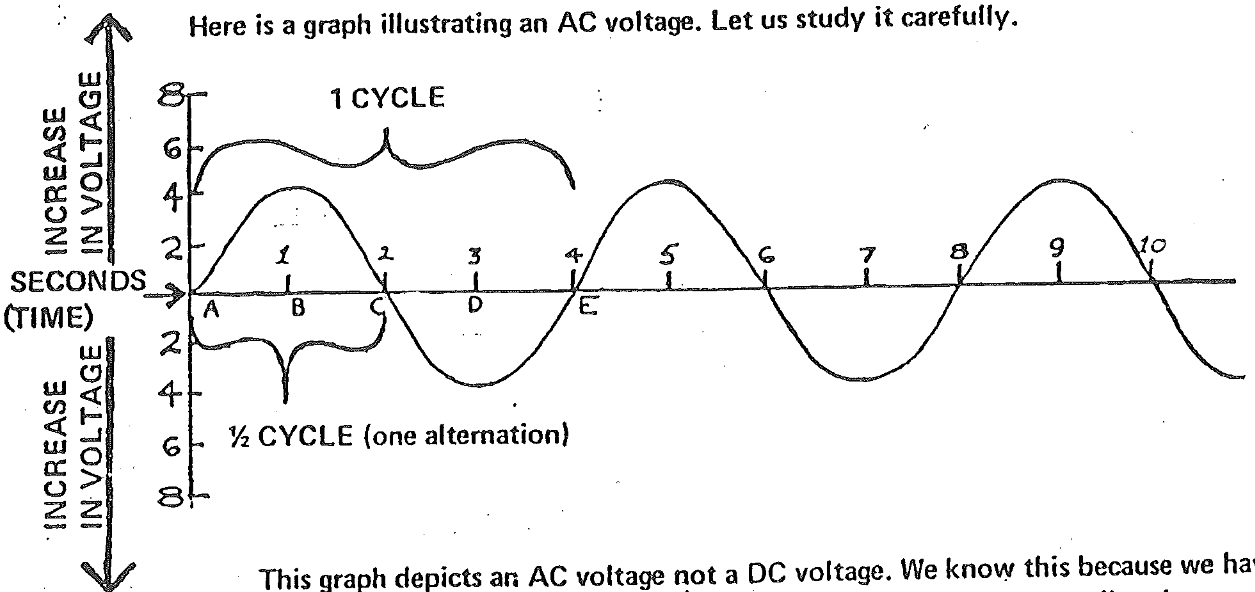
It is important to realize that this graph depicts a DC voltage. Voltage, though changing, was always in one direction. It either increased, stayed the same, or decreased, but never reversed itself.

## Depicting AC Voltage

Here is a graph illustrating an AC voltage. Let us study it carefully.



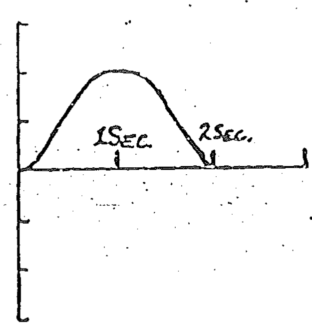

This graph depicts an AC voltage not a DC voltage. We know this because we have decided to indicate everything above the horizontal line as being in one direction, and everything below the horizontal line as being in the opposite direction. Let us explain:

Before we begin, there is zero time and zero voltage.

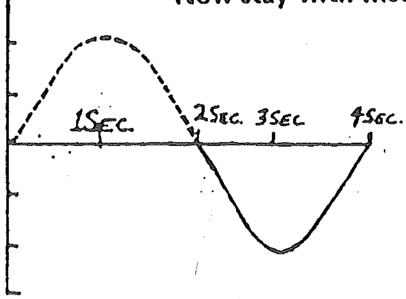
In the first second, the voltage rises from zero to four volts.

In the next second (two seconds total) the voltage drops from four volts back to zero volts.

One half cycle or one alternation has been completed. The voltage has gone from zero to four volts and back to zero (a to c on the graph).




Now stay with me:



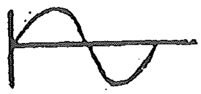

In the next second (three seconds total) the voltage again goes from zero to four volts – but in the opposite direction. The voltage indicated from c to d on the graph is not a decrease, but an increase. (Remember everything below the horizontal line indicates a voltage in the opposite direction from that above the line.)

In the next second (four seconds total) the voltage drops from a high of four volts back to zero volts. A second one-half cycle or alternation has been completed.

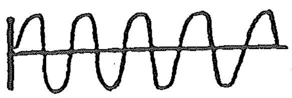
A total of one cycle has taken place in four seconds.

## Cycles and Frequency

Let us make sure we understand the relationship between cycle and frequency.



Cycle — One complete back and forth motion.



Frequency — The number of cycles in a given length of time (in other words, their frequency of occurrence.)

Thus:

If a cycle of AC occurs once every second we have a frequency of one CPS (cycles per second).

If 60 cycles of AC occur once every second we have a frequency of 60 CPS.

With the use of generators and oscillators (to be introduced shortly) it is possible to generate frequencies from a few cycles per second to billions of cycles per second.

### Hertz = CPS

In the early 1960s it was decided, in honor of the German physicist Heinrich Hertz, to replace the term "cycles per second" (CPS) with Hertz (Hz).

Thus:

60 CPS becomes 60 Hz.

20,000 CPS becomes 20,000 Hz.

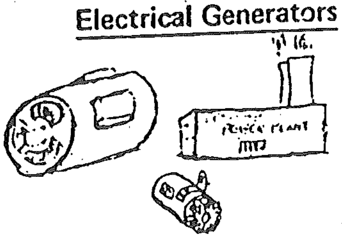
Heinrich ~~C. R.~~ S. HERTZ

## METHODS OF PRODUCING AC

There are basically two methods of producing an alternating current:

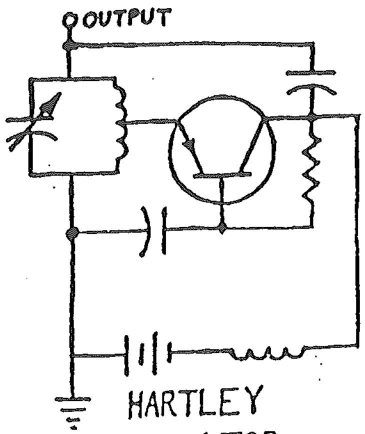
With electrical generators or with electronic oscillators.

### Electrical Generators



These are electromechanical devices that produce a high current at relatively low frequency. They generate large amounts of electrical power. Generators work on the principle of electromagnetism (we will look into electromagnetism in Lesson 3), and are found in equipment as diverse as automobile engines and power generating plants.

## Electronic Oscillators




These are electronic circuits that are designed to produce lesser amounts of current but at frequencies up to billions of cycles per second. They find applications in audio and radio frequency generating equipment. Some typical oscillators are listed here:

1. Sirens
2. Alarms
3. Radios
4. TVs
5. Sonars
6. Electronic musical instruments
7. Radar
8. Electronic test equipment

We will study oscillators more closely in Unit III.

SUMMING UP

In Lesson One we reviewed the concept of current flow and introduced the ampere as its unit of measurement. We discussed the need for direct current, pointing out that three major electronic components, vacuum tubes, transistors, and integrated circuits require a source of DC. Next, alternating current was introduced, and along with it a way of illustrating voltages and currents against time, through the use of graphs. Finally, methods of producing alternating current by generator and oscillator were briefly previewed in preparation for more detailed exploration in lessons to come.

# UNIT 2 LESSON 1 QUESTIONS

1. Explain why, in a DC circuit, current flows everywhere in the circuit at the same time.

2. List three electronic components that require the use of DC.

3. List the two primary sources of DC

4. What is the frequency of alternation of AC provided by your wall socket at home?

5. What is the frequency of alternation of AC in Europe? It's not in the book, but if you ask enough people, you will surely find out!

6. Why is AC transmission superior to DC transmission?

7. What problem is associated with the transmission of electrical power at low voltage levels?

8. What does the term "hertz" mean?

9. For the AC voltage graphed on page 1-5, how long does it take to complete

   (a) one cycle? 4 s
   (b) two cycles? 8 s

10. What is the frequency of the AC voltage graphed on page 1-5? .25 Hz

11. Draw a neat graph showing an alternating voltage with a frequency of 5 Hz.

12. List two methods of producing an alternating current.

13. List four electronic devices that make use of oscillators.

**Objectives:**

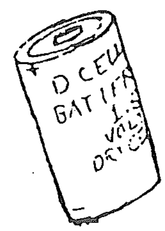
In this lesson you will:

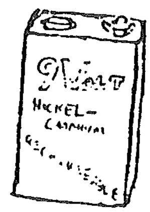
a. Learn how a basic cell converts chemical energy into electrical energy.

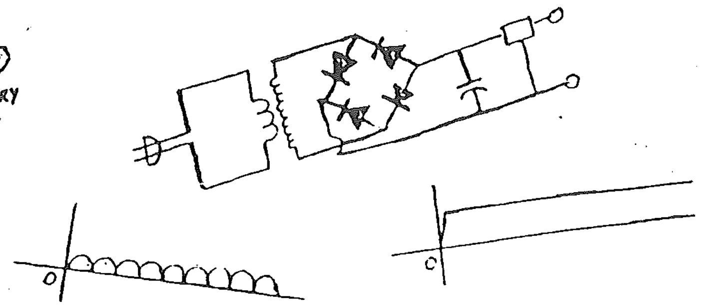
b. Learn how zinc-carbon, alkaline, mercury, nickel-cadmium, and solar cells operate.

c. Learn how cells or batteries can be connected in series and parallel for more current and voltage.

d. Learn how power supplies are organized to change AC into DC.





## METHODS OF PRODUCING DC

### Batteries and Power Supplies

As was mentioned in Lesson 1, the current and voltage requirements of today's electronic devices allow for the extensive use of batteries.

Let us compare the voltage and current needs of vacuum tubes, transistors, and integrated circuits.

| Vacuum Tubes | Transistors | Integrated Circuits |
|---|---|---|
| voltage in the hundreds | voltage, 3-18 | voltage, 3-15 |
| current in amperes | current in the milliamps (thousandth of an ampere) | current in the microamps (millionth of an ampere) |

As you can see — solid state components such as transistors and integrated circuits operate in voltages from 3 to 18 and draw current in the order of milliamperes and even microamperes. Such power requirements are easily supplied with today's batteries.

Let us list a few advantages that batteries provide:

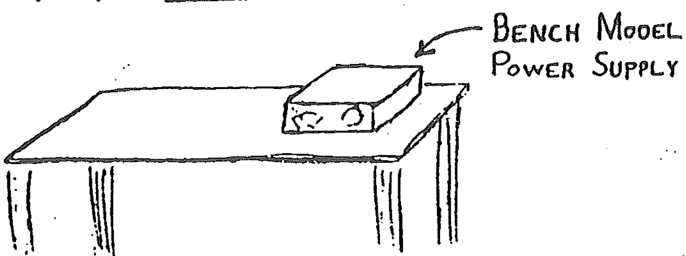
* Portability
* Long Life
* Easy installation and replacement
* High efficiency
* Small size

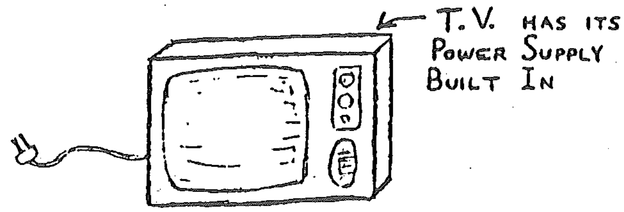
All these advantages and more make for the widespread use of batteries. We will look at them in more detail shortly.

Although the use of batteries is growing rapidly, they are a very expensive source of power relative to what is available at your wall socket. The need for a continuous, high current, dependable source of DC, where portability is not the concern, is very much in demand.

Such requirements can only be met by power supplies — fundamental electronic circuits that change the AC available at your wall socket to smooth steady DC at voltages ranging from a few to thousands.

Power supplies come in two forms. They are either separate units known as <u>bench models</u>, or, they are <u>built into</u> the electronic device requiring DC.

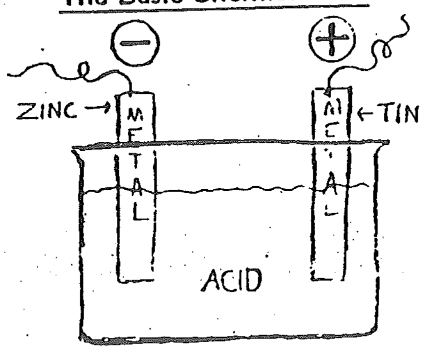



We will take an extensive look at power supplies, beginning with this lesson, and then carrying through in detail in Lessons 4 through 9.

## BATTERIES

### The Basic Chemical Cell



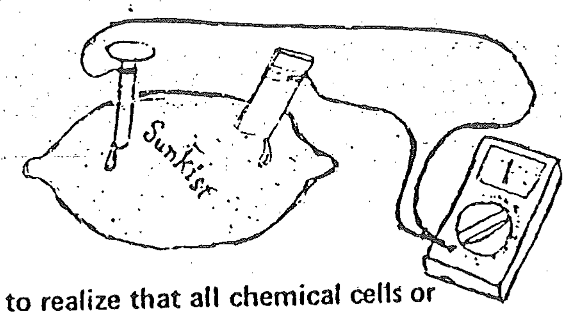

The basic cell stores energy in <u>chemical</u> form. When that energy is released it is converted into <u>electrical energy</u> for our use.

A basic chemical cell consists of:

- Two dissimilar metal plates
- Acid or electrolyte solution

Due to chemical action, <u>excess</u> electrons are accumulated at the negative terminal — while a <u>lack</u> of electrons exist at the positive terminal. We now have a difference in charge, or voltage.

### A Lemon Cell




The requirements for a simple cell outlined above can be met with a lemon, to supply the acid, and two dissimilar metals (an iron nail and copper strip for example.) Such a cell can produce more than <u>one volt</u>.

As crude as this lemon cell may seem, it is important to realize that all chemical cells or batteries are basically made of the materials illustrated, that is:

Two metal plates separated by an acid solution.

Before we proceed to investigate the different types of cells, a <u>few terms need</u> to be introduced. Look them over carefully.

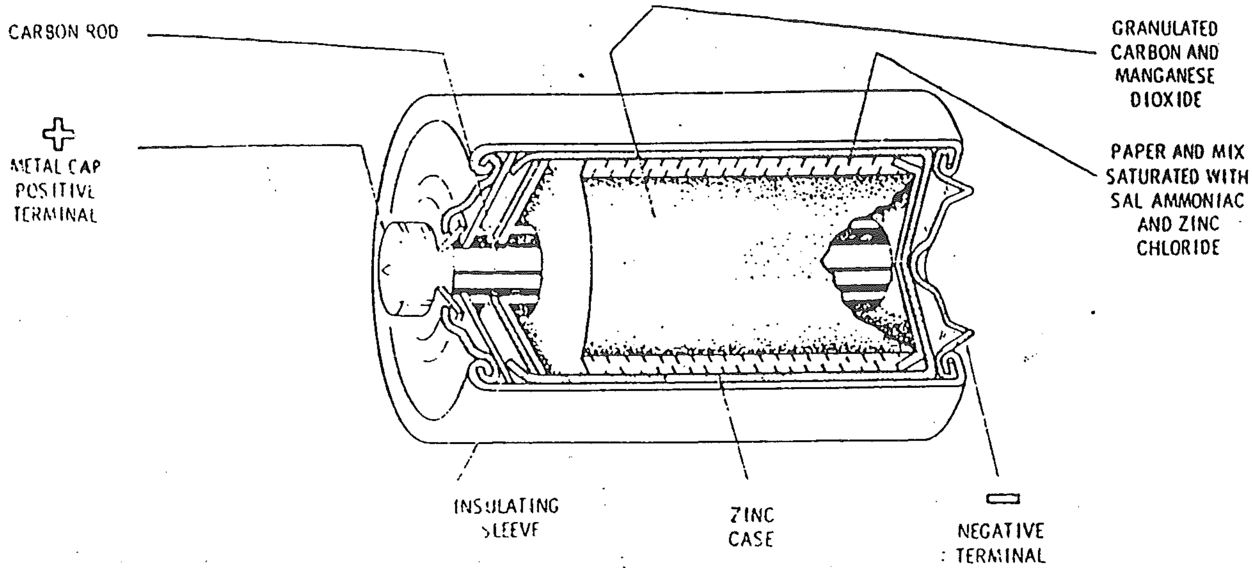
* Cell — The basic electrochemical device for producing electricity.
* Battery — Two or more cells connected together.
* Primary Cell — One that is <u>not</u> rechargeable.
* Secondary Cell — One that <u>is</u> rechargeable.

- 7 -

## The Carbon-Zinc or Dry Cell

The basic characteristics of a carbon-zinc cell are:

- It has extensive shelf life.
- It is the most widely used standard cell.
- It is a primary cell.
- It produces 1.5 volts.
- It comes in sizes AAA, AA, C, and D. The larger the cell the more current it can produce over a specified period of time.



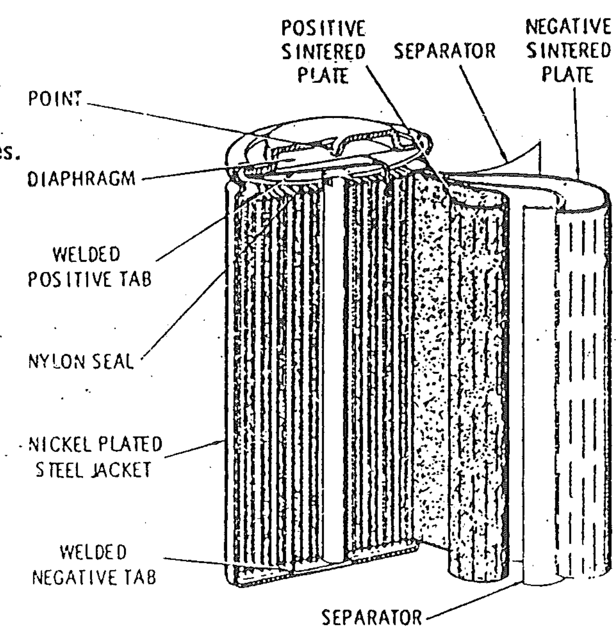

The carbon-zinc cell consists of:

* A negative plate made of zinc.
* A positive plate made of carbon.
* An acid (electrolyte) of sal ammoniac and zinc chloride.

Carbon-zinc cells find extensive use in toys, radios, and portable equipment requiring <u>moderate</u> current levels. Remember though, since they are a primary cell, they are non-rechargeable.

## Nickel-Cadmium Cell

Nickel-cadmium cells are available in standard sizes and produce 1.25 volts. Their main advantage lies in their rechargeability — up to 1,000 times in many instances.



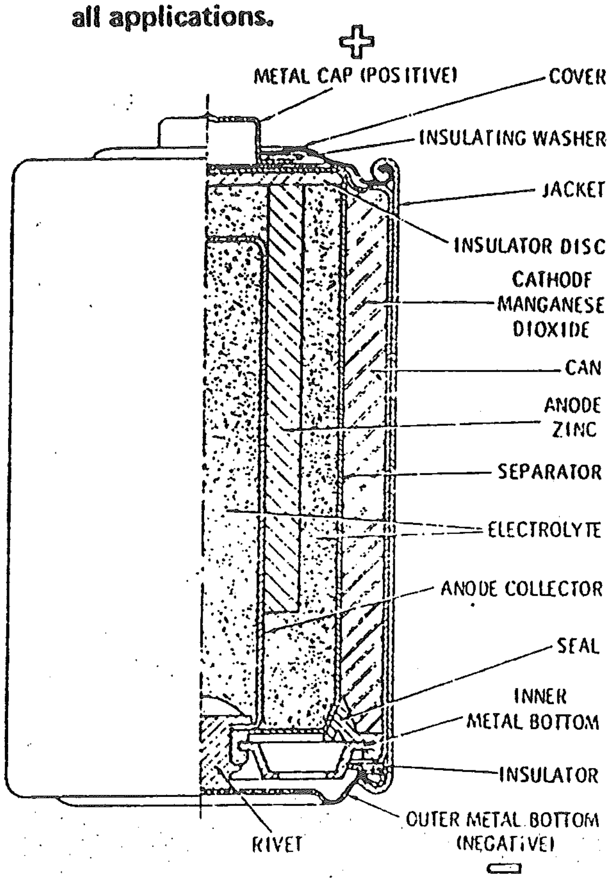

A nickel-cadmium cell consists of:

* A negative plate made of metallic cadmium.
* A positive plate made of nickelic hydroxide.
* An acid (electrolyte) of potassium hydroxide.

Nickel-cadmium or ni-cad's are used wherever rechargeability and long life is desirable.

## The Alkaline Cell

The alkaline cell is similar to the carbon-zinc cell and can be interchanged with it in almost all applications.

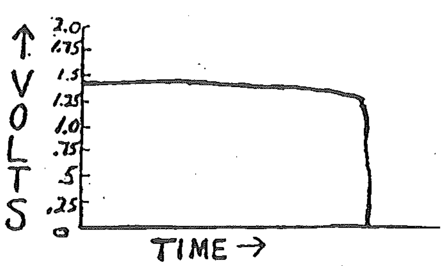



The main advantage of the alkaline cell is that it produces more current for longer periods of time. While more expensive than carbon-zinc cells, they are usually worth the additional cost. Also, some types of alkaline cells can be recharged.

Alkaline cells are ideal for powering photoflash units, motor-driven toys, flashlights, and other equipment requiring a high current source.

