ENERGY TRANSPORT AND CONVERSION

Introduction to Generators and Motors

Lecture# 6A

(Basic Electricity Book)

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Introduction to Generator and Motors

You will remember from Part 1 of *Basic Electricity* that several different forms of energy can be converted into electrical energy and that, conversely, electrical energy can be converted into several other forms of energy.

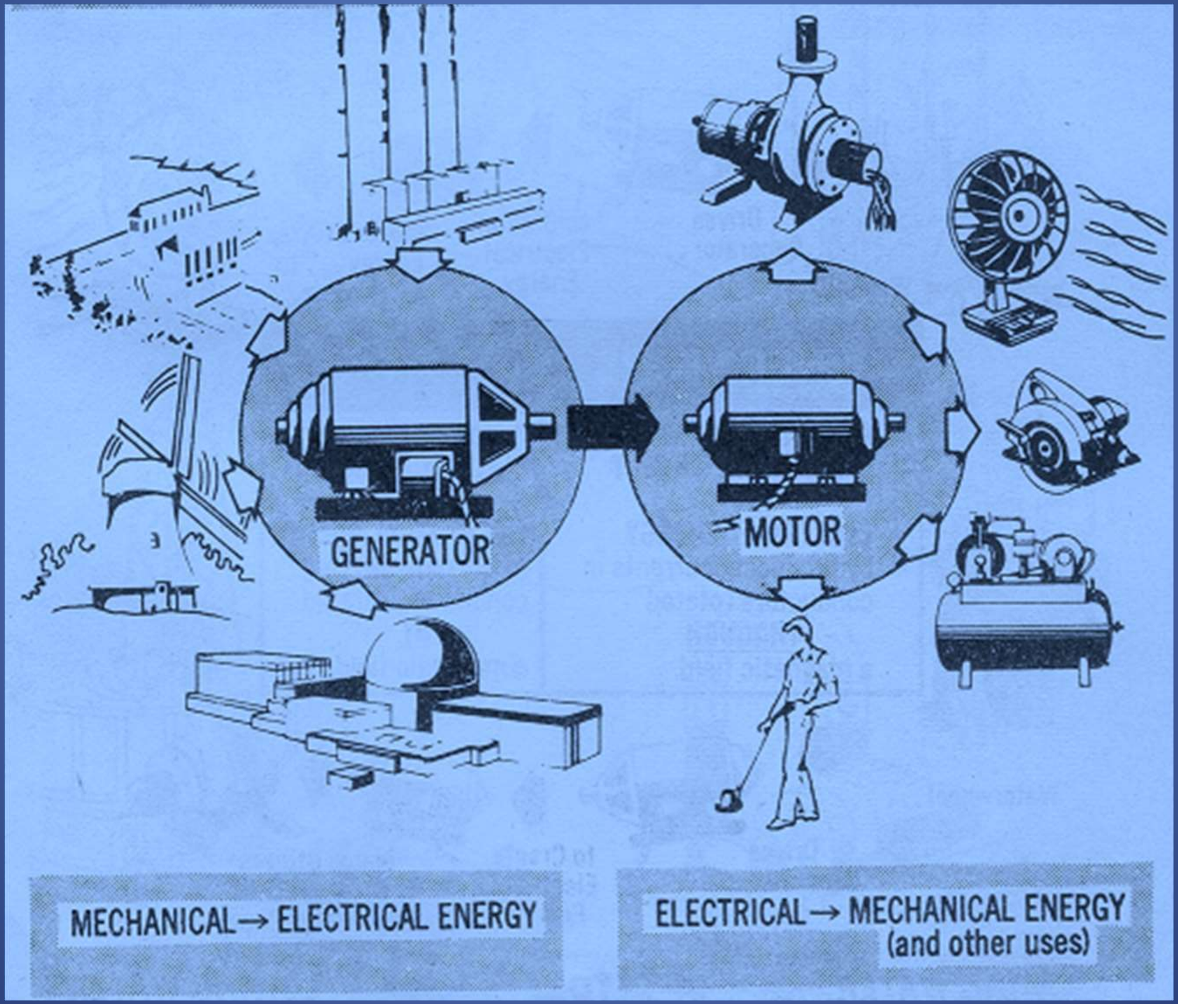
The **electric generator** is the device which converts *mechanical energy into electrical energy*. The **electric motor** is the device which converts *electrical energy back into mechanical energy*.

The generator is the basic mechanism used to provide almost all the electrical energy we use today. A problem of increasing gravity is to find the energy sources needed to run these generators. Because of this problem, it may become increasingly necessary to use new and alternative sources of energy in the future.

But today, in the last third of the 20th century, we depend almost entirely on the electric generator for the electrical energy we use.

It goes without saying that electrical energy is used for many other purposes than that of providing mechanical energy through the use of motors.

Introduction to Generator and Motors



Introduction to Generator and Motors

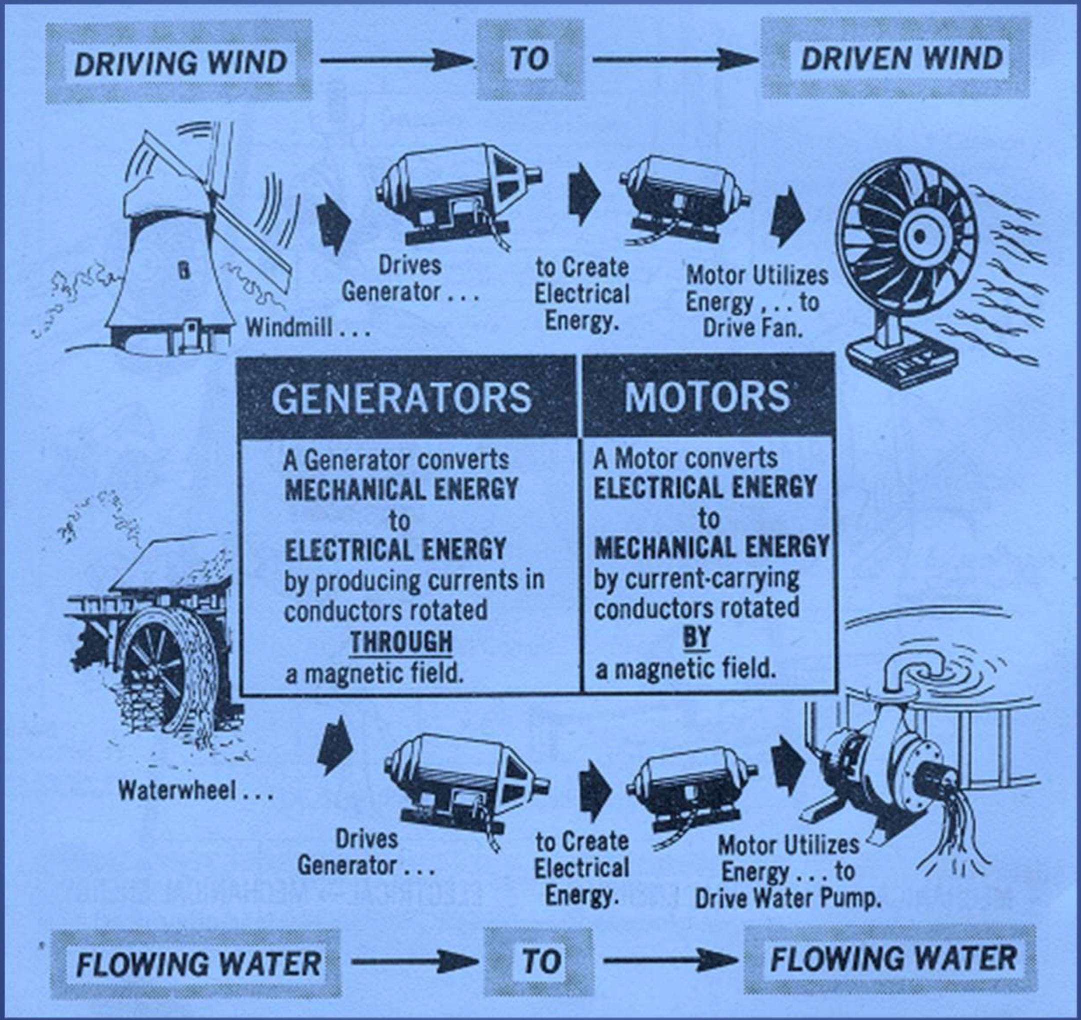
In this volume, you will find out how generators and motors work, how they are controlled and how to fault-find in them. You already know all the general principles necessary to understand what is happening.

