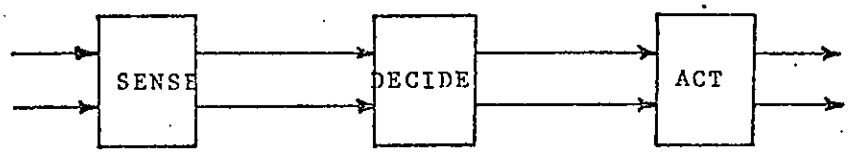
TITLE: WHAT ELECTRICITY DOES IN EVERY ELECTRICAL AND ELECTRONIC SYSTEM

LECTURER:

DATE:

INTRODUCTION

Any electrical system can be broken down into three basic elements of organization: The elements of (a) sense, (c) decide, and (c) act.



(a) Sense:- The system must have inputs, and typically this input information is non-electrical. For example the start button in a control circuit.

(b) Decide:- Between the elements we must have a flow of information, and different information can be produced from the decide stage.

(c) Act:- In the final stage, we have a conversion of information into the desired action. This action can be either (1) work or (2) information in a desired form.

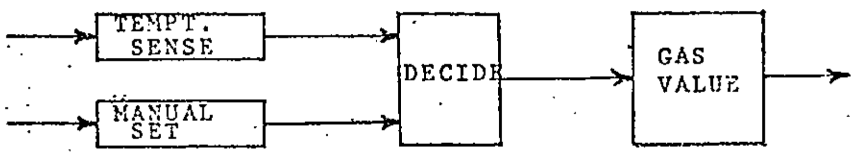
(1) WORK:- For example, might be the rapid turning of the bit by the motor in an electric drill.

(2) INFORMATION:- in a desired form might be the numbers displayed as the answer on an electronic desk calculator.

So this is all that any electrical system will do - manipulate information or perform work. And in every system, we will find information being input, we will find a flow of information internally, and we will find resultant actions.

EXAMPLE I:- There is a familiar human analogy to this. You touch a hot stove, your fingers SENSE the heat; this is the input of information. The information travels to our brain; this is the DECIDE portion of the system. A decision is made, and the resultant information then travels to the ACT stage, your arm. At this point, the information is converted into the desired action, the quick removal of your hand; this removal of the hand is work.

EXAMPLE II:- We will look at a thermostatic control system for a central heating unit.



This system must have (a) a temperature-sensing device, and it must have (b) a control that can be set at the desired temperature. Both of these devices convert external information into a form that can be handled internally.

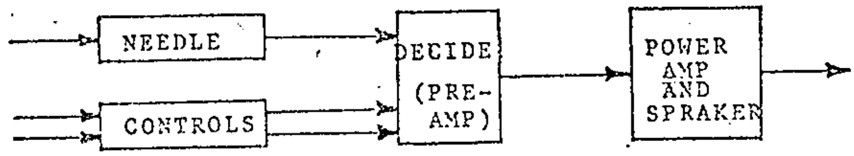
(a) The temperature - sensing device - which is a kind of thermometer, tells the system when the room temperature has fallen below, or risen above, the desired level.

(b) The control - tells the system what that desired level is.

Thus, these devices convert external information to internal information that can be handled by the system.
Next the system has to use these two streams of information and arrive at a decision. In this case, it is a decision that in essence tells the fuel valve either to turn-on or to turn-off. If the decision is "turn-on", the fuel valve actuator converts this information into the action of moving the rather heavy valve parts.

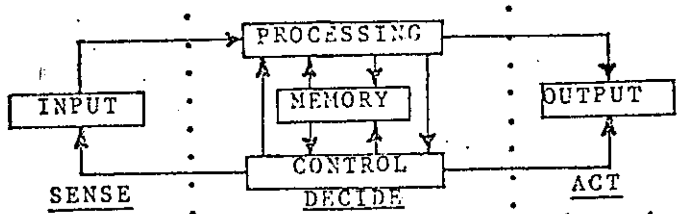
So here again our system is organised into the three stages of sense, decide, and act and we have dealt with either information or work: Information at the input, work at the output.