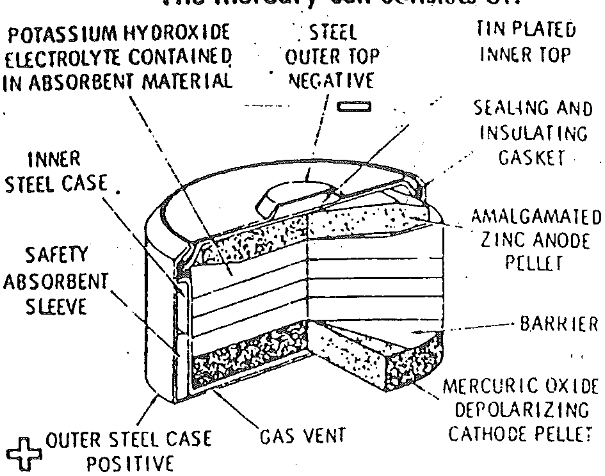
## Mercury Cell

The basic characteristics of a mercury cell are:




- It delivers approximately 1.33 to 1.40 volts at a very constant rate of discharge. This is indicated in the discharge curve to the left.
- It is small in size. Some are as tiny as an aspirin tablet.
- It has a high efficiency for its size.
- It is a primary cell.

The mercury cell consists of:




* A negative plate made of mercuric oxide.

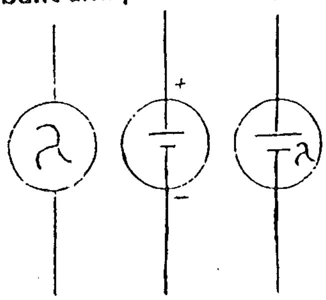
* A positive plate made of zinc.

* An acid (electrolyte) of potassium hydroxide and zincate.

Mercury cells, because of their small size and high efficiency find wide usage in hearing aids.

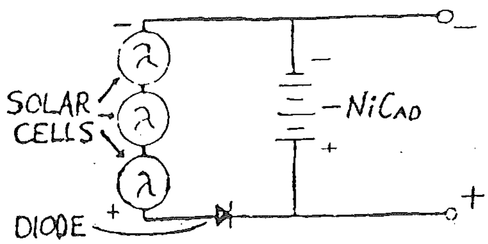
## Solar Cell

Increasing interest is being shown in the use of solar cells — devices that convert light energy directly into electrical energy. While their overall efficiency is still quite low (20%), once built and put into use, the power they provide is essentially free.



Solar cells are of two types, selenium and silicon. They both convert light directly into electricity. Each cell has a particular voltage and current rating. It is possible to connect these cells in series and parallel to increase their power ratings. I have 36 ½-volt-100ma (thousandths of an ampere) solar cells connected to provide 9 volts at 200ma. This array has been powering a 5-transistor radio for over six years at no cost beyond the original investment of $12.00.

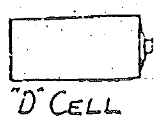
One very practical use of solar cells is to recharge nickel-cadmium batteries. A typical setup is shown here:

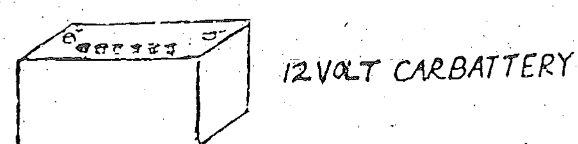



The battery will discharge only when more current is drawn from the circuit than the cells are able to supply. When the circuit is not operating, the cells will recharge the battery. The diode prevents the battery from discharging through the solar cells.

## BATTERIES IN SERIES AND PARALLEL

What we have been discussing so far are cells — chemical (and solar) units that produce a voltage. When you combine two or more cells you have a battery.



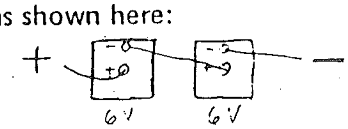

It is possible to connect cells or batteries in series and parallel to increase their voltage and current.

Question: If you had two 6 volt batteries, how would you connect them to obtain 12 volts?

Answer: Connect the two batteries in series.

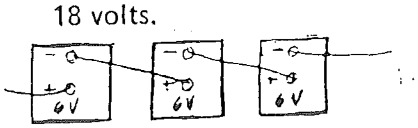
What is a series connection?

A series connection means the negative pole of one battery is connected to the positive pole of another battery as shown here:

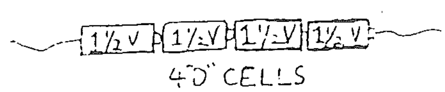



When this happens, the voltage adds, 6 volts + 6 volts = 12 volts.

This connection provides 18 volts.




This connection provides 6 volts.

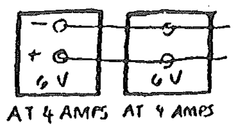


**Question:** If you had two 6 volt batteries how would you connect them to produce more current?

**Answer:** Connect the two batteries in parallel.

What is a parallel connection?

A parallel connection means the positive poles are connected together and the negative poles are connected together as shown here:

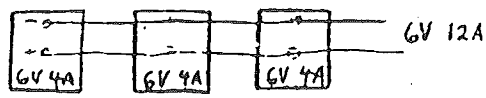



When this happens, the voltage does not add, but the current does.

4 amperes + 4 amperes = 8 amperes.

This set-up will provide twice as much current, or, if the load requires only 4 amperes, it will deliver 4 amperes for twice as long.

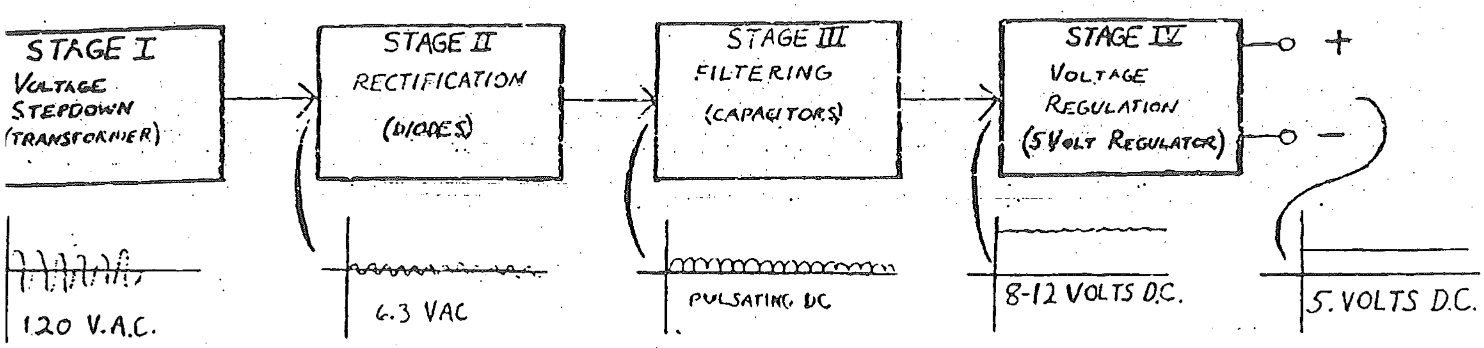
This connection provides 12 amperes at 6 volts.




## INTRODUCTION TO POWER SUPPLIES

As we mentioned in the beginning of our lesson — power supplies are circuits that change AC to DC. Available at your wall socket is a 120 volts at 60 cycles alternating current. A power supply whether of the bench type or built-in, will take that 120 volts AC and through a series of steps, or stages, alter it to produce a steady DC at the voltage desired.

To introduce you to the power supply, a block diagram for the 5-volt power supply project contained in Unit II is shown below. Most power supplies are organized in the same manner, so study the diagram carefully.




**Stage I**

Takes the 120 volts AC input from the wall socket and reduces it to 6.3 volts AC. The major component is the transformer. (Some power supplies will, through the use of a transformer, step the voltage up as well as down.)

**Stage II**

The 6.3 volts AC is now changed to a pulsating DC through the use of rectifiers in the form of a "bridge" (usually containing four diodes).

**Stage III**

Through the use of electrolytic capacitors, the pulsating DC (PDC) is "filtered" into a smooth DC.

**Stage IV**

A voltage regulator now takes the smooth DC which can range anywhere from 6 to 10 volts and insures that only a steady 5 volts will be made available at all times.

We will be looking into each of these stages in detail starting with Lesson 4.

SUMMING UP

In lesson two we explored some reasons for the growing popularity of batteries and analyzed the workings of a simple chemical cell. We reviewed the major characteristics of the more widely used chemical cells such as carbon-zinc, alkaline, mercury and nickel-cadmium and touched on the fundamental aspects of the solar cell — a device that turns sunlight directly into electricity. We showed how cells and batteries can be connected in series and parallel to increase both the current and voltage available. Finally, we outlined the various stages of a typical power supply in preparation for a more in-depth study in lessons 4 through 9.

## UNIT 2 LESSON 2 QUESTIONS

1. List five advantages of batteries or cells as DC sources.

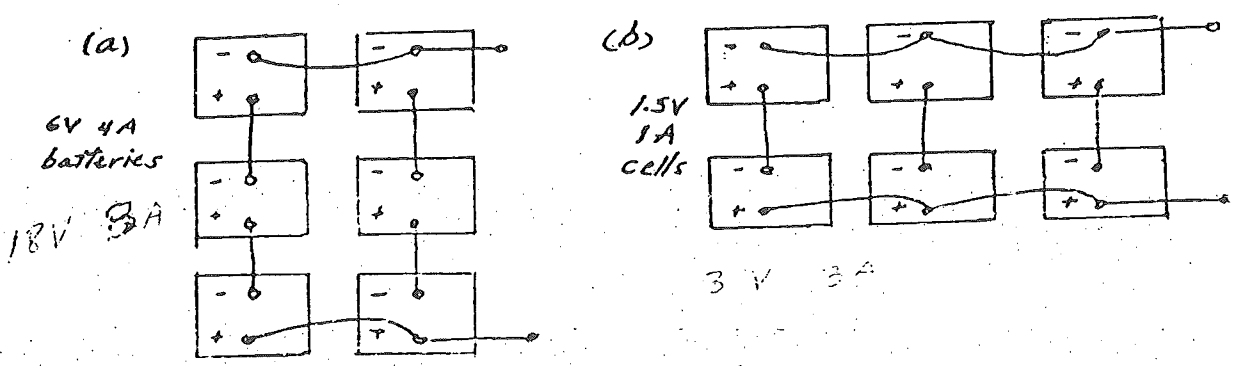
2. What is the main principle of operation of the chemical cell?

3. Describe the basic components of a simple chemical cell.

4. List advantages and disadvantages of:

   (a) the carbon-zinc cell
   (b) the alkaline cell
   (c) the mercury cell
   (d) the nickel-cadmium cell

5. It is possible to connect cells or batteries in series <u>and</u> parallel to increase both current and voltage. Find the voltage output and the current capability of the two combinations shown below.




6. Draw a block diagram, and label the stages, of a basic power supply.

## LESSON 3 – ALTERNATING CURRENT – HOW IT IS GENERATED, DISTRIBUTED, MEASURED, AND PRICED

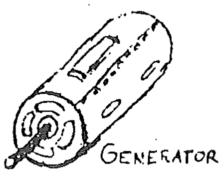
Objectives:

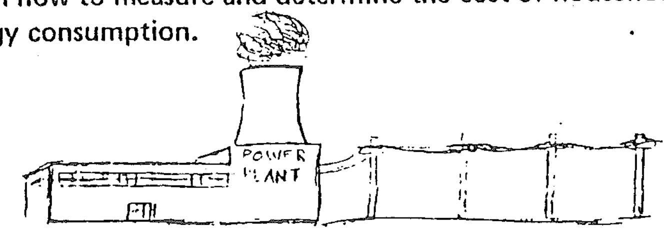
In this lesson you will:

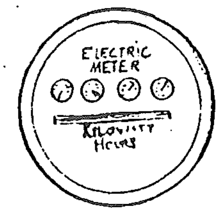
a. Learn how electric generators operate.

b. Learn how power plants produce electrical energy.

c. Learn how to measure and determine the cost of household electrical energy consumption.

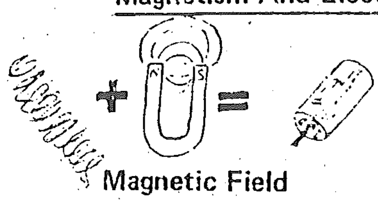



### ELECTRIC GENERATORS

#### Magnetism And Electric Generators




Magnetic Field

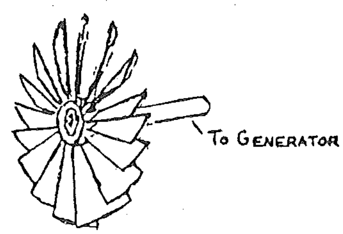
Coil of Wire Generator

When a coil of wire (a conductor) is passed through a magnetic field (produced by a magnet) a current will be induced into the coil of wire. A device built using this principle is known as an electric generator.

Such generators are used to produce over 95 percent of the electricity in this country. The electricity supplied to your home, office, or factory is produced using electric generators.

Regardless of the type of power generating plant—hydroelectric (water) steam, atomic, geothermal, wind, etc. in their final production process all will rotate a turbine which is connected to an electric generator.

So, before we look at power plants in detail, let us explain the working of a basic electric generator.

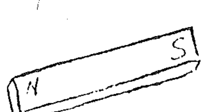



TURBINE

#### Magnetism

In order to understand how magnetism can produce electricity we need to take a quick look at the basic magnet itself.

Permanent magnets come in two popular shapes:

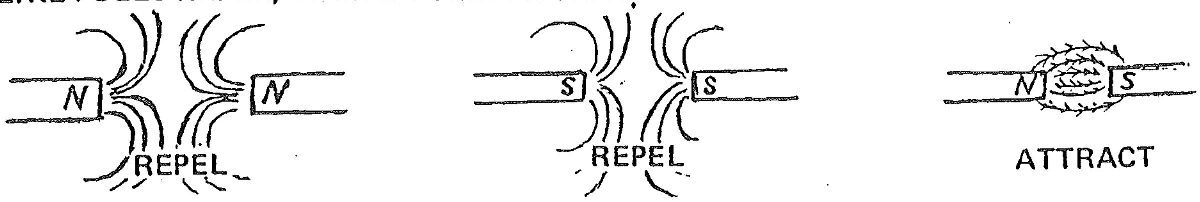



Bar shaped

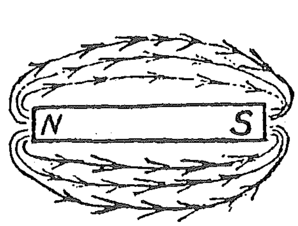

Horseshoe shaped

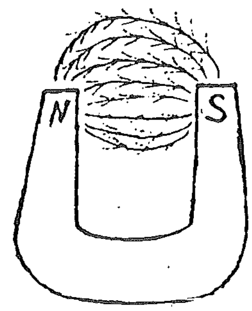
All such magnets have a north and south pole that attract or repel each other based on the following principle:

LIKE POLES REPEL, UNLIKE POLES ATTRACT.



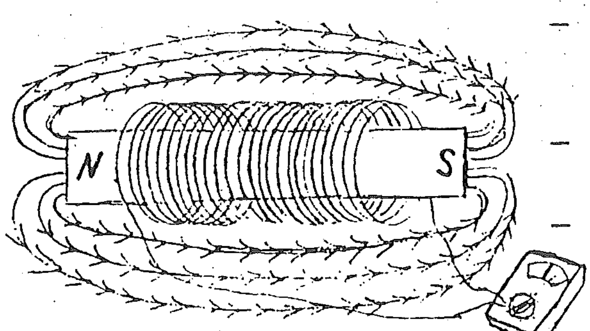

Surrounding every magnet there exists a magnetic field. The shape of this field is determined primarily by the shape of the magnet.



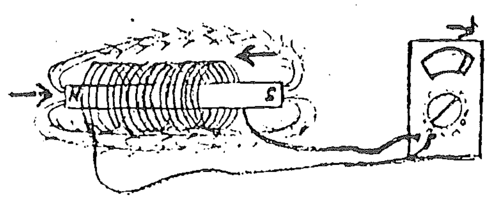



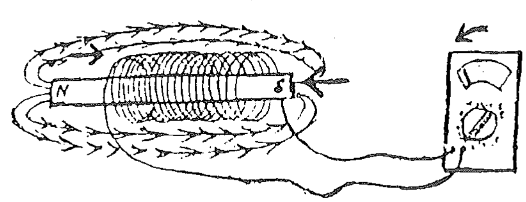

Generating Electricity

If a conductor such as a coil of copper wire is made to cross a magnetic field, the free electrons in the conductor will move in one direction, resulting in current flow. Here is how it works:



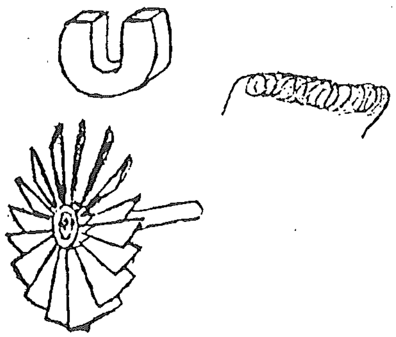

- A coil of wire is placed around a permanent magnet. Attached to the coil is a meter. (Notice the coil is not connected to a battery or any other source of power.)
- A magnetic field exists around the permanent magnet.
- If the coil and magnet just sit there, neither moving, nothing will happen, that is no current will flow in the coil of wire.
- If however, the coil of wire can be made to "cut across" the magnetic field, current will be produced. This can be done by: moving the coil, moving the magnet, or moving both the coil and magnet.
- As the coil moves toward one pole, current will move through the coil in one direction. As the coil moves toward the other pole, current flows through the coil in the opposite direction. The result is alternating current.





## The Basic AC Generator

To make a workable generator one would need:

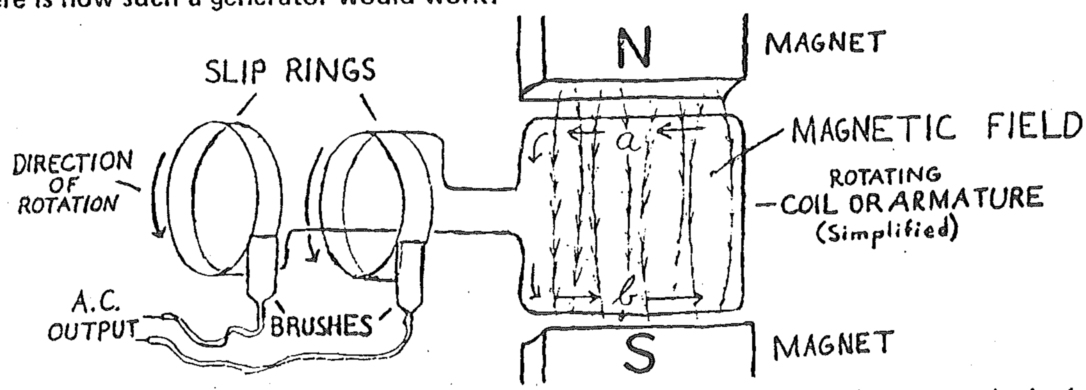


a. A large magnet.

b. A coil with a large number of turns.

c. A mechanical means of rotating the coil as quickly as possible through the magnetic field. (The faster the wires in the coil cut the magnetic field, the more current that is produced.)

Here is how such a generator would work:



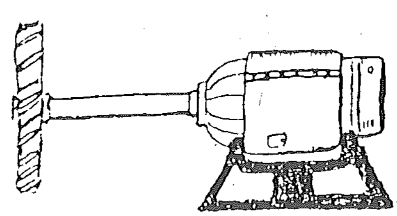

As the coil of wire (only one loop is shown for simplicity) is rotated counter clockwise through the magnetic field, current is induced into the coil in the direction indicated. As coil segment "a" moves <u>down</u>, current is generated in one direction. At the same time coil segment "b" is moving <u>up</u>, generating current in the opposite direction. Yet the total effect is for current to flow completly through the conductor (coil) in one direction (counter clockwise.)

As the coil is rotated through the next half cycle (rotation) current is induced in the opposite direction. The result, after one complete revolution, is the generation of an <u>alternating</u> current.

Power plants that produce our electricity operate on the principles just outlined. Let us take a look at them.

## ELECTRICAL POWER GENERATING PLANTS

As was stated a moment ago — in addition to the need for a large magnet and a coil with many turns of wire, a means of moving the coil rapidly through a magnetic field is required to make a practical generator.



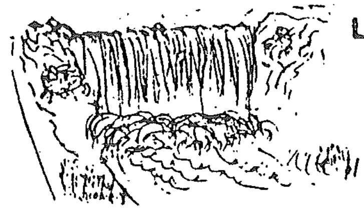
Turbine Generator

In a large generating facility a turbine is attached to the armature or coil of an electric generator.

When the turbine moves around, the coil (or armature) will also move around.

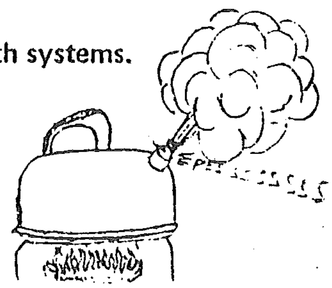
But how do we get the turbine to move? There are essentially two methods:

* Mechanical energy from falling water (hydroelectric power plants.)



* Mechanical energy from steam, developed by heating water.

Let us take a look at both systems.

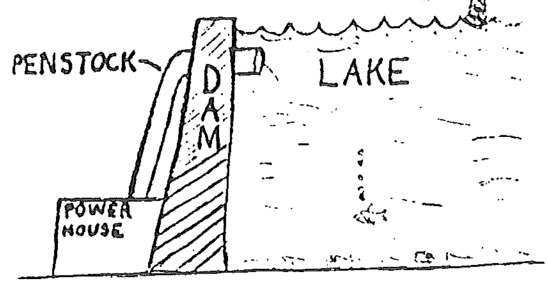


## Hydroelectric Power Plants

In the hydroelectric system (which produces about 16 percent of our nations electrical needs) energy to turn the turbine is provided by falling water.

One of the most practicle ways (although not the only) to create falling water, is to dam up a river. This creates a lake behind the dam. When water is let out of the lake it falls through huge intake structures called penstocks, to the power house below the dam.

The turbine is located in the power house, and as the water "hits" the buckets or blades of the turbine it rotates, driving the electric generator.