Although there are many different types of both generators and motors, you will find them all in essence very similar. All electric generators and motors make use of the interaction between moving conductors and stationary magnetic fields, or between stationary conductors and moving magnetic fields. You will even find important examples of both the conductor and the magnetic field moving one with respect to the other.

The essential point is that there must be *relative movement* between a magnetic field and a current-carrying conductor. The operation of any generator or motor—whether it works on d.c. or on a.c.—depends solely on the effects of this basic interaction.

With that cardinal point firmly in your mind, you will find little real difficulty in understanding the different ways in which these conductors and magnetic fields are arranged to produce the different types of output—electrical or mechanical—which you are going to learn about in this Part 5 of *Basic Electricity*.

Introduction to Generator and Motors



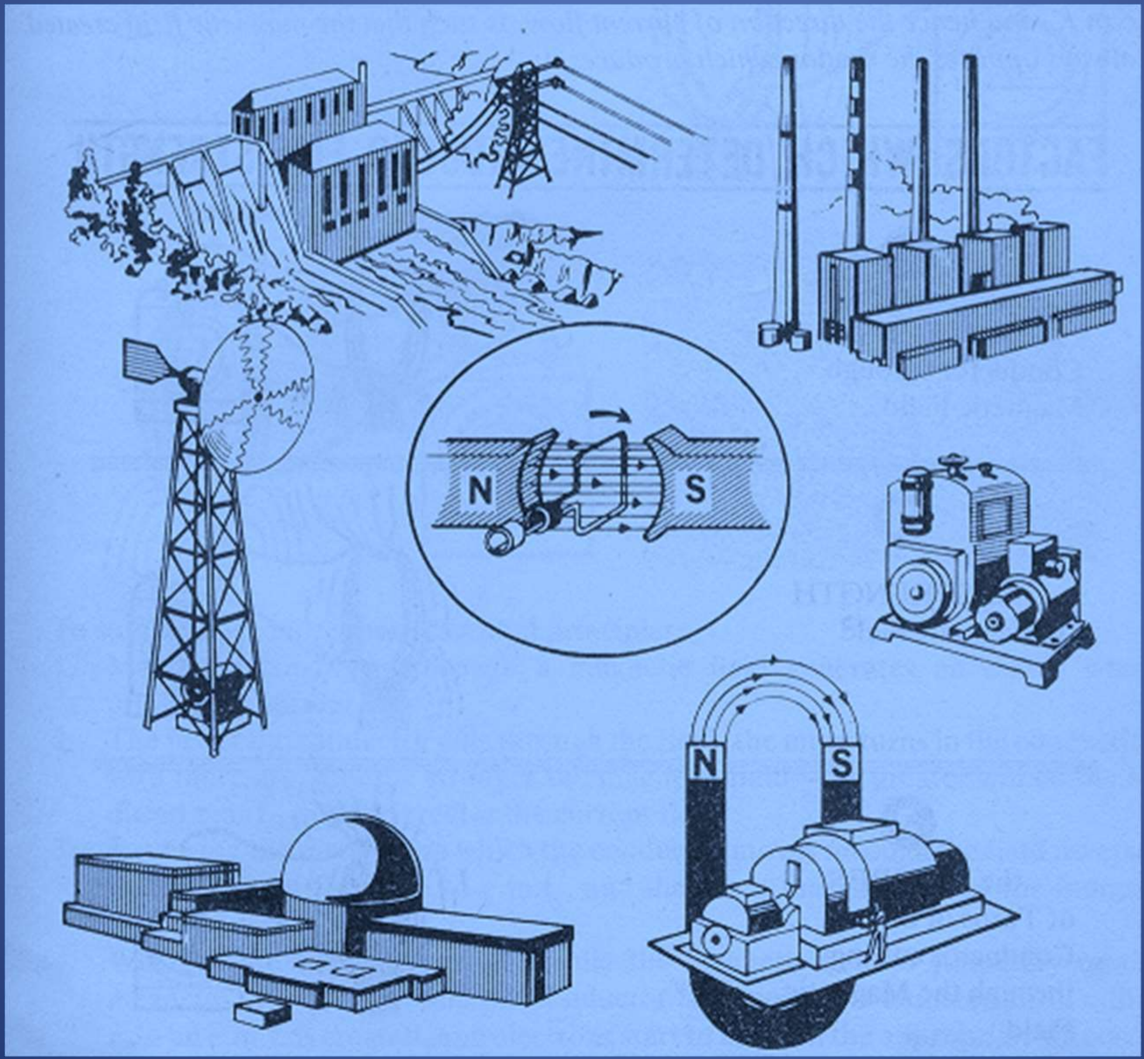
The Sources of Energy Generators

You learnt in Part 1 that an electromotive force—a "voltage"—is induced in a conductor when it moves a magnetic field. All the power stations supplying almost all the electric power consumed in the world today make use of this simple principle to convert some other source of energy into electrical energy.

Most power stations use the heat energy produced by burning fossil fuels such as coal, oil or natural gas to produce steam. This steam is then used to drive a turbine coupled to a generator.

Several changes in the form of the energy thus take place. The *chemical* energy of the fuel is first converted into *heat* energy. The heat energy is converted into the *mechanical* energy of motion in the turbine. And finally, the mechanical energy of motion is converted into *electrical* energy in the generator. Whatever the original source of energy—coal, oil, gas, uranium, plutonium, a head of water, the sun, the wind—the final step is always the conversion of the *mechanical* energy of rotation into *electrical* energy in a generator.

The Sources of Energy Generators



THE ELEMENTARY GENERATOR

You know that electricity can be generated by moving a conductor through a magnetic field. As long as there is relative motion between the conductor and the field, a movement of electrons will be generated in the conductor.

The generated voltage is called an *induced e.m.f.*—or, perhaps more commonly, an *induced voltage*; and the method of generating it by cutting across a magnetic field with a conductor is called *induction*.

You also know that the amount of voltage induced in the conductor cutting through the magnetic field depends on a number of factors:—

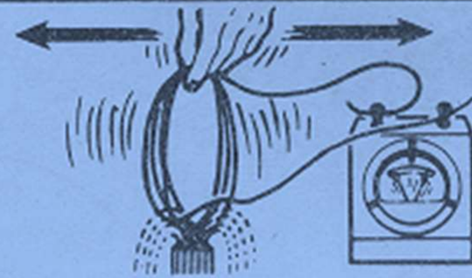
1. If the speed of the relative cutting action between the conductor and the magnetic field increases, the induced e.m.f. will increase.
2. If the strength of the magnetic field is increased, the induced e.m.f. will also increase.
3. If the conductor is formed into a coil so that the number of turns cutting through the magnetic field is increased, the induced e.m.f. is increased again.