EXAMPLE III:- This time we will look at a record-player or hi-fidelity system.



First, we have input from the needle and cartridge; they perform a sensing function as the groove in the record passes under the needle. We also have input from the hand controls for volume and tone. The internal electrical information from these input devices usually goes to a preamplifier which, in effect, decides what the loudspeaker should do - the decision being based on the input information signal to the power amplifier. The amplified signal passes on to the loudspeaker, which finally acts to produce sound in the air.

EXAMPLE IV:- Finally we will look at computer organization. There are two types of computer - digital and analogue, and we will look at the digital computer, which consists of five subsystems.



(a) Input:- The input subsystem accepts data in machine-readable form (e.g. punched cards, perforated paper tape, magnetic tape, magnetic-ink chatacters etc). translates them into computer code, and transmits them to the processing system for storage in the computer's memory.

(b) Memory- The memory, or storage system, stores data and instructions in binary form, using a large bank of two-state electronic devices (most commonly magnetic cores). An address provides a unique identification for each memory location.

(c) Control:- The control subsystem originates commands that specify exactly what each part of the computer system is to do and when each operation is to begin.

(d) Processing:- The processing subsystem is also called the arithmetic unit. It performs the four basic arithmetic operations, makes logical comparisons, and edits data to alter their form.

(e) Output:- The output subsystem accepts binary data from the computers memory and translates them into the form required by output media. Output media include punched cards, perforated paper tape, high-speed printers, magnetic tape, and video displays.

So, even the most sophisticated electrical system can still be split up into the three basic stages.

TITLE: HOW ELECTRICAL INFORMATION CAN BE TRANSMITTED.

LECTURER:

DATE:

Now that we have looked at how electrical systems are organized, the next step is to consider how information is handled within these systems.

We will start with a basic statement: We can only do two things to electricity between the power source and the point of use. We can switch it - as in an "on or off" function - or we can regulate it, as when we vary the resistance.

DIGITAL
The method that involves sending information by switching is called the "digital method". All modern digital computers use this method of transmitting informatinn.

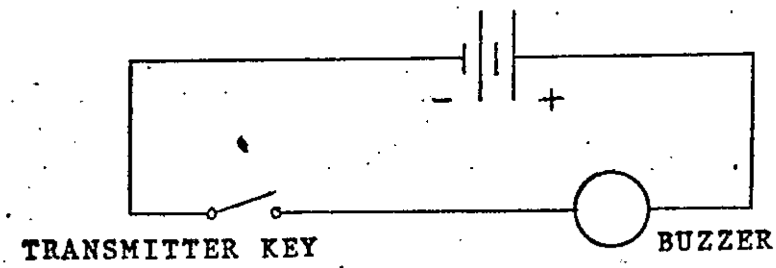
ANALOGUE
In contrast the method of sending information by regulating is called the "analogue method". Radios, record players, and analogue computers provide examples of information carried by the analogue method.

We will now look at the digital method in more detail.

(1) HOW INFORMATION IS SENT BY THE DIGITAL METHOD.

Digital computers use the same basic transmission method as a simple telegraph circuit.

Let's look at the logical basis of telegraph code, to see how we might use such a technique in a computer:



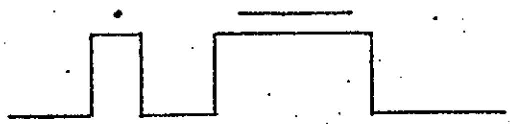
SIMPLE OLD FASHIONED TELEGRAPH C.C.T.

Obviously, when we press the key turning the switch on, the voltage on the switch side of the buzzer goes high, current flows, and the buzzer operates.

When the switch returns to the off position, the current flow stops and the buzzer becomes silent.

We can say, then, that it is a change in voltage in the wire that carries the information. Thus, depending on when the key is pressed will determine what kind of waveform is created.

For example:



This waveform is equivalent to a dot and dash in morse code, which gives the letter "A", and it is brought about simply by switching on and switching off.