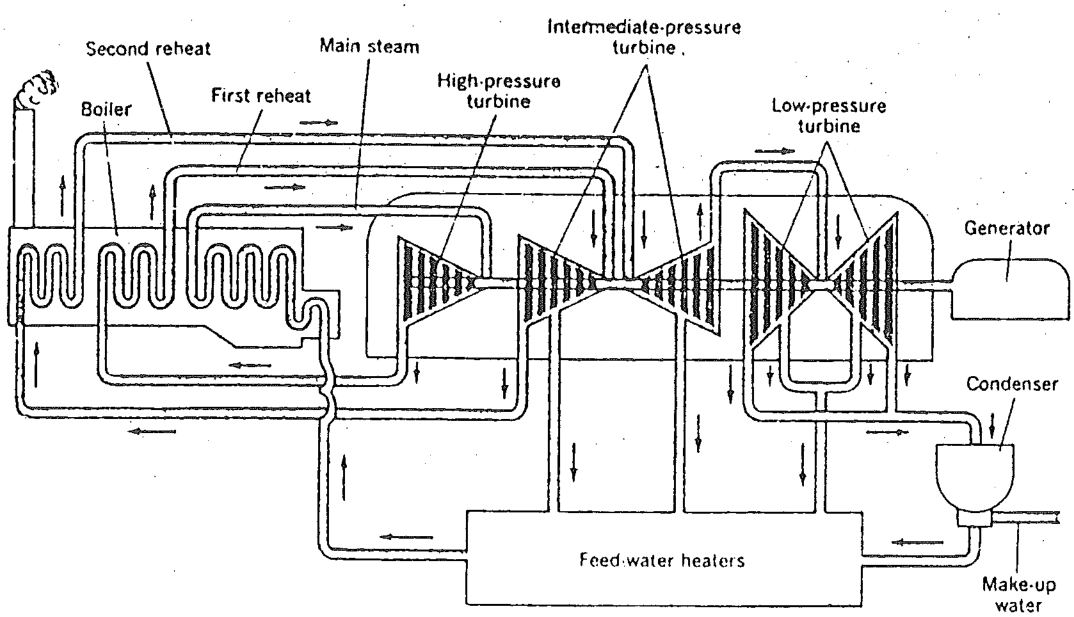



## Steam Electric Generating Plants

Steam electric generating plants provide the vast majority of electrical power in our country – approximately 62 percent.

In steam plants, water is heated to produce steam which is fed under pressure to a turbine. Steam rushing against the turbine blades causes the turbine to rotate, driving the electric generator.

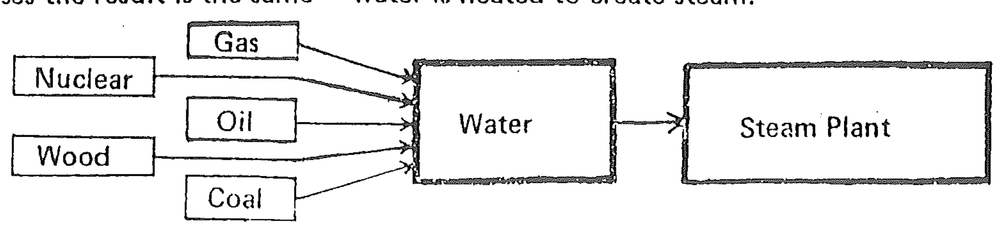
A typical steam generating system is shown here:




The methods of heating the water in a steam plant, though varied, fall into two broad categories:

- Heat derived form the burning of fossil fuels.
- Heat derived from nuclear reaction (nuclear power plants.)

In both cases the result is the same – water is heated to create steam.

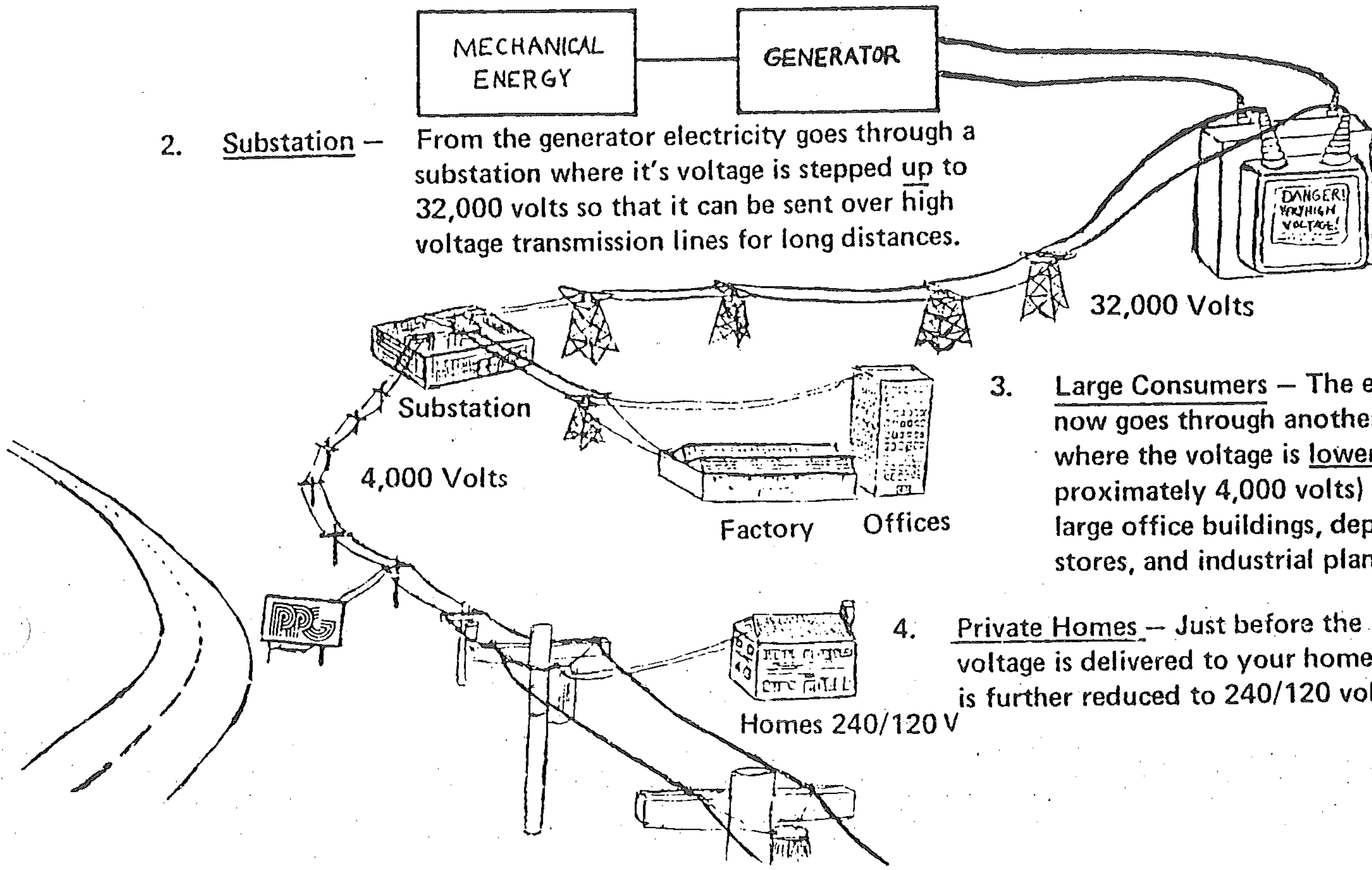


## ELECTRICAL DISTRIBUTION SYSTEM

Regardless of how electrical energy is generated, it must of course be distributed to homes, offices, and factories. A typical distribution system would look like this:

1. Power Plant — Various methods are used to drive electric generators, where the electricity is actually made.

2. Substation — From the generator electricity goes through a substation where it's voltage is stepped up to 32,000 volts so that it can be sent over high voltage transmission lines for long distances.



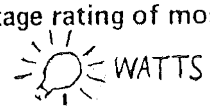

3. Large Consumers — The electricity now goes through another substatic where the voltage is lowered (to ap· proximately 4,000 volts) and fed tc large office buildings, department stores, and industrial plants.

4. Private Homes — Just before the voltage is delivered to your home it is further reduced to 240/120 volts AC.

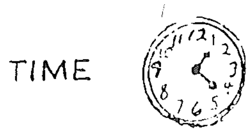
## ENERGY COST AND MEASUREMENT

Energy is the capacity for doing work. Household appliances consume electrical energy and in the process perform work. It is important to know how much energy a given appliance consumes. This will aid you in identifying where energy is wasted and conservation efforts should apply.

The wattage rating of most appliances is listed on the appliance itself.

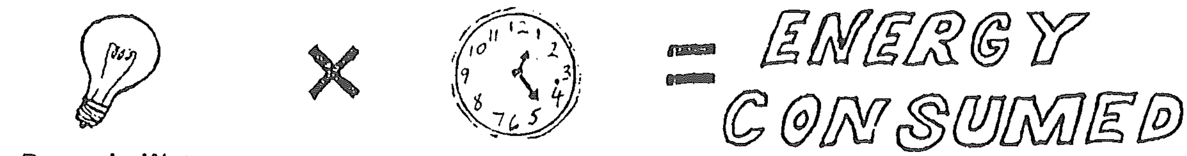



Wattage ratings are an indication of the rate at which a uses electric energy.



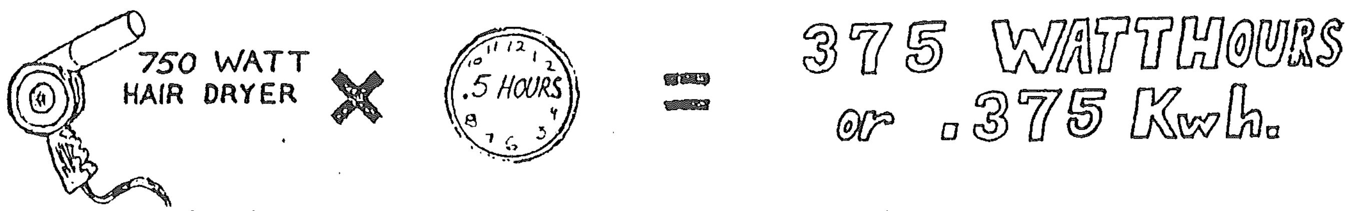

Energy is the wattage rating over time. If you know how fast a car traveled and you multiply by how long it traveled, you can tell how far it went.

In the same way if you know the rate at which energy is used, wattage, and you multiply it by how long it was used, you will find the total energy consumed.




Power in Watts — Time in Hours — IN WATT HOURS OR KILOWATT-HOURS.

ıre a couple of examples:


ote: — One kilowatt hour (kwh) = 1,000 watt hours. A kilowatt is a more convenient term to use.

ıergy Consumption Chart

The chart below lists twenty common household appliances along with their:

Average wattage rating.

Average hours used per year.

Estimated kwh per year.

You arrive at the estimated kwh by multiplying the wattage rating times the hours used, then viding by a thousand.

| ITEM | CHECK OFF | AVERAGE WATTAGE RATING | AVERAGE HOURS USED PER YEAR | ESTIMATED kwh USED PER YEAR |
|---|---|---|---|---|
| · conditioner (room) | | 900 | 1,000 | 900 kwh |
| anket (electric) | | 177 | 831 | 147 kwh |
| n (attic) | | 370 | 1,467 | 377 kwh |
| aver (electric) | | 14 | 129 | 1.8 kwh |
| dio/record player | | 109 | 1,000 | 109 kwh |
| / color solid state | | 250 | 2,200 | 550 kwh |
| / black and white | | 108 | 2,186 | 236 kwh |
| wing machine | | 75 | 147 | 11 kwh |
| cuum cleaner | | 630 | 73 | 46 kwh |
| ender | | 386 | 39 | 15 kwh |
| n opener | | 240 | 4 | 1 kwh |
| ffee maker | | 894 | 119 | 106 kwh |
| en, microwave | | 1,450 | 131 | 190 kwh |
| nge with oven | | 12,200 | 96 | 1,171 kwh |
| ezer (15 cu. ft.) | | 341 | 3,504 | 1,195 kwh |
| frigerator | | 396 | 3,791 | 1,501 kwh |
| othes dryer | | 4,856 | 205 | 995 kwh |
| on (hand) | | 1,008 | 143 | 144 kwh |
| ashing machine | | 512 | 201 | 103 kwh |
| ater heater | | 2,475 | 1,705 | 4,220 kwh |

UNIT 2 LESSON 3 QUESTIONS

1. Explain the operation of an electrical generator. Include in your explanation:

(a) a discussion of the basic principle upon which the generator works.
(b) a labelled diagram showing a simple generator, with an explanation of how this setup produces current.

2. List the two most predominant types of electrical generating systems.

#. What does the wattage (power) rating of a device tell you?

4. Find the energy used (in watt-hours) by the following devices:

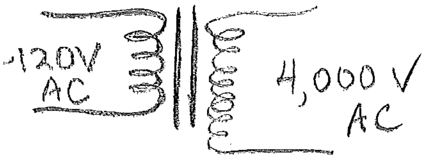
(a) a 1200 watt tea kettle operated for 12 hours 14.4 kwh
(b) a 750 watt baseboard heater operated for 1.5 hours. 1.125

5. At 6 cents per kilowatt-hour, what would it cost to operate a 7.5 watt night light 24 hours a day for a period of one year? Show calculations. 3.94

6. On the chart below, list the items from the table on page 3-6 that you use most frequently. List the estimated kwh used per year. Multiply this value by 6 cents ( $.06) (an average value). The result will be the cost per year to run that appliance.

| | ESTIMATED kwh USED PER YEAR | X | CURRENT PRICE PER kwh | = | COST PER YEAR |
|---|---|---|---|---|---|
| example: fan (attic) | 377 | | .06 | | $18.62 |
| 1. | | X | | = | |
| 2. | | X | | = | |
| 3. | | X | | = | |
| 4. | | X | | = | |
| 5. | | X | | = | |
| 6. | | X | | = | |
| 7. | | X | | = | |
| 8. | | X | | = | |
| 9. | | X | | = | |
| 10. | | X | | = | |

A)



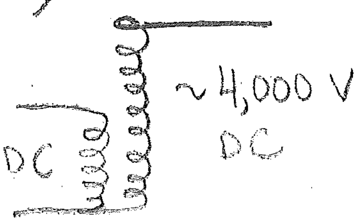

1) STEP-UPs VOLTAGE
2) SEPARATEs 2 circuits

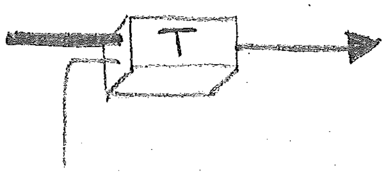
$P1 = P2$

$V_1 \cdot I_1 = V_2 \cdot I_2$

$120V \cdot 10A = 4{,}000 \cdot x \Rightarrow x = \frac{1200}{4000} = 0.3\ A$

B)

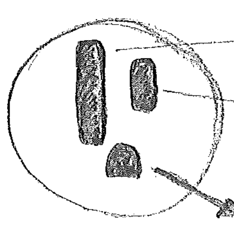



TO THE STROBE LIGHT

1) STEPs UP VOLTAGE
2) DOESN'T SEPARATE 2 circuits

## WALL SOCKET



| | WIRE COLOR: | |
|---|---|---|
| NEUTRAL | (WHITE) | |
| HOT | (BLACK) | |
| GROUND | (GREEN) | → CONNECT TO THE METAL CASE |

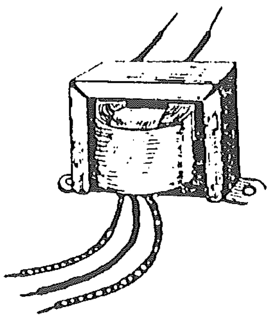
PRONGs

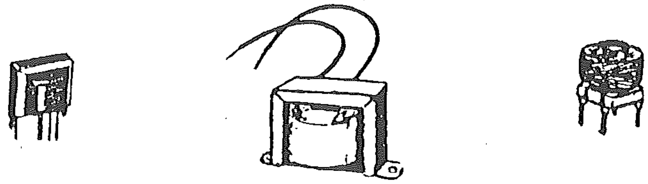
# Lesson 4 – TRANSFORMERS

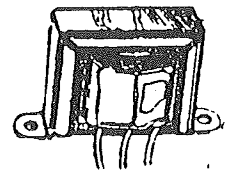
OBJECTIVES:

In this lesson you will:

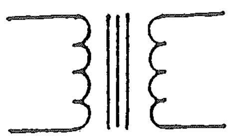
- * Learn what a transformer is and what it is used for.
- * Learn how a transformer is constructed.
- * Learn about electromagnetism, the principle of transformer operation.
- * Learn how a transformer functions in a power supply.







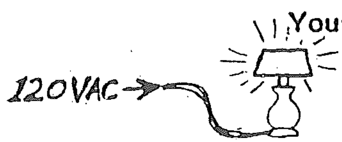
## WHAT IS A TRANSFORMER?



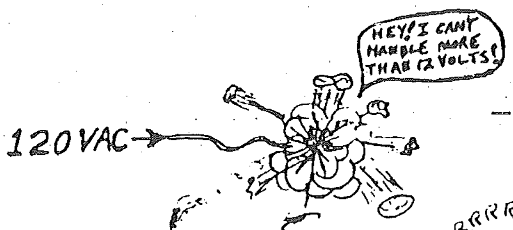
A transformer is an electrical component that, through magnetic induction, transfers electrical energy from one circuit to another. In the process it will usually step up or down voltage (and current). A transformer operates on AC (alternating current).

Here is an example of how it is used:

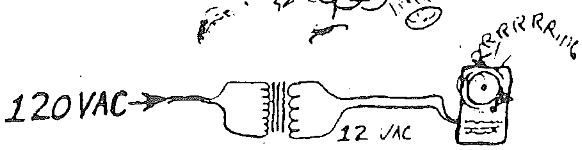
Your wall socket makes available 120 volts AC at up to 30 amperes.




– An ordinary lamp will operate directly on 120 volts AC. Just plug it in and it lights up. The lamp needs 120 volts AC and "draws" on an average of one to two amperes of current.




– But what if you had an electrical device such as a doorbell or small motor that ran on 12 volts AC? If you plugged such a device directly into the 120 volt wall socket it would blow up. You will need to step the 120 volts down to 12 volts. That is where the transformer comes in.




A 12 volt transformer will step down the 120 volts AC to 12 volts AC to power the doorbell or motor.

The ability of a transformer to step-up or down a voltage or current is important for two reasons:

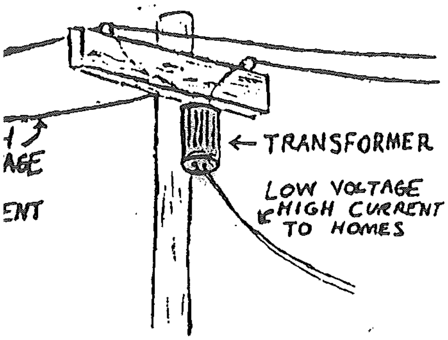
One – It allows us, using alternating current, to transmit electrical power over long distances.

Two – Once electrical power arrives at our home, its voltage and current can again be stepped up or down for use in numerous electrical and electronic devices.

Let us look at these two points for a moment.

DC → Low Voltage, High Current
AC → High Voltage, Low Current

## Transmitting Electrical Power



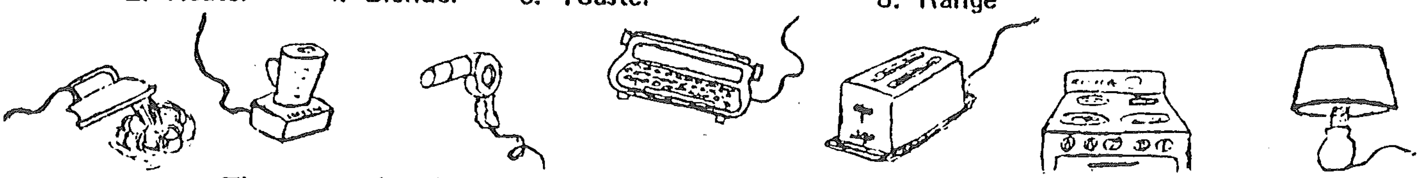

It is very difficult and wasteful to transmit large amounts of current over long distances. The idea is to transmit large amounts of voltage (at low current levels). In that way, power losses are kept to a minimum.

But our homes require relatively low voltages (240/120) at high currents (15- 50 amperes). How do we go from the power lines that may be carrying 4,000 to 50,000 volts (at low current) to 240/120 volts at high current? You guessed it – we use a transformer. Those cylindrical things stationed on telephone poles are transformers that step down the 4,000 volts being carried by the power lines to 240/120 volts for use in our homes.

## Transformers in Electrical Equipment

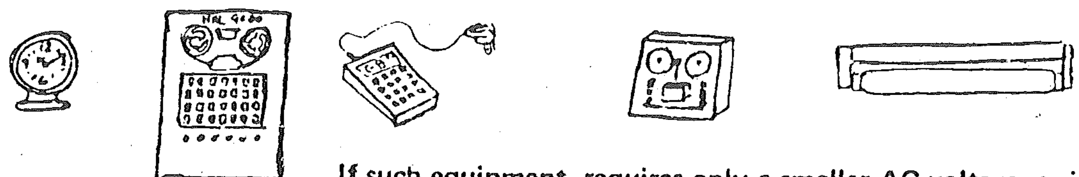
There are many electrical devices in your home that are designed to run directly on 240/120 volts AC and do not need a transformer. Here are just a few:

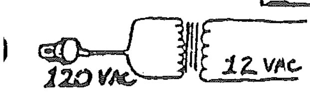
1. Iron
2. Heater
3. Hair dryer
4. Blender
5. Electrical typewriter
6. Toaster
7. Lights
8. Range



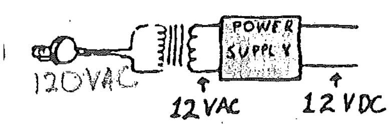
There are other devices, however, that require a different AC voltage (usually smaller) or even a DC voltage. These items are mostly electronic, such as:

1. Clocks
2. Lights
3. Computers
4. Calculators
5. Electrical typewriter
6. Doorbell

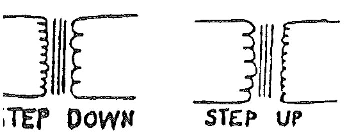





If such equipment requires only a smaller AC voltage, a simple step-down transformer is placed between the wall socket and the device. (A step-up transformer would be used for AC voltages higher than 120 volts.)