The polarity of the induced e.m.f. is always such that the resulting current flow builds up a field of its own which reacts with the field of the magnet and *opposes* the movement of the current through the coil. This phenomenon is expressed in **Lenz's Law**, which states that: *In electromagnetic induction, the direction of the induced e.m.f., and hence the direction of current flow, is such that the magnetic field created always opposes the motion which produces it.*

FACTORS WHICH DETERMINE INDUCED EMF STRENGTH

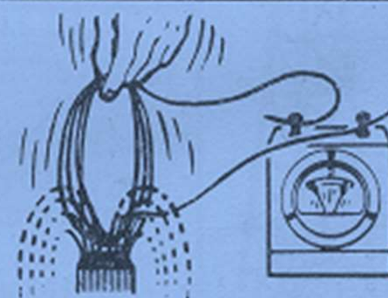
1

. . . the SPEED of Conductor through Magnetic Field



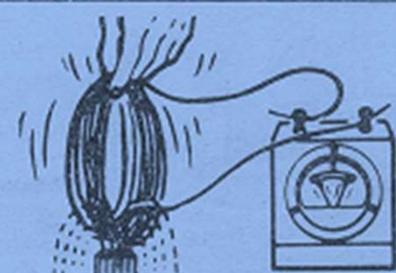
2

. . . the STRENGTH of Magnetic Field



3

. . . the NUMBER of Turns of the Conductor cutting through the Magnetic Field

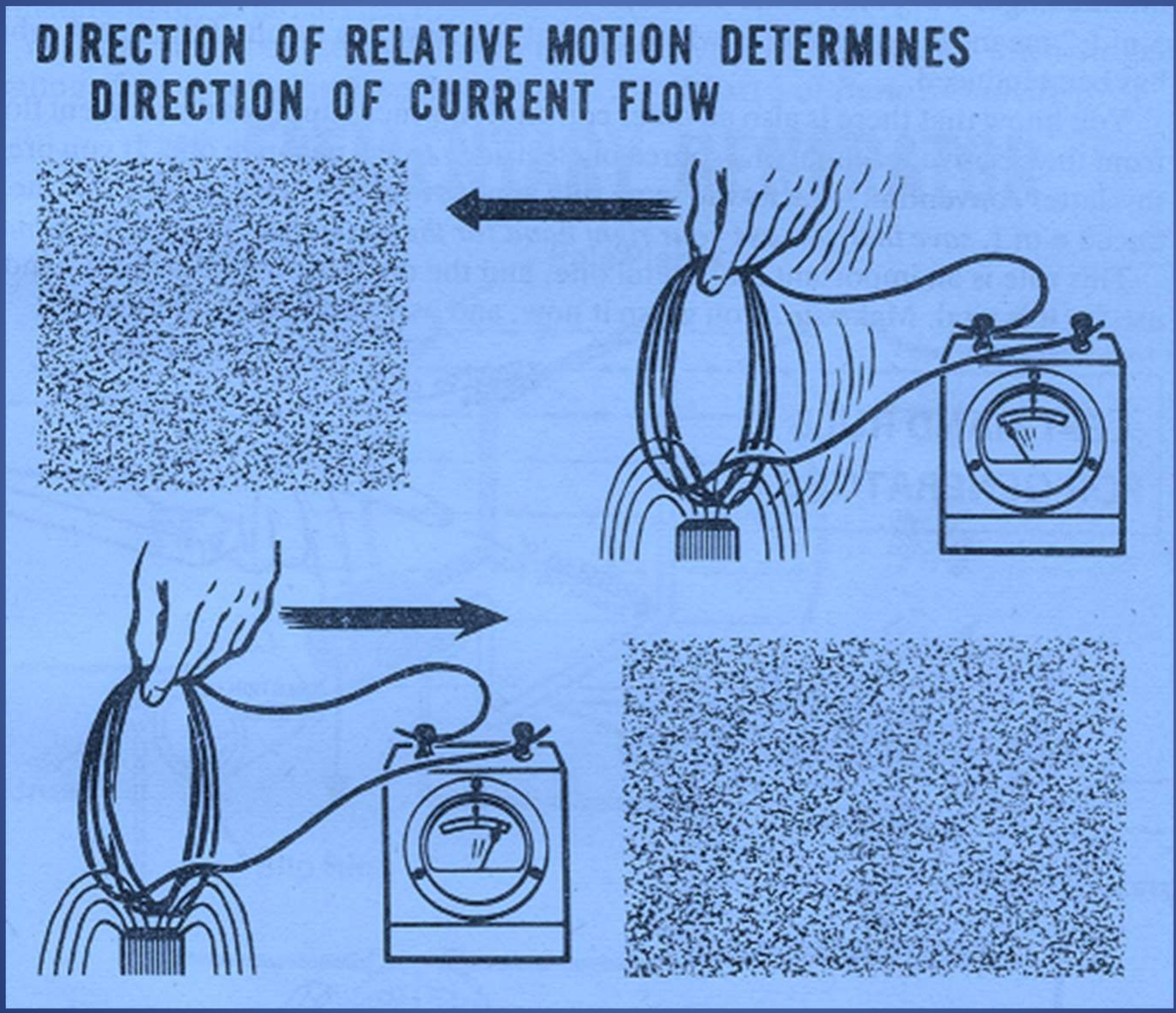


Electricity from Magnetism

The induced voltage (V) in any conductor cutting a magnetic field is proportional to the strength of the magnetic field times the speed at which the conductor moves through the field. In formula:

$$V \approx \textbf{Strength of Flux} \times \textbf{Speed of Relative Movement}$$

The polarity of the induced voltage, and therefore the *direction of the generated current flow*, is always determined by the direction of the relative motion between the magnetic field and the cutting conductor.


DIRECTION OF RELATIVE MOTION DETERMINES
DIRECTION OF CURRENT FLOW

To sum up once more these essential principles:

1. Moving a conductor through a magnetic field generates an e.m.f. which produces a current flow.
2. The faster the conductor cuts through the field, the more turns in the conducting wire there are, and the stronger the magnetic field—the greater will be the induced e.m.f., and the greater the current flow.
3. Reversing the direction in which the conductor moves through the field reverses the polarity of the induced e.m.f., and therefore the direction of the induced current flow.
4. Whether the conductor moves while the magnetic field is stationary or the magnetic field moves while the conductor is stationary is immaterial. In either case an e.m.f. is created, and electrons start to move in the appropriate direction along the conductor.