DIGITAL METHOD AS USED IN A COMPUTER.

Now let's see how this digital method works in a computer. Digital computers are designed to handle numbers not letters. But morse code numbers are cumbersome, with five characters for each digit, so computers use a more efficient code called the "binary number code". Where a low voltage represents a zero, and the higher voltage represents a one.

DECIMAL SYSTEM

This binary system is best explained by making reference to the familiar decimal system. As you know, the base is ten, and ten numerals, 0,1,2,.....9, are required to express an arbitary number. To write numbers larger than 9, we assign a meaning to the position of a numeral in an array of numerals.

For example, the number 1,264 has the meaning:

$$1{,}264 = 1\times10^3 + 2\times10^2 + 6\times10^1 + 4\times10^0$$

Thus the individual digits in a number represent the coefficients in an expansion of the number in powers of 10. The digit which is farthest to the right is the coefficient of the zeroth power, the next is the coefficient of the first power, and so on.

BINARY SYSTEM

In the binary system of representation the base is 2, and only the two numerals 0 and 1 are required to represent a number. The numerals 0 and 1 have the same meaning as in the decimal system, but a different interpretation is placed on the position occupied by a digit.

In the binary system the individual digits represent the coefficients of powers of two rather than ten as in the decimal system. For example, the decimal number 19 is written in the binary representation as 10011 since:

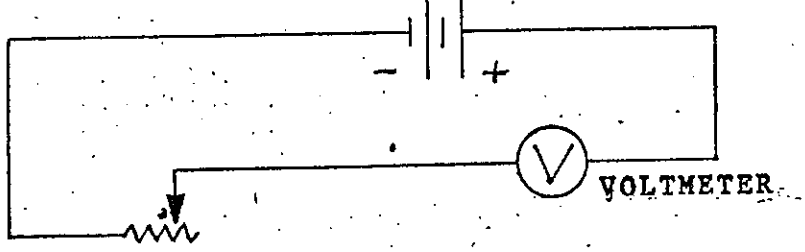
$$\begin{aligned} 10011 &= 1\times2^4 + 0\times2^3 + 0\times2^2 + 1\times2^1 + 1\times2^0 \\ &= 16 + 0 + 0 + 2 + 1 = 19 \end{aligned}$$

This simple principle of transmitting digital information, using the binary code, where "binary" means "two - state", on or off, has remained the same from the old-fashioned telegraph system through today's most modern and powerful digital computer.

Later on we will look at the electronic devices known as logic gates, or circuits which are capable of handling the binary code.

(2) HOW INFORMATION IS SENT BY THE ANALOGUE METHOD

Again we can use a simple circuit to illustrate this method.



Obviously in this circuit the variable resistor regulates the voltage in the line to the meter, and we will let some measurement of the voltage in the line stand directly for a number we want to transmit.

Suppose that we regulate the voltage to 7 volts, by using the variable resistor. Then, when we read the meter, it could read the actual number seven, or by arranging a different code it could mean double seven, or the square of seven etc. If we changed the voltage by regulating the variable resistor we then transmit a different number.

A tremendious variety of electrical systems use voltage analogue to transmit information.