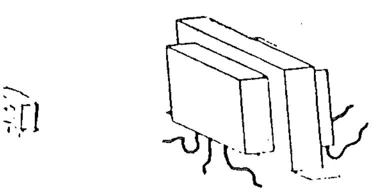



If the equipment requires DC at higher or lower voltages than is available at the wall socket (120 volts AC) then a power supply is used. Remember, a power supply is a device that changes AC to DC.



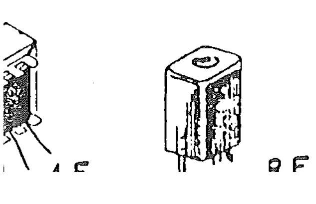

The first stage or section of that power supply will consist of a transformer to step up or down the AC voltage to the approximate value needed. The rest of the power supply changes the AC to DC.

Therefore, as you can see, from the power generator to the electrical devices in your home – if an alternating current needs to be stepped up or down anywhere along the way – a transformer is required.



## CONSTRUCTION OF A TRANSFORMER

Transformers come in all sizes, from tiny little units no bigger than a thimble, to huge devices larger than a truck. Of course, the range of sizes found in the electrical equipment in your home is not that wide. Here we encounter transformers from an ounce or two, to five or ten pounds.

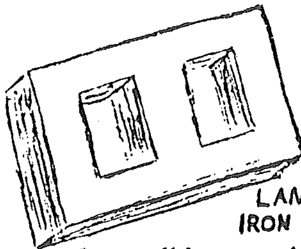


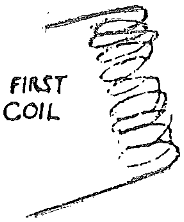
* The lighter and smaller variety tend to be of the audio frequency (AF) or radio frequency (RF) type. These transformers are designed primarily to couple energy (through electromagnetic induction) from one circuit to another. We will have a chance to study these types more closely in Unit III which deals with amplifiers and oscillators. For now, we will concentrate

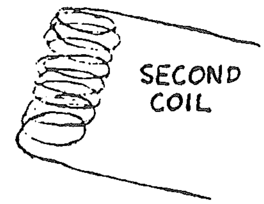
## The Power Transformer

A power transformer is one that is designed to deal with the power available from the wall socket, usually 120 volts AC at up to 10 amperes. It takes that voltage and steps it up or down.

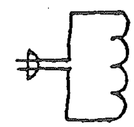
In actual construction, the transformer will consist of an iron core (in laminated form) with two or more coils of wire wound around it.



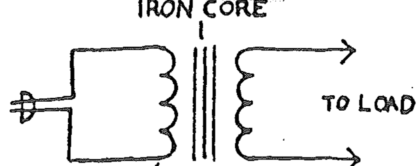




One coil is wound onto the iron core and the second coil is wound over the first coil. They do not short together because each coil is coated with an insulating substance such as lacquer or shellac.




One coil is known as the primary and is always connected to the source of power. With a power transformer it will be the wall socket.




schematic symbol

The other coil is known as the secondary. It receives electrical pow from the primary coil (through electromagnetic induction) and delivers it to a load such as a bell, motor, or the "bridge" rectifier of a power supply.

Remember — the power transformer consists of two coils wound on an iron core.

## THE PRINCIPLE OF TRANSFORMER OPERATION — Electromagnetism

Before we investigate electromagnetism, let us make sure we understand the relationship between current, voltage and power; and the difference between AC and DC.

### Power

$$E \times I = P$$

Power is simply voltage times current. The unit of measurement is the watt. If 120 volts is pushing 3 amperes of current through a circuit, we have 360 watts of power.

120 volts x 3 amperes = 360 watts.

It is not always convenient to write out the words, current voltage, or power. We therefore use letter symbols to keep things short.

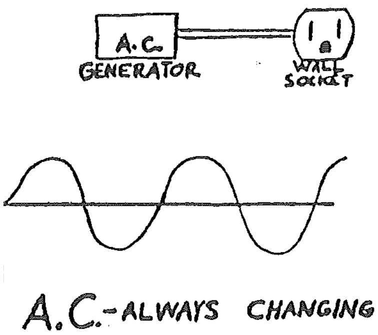
The letter symbol for current is I, for voltage E, and for power P. Thus we can say:

E x I = P, or voltage times current equals power.

## AC and DC

DC, remember, is current moving in one direction over an extended period of time. It is the type of current derived from batteries or power supplies.


AC, on the other hand, is current that is moving first in one direction, then in the opposite direction, back and forth. The number of times it moves back and forth (one cycle) in one second is known as its frequency. An alternating current of 60 cycles per second (60Hz) is available at your wall socket. It is the type of current produced by AC generators. If you plug something into the wall socket (such as a lamp), it will use 120 volts of pressure to push electrons in the lamp's circuit (current) back and forth 60 times per second. How much current the lamp uses depends on the design of the lamp circuit.



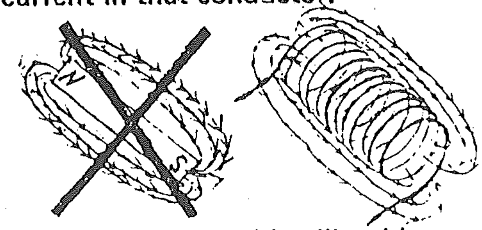

Notice an interesting characteristic of the AC available at your wall socket? it is always changing — that is, it is never at a fixed value for any length of time. It is either increasing or decreasing in one direction or the other. This will be a very important point to remember when when discussing electromagnetism — the principle upon which a transformer operates.

## Electromagnetism

In a previous lesson we saw how magnetism can produce electricity. If a magnetic field is made to cross a conductor it will induce a voltage, and thus a current in that conductor.

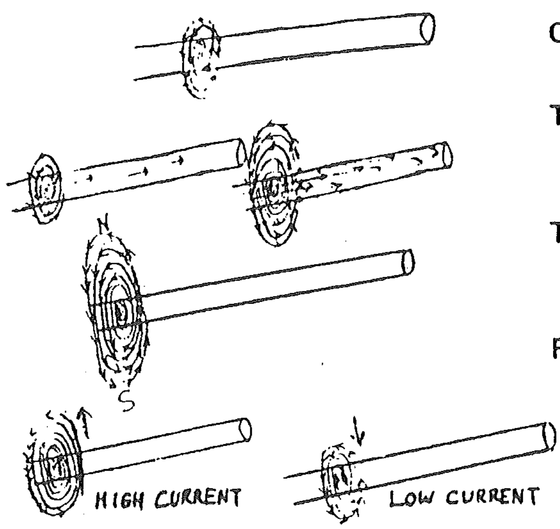
This is what we want to do in the secondary winding (coil) of the transformer.

We will not, however, do it using the magnetism from a permanent magnet, but from that produced by electromagnetism.



Electromagnetism is the magnetism created by electricity. It works something like this:

Surrounding every current carrying wire is a magnetic field. Regardless of how the current is produced — battery, generator, etc. it will be surrounded by a magnetic field with the following characteristics:

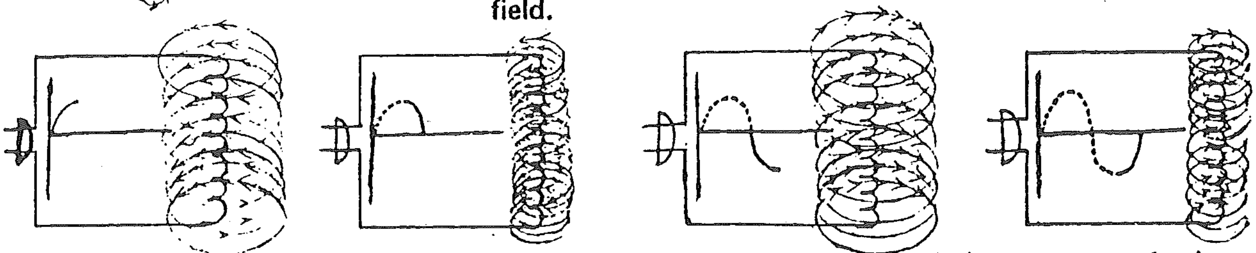



One — The magnetic field starts from the center of the wire and moves out.

Two — The strength of the magnetic field is related to the amount of current in the conductor. The more current, the stronger and further out the magnetic field.

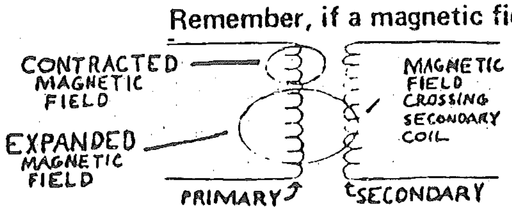
Three — The magnetic field has a direction and a polarity — thus it is similar to the magnetic field generated by a permanent magnet.

Four — The magnetic field expands and contracts as the current increases or decreases. If the current is always changing (AC) the magnetic field is always changing, moving out or back in. Now we can see how an alternating current, applied to a coil of wire, will produce a moving magnetic field.



As the AC goes through one complete cycle it creates a magnetic field (electromagnetism) that expands and contracts in one direction, and then in the opposite direction. Since the current is always increasing or decreasing, the magnetic field is always expanding or contracting.

If we now place a second coil of wire very close to the first (wound on top of it), the magnetic field created by the alternating current in the first coil will always be crossing the secondary coil. Remember, if a magnetic field is made to cross a conductor (secondary coil) it will induce a voltage and current in that conductor. This is exactly what we now have. Only instead of the current being created by a permanent magnet moving back and forth — it is created by an electromagnet.



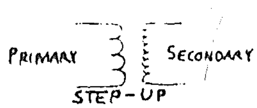

Thus we have a basic transformer. Now all we need to do is see how the transformer steps up or down the incoming voltage.

## Stepping the Voltage Up or Down

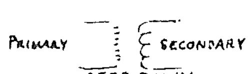
A step-up transformer is one that increases or steps up the incoming voltage.

A step-down transformer is one that decreases or steps down the incoming voltage.

Whether a transformer steps up or steps down the incoming voltage is determined by the number of turns of wire in the secondary coil compared to the number of turns in the primary coil.



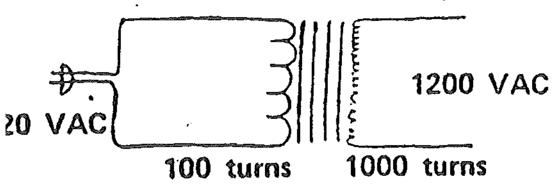

If there are more turns in the secondary than in the primary, the voltage is stepped up.




If there are fewer turns in the secondary than in the primary, the voltage is stepped down.

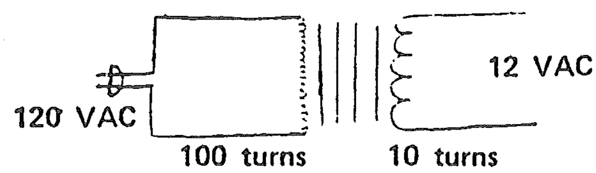
Here is an example:

**Step-up transformer**




1:10 Ratio $\frac{10}{1}$ X 120 volts = 1,200 volts

**Step-down transformer**

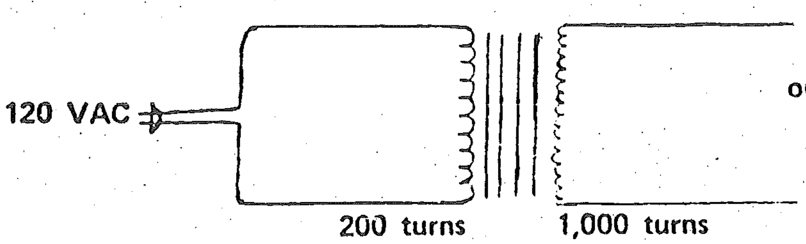



10:1 ratio $\frac{1}{10}$ X 120 volts = 12 volts

**The Step-Up Transformer**

Here there are ten times as many turns of wire in the secondary coil as there are in the primary coil. Therefore, the voltage is increased by ten times – to 1,200 volts.

What would be the output voltage of this transformer?



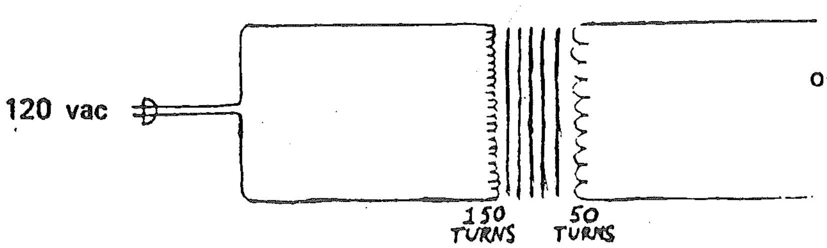

1 to 5 ratio – therefore the output is 5 times the input voltage

answer = 600 VAC

**The Step-Down Transformer**

Here the secondary has one-tenth the number of turns as the primary. Therefore, the voltage is decreased to one-tenth of 120 volts AC – or 12 volts AC.

What would be the output voltage of this transformer?

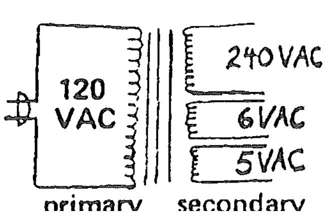



3 to 1 ratio – therefore the output is 1/3 of the input voltage

answer = 40 VAC

**Multiple Secondaries**

Some transformers are built with multiple secondaries, that is, more than one secondary coil. Here is an example:

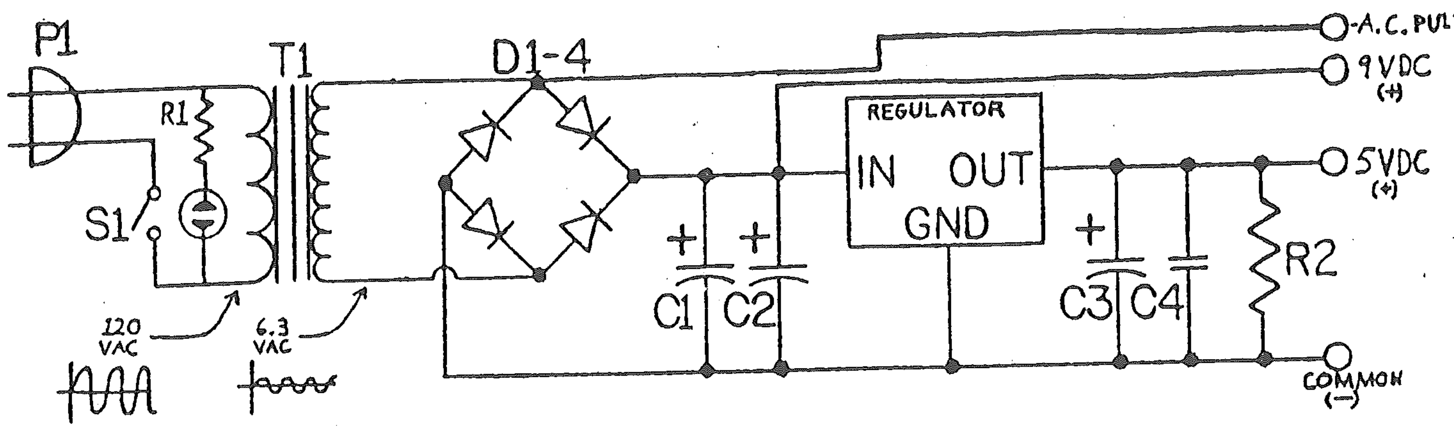



Such transformers save cost, space, and weight in applications where various secondary voltages are needed.

## THE TRANSFORMER IN A POWER SUPPLY

As a final matter, let us now take a quick look at how the transformer operates in a power supply.

Here we have the complete schematic of the power supply project for Unit II.




In this power supply the power transformer steps-down the incoming 120 volts AC to 6.3 volts AC. Here is what happens:

- When S1 is closed 120 volts AC appears across the primary coil. The Ne-2 bulb is used as a pilot light.
- The AC traveling through the primary creates a magnetic field that cuts across the secondary, inducing a voltage.
- Since the number of turns in the secondary is less than the number of turns in the primary, the voltage is stepped down.

The 6.3 volts AC appearing across the secondary coil of the transformer will now be fed to the rest of the power supply where it will be changed to DC.

## SUMMING UP

In Lesson Four we saw how a transformer is used to step up or down an AC voltage; from the power generating plant to the electrical devices in your home. We saw how a transformer is constructed and how it operates using the principles of electromagnetism. Next, we learned how a transformer can increase or decrease an incoming voltage by winding the secondary coil with more or less turns of wire than the primary. Finally, we saw how a transformer operates in a power supply to step up or down the line voltage to the approximate DC voltage of the power supply output.

## UNIT 2 LESSON 4 QUESTIONS

1. What is the main purpose of a transformer?
2. List four devices that require the use of a transformer.
3. List two important reasons why we use a transformer to step up or down a voltage or current.
4. Why will a transformer not operate with DC?
5. What is meant by the term "electromagnetism"?
6. In a short paragraph, with illustrations if appropriate, summarize the principle of operation of the transformer.
7. Which of the two transformer coils is always connected to the source of power?
8. In a step-up transformer, which coil has more turns, the primary or secondary coil?
9. A transformer delivers 12 volts at 2 amps. How much power is being delivered?
10. A transformer has 1000 primary turns and 500 secondary turns. What is the secondary voltage if the primary voltage is 120 V?
11. A transformer has 100 primary turns and 300 secondary turns. What is the secondary voltage if the primary voltage is 120 V?
12. If a transformer is 100% efficient, power in is equal to power out. Find the primary current required by a transformer delivering 24 V at 5 amps, when the primary voltage is 120 volts. 1A
13. What is a multiple-secondary transformer?

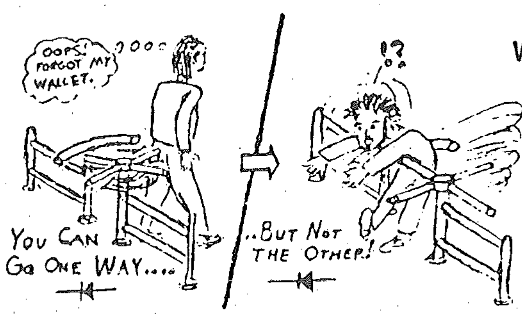
# LESSON 5 - DIODES AND CAPACITORS

Objectives:

In this lesson you will:
* Learn what a diode is and what it is used for.
* Learn how a diode is constructed.
* Learn about the basic principles of diode operation along with many applications..
* Learn how diodes function in a power supply.
* Learn how a capacitor operates as a ripple filter in a power supply.

## WHAT IS A DIODE?

A diode is an electronic one-way gate. It allows current to pass through it in only one direction. As such, it aids us in converting alternating current (AC) to direct current (DC).

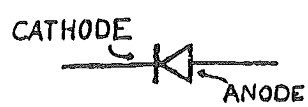



Without the diode, modern electronics would be very different indeed. It is one of the simplest, yet most widely used, electronic components. Familiarization with its function will enable you to understand the operation of many electronic circuits. In addition, diodes are simpler than, but similar to, transistors. If you understand diode operation, you are halfway to understanding transistors.

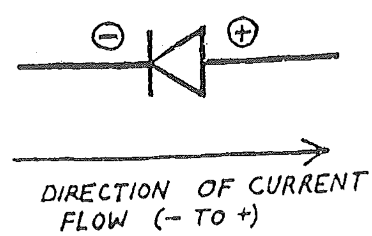
### One-Way Gate

The diode is a two element electrical device. One element is known as the cathode, the other element the anode.

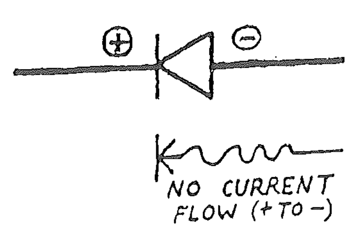
Here is the schematic symbol.




* If the cathode is negative with respect to the anode, the diode will conduct or pass current as shown.

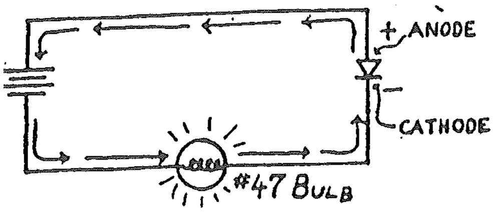



* If the cathode is positive with respect to the anode, the diode will not conduct current.



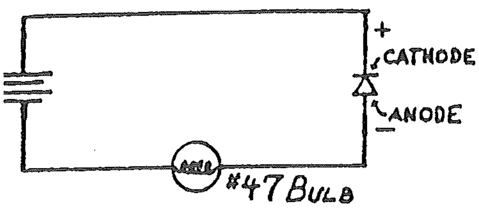
The two circuits below illustrate how the diode allows current to flow in one direction only.

Diode Connected Correctly (right polarity)



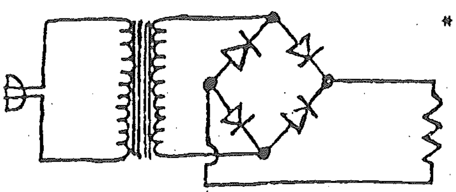

In this circuit, current will flow and the lamp will light. The diode's cathode is negative with respect to the anode. The diode "opens its gate", so to speak, and current is allowed to flow.

Diode Connected Incorrectly (wrong polarity)




In this circuit, current will not flow and the lamp will not light. The diode's cathode is positive with respect to the anode. The diode "shuts its gate" so to speak, and no current is allowed to flow.