The Left-Hand Rule for Generators

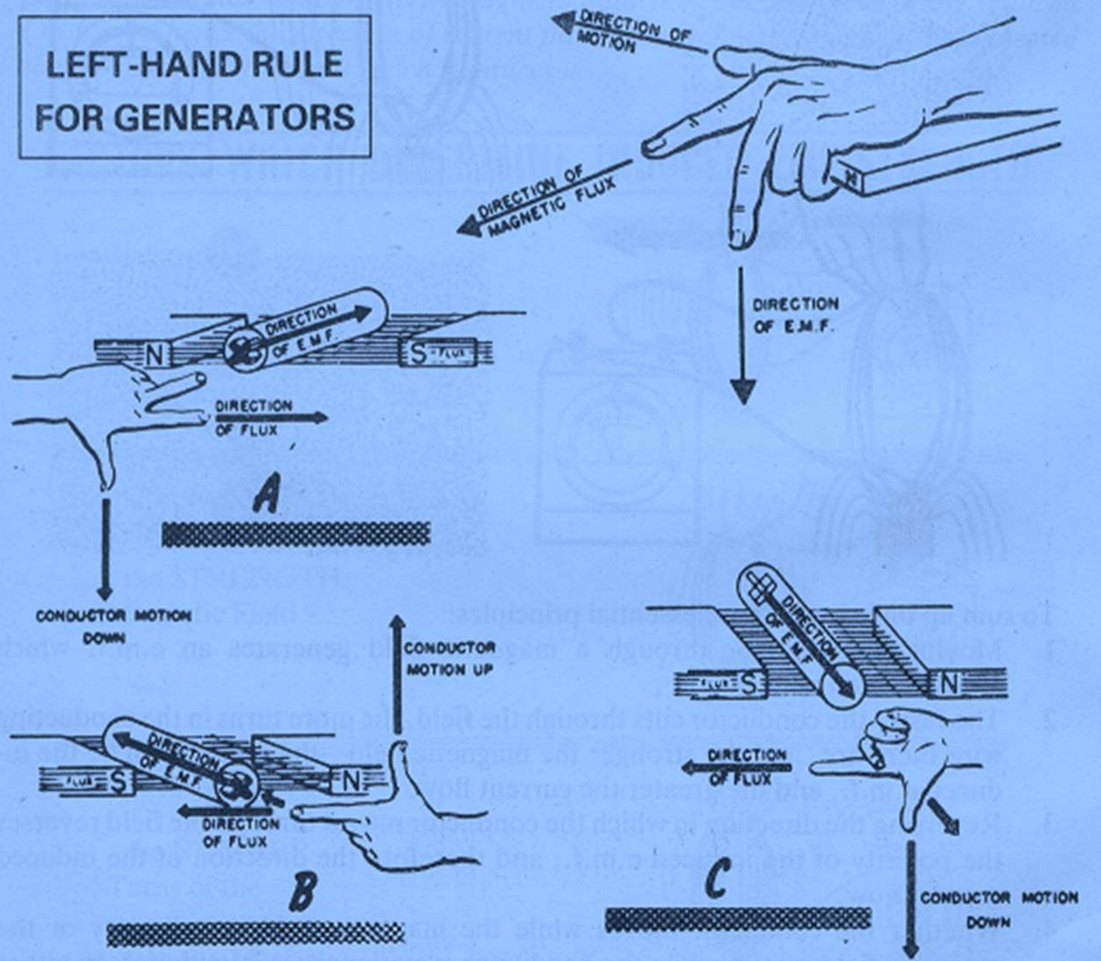
There is a simple way of remembering the direction of the e.m.f. induced in a conductor moving through a magnetic field. *Provided you accept the Electron Theory convention for the direction of current flow—from negative to positive—it is called the*

Left-Hand Rule for Generators.

The rule states that if you hold the thumb and the first and middle fingers of your left hand at right angles to one another, with the first finger pointing in the direction of the flux and the thumb pointing in the direction of motion of the conductor, your middle finger will point in the direction of the induced e.m.f. "Direction of induced e.m.f." means the direction in which current will flow as a result of the e.m.f. which has been induced.

You know that there is also an older convention which supposes that current flows from the positive terminal of a source of electricity to the negative one. If you prefer this latter convention, exactly the same rule applies for finding the direction of the induced e.m.f. *save that you use your right hand for the test instead of your left hand.*

This rule is an important and useful one, and the distinction about which hand to use for it is vital. Make *sure* you grasp it now, and use it correctly in future.



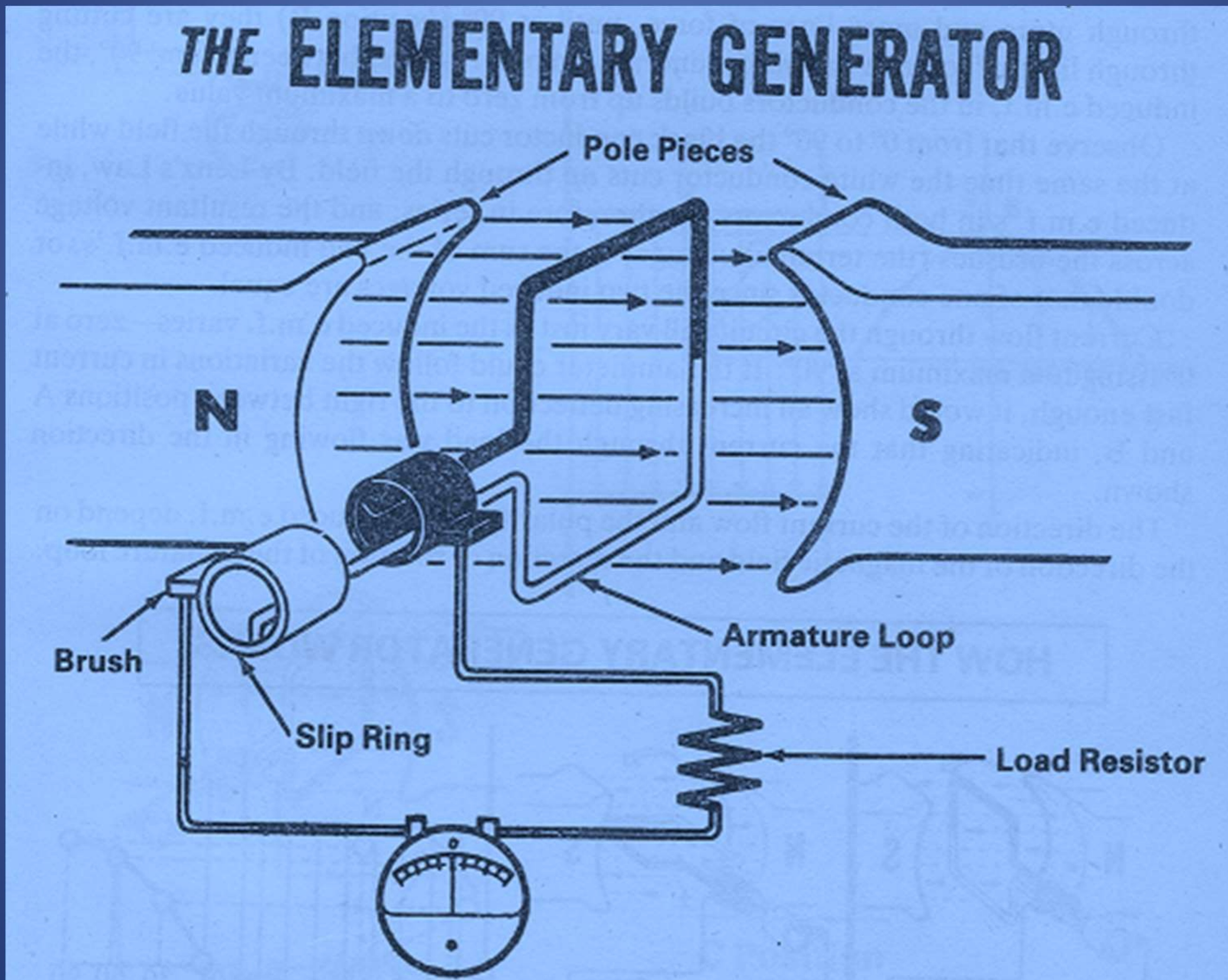
A useful convention also exists that a conductor shown as ⊕ means that the current is flowing *away* from the observer, whereas one shown as ⊙ means that the current is flowing *toward* the observer. This convention will be used from now on.