EXAMPLE - CAR FUEL GAUGE

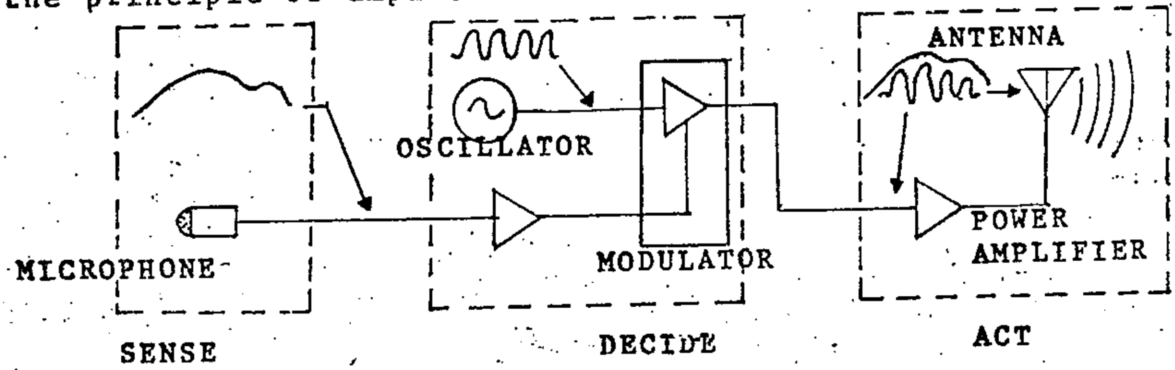
Most old-fashioned car fuel gauges used voltage analogue. A float in the petrol tank controls the variable resistor. As the level of petrol changes, the voltage going to the fuel gauge changes. Such a gauge is really a voltmeter whose dial is marked from empty to full instead of in volts.

Other examples of voltage analogue devices include analogue computers, where voltage stands for numbers or mathematical functions of numbers. In telephones, the voltage stands for fluctuating air pressure, which the ear interprets as sound.

AMPLITUDE MODULATION

An interesting variety of voltage analogue is called "amplitude analogue" or more commonly "amplitude modulation".

Amplitude Modulation or AM is used in Radio Broadcast Services, and AM radios get their name from the fact that they operate on the principle of amplitude modulation.



As illustrated above, the transmitter radiates electromagnetic radio waves in all directions by means of its antenna. Receivers can pick up the transmitted radio waves by means of a receiving antenna or aerial.

CARRIER: The desired voice or music information that is to be sent is not suitable by itself for wireless transmission. However inside the transmitter is an oscillator which generates high-frequency sine waves. This waveform is known as the carrier and it is an electromagnetic radio wave that is modulated by the desired information.

MODULATION: This is where the amplitude of the high-frequency wave or the carrier is varied in accordance with the audio in information to be transmitted.

The carrier is chosen for the best radio transmission, and examples of carrier frequencies for commercial radio stations are 1,323KHz for 5AD and 1,197KHz for 5KA.

Thus, for AM the amplitude of the carrier wave varies with the modulation, however for FM or frequency modulation, which is another method of radio transmission, the modulating voltage varies the frequency of the carrier wave.

CONCLUSION: In summary, we can say that all analog methods are based on regulating various properties of electricity. On the other hand, all digital methods are based on switching electricity on and off.

TITLE: TRANSISTOR - THE KEY TO MODERN ELECTRONICS

LECTURER:

DATE:

We have discussed earlier, that there are only two things that can be done to electricity between a power source and a point of use. It can be switched or it can be regulated.

We looked at two simple circuits that illustrated how switching and regulating could be achieved manually. However, if we required switching and regulating in thousands of different circuits, then obviously it could not be done by manual means with any degree of efficiency.

VACUUM TUBE OR VALVE

The great break through that made modern electronics possible was the invention of the vacuum tube. It provided a method for controlling electrical power by electrical means, rather than by mechanical or manual methods. The great benefit of regulating functions at high speed - millions of times per second.

TRANSISTOR

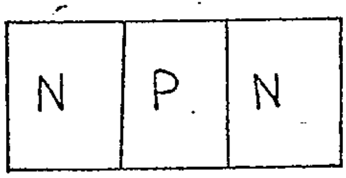
Invention of the transistor, in turn, provided major improvements over the vacuum tube. The transistor does the same things that a vacuum tube does; it switches and regulates by electrical means.

Compared to the vacuum tube, however, the transistor has many outstanding advantages:

1. It requires no heater current.
2. It is very small and light.
3. It is mechanically sturdy and long-lasting
4. It operates at desirably low voltages but can carry relatively high current.
5. It is thousands of times more reliable than the vacuum tube.

CONSTRUCTION OF TRANSISTOR

The heart of every transistor is a small piece of semiconductor material, most often germanium or silicon.