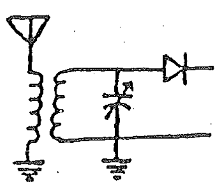
Acting as one-way gates for current flow, diodes find many important applications. Here we list just a few. We will explore them in more detail later on.



SIMPLE POWER SUPPLY

* Diodes as Rectifiers

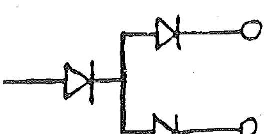
Rectifiers are electrical devices that change AC to DC. Diodes, employed as rectifiers, change the AC output of a transformer to pulsating direct current (PDC). This is a critical step in any power supply's conversion of AC to smooth DC.



PARTIAL RADIO CIRCUIT

* Diodes in Radio Frequency Circuits

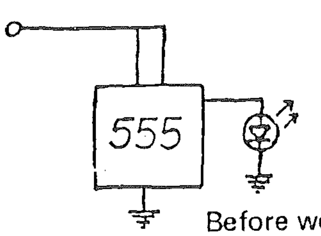
Diodes have been used for years in radios to demodulate incoming radio frequency signals. Even the first crystal sets used galena crystals or diodes for this purpose.



LOGIC CIRCUIT

* Diodes in Logic Circuits

Diodes are used in switching or logic circuits to control many functions from car starter controls to complex computer systems.




* Diodes as Light Indicators

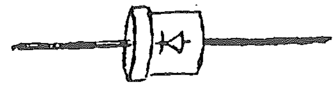
Light emitting diodes (LEDs) are special types of diodes that emit light when the cathode is negative in respect to the anode. They come in a variety of colors and are used as pilot lights, digital readouts, and in numerous electronic games.

Before we explore these diode applications in detail, let us take a look at the diode's physical characteristics and how it operates.

## DIODE CONSTRUCTION

Diodes come in various shapes and sizes, a few of which are shown below. It is most important to identify or locate the cathode end of the diode. This end is usually characterized by a band or "atypical" marking of some type. Study these drawings carefully.

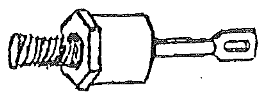

GLASS DIODE
colored bands are always toward cathode end



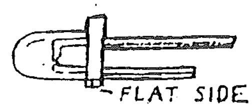
POWER DIODE
metal case is the cathode end

PLASTIC DIODE
band indicates the cathode end

EPOXY DIODE
tapered end is the cathode



POWER DIODE
threaded end is usually the cathode




LIGHT EMITTING DIODE
flat edge or short lead is cathode

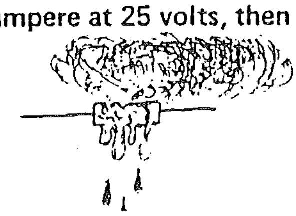
### Voltage and Current Ratings

Diodes are rated in terms of their current and voltage handling ability. As an example, a 1N4001 diode is rated at 1 ampere and 50 volts.

This means that the 1N4001 diode can handle up to 1 ampere of current and up to 50 volts of electrical pressure. If either one of these factors, current or voltage, is exceeded, the diode could be damaged.

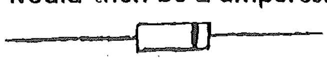
However, the ratings given represent the maximum current and voltage that can be applied. If a circuit requires, let us say, one-half ampere at 25 volts, then the 1N4001 diode would work fine.

1N4001
Up to 1 Amp / 50 Volts

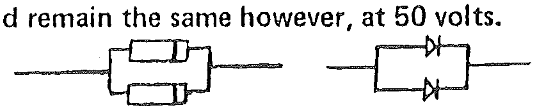


If more than 1 Amp or 50 Volts is applied diode will be destroyed.

It is possible to place diodes in parallel to increase their total current handling ability. If two, 1 ampere, 50 volt diodes (1N4001) were placed in parallel, their combined current rating would then be 2 amperes. Their total voltage rating would remain the same however, at 50 volts.



1N 4001
1 amp / 50 volts



1N 4001 (Parallel Connection)
2 amps / 50 volts

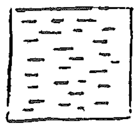
# DIODE OPERATION

Semiconductor diodes are made of the same materials as those used in the construction of transistors and integrated circuits, silicon and germanium. The silicon diode is the more popular of the two because it can handle a greater amount of current.

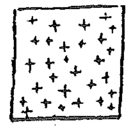
During manufacture, a block of silcon is treated (doped) with arsenic, such that it has a slight excess of electrons. It then becomes known as a N-type material.

Another block of silcon is treated (doped) with boron such that it has a slight deficiency of electrons. It then becomes known as a P-type material.

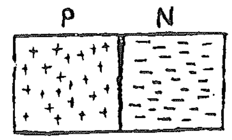
N-type
Excess of Electrons –



P-type



Deficiency of electrons results in excess of protons +

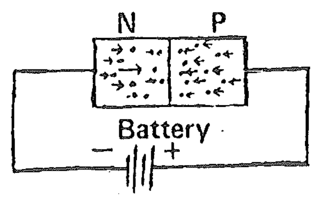



PN-Junction Diode

When these two blocks of silcon are fused together they form what is known as a PN Junction Diode. In the process a voltage barrier is formed at the junction preventing the electrons in the N-type material from moving over to the P-type material.

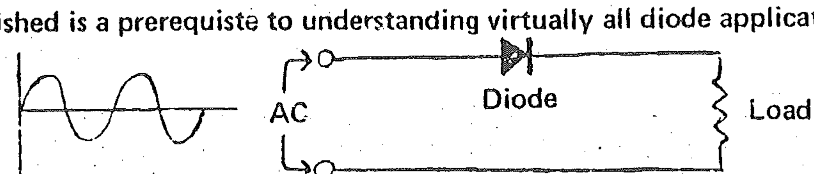
However, if a voltage is applied as shown, the barrier is overcome and the diode conducts. Remember – like charges repel, unlike charges attract.

The electrons from the battery repel those in the N-type material across the junction. At the same time protons in the battery pull these same electrons across to complete the circuit.

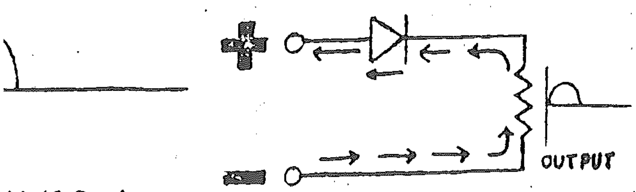



## Converting AC to DC

One of the principle functions of a diode is to convert AC to DC. When this occurs the process is known as rectification and the diode is acting as a rectifier. Knowing how this is accomplished is a prerequiste to understanding virtually all diode applications.

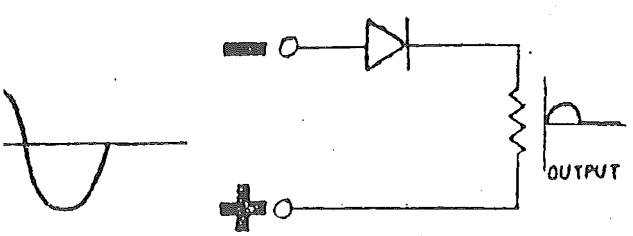



Basic Rectifier Circuit




Half Cycle

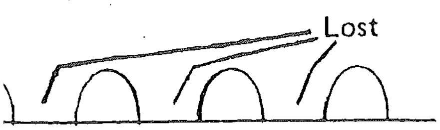
During the first half cycle the upper terminal of the AC source is positive with respect to the lower terminal. Therefore the anode of the diode is positive with respect to the cathode and the diode will conduct current.




d Half Cycle

During the second half cycle the upper terminal of the AC source is negative with respect to the lower terminal. Therefore the anode of the diode is negative with respect to the cathode and the diode will not conduct.

As the incoming AC continues, we will have a pulsating direct current across the load resistor. We know the result is DC because current flows through the resistor in only one direction. Admittedly the current is pulsating, and for half of the time it is not even there. We have converted AC to DC by eliminating half of the AC cycle. This is not a particularly efficient way to go about such a conversion. Shortly we will see how it is quite easy to "recover" that lost half cycle and take full advantage of all the power available.



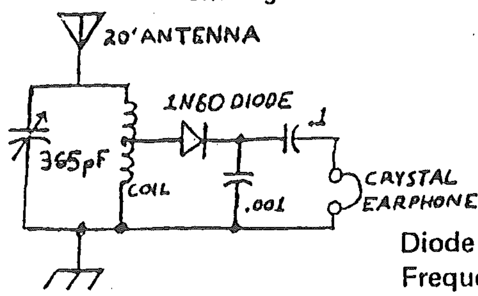

Wave Form of PDC
(Pulsating Direct Current)

# DIODE APPLICATIONS

Let us take a look at some typical diode applications.

## Signal Diodes

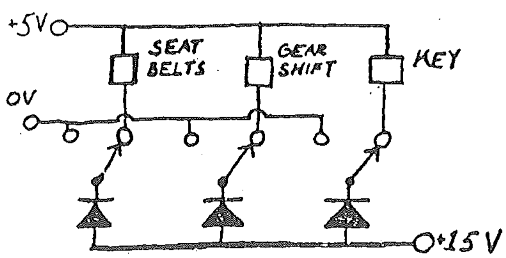
Small germanium diodes are used as rectifiers in crystal radio receivers. Originally such radios used a galena (lead sulfide) crystal as the detector or rectifier. Today a simple 1N60 germanium diode will do the job. When used to detect a radio frequency signal these diodes are referred to as signal diodes.




Diode "Detects" Radio Frequency Signals.

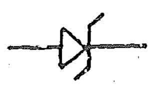
## Switching Diodes

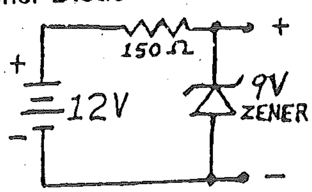
Diodes can be connected to form basic logic circuits that are used to control many function. Oftentimes several conditions must be met before a desired function is to begin. An example could be in the starting of a modern car, where the seat belts must be fastened, the gear shift must be in park, and the key must be turned on. If any one of these conditions is not met, the car will not start. A logic circuit, using diodes to accomplish this, might look like the one here.




## Zener Diodes

The zener diode is a special type of diode that can be used as a voltage regulator. We will explore its operation more fully in Lesson 7 which deals with the subject of voltage regulation in power supplies.

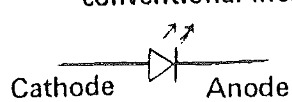
Schematic Symbol for Zener Diode 




The circuit to the left shows how a 9 volt zener diode could be used to "step down" the 12 volts available at your cars cigarette lighter, to 9 volts for operating small transistor radios and similar electronic devices. The zener diode will only "pass" the amount of voltage it is rated at. In this case even though the input voltage is above 9 volts only the latter voltage is made available to the load.

## Light Emitting Diodes (LEDs)

An LED is a diode specifically designed, while conducting current, to emit light. The light can be red, amber, yellow, or green, or it may be infrared and thus invisible. Compared to conventional incandescent lamps LEDs are very small in size. Actually the LED consists of a tint "chip" only a few thousandths of an inch across mounted in a relatively large plastic package.




The life expectancy of an LED is almost endless. Once wired in and operating within specified ratings an LED should last forever.

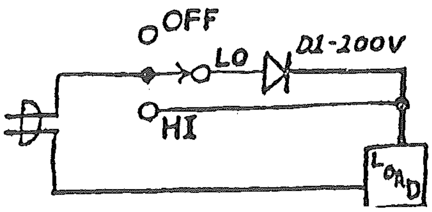
LED's Have A Very Long Life

## Diodes As Rectifiers

Although rectifiers are used primarily in power supply circuits (as we will see shortly) they have other interesting uses, two of which are shown here.

### A power control circuit.

This circuit may be used as a:

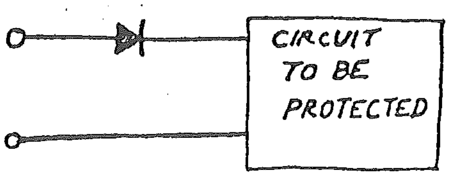



- Incandescent lamp dimmer.
- Soldering iron control.
- Heater control.
- "Instant-on" for AC radios.
- Two-speed control for power tools.

In operation, full power is supplied when S1 is in the "high" position while only pulsating direct current (half-wave) is available when the switch is in the low position, limiting the power supplied to the load.

### Polarity protection circuit.

It is very easy to damage solid state (transistor and IC) circuits by connecting them to a power source of incorrect polarity. By using this polarity protection circuit you can avoid such potentially dangerous problems. The diode permits the application of DC with correct polarity, but blocks the application of power with reverse polarity. Since the circuit consists of only a diode, it can be built right into the equipment being protected.

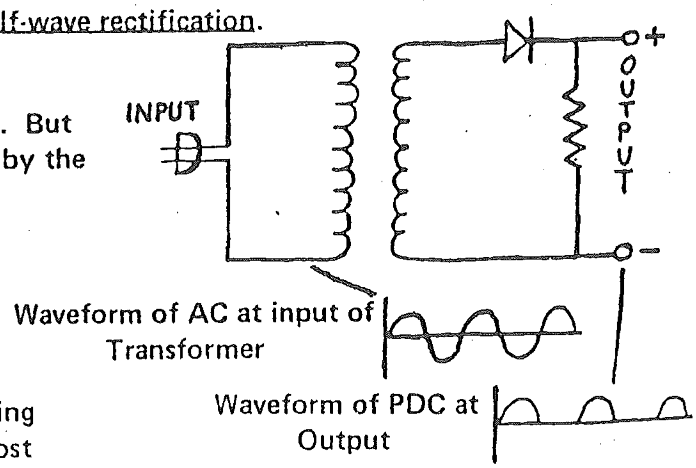



Polarity Protection Circuit

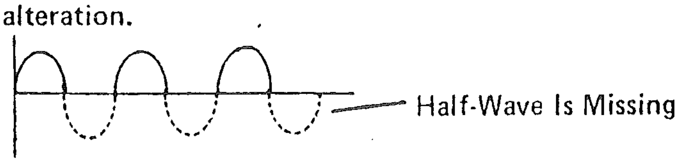
## DIODES IN POWER SUPPLIES

Earlier we showed how a diode, acting as a rectifier, could convert AC to DC. What was shown then, and depicted again here, is known as half-wave rectification.

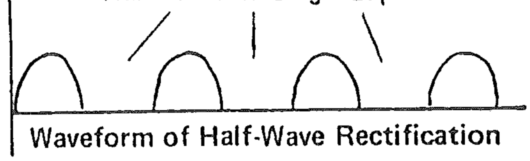
The output is pulsating direct current (PDC). But the original AC wave is missing – simply lopped off by the diode. Although this type of circuit has been used extensively in inexpensive AC radio power supplies, two problems come quickly to mind:



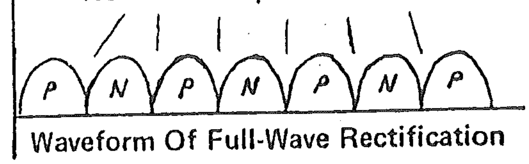

One – Half-wave rectification is wasteful. Converting AC to DC by eliminating half the AC is almost like cheating. We have to find a way to recover that lost one-half cycle or alteration.



Two — Half-wave rectification is difficult to filter. Changing PDC to smooth DC, the kind we would get from a battery, requires "filling in" the spaces between the pulses. This is known as filtering, and is done primarily with electrolytic capacitors. Obviously it would be easier to "fill in the gaps" if they were not so wide apart. If we can recover the half cycle AC that is missing and place it in between the positive cycles we would have full-wave rectification. Not only would this restore half of the original power, but would make the job of filtering much easier.



Waveform of Half-Wave Rectification

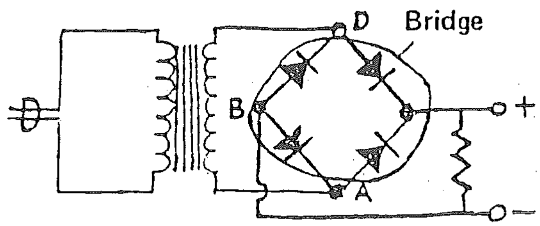


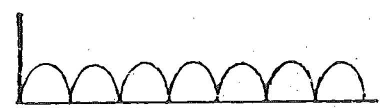
Waveform Of Full-Wave Rectification

Let us now take a look at full-wave rectification as it is used in a typical power supply.

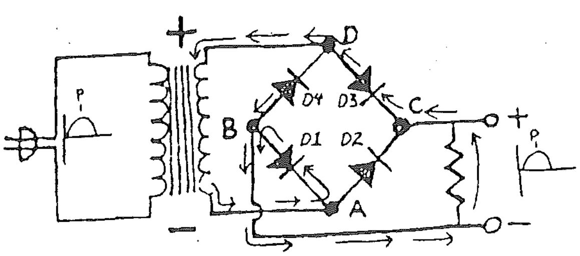
## Full-Wave Rectification

Here is a circuit designed to provide full-wave rectification. Notice that instead of one diode we now use four. This diode configuration is known as a bridge. The output current across the load is still PDC but we have recovered the negative half cycle lost during half-wave rectification. Here is how it works:





Waveform of Voltage Across Load Resistor

During the positive half cycle the top of the transformer secondary is positive, the bottom half negative. The sequence of current flow is as follows:




One — Current arrives at junction A and then goes through D1. It cannot go through D2 because D2 is not of the correct polarity.

Two — When current arrives at junction B it proceeds around and up through the load resistor. It cannot go through D4 because it is not of the correct polarity.

Three — When current arrives at junction C it would seem to have a choice; go through D3 or D2. But the anode of D3 is positive, therefore the current will go through D3.

Four — When the current reaches junction D it would again seem to have a choice. Yet it will not go through D4, but straight to the positive end of the transformer.

Now let us follow what happens during the negative half cycle.

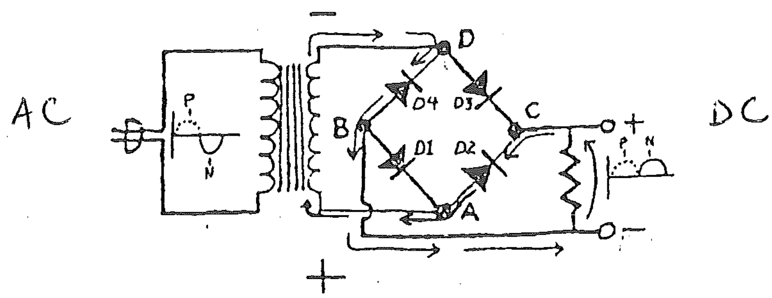
During the negative half cycle the top half of the transformer secondary is negative, the bottom half positive. The sequence of current is as follows:

One – Current now arrives at junction D first. Because of diode polarity it will travel through D4 to junction B.

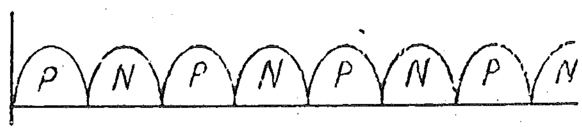
Two – Again, because of diode polarity, the current will not go through D1 but travels around and up through the load resistor.

Three – After arrival at junction C the current will travel through D2 because its anode is positive.

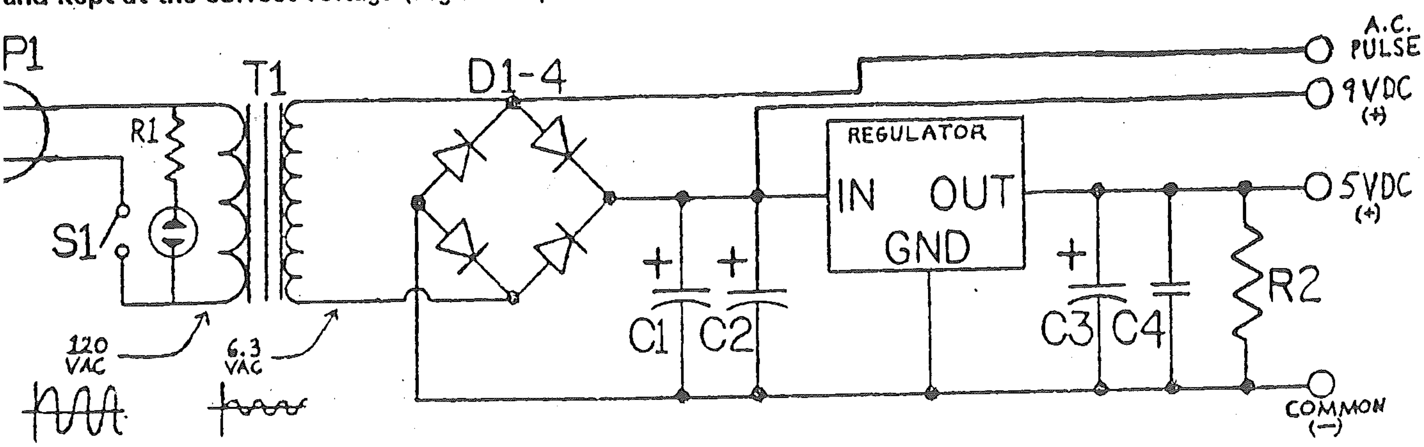
Four – Finally, at junction A the current will head straight for the positive end of the transformer.




We have now completed one cycle of alternating current. The output across the load resistor is PDC with every half cycle accounted for. None of the incoming AC is wasted or cut out.




Now that we have completed lessons 4 and 5 we are half way through our analysis of the basic power supply. We have seen how the transformer takes the 120 volts AC and steps it down to 6.3 volts AC. The diode bridge then takes the 6.3 volts AC and converts it into fullwave pulsating direct current. Now all that remains is to see how the PDC is smoothed out (filtered) and kept at the correct voltage (regulated.)