The Elementary Generator

An elementary generator consists of a loop of wire so placed that it can be rotated in a uniform magnetic field to cause an induced current flow in the loop. Sliding contacts are used to connect the loop to an external circuit in order to use the induced e.m.f.

The *pole pieces* are the North and South poles of the magnet which supplied the magnetic field. The loop of wire which rotates through the field is called the *armature*. The ends of the armature loop are connected to rings, called *slip rings*, which rotate with the armature. *Brushes* ride up against the slip rings to connect the armature to the external circuit.

You will remember meeting exactly the same elementary generator when the generation of a.c. was being described on page 3.9 of Part 3 of *Basic Electricity*.



THE ELEMENTARY GENERATOR
Pole Pieces
N
S
Armature Loop
Brush
Slip Ring
Load Resistor

In the description of the generator action given in the following pages, you should visualize the loop as rotating through the magnetic field—though you should constantly bear in mind that precisely the same results would be achieved if you arranged for the magnetic assembly to rotate round a stationary armature.

As the sides of the loop cut through the magnetic field, an e.m.f. is induced in them which causes a current to flow through the loop, slip rings, brushes, centre-zero ammeter and load resistor—all connected in series.

The magnitude of the induced e.m.f. generated in the loop, and therefore of the current that flows, depends on the position of the loop in relation to the magnetic field.

Elementary Generator Operation

You will remember from Part 3 how the elementary generator works.

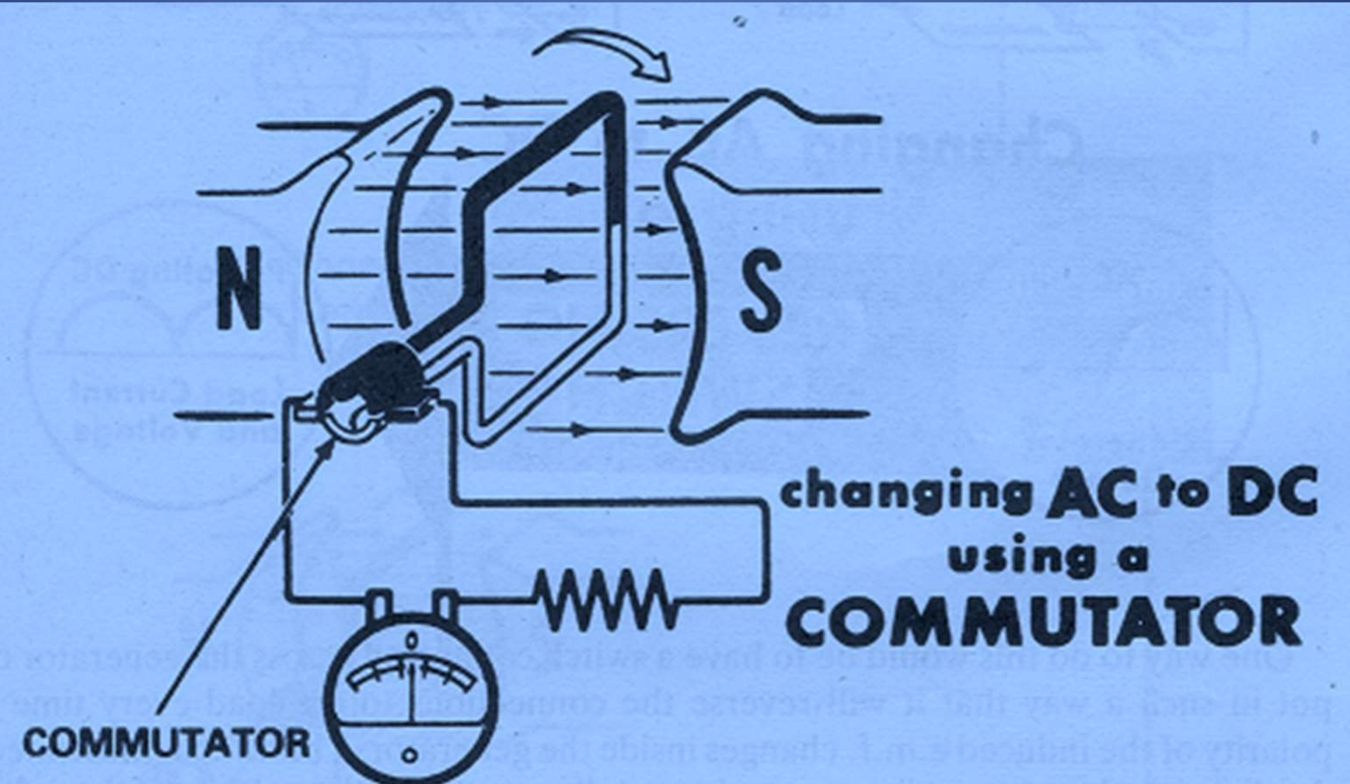
Assume that the armature loop is rotating in a clockwise direction, and that its initial position is at A (zero degrees). In position A, the loop is perpendicular to the magnetic field, and the conductors of the loop (marked here, for identification purposes, black and white respectively) are moving parallel to the magnetic field. When a conductor is moving parallel to a magnetic field, its relative motion is zero, it cuts through no line of force, and no e.m.f. is generated in the conductor. This applies to the conductors of the loop at the instant they go through position A—no e.m.f. is induced in them, and therefore no current flows through the circuit. The ammeter reads zero.

As the loop rotates from position A towards position B, the conductors cut through more and more lines of force, until at 90° (position B) they are cutting through lines of force at the maximum rate. In other words, between 0° and 90°, the induced e.m.f. in the conductors builds up from zero to a maximum value.

Observe that from 0° to 90° the black conductor cuts ***down*** through the field while at the same time the white conductor cuts ***up*** through the field. By Lenz's Law, induced e.m.f.'s in both conductors are therefore in series; and the resultant voltage across the brushes (the terminal voltage) is the sum of the two induced e.m.f.'s, or double that of one conductor since the two induced voltages are equal.

Current flow through the circuit will vary just as the induced e.m.f. varies—zero at 0° rising to a maximum at 90°. If the ammeter could follow the variations in current fast enough, it would show an increasing deflection to the right between positions A and B, indicating that the current through the load was flowing in the direction shown.

The direction of the current flow and the polarity of the induced e.m.f. depend on the direction of the magnetic field and the direction of rotation of the armature loop.



You will learn later on when you study d.c. generators that a device called the *rectifier*, which you learnt about when you were studying a.c. meters, can also be used to convert a.c. to pulsating d.c.

