can:

- ◆ 4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

◆Next Generation Science Standards – Grades 5-8 (Ages 10-14).

Motion and Stability: Forces and Interactions

- ◆ MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

Energy

- ◆ MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

◆Standards for Technological Literacy - All Ages

Technology and Society

- ◆ Standard 7: Students will develop an understanding of the influence of technology on history.

Design

- ◆ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

The Designed World

- ◆ Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.