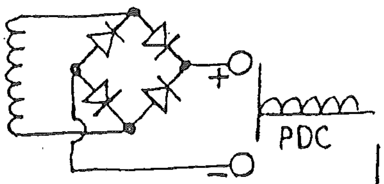


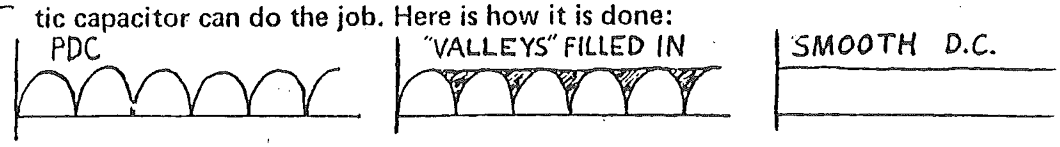

## SUMMING UP

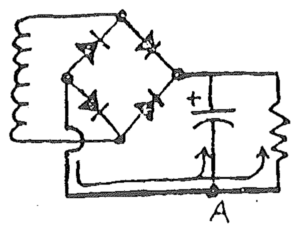
In Lesson 5 we saw how diodes, acting as one-way gates, can convert AC to DC. We saw how diodes are constructed, and reviewed the more popular types. We investigated some important diode applications in radio detection, switching, voltage regulation, and rectification circuits. Finally, we studied in detail the operation of a diode bridge in converting AC to pulsating direct current (PDC) in a basic power supply.

## CAPACITORS IN POWER SUPPLIES

One of the most important applications for a capacitor is as a filter in a power supply. By filter we mean a circuit that will aid in changing pulsating direct current to smooth DC. As you will recall from Lesson 5, the output of a full-wave bridge rectifier is PDC. What we want is a smooth DC to power vacuum tubes, transistors, and integrated circuits. We get smooth DC by "filling in" the "valleys" between the PDC. A large electrolytic capacitor can do the job. Here is how it is done:



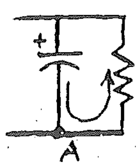



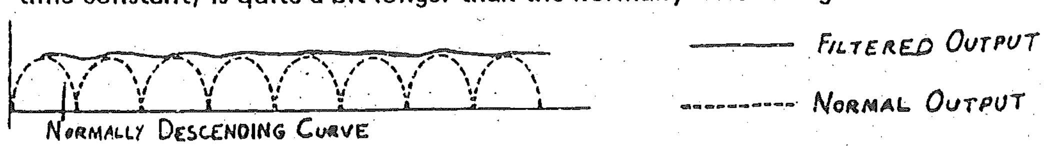




Without C1, current would travel in pulses up through R1. It starts at zero — reaches a maximum value — descends to zero again, and repeats. The current is always changing, either increasing or decreasing — in one direction.

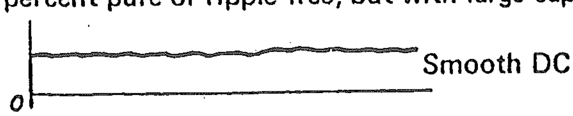
With C1 in the circuit, current still travels in pulses up through R1. But when it arrives at point A some of the current is diverted to the lower plate of C1, filling it with electrons.

When the current pulse starts to decline, (see illustration) the capacitor will unload its charge of electrons. They will rush down to point A. Because of diode polarity the electrons have only one way to go and that is up through R1. With the resistance of R1 in series with C1 the discharge time (remember the RC time constant) is quite a bit longer than the normally descending curve.

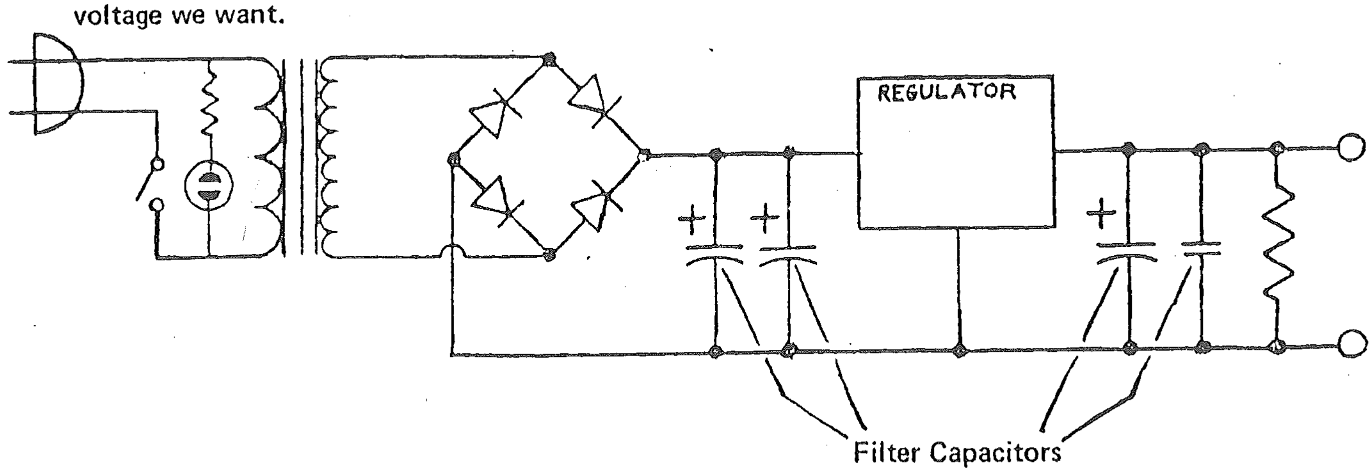



The resulting wave form looks like the one shown here. Such an output is called Filtered Voltage. It is not a hundred percent pure or ripple free, but with large capacitors, ripple can be less than one percent of the output voltage.




We should now be able to see how the power supply changes 120 volts AC to smooth DC. All that remains is to investigate how this smooth DC can be "regulated" to the exact voltage we want.



# UNIT 2 LESSON 5 QUESTIONS

1. Draw the schematic diagram for a semiconductor diode, and label anode and cathode.

2. Under what circumstances will a diode conduct?

3. Under what circumstances will a diode not conduct?

4. How can one identify the cathode on a diode?

5. A circuit calls for a 1N4005 (1A/600V) diode. All you have are 1N4001 (1A/200V) and 1N4007 (1A/1000V) diodes. Could you use either of these as a substitute diode in the circuit? Explain.

6. How is an N-type semiconductor made? (one sentence)

7. How is a P-type semiconductor made? (one sentence)

8. When a diode is used as a rectifier, what is its function?

9. State six applications for the semiconductor diode.

10. Draw the schematic diagram for a half-wave rectifier circuit. Sketch the voltage wave form across the transformer secondary, and across the rectifier output.

11. Draw the schematic diagram for a full-wave bridge rectifier. Sketch the voltage waveform across the transformer secondary, and across the rectifier output.

12. Draw diagrams showing the direction of electron flow through a bridge rectifier and load resistor, for both transformer voltage polarities.

13. When does the filter capacitor in a power supply charge? What device does this charge move through?

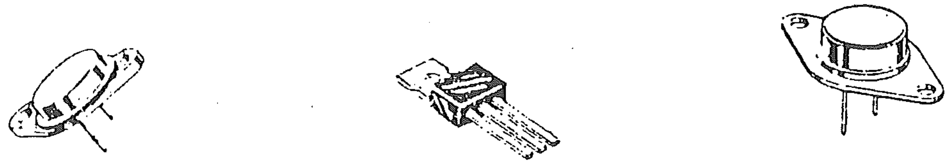
14. When does the filter capacitor in a power supply discharge? What device does this charge move through?

## Lesson 6 – VOLTAGE REGULATION

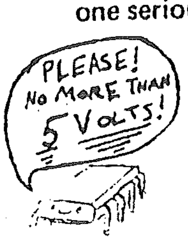
OBJECTIVES:

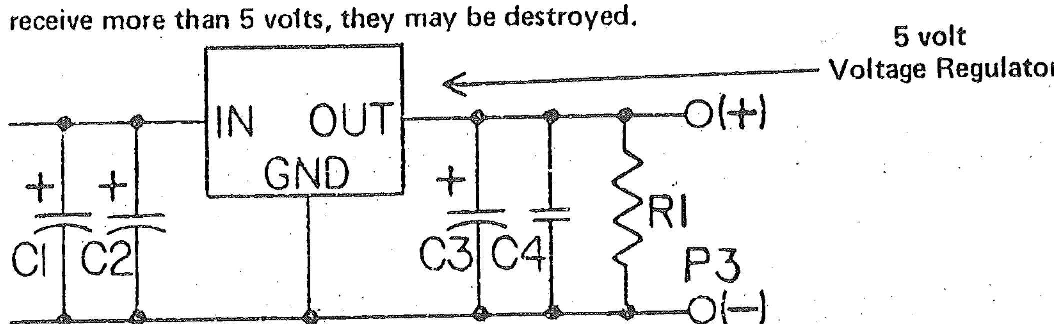
In this lesson you will:

* Learn why power supplies need to produce a regulated voltage.
* Learn how zener diodes act as voltage regulators.
* Learn how three-terminal voltage regulators operate.



In Lesson 7 we are going to investigate voltage regulation as it is used in many power supplies. So far (lessons 4, 5 and 6) we have seen how a power supply can step down 120 volts AC, then rectify and filter it to produce a smooth direct current. The power supplies voltage output, depending on various physical characteristics, is anywhere from 8 to 11 volts (for a 6 volt power supply.) Such a power supply can and does find wide application. Yet, there is one serious drawback. Many of the components and circuits we will be dealing with require a steady, unvarying DC voltage of a particular value. All TTL integrated circuits, for example, require 5 volts ± ¼ volt. If for any reason these ICs receive more than 5 volts, they may be destroyed.



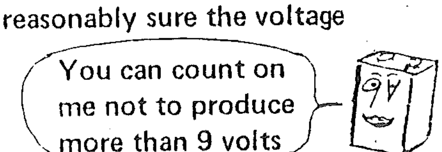




In studying about voltage regulation we will first see why power supplies produce unregulated or unpredictable voltages. We will then explore the basic features of zener diodes and three-terminal voltage regulators.

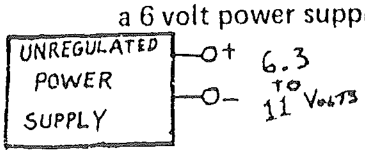
## THE NEED FOR VOLTAGE REGULATION

As we mentioned earlier, TTL integrated circuits require a steady 5 volts to power them. Anything less and they will not work, anything more and they could be destroyed. There are other components that require a fixed and predictable voltage. These could be almost any voltages, though 9, 12, 15, and 24 are the more called for.

If one uses batteries to power electronic devices you can be reasonably sure the voltage designated is the maximum voltage available. A 9 volt battery, because of age or use, may be putting out less than 9 volts, but rarely will it put out more.

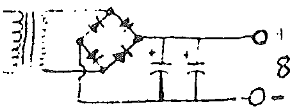



With power supplies things are different. Because of factors to be discussed in a moment, a 6 volt power supply for example can deliver anywhere from 6.3 to 11 volts. This would be unacceptable for use with TTL ICs requiring 5 volts. Let us see why a power supply can produce such a wide range of voltages.



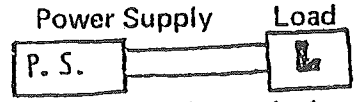
## Power Supply Variations

The schematic for a 6 volt unregulated power supply is shown here. Without a load (no power being drawn from the power supply) the output voltage will measure from 8 to 11 volts depending on the size of the filter capacitors and transformer. The larger the capacitors the more charge they will hold, so ripple is reduced and the average voltage is higher. Ironically smaller and less expensive transformers have a few extra turns wound on their secondary coil in order to compensate for other losses. The result is often an extra volt or two. These two components then, can add 2 to 5 volts beyond what might normally be expected from the power supply.




## Load Variations

Another factor that affects the output voltage of an unregulated power supply is the changing current requirements of the load. As the demand on the power supply increases (because more current is being drawn) the 11 volt DC output will drop down lower and lower until it reaches 6 to 7 volts. As the load's current demand changes it affects the voltage stability or output. Again this is undesirable for many applications, especially TTL circuits requiring 5 volts over a wide range of current demands.



As current demand of load changes so does voltage output.

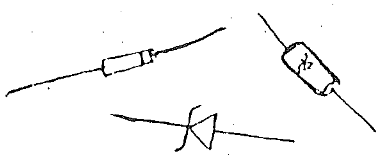
A voltage regulator will keep the output voltage steady at its designated rating (example 5 volts) regardless of:

One, what the unregulated power supply may be producing.

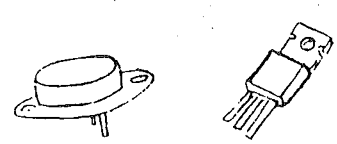
Two, the changing current requirements of the load.

Such voltage regulators are either simple zener diodes or a combination of zener diodes and transistors in one package, known as a three-terminal voltage regulator. Let us now take a look at each one in turn.

Zener Diodes



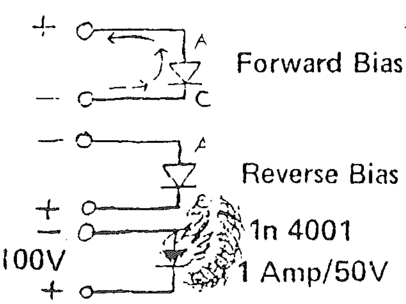
Three – Terminal Voltage Regulators



## THE ZENER DIODE AS AN INEXPENSIVE VOLTAGE REGULATOR

### The Basic Diode

Let us review the characteristics of an ordinary silicon diode.




When a silcon diode is "forward biased," the anode positive and the cathode negative, it will conduct.

When the diode is "reverse biased," the anode negative and the cathode positive, it will not conduct.

If a reverse voltage is applied to such a diode, in excess of its rated capability, it will "break down" and probably be destroyed.

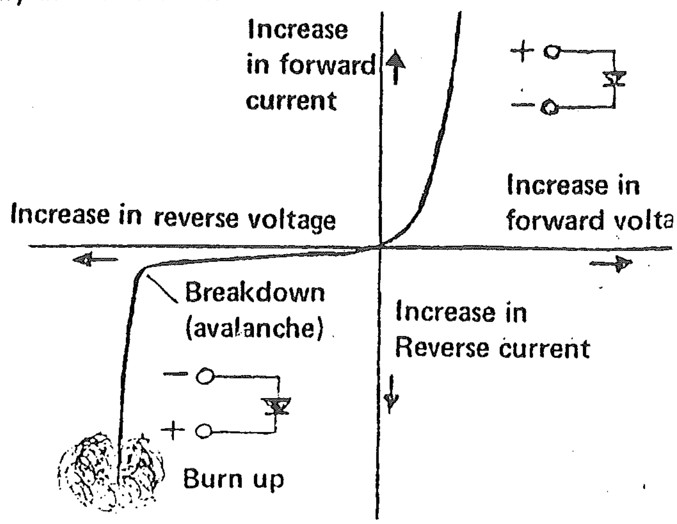
What has just been said can be depicted graphically as shown here.

Note the following points:

___ As the forward voltage increases the forward current increases and the diode conducts.

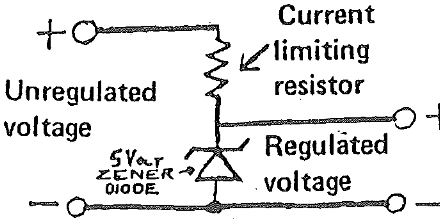
___ As the reverse voltage increases there is only a very slight reverse current. (This is known as leakage current and is too small to be significant.)

___ Yet as the reverse voltage continues to increase there is a point reached where the diode breaks down and rapidly conducts (reverse current.) In a matter of moments the current will be enough to destroy the diode.




## The Zener Diode

A zener diode is a special type of diode that is built to break down at a given voltage and serve a useful purpose as it does. The schematic symbol for a zener diode is shown to the left.


A zener diode is connected in a circuit with reverse bias, that is a positive voltage to the cathode and a negative voltage on the anode. The zener diode is rated at a particular voltage, let us say 5 volts. Here is how it works:

___ As long as the unregulated voltage appearing across the zener diode is less than 5 volts it will not conduct.

___ If the unregulated voltage exceeds 5 volts the zener diode will "break down" or avalanche, and the diode conducts.

___ Yet, instead of being destroyed, it will continue to conduct current. Furthermore, the voltage across the zener diode will remain constant at 5 volts. The regulated voltage across the zener diode will be 5 volts.

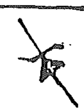
— Thus anything connected to the regulated output can be assured of receiving no more than 5 volts regardless of the incoming unregulated voltage. The zener diode acts as a voltage regulator.

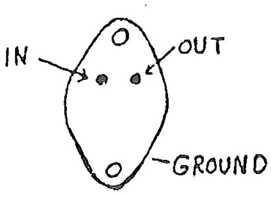
Zener diodes are available with ratings from 2 volts to 300 volts and ¼ watt to over 100 watts. They find wide use in circuits requiring voltage regulation at low to moderate current levels.

## THE THREE-TERMINAL VOLTAGE REGULATOR

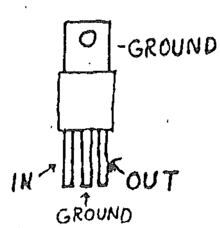
Zener diodes, while useful in many voltage regulating applications, have one major drawback: they cannot supply a lot of current to the load. If a significant amount of current is required the zener diode must be given help in the form of additional components, particularly transistors. Such a voltage regulating circuit could become quite complex as illustrated in the accompanying data sheet for the LM309. Fortunately all these discrete components (transistors, zener diodes, resistors, etc.) now come packaged in one case the size of an ordinary power transistor. Such a device is known as the three-terminal voltage regulator.

Zener diode often times cannot take the current



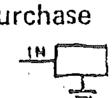



TO-3 CASE




TO-220 CASE

The terminals are input, ground, and output. All you do is purchase the regulator for the voltage you want out, connect a slightly higher voltage in, and ground the case.




Three-terminal regulators come in a wide range of voltages with 5, 12, 15, and 24 volts being the most popular. Current handling ability can reach 5 amperes.

All three-terminal regulators have an interesting feature known as automatic thermal shutdown. If the power levels for the regulator are exceeded, an automatic sensor circuit will detect the resulting increase in chip temperature and shut down the regulator to protect it.

## Data Sheet

### LM309 five-volt regulator

### general description

The LM309 is a complete 5V regulator fabricated on a single silicon chip. It is designed for local regulation on digital logic cards, eliminating the distribution problems associated with single-point regulation. The device is available in two common transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1A.

The regulator is essentially blow-out proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating.

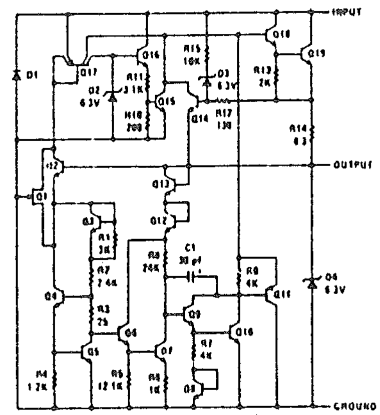
Considerable effort was expended to make the LM309 easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response somewhat. Input bypassing is needed, however, if the regulator is located very far from the filter capacitor of the power supply. Stability is also achieved by methods that provide very good rejection of load or line transients as are usually seen with TTL logic.

Although designed primarily as a fixed-voltage regulator, the output of the regulator can be set to voltages above 5V, as shown below. It is also possible to use the circuit as the control element in precision regulators, taking advantage of the good current-handling capability and the thermal overload protection.

To summarize, outstanding features of the regulator are:

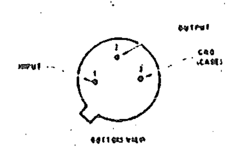
- Specified to be compatible, worst case, with TTL and DTL
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required

### schematic diagram



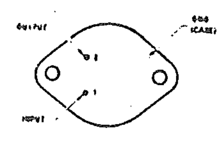

### connection diagrams

TO-5 (H)



Order Number LM309H
See Package 9

TO-3 (K)



Order Number LM309K
See Package 18

### electrical characteristics (Note 1)

| PARAMETER | CONDITIONS | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| Output Voltage | $T_j = 25°C$ | 4.8 | 5.05 | 5.2 | V |
| Line Regulation | $T_j = 25°C$<br>$7V \leq V_{IN} \leq 25V$ | | 4.0 | 50 | mV |
| Load Regulation<br>LM309H<br>LM309K | $T_j = 25°C$<br>$5 mA \leq I_{OUT} \leq 0.5A$<br>$5 mA \leq I_{OUT} \leq 1.5A$ | | <br>20<br>50 | <br>50<br>100 | <br>mV<br>mV |
| Output Voltage | $7V \leq V_{IN} \leq 25V$<br>$5 mA \leq I_{OUT} \leq I_{max}$<br>$P < P_{max}$ | 4.75 | | 5.25 | V |
| Quiescent Current | $7V \leq V_{IN} \leq 25V$ | | 5.2 | 10 | mA |
| Quiescent Current Change | $7V \leq V_{IN} \leq 25V$<br>$5 mA \leq I_{OUT} \leq I_{max}$ | | | 0.5<br>0.8 | mA<br>mA |
| Output Noise Voltage | $T_A = 25°C$<br>$10 Hz \leq f \leq 100 kHz$ | | 40 | | μV |
| Long Term Stability | | | | 20 | mV |
| Thermal Resistance<br>Junction to Case (Note 2)<br>LM309H<br>LM309K | | | <br><br>15<br>3.0 | | <br><br>°C/W<br>°C/W |

Note 1: Unless otherwise specified, these specifications apply for $0°C \leq T_j \leq 125°C$, $V_{IN} = 10V$ and $I_{OUT} = 0.1A$ for the LM309H or $I_{OUT} = 0.5A$ for the LM309K. For the LM309H, $I_{max} = 0.2A$ and $P_{max} = 2.0W$. For the LM309K, $I_{max} = 1.0A$ and $P_{max} = 20W$.