Converting A.C. to D.C. by Use of the Commutator

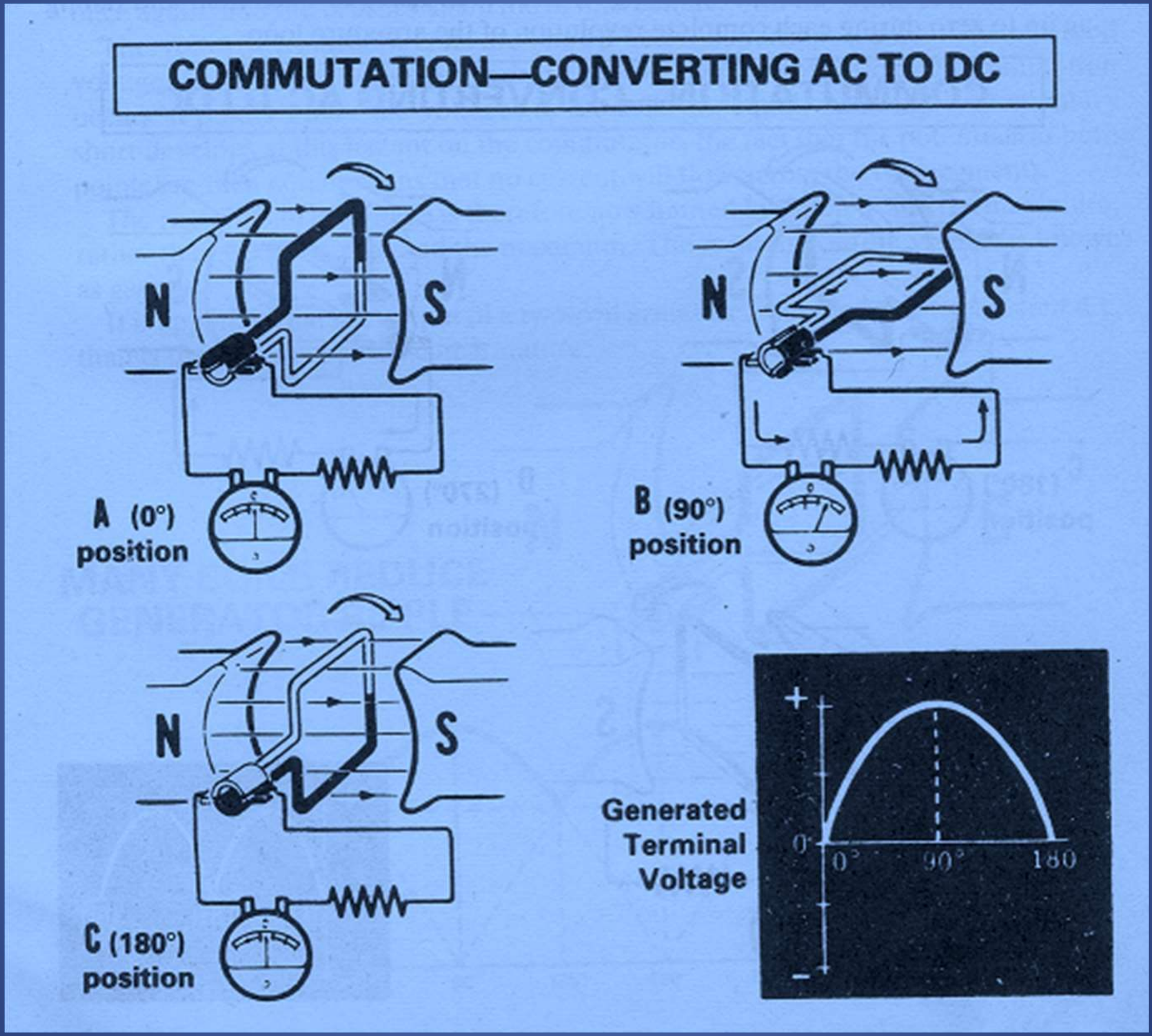
You should now follow out in detail the action of the commutator in converting the generated a.c. into d.c. In position A, the loop is perpendicular to the magnetic field, no e.m.f. is generated in the conductors of the loop, and no current flows. The brushes are in contact with both segments of the commutator, effectively short-circuiting the loop. This short circuit creates no problem, for there is no current flow.

The moment the loop moves slightly beyond position A (0°), however, the short circuit ceases to exist. The black brush is now in contact with the black segment and the white brush in contact with the white segment.

As the loop rotates clockwise from position A to position B, the induced e.m.f. starts building up from zero, until at position B (90°) the induced e.m.f. is a maximum. Since the current flow varies with the induced e.m.f., current flow will also be a maximum at 90°.

As the loop continues rotating clockwise from position B to C, the induced e.m.f. decreases, until at position C (180°) it becomes zero once again.

The waveform pictured below shows how the terminal voltage of the generator varies from 0° to 180°.

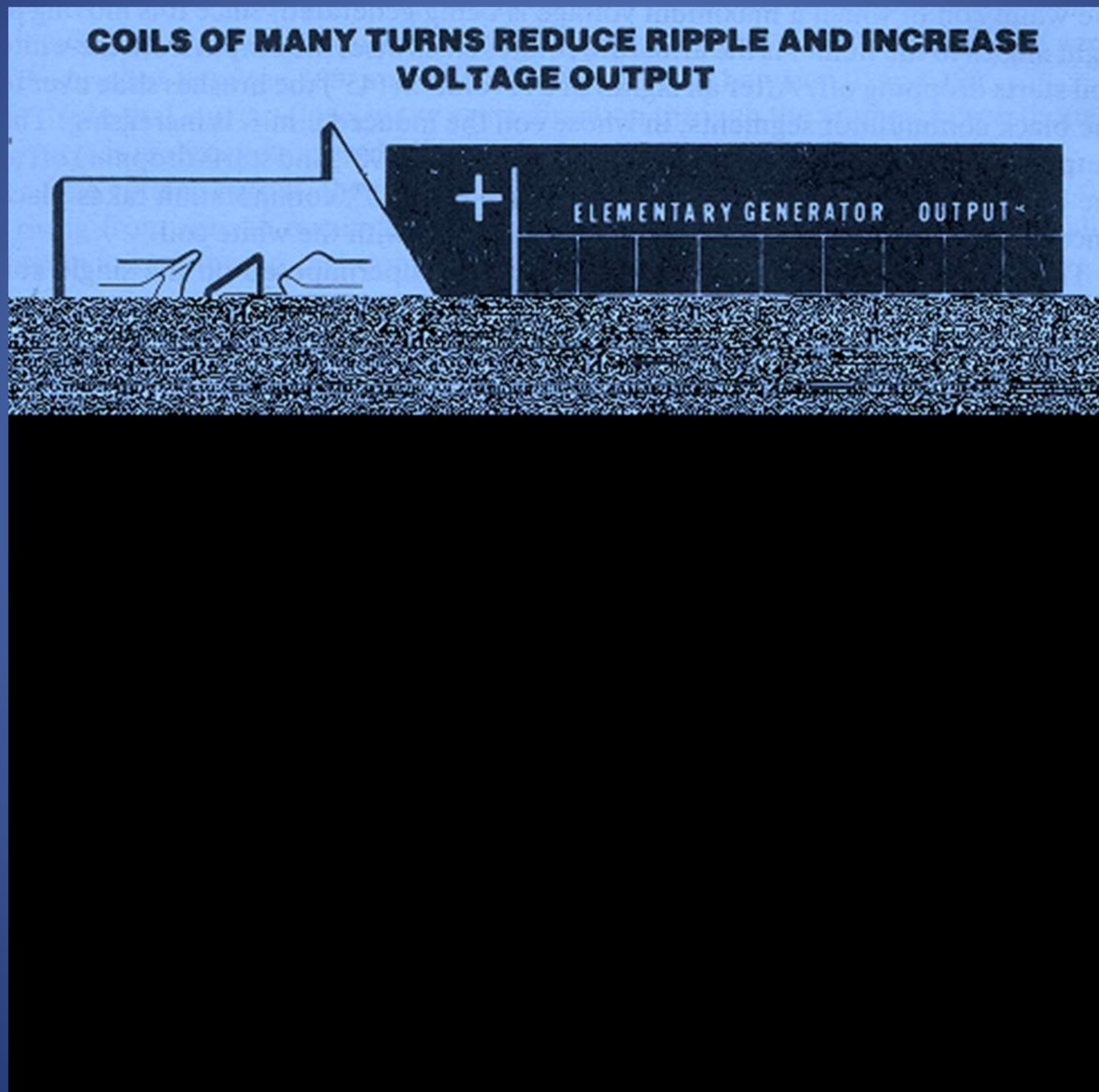

COMMUTATION—CONVERTING AC TO DC
N
S
A (0°) position
B (90°) position
C (180°) position
Generated Terminal Voltage
+
−
0°
90°
180

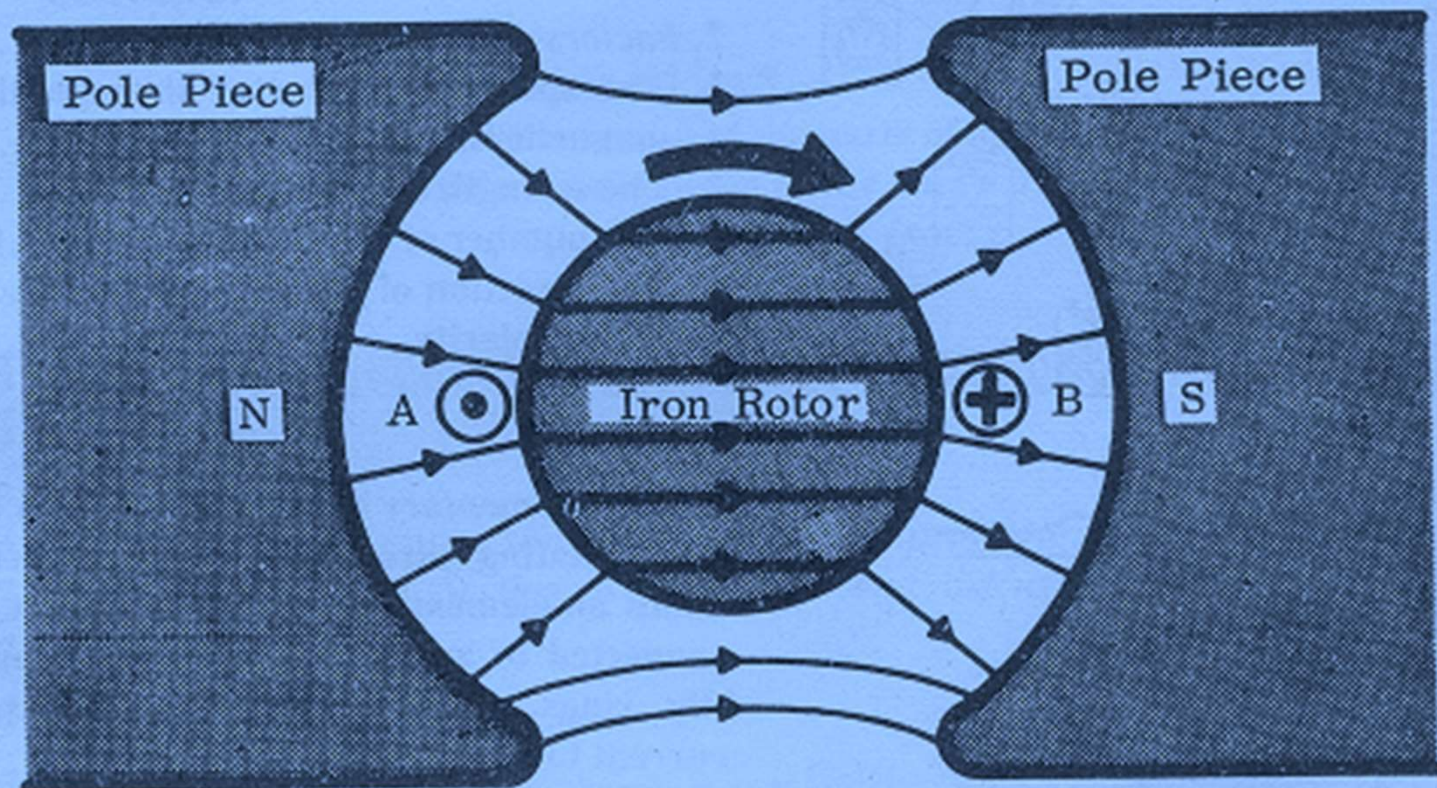
Improving the D.C. Output

Before you learnt about generators, the only d.c. voltage you had met was the smooth and unvarying voltage produced, for example, by a battery. Now you find that the d.c. output of an elementary d.c. generator is very uneven—a pulsating d.c. voltage varying periodically from zero to a maximum. Although this pulsating voltage is d.c., it is not constant enough to operate many d.c. appliances and equipments. The elementary d.c. generator must therefore be modified so that it produces a *smoother* output.

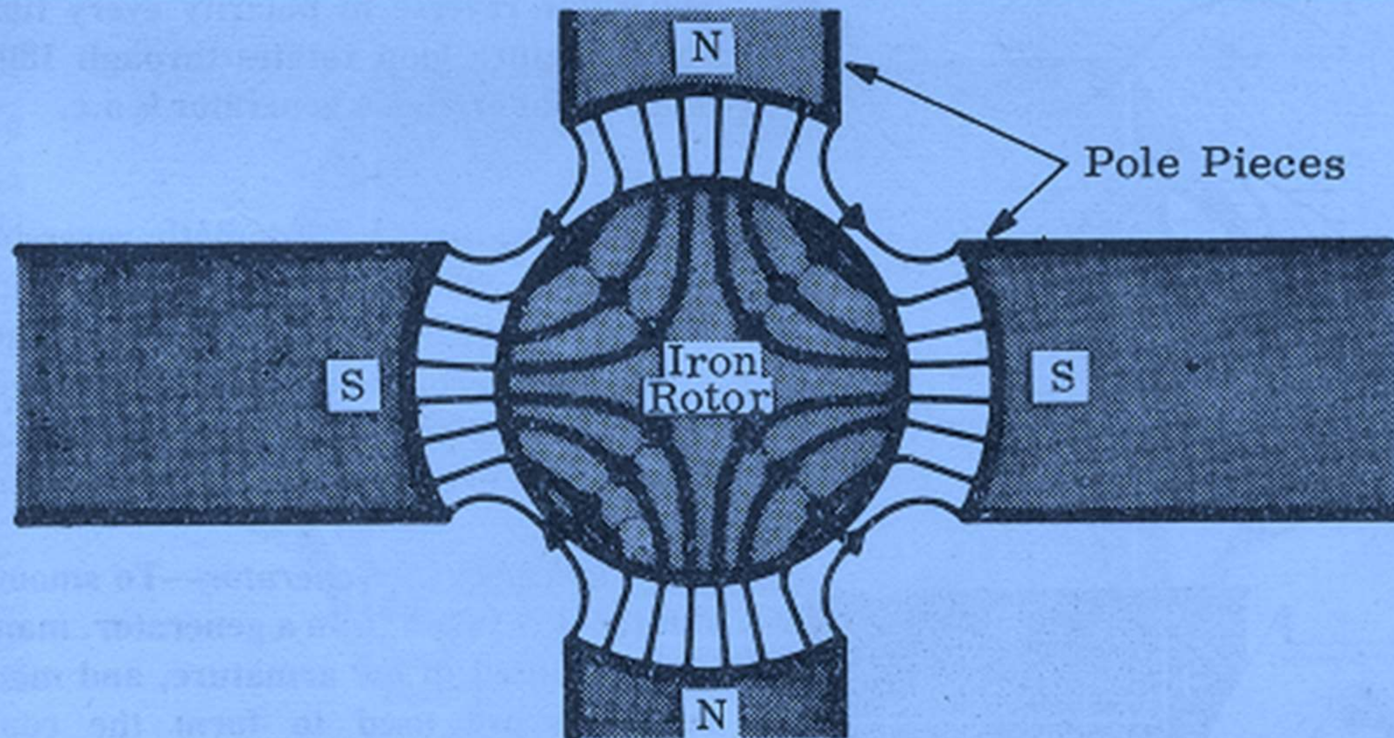
This is done by adding more coils of wire to the armature. The illustration shows a generator with the two coils of the armature positioned at right angles.