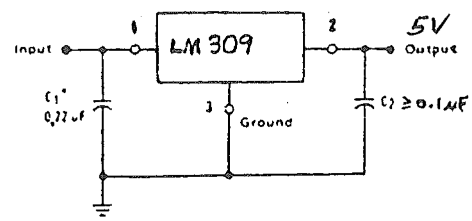
Note 2: Without a heat sink, the thermal resistance of the TO-5 package is about 150°C/W, while that of the TO-3 package is approximately 35°C/W. With a heat sink, the effective thermal resistance can only approach the values specified, depending on the efficiency of the sink.

**absolute maximum ratings**

| | |
|---|---|
| Input Voltage | 35V |
| Power Dissipation | Internally Limited |
| Operating Junction Temperature Range | 0°C to 125°C |
| Storage Temperature Range | -65°C to 150°C |
| Lead Temperature (Soldering, 10 sec) | 300°C |

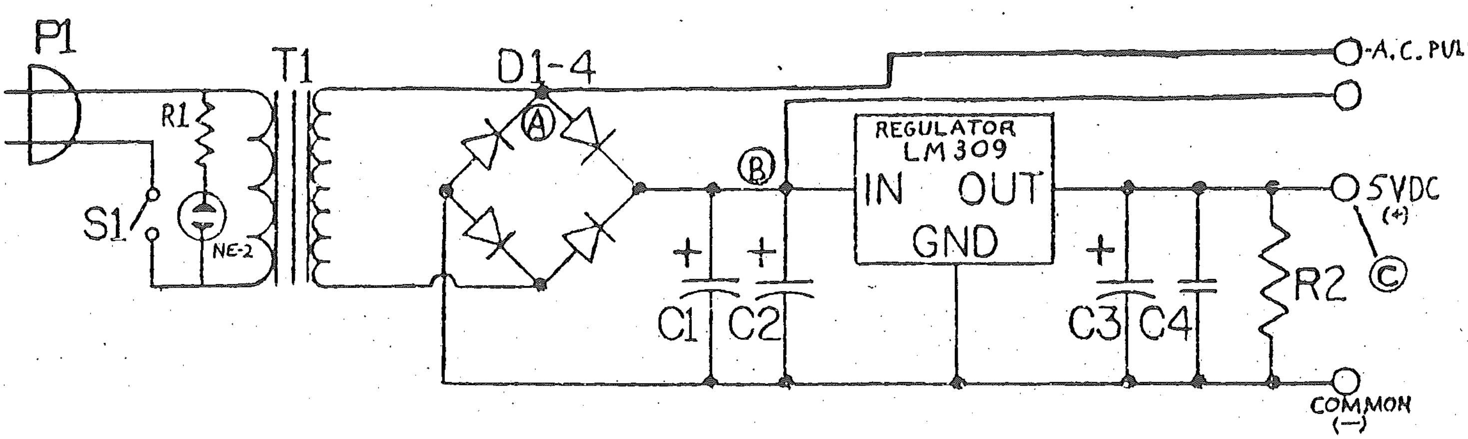
TYPICAL APPLICATION

FIXED 5.0 V REGULATOR




## THE VOLTAGE REGULATOR IN A POWER SUPPLY

Here is the complete schematic for a one ampere, 5 volt fully regulated power supply.




____ At point A we have AC at approximately 11 volts. This can be useful for timing circuits requiring a 60 Hz signal.

____ At point B after the filter capacitors, but before the voltage regulator, we can expect to find 8 to 11 volts DC. This voltage can be used for many projects requiring 6 or 9 volts.

____ At point C we have the 5 volt regulated output. This will be particularly valuable for projects using TTL ICs.

## SUMMING UP

In Lesson 7 we have discovered why power supplies produce an unregulated output voltage and why whis is undesirable. Next, we explored the fundamental characteristics of two voltage regulators, the zener diode and the three-terminal voltage regulator. Finally, we examined the complete power supply with its LM 309 voltage regulator.

# UNIT 2 LESSON 6 QUESTIONS

1. State two reasons for voltage fluctuations in a power supply.

2. State the main purpose for a voltage regulator.

3. Name two common types of voltage regulator.

4. Draw the schematic diagram for a simple zener diode voltage regulator, and explain what would happen if the current limiting resistor were not included in the circuit.

5. When being used as a regulator, is a zener diode forward biased or reverse biased?

6. What is the advantage of an IC regulator over a zener diode regulator?

Before answering questions 7, 8 and 9, make sure you have carefully studied the information on the LM 309 voltage regulator.

7. What current can be delivered by an LM 309 regulator:
   (a) in a TO-5 package? 200mA
   (b) in a TO-3 package? 1A or more

8. What maximum input voltage will the LM 309 accept? 35V

9. If a voltage applied to an LM 309K regulator is 20V, and the regulator is delivering one amp of current,

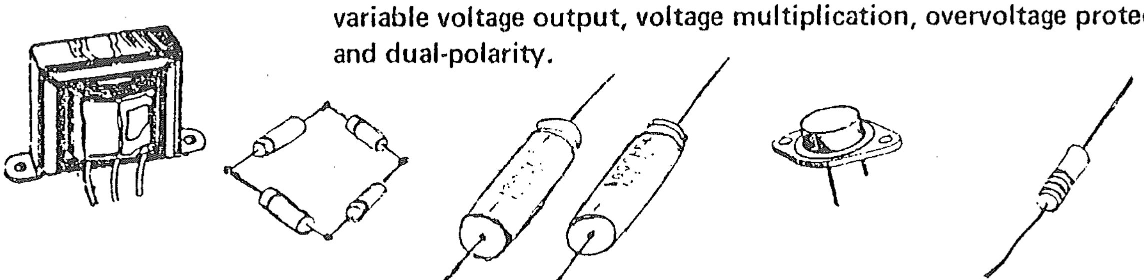
   (a) What is the voltage between input and output? 15V
   (b) What power is being dissipated by the regulator? (hint: use the answer to part (a) in your calculation.) 15W
   (c) What is the effect of this power on the regulator? heat
   (d) What will happen to the IC if it gets too hot? shuts down
   (e) If you were to accidently short the output to ground, what would happen? shuts down

## Lesson 7 – THE COMPLETE POWER SUPPLY

OBJECTIVES:

In this lesson you will:

* Examine the overall operation of a fully-regulated power supply.
* Examine special features of the major power supply components.
* Investigate the characteristics of special power supplies such as: variable voltage output, voltage multiplication, overvoltage protection, and dual-polarity.



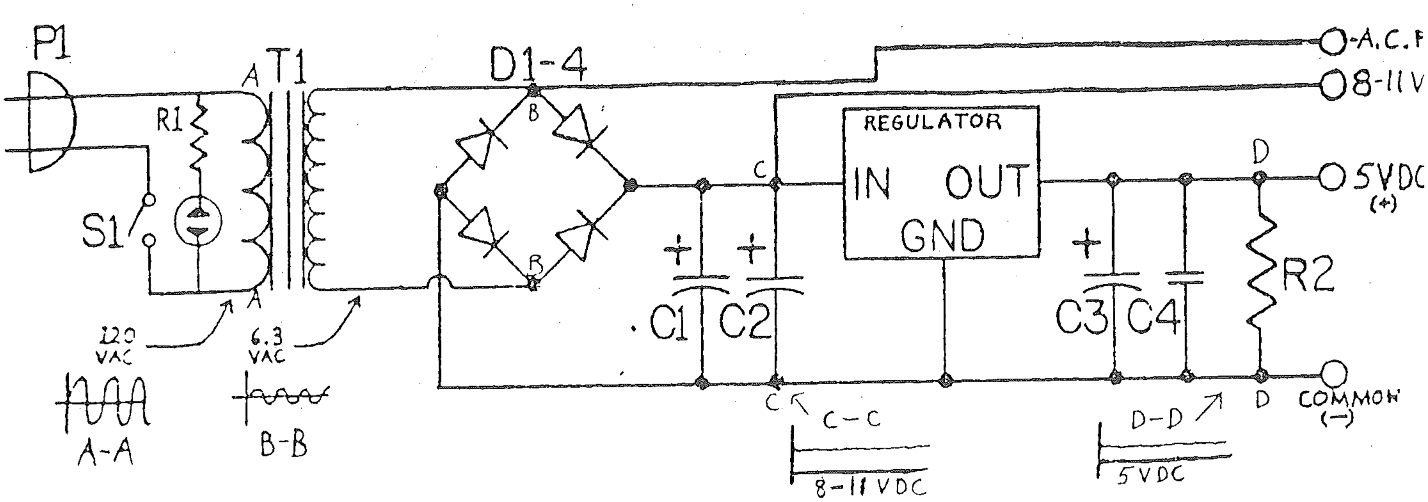
In previous lessons we have studied the major components that make up a typical regulated power supply. It is now time to consider the completed power supply as a unit in itself. We will first look at the entire circuit by tracing the incoming AC voltage through each stage of the system. Then, we will re-examine the significant components, discussing new and important characteristics such as:

— The use of a center-tapped transformer.
— The use of a bridge-rectifier assembly.
— The use of high-level filter capacitors.
— The use of "noise" elimination capacitors with voltage regulators.
— The use of a bleeder resistor.

In the second half of Lesson 8, we will investigate other power supplies with distinctive features like: variable output, voltage multiplication, over voltage protection, and dual-polarity.

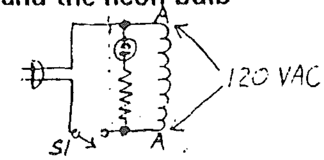
### THE FULLY REGULATED POWER SUPPLY

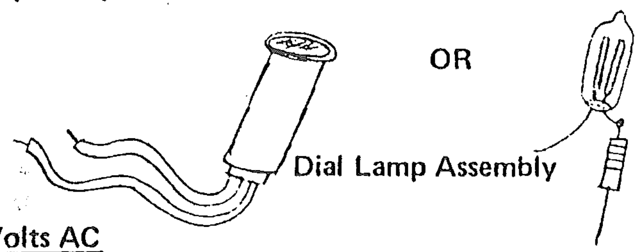
The schematic for a fully-regulated DC power supply is shown here along with graphs of voltage waveforms at key points. Let us examine it closely.



## 120-Volt AC Input

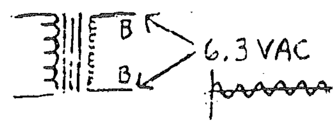
The line cord plugs into a wall socket with 120-volts AC at 60Hz. When switch S1 is closed, 120-volts AC appears across the primary winding of the transformer and the neon bulb which is in series with resistor R1. The function of the neon bulb is simply to act as a pilot light to let you know the power supply is on. The neon bulb must have a resistor (33k to 150k) in series with it to limit current to a safe value. Many such pilot lights come encapsulated with the resistor already connected. There is no polarity involved so it is simply placed across the transformer primary coil in either direction.



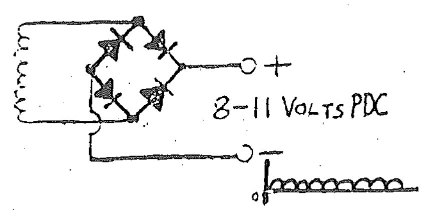

## Down To 6.3-Volts AC

The transformer steps the 120-volts AC down to approximately 6.3-volts AC that will appear across the bridge rectifier at points B-B. Notice that we are still dealing with AC (A transformer does not change AC to DC).



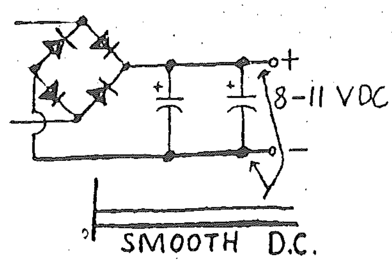

## AC Converted to PDC

The four diodes (arranged in a bridge) convert the AC to pulsating direct current (PDC). The output of the bridge rectifier is full-wave rectification as shown here.



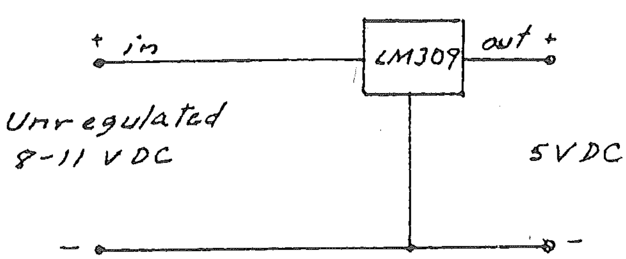

## Smoothing Out The PDC

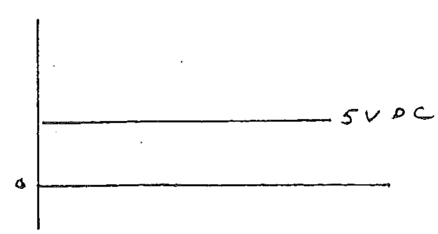
The filter capacitors, by charging and discharging at the appropriate time, fill in the "valleys" between the peaks of the pulsating direct current. The result is a smooth DC at anywhere from 8 to 11 volts.




## Regulating To A Steady 5-Volts

Finally, we use a three-terminal voltage regulator (LM309) to provide 5-volts at up to 1-ampere of current. Regardless of the power supply input voltage (up to 35 volts) or the load fluctuations, only 5-volts will appear between the negative terminal and the output of the LM309.



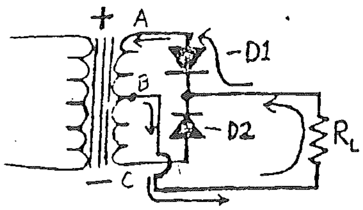



## SPECIAL FEATURES OF THE MAJOR POWER SUPPLY COMPONENTS

In lessons 4 through 7, we examined the major components that comprise the regulated power supply. Let us now look at each one again, with emphasis on special features we did not have a chance to pursue before.

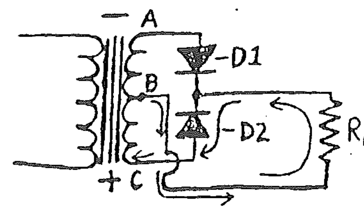
### The Center-Tapped Transformer

Here we see three types of rectifier circuits that convert AC to PDC. We have already examined the half-wave and full-wave bridge rectifier. The third method, using two diodes and a center-tapped transformer is widely used and we should be familiar with how it works.




First, notice that the output, even though we are using only two diodes, is full-wave rectification.

During one-half cycle of AC the top of the center-tapped secondary coil is positive (A), the bottom half negative (C). The center tap (B) is neutral or at a voltage half-way between that of a A and B. In this situation, current will flow from the center tap, up through RL (the load) to the junction of D1 and D2. At that point, current will travel through D1, which is forward biased, to the positive end of the secondary coil at point A.

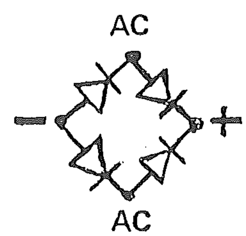


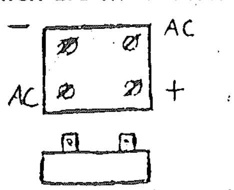

During the next half-cycle of AC, the top of the center-tapped secondary coil is negative (A), the bottom half positive (C). Again current will flow from the center tap, up through RL to the junction of D1 and D2. This time the current will travel through D2, which is forward biased, to the positive end of the secondary coil at point C.

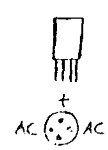
One complete cycle of alternating current has been converted into full-wave pulsating direct current. It should be noted that when using a center-tapped transformer it must be rated at twice the voltage of one without a center tap. If you would normally use a 6.3-volt AC transformer, one rated at 12.6-volts AC would now be required.

### The Bridge Rectifier Assembly

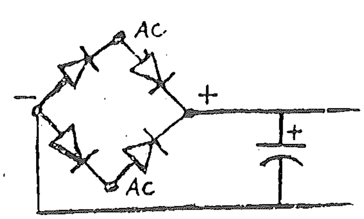
In order to form a full-wave bridge rectifier four diodes are necessary. Separate diodes, with proper current and voltage ratings can and are often used. Lately however, in response to the demand for quick and easy assembly, four diodes have been formed or molded into a convenient little package; two styles of which are shown here.



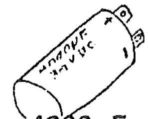

Alternating current from the transformer's secondary coil is connected to points marked AC. Polarity at the input of the bridge is unimportant since we are dealing with alternating current. The negative and positive terminals of the output of the bridge are placed across the filter capacitor.




Bridge rectifier assemblies have both a current and voltage rating. An example would be 100PIV/2-amperes. This unit can handle up to 100 volts and up to 2 amperes of current.

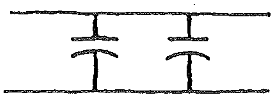
## Choosing The Right Filter Capacitor

The filter capacitors smooth out pulsating direct current from the rectifiers to create nearly pure DC required by the electronic circuitry load. The value of these capacitors is critical to the performance of the power supply. The total capacitance should be no less than 1000uF per ampere of output current. A typical 5-volt, 4-ampere DC power supply would require no less than 4000 microfarads for good filtering.



4000uF

A 4000uF capacitor, at let us say 50 volts, would be quite large. As you already know, it is possible to place capacitors in parallel to increase the total capacitance. The power supply project that comes with Unit II has two 1000uF capacitors connected in parallel for a total of 2000uF of filtering. Since the power supply is rated at 1-ampere, this is twice the minimum capacitance required.



Capacitor in Parallel

## Voltage Regulators and Noise Bypass Capacitors

In Lesson 7 we examined a standard three-terminal voltage regulator, the LM309. In addition to the LM309 series, there is the LM340 group of regulators in which the output voltage is indicated by a number suffix added to the basic series number. For example, the LM340-5 is a 5-volt regulator, while the LM340-12 is a 12-volt device. Another popular regulator family is the 7800 series. The output voltage is given by the last two digits in the type number (7805 for 5-volts and 7812 for 12-volts output, for example.)

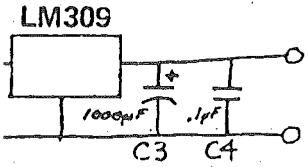
LM309

LM340

7800

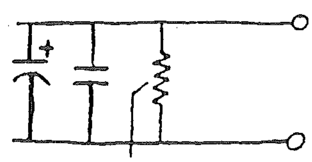
You may have been wondering what capacitors C3 and C4 are used for in the 5-volt power supply we have been studying. These are known as noise bypass capacitors and they should be placed across the output terminals of the voltage regulator. They aid in eliminating transient load variations.

LM309



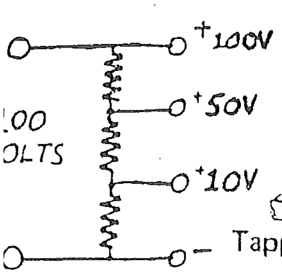

## Bleeder Resistors And Voltage Dividers

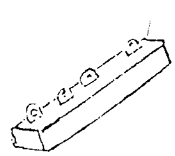
The purpose of a bleeder resistor is to provide a discharge path for the filter capacitors. In power supplies that do not employ voltage regulators, this resistor also acts to prevent sharp increases in voltage output under light or no-load conditions. If the charge is not "bled off" of large filter capacitors they can store electrical energy for many hours. This represents a dangerous source of voltage lying around waiting for discharge — possibly across you. So, when building power supplies of any type, it is always a good idea to include a bleeder resistor.




Bleeder Resistor

Bleeder resistors can also serve double duty as voltage dividers. They can be tapped to provide one or more voltages lower than the maximum voltage of the power supply.



Tapped Resistor

A voltage divider can be either two or more resistors in series, a fixed resistor with taps at different points, or a variable resistor capable of producing a variety of voltages. A power supply, having its DC output connected to a variable resistor such as a potentiometer, can supply a varying voltage output depending upon the position of the potentiometer arm.

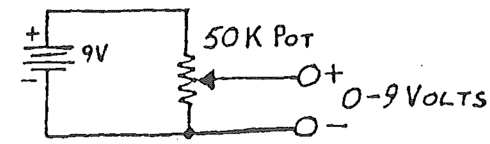
# SPECIAL PURPOSE POWER SUPPLIES

Before we conclude our discussion of power supplies, let us briefly consider four additional features available with more specialized DC power sources. We will be examining variable power supplies, voltage multiplication, over-voltage protection, and dual-polarity power supplies.

## Variable Power Supplies

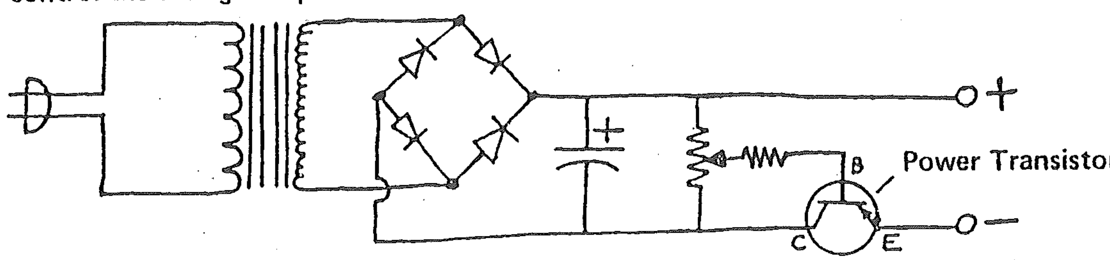
There are many times in which a variable output voltage is desirable. A 0-15 volt power supply could be built to power a variety of projects from LED flashers to CB Radios.

In the previous section, we showed how a potentiometer, connected across the power supply output, will allow you to vary the output voltage. This happens because the potentiometer acts as a, continually varying, voltage divider. Such a system is a bit crude but it can work. It is even possible to connect a potentiometer across a battery to form what is commonly referred to as a "quick and dirty" power supply. In an emergency, I have built just such a circuit to power TTL ICs.




"Quick and Dirty"

But for better voltage regulation and less current drain, it is best to use a transistor to control the voltage output. Here is how it works.




The potentiometer controls the power transistor by determining how much voltage is placed on its base.

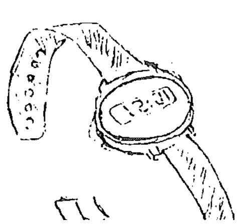
By controlling voltage on the base, the transistor will allow more or less voltage to be fed to the load.