Note that the commutator is now broken up into four *segments*, with opposite segments connected to the ends of a coil. In the position shown, the brushes connect to the white coil in which a maximum voltage is being generated, since it is moving at right angles to the field. As the armature rotates clockwise, the output from the white coil starts dropping off. After an eighth of a revolution (45°) the brushes slide over to the black commutator segments, in whose coil the induced e.m.f. is increasing. The output voltage starts to pick up again, reaches a peak at 90°, and starts dropping off as the black coil cuts through fewer lines of force. At 135°, commutation takes place once again, and the brushes again move into contact with the white coil.


COILS OF MANY TURNS REDUCE RIPPLE AND INCREASE VOLTAGE OUTPUT
+
ELEMENTARY GENERATOR OUTPUT

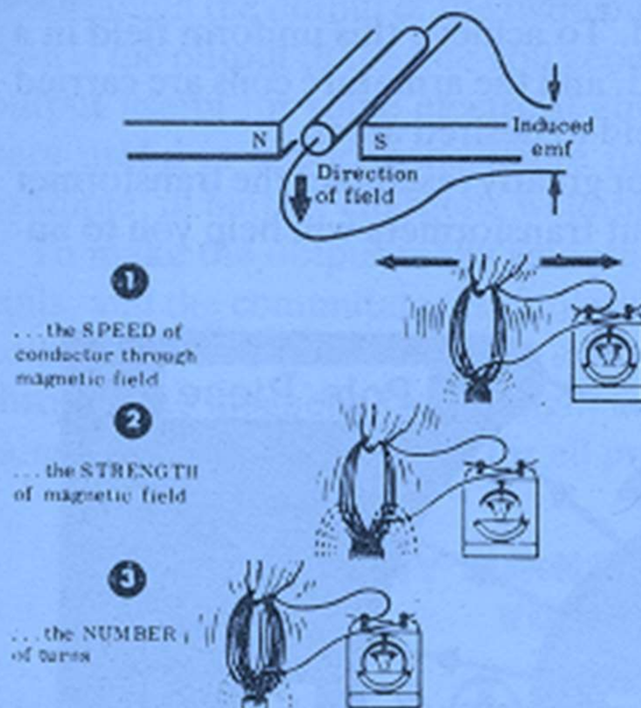


The flux can be made greater and even more uniform by using more than one pair of poles. Two pairs of poles are common, but more may be found in use in large machines.



The generator can clearly be arranged in several different configurations, just so long as the principle of *conductors cutting through magnetic fields* is preserved. You will meet some of these different configurations later on in this Part 5 of *Basic Electricity*.

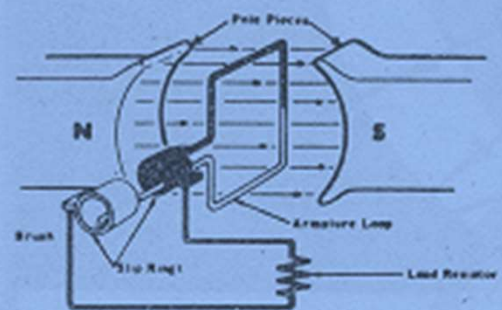
REVIEW of the Elementary Generator



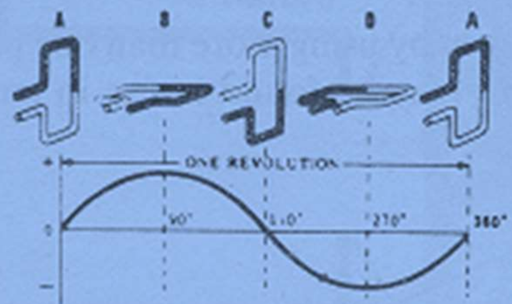
1. *Induced E.m.f.*—E.m.f. is induced when a conductor moves through a magnetic field and cuts through its lines of force.

2. *Factors Affecting Induced E.m.f.*—

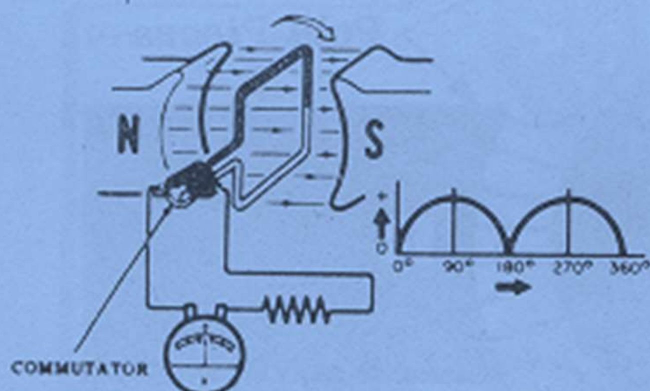
1. The speed of conductor through the magnetic field.
2. The strength of the magnetic field.
3. The number of conductors (or turns.)
4. The direction of relative motion determines polarity.



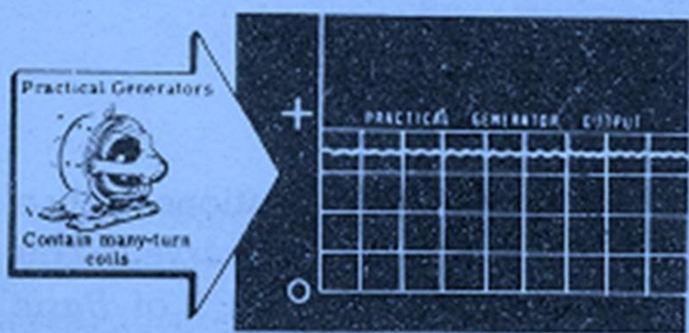
3. *The Elementary Generator*—A loop of wire rotating through a magnetic field forms an elementary generator when it is connected to an external circuit through slip rings. The induced e.m.f. causes current to flow in the external circuit.



4. *Elementary Generator Output*—The e.m.f. and current flow of an elementary generator reverse in polarity every time the armature loop rotates through 180°. The output of such a generator is a.c.



5. *Commutator*—An automatic reversing switch on the generator shaft which switches coil connections to the brushes every half-revolution of an elementary generator. Its purpose is to provide a d.c. output. The process is called commutation.



6. ***Practical D.C. Generator***—To smooth out the d.c. taken from a generator, many coils are used in the armature, and more segments are used to form the commutator. A practical d.c. generator produces a voltage output which is near maximum at all times, and which has only light ripple.