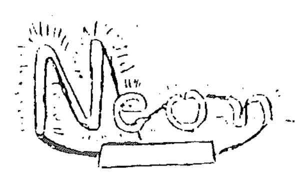
By combining a zener diode or three-terminal voltage regulator with the transistor circuit just examined, a regulated variable power supply can be built.

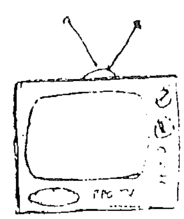
## Voltage Multiplication

The diode-capacitor voltage multiplier is a very simple but extremely useful power supply circuit. Such a voltage multiplier circuit allows the user to obtain a larger DC voltage than that available from a battery or transformer/rectifier power supply.

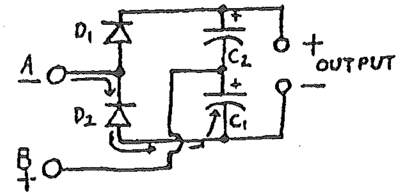
Voltage multiplication networks have wide application in many semiconductor circuits. They are commonly used in digital watches to obtain the required operating voltages from a single mercury cell. Voltage multipliers are also used to obtain the high voltages needed to power neon glow lamps, electrofluorescent displays and semiconductor lasers. Furthermore, such multipliers are often found in the high voltage sections of color television receivers.





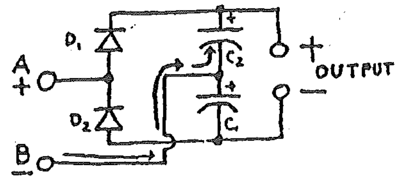



The basic voltage multiplier operates on the principle of charging and discharging capacitors with the help of "steering" diodes. Here is how it works:




—In operation an AC voltage is applied across the input terminals.

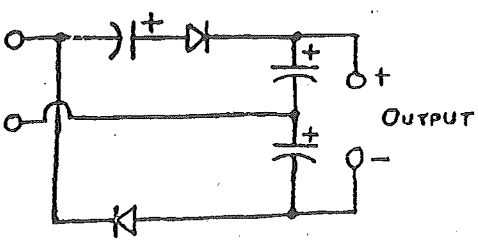
—During the negative half-cycle of the input signal terminal A is negative with respect to terminal B. C1 charges up to the peak value of the input voltage.



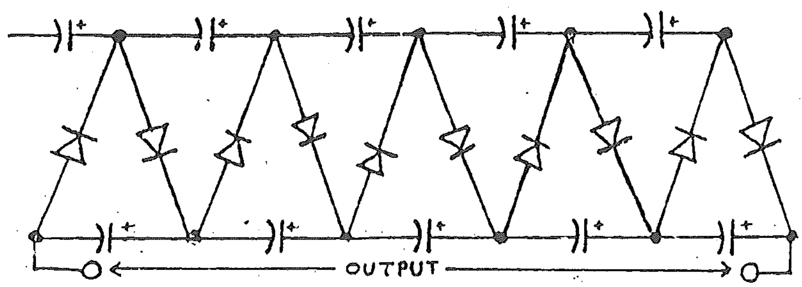

—During the positive half-cycle, C2 charges up to the peak value of the input voltage.

—Since C1 and C2 are in series, the output voltage is double the peak input voltage.

Here are two circuits employing voltage multipliers. One is a voltage tripler, the other is a ten-stage voltage multiplier. The latter circuit could take a 12-volt input from a digital IC circuit and supply enough voltage to power neon glow lamps.

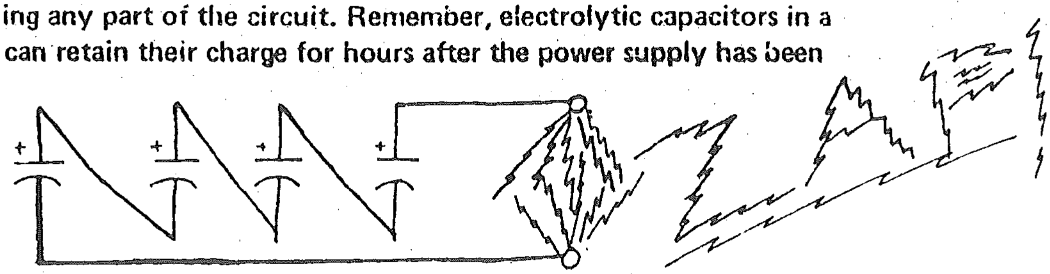



Voltage Tripler

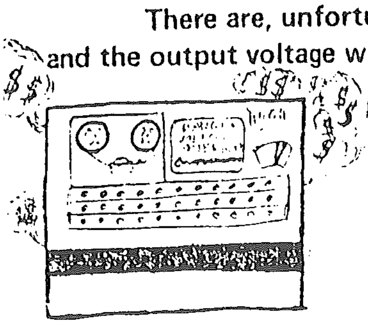



Ten-stage Multiplier

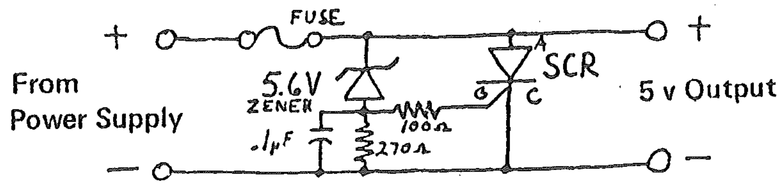
A word of caution is perhaps in order. Voltage multipliers can easily produce very high output voltages. Always use extreme caution and make sure all capacitors are fully discharged before touching any part of the circuit. Remember, electrolytic capacitors in a voltage multiplier chain can retain their charge for hours after the power supply has been turned off.



## Overvoltage Protection For Power Supplies



There are, unfortunately, occasions when voltage regulators will fail to act properly and the output voltage will rise dramatically. If this were to happen to a power supply operating an expensive computer, the result would be disastrous. (An expensive computer is defined as one that you have sunk money into.) The overvoltage circuit shown below, while costing only a couple of dollars in parts, could save you many times that amount by short circuiting your power supply output to ground. It is called a "crowbar" because it acts as a conducting metal crowbar would if it were connected across your power supply. Here is how it works:




— Normally the 5-volts coming from the power supply is too low to allow the zener diode to conduct. The SCR is not operated and the 5-volts appears as the output.

— When the voltage coming from the power supply exceeds 5.6-volts the zener diode conducts and generates a voltage across R2. (Remember our discussion about voltage drop.)

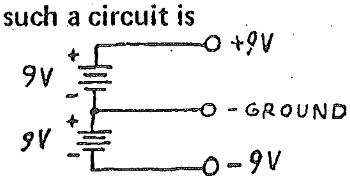
— The voltage is then applied, via R1 to the gate of the SCR, which triggers it on.

— When this occurs, a short circuit develops across the output (the SCR when conducting is just like a piece of wire) which causes the fuse to blow and shut down the power supply.

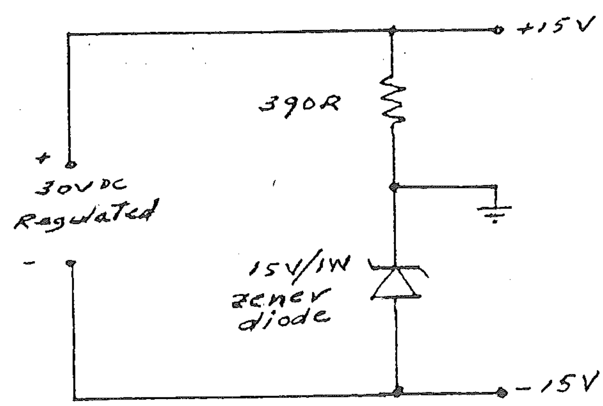
As with voltage regulators themselves, all the discrete components now come neatly packaged in one TO-3 type case.

## Dual-Polarity Power Supplies

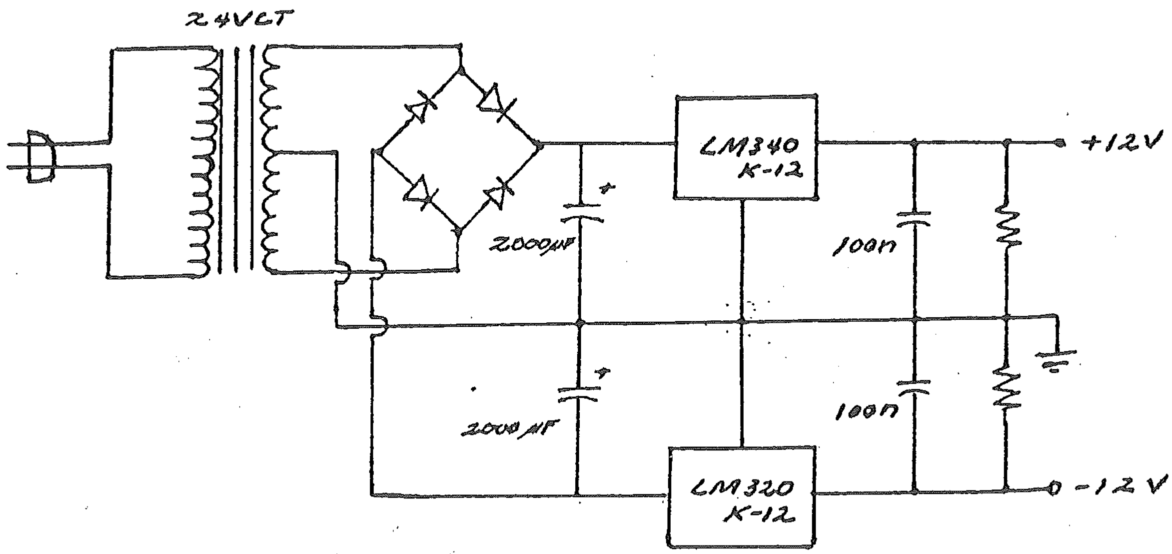
Many circuits, especially those using linear ICs such as Op Amps require a dual-polarity power supply. This type of power supply delivers a positive and negative voltage with reference to a common ground. Perhaps the simplest way to fashion such a circuit is to connect two batteries in series. One terminal is 9-volts positive with respect to ground, the other terminal is 9-volts negative with respect to ground.




If you have a regulated single-polarity supply, the schematic diagram below shows how to use a zener diode and a resistor to produce a dual-polarity supply. It works well in a pinch, but as most common zener diodes are low power devices, its current capabilities are limited. The circuit here uses a 1-watt zener diode, and is designed to deliver only about 25 mA of current with adequate regulation.



With the disadvantages of the previous dual-polarity supply circuits quite apparent, we can see that it would be desirable to produce a properly designed dual-polarity supply. The schematic for such a power supply is shown here:




Note the following points:

- * The circuit uses a full-wave bridge but is actually wired as two half-wave rectifiers since the transformer center tap is the common ground.
- * The negative terminal of the bridge feeds the negative supply, the positive terminal feeds the positive supply.
- * Independent voltage regulators are used for each side. The LM340K-12 is a positive 12-volt regulator while the LM320K-12 is a negative 12-volt regulator.

While dual-polarity power supplies come in a wide range of voltages, they are for the most part, constructed along the lines outlined above.

## SUMMING UP

In Lesson 8 we examined the overall operation of a fully regulated power supply. We analyzed special features of the major power supply components such as: the center-tapped transformer, bridge rectifier assembly, noise bypass capacitor, and bleeder resistor. Finally, we considered in some detail, variable power supplies, voltage multipliers, overvoltage protection, and dual-polarity power supplies.

# UNIT 2 LESSON 7 QUESTIONS

1. List the four steps necessary to convert from 120VAC to a regulated DC voltage.

2. Draw the schematic diagram for a full-wave rectifier using two diodes and a center-tapped transformer. Using two different colours, draw arrows indicating electron flow in the circuit for both transformer polarities.

3. What "rule of thumb" is used to determine the minimum capacitance for a ripple filter in a DC supply? 1000μF/A

4. What is the purpose of a noise bypass capacitor and where is it connected in a circuit?

5. What output voltages are delivered by the following regulators?

(a) LM 309 5V
(b) LM 340-5 5V
(c) LM 340-12 12V
(d) 7815 15V
(e) LM 320-12 -12V

6. What is the purpose of a bleeder resistor?

7. Explain how a potentiometer acts to produce a variable voltage.

8. Draw a schematic diagram showing how a voltage regulator, a potentiometer and a PNP transistor can be combined to produce a variable regulated voltage supply.

9. List three devices that use voltage multipliers.

10. Draw the schematic diagram for a voltage doubler circuit, and draw arrows showing electron flow for both alternations of the transformer. Use a different colour for each of the two paths.

11. Why was the electronic crowbar named as it was?

12. What is the purpose of a crowbar circuit?

13. Briefly explain the operation of the crowbar circuit.

14. Describe three ways of producing a dual-polarity power supply.

# AMPLIFIERS

## INTRODUCTION

In many electronics applications, we want to make a voltage or current signal larger than it originally was. Any device capable of doing this is called an **amplifier**. In its simplest sense, a transistor is a current amplifier, since a small base current (the **input** current) controls a much larger collector current (the **output** current). By installing resistors at appropriate points in a circuit, we can easily translate a current into a voltage (think about Ohm's Law) or a voltage into a current, so it is easy to construct a circuit in which a transistor can act as a voltage amplifier. Figure (1) shows a simple one-transistor voltage amplifier. An input voltage causes changes in current flowing between the base and the emitter, and these changes in base current cause changes in the collector current. Changing current through Rc means that the voltage at the output changes as well, and it is easy to construct a circuit in which the output voltage fluctuations are much larger than the input voltage changes. The ratio of output voltage to input voltage is called **voltage gain**. For example, if an amplifier produced an output voltage of 20 volts for an input voltage of 5 volts, it would have a voltage gain of 20/5 = 4.

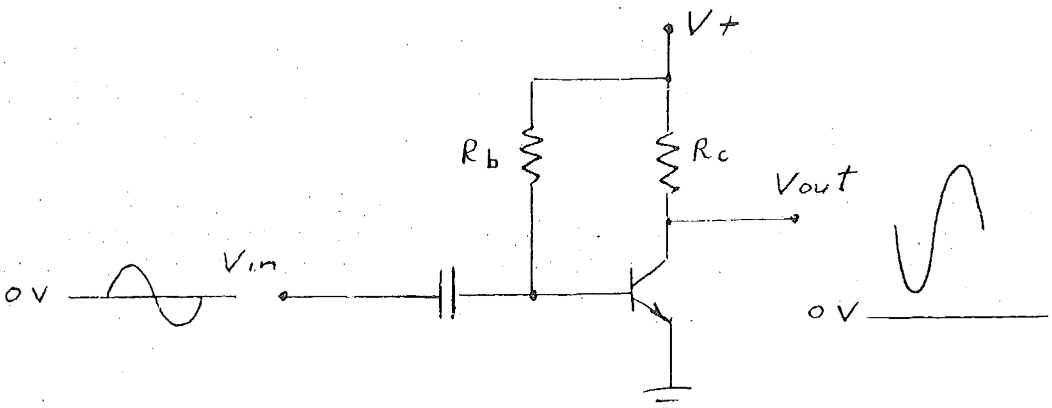



Figure (1) A simple transistor amplifier

Any amplifier can be represented by the figure shown in figure (2). There can be lots of complex electronic stuff inside the triangle, but for many purposes all we need to know is that if we apply a voltage at the input, a larger voltage will appear at the output.

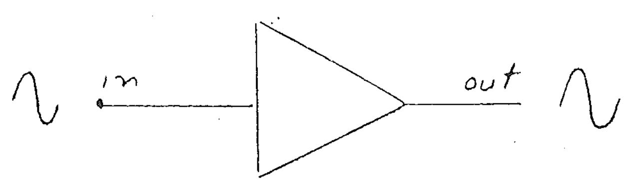



Figure (2)
Amplifier symbol

Figure (3) looks almost the same, but it is an **inverting** amplifier, in that the output voltage is exactly the opposite of the input voltage. Note the difference between the input and output waveforms.

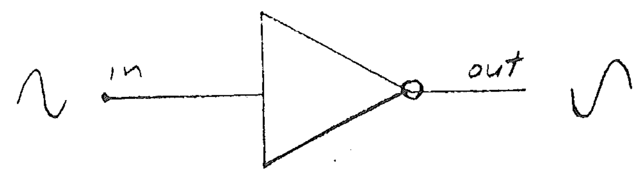



Figure (3)
Inverting amplifier

THE OPERATIONAL AMPLIFIER

The operational amplifier has been around for several decades, and has proven itself to be a versatile and most useful workhorse for the circuit designer. We will look at some of its most elementary characteristics, and explore how it can be used to construct a simple voltage amplifier.

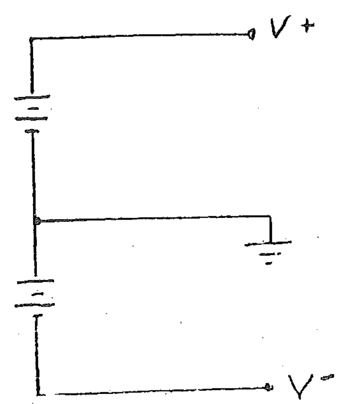



Figure (4)
A simple dual-polarity power supply

The first thing to note about the "op amp", as it is called by its friends, is that it uses a dual-polarity supply, that is a supply with one voltage which is positive with respect to ground and one voltage which is negative with respect to ground. The easiest way to achieve this is to connect two batteries in series, plus to minus, as shown in Fig. (4), with ground being the point of connection With two power supplies, the op amp is capable of accepting and processing true alternating voltage.
There are other ways of achieving a dual-polarity supply, but they will be discussed later.

The next thing to note about the op amp is that there are two inputs, one for which the output has the same phase as the input (the **non-inverting** input), and one for which the output appears inverted (of course, the **inverting** input!) See Fig. (5).

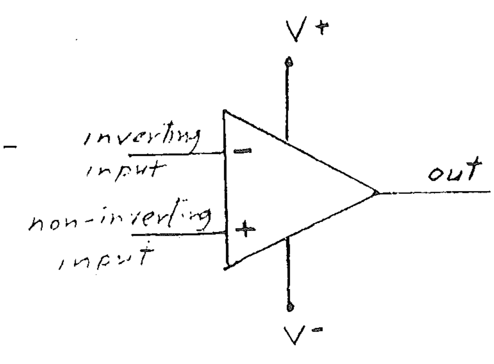



Figure (5) The op amp has two inputs

If the inverting input is grounded, and a signal is fed into the non-inverting input, the output voltage appears as in Fig. (6). If the non-inverting input is grounded, and a signal is fed into the inverting input, then of course the amplified output signal is inverted, as shown in Fig. (7).

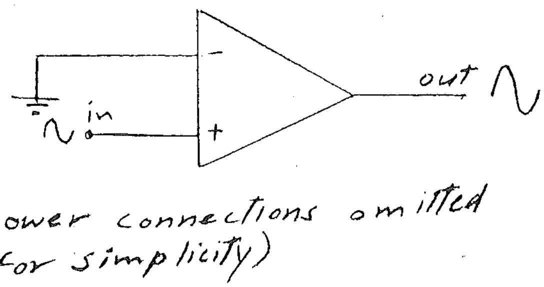



Figure (6)

A non-inverting amplifier

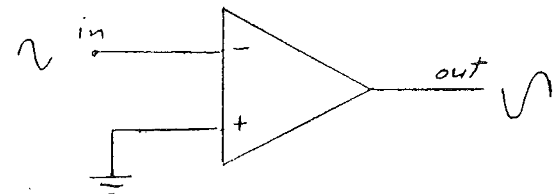



Figure (7)

An inverting amplifier

Another important feature of the op amp is that without external components, it has absolutely enormous voltage gain, usually greater than 100,000. This means that if you were to just connect power and an input voltage, the output would normally just slam over to the maximum positive or negative voltage, depending on the input polarity, and wouldn't be of much use. Of course, it has been designed with this feature for a reason, as we shall now see.

FEEDBACK

Feedback is the process of re-routing some of the output signal back to the input. If it is brought back to the inverting input, we have **negative** feedback. This is the type of feedback used with the op amp. Positive feedback is used in some circumstances, but we won't deal with it here. Negative feedback with op amps has several effects, and we will discuss two here. The first effect is that the gain of the amplifier is reduced. By choosing the right amount of feedback, we can control the gain of the amplifier. Negative feedback also has the advantage of reducing the amount of distortion that the

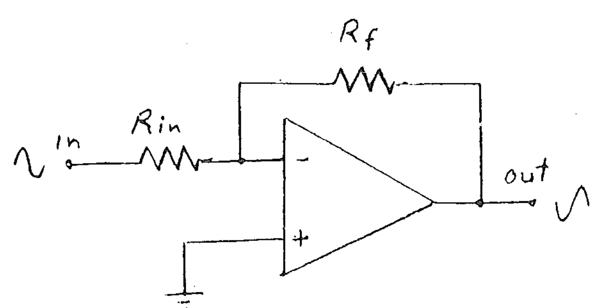



Figure (8)

An inverting amplifier with negative feedback amplifier produces, and is used in many amplifiers for this reason. Figure (8) shows an inverting amplifier with negative feedback. In this case, the voltage gain of the amplifier is given as $R_f/R_{in}$. A non-inverting amplifier with negative feedback is shown in Fig. (9), with the gain of this amplifier given as $(R_{in} + R_f)/R_{in}$.

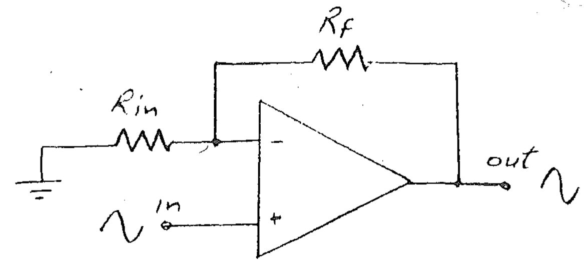



Figure (9)

a non-inverting amplifier with negative feedback