As the cross-section of a transistor shows, the transistor is processed so it has three distinct sections, or regions, designated as either "P type" or "N type".

P TYPE MATERIAL

The P type material is created when either silicon or germanium, which both have four electrons in their outer shells, have had very small amounts of impurity added to them, and the impurity is such that it has three electrons in its outer shell. This electron deficiency can be considered as a positive charge and will contribute to current flow.

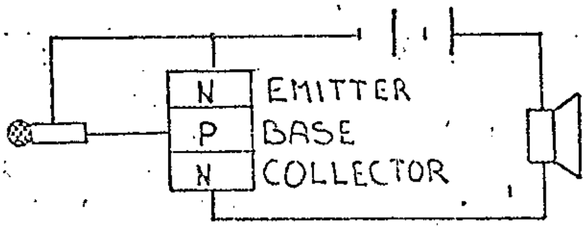
N TYPE MATERIAL

The N type material is created when a small amount of impurity with five electrons in its outer shell, has been added to a piece of semiconductor. This extra electron constitutes a negative charge, and will also contribute to current flow.

This transistor is an NPN type and the other type is PNP. This piece of semiconductor material can be made to act as a variable resistor, or as a switch. It can be made to conduct current, to throttle it partially, or to block it entirely.

TRANSISTOR AS A REGULATOR

Let's put our transistor into a simple circuit and see how it functions as a regulator.



If there is no sound going into the microphone, then nothing will happen. The transistor will merely block the flow of electricity from the battery to the loudspeaker.

BASE

If we consider electronflow, which is opposite to conventional current, then to make current flow, we must withdraw electrons from the central region, called the "base" to permit the current to flow from one N region to the other. This is achieved by directing sound into the microphone. The more electrons we withdraw, the more current will flow.

EMITTER

One N region is called the "emitter", because as we extract electrons from the base, this region will emit electrons across the base region.

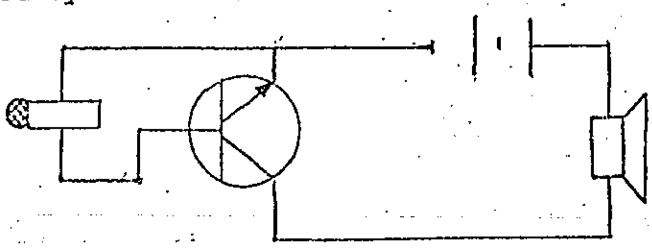
COLLECTOR

The other N region is called the "collector" because it's the region where the flowing electrons will be collected and then pass on down the wire to the loudspeaker.

The wire that is hooked from the microphone back to the emitter of the transistor is there to give the electrons withdrawn from the base a place to go - to complete the circuit.

CORRECT SYMBOL

The block form of the transistor, can now be replaced by the correct symbol.



In the symbol, the vertical line represents the base. The plain diagonal represents the collector, and the diagonal with the arrow represents the emitter.

The emitter arrow always points in a direction that is opposite to that of electron flow. The symbol is properly completed by drawing a circle around it, but the same symbol without a circle has the identical meaning. For the PNP transistor, the arrow is drawn pointing inwards.

TRANSISTOR AS AN AMPLIFIER

We have established that one of the marvelous qualities of a transistor is its ability to control electrical power by electrical means. With this circuit, the electrical control is initiated by a microphone, a device that can produce fluctuating electric current corresponding to fluctuating sound waves.

SMALL POWER

However, the microphone can produce only a tiny trickle of power. If we attached it directly to a loudspeaker, you probably wouldn't hear any sound even with your ear pressed against the speaker. But with the simple circuit concept you see here, you can produce enough sound to keep the neighbours awake.

POWER RATING

Just for the sake of illustration, we will assign the microphone a power output ranging from zero to five mW. But the power produced by the battery in the main circuit can range from zero to 500 mW. Where mW = milliwatts.

SOUND WAVE

Now let's assume that a single sound wave hits the microphone and creates a power output of three milliwatts. The microphone pumps a surge of electrons from a lower voltage (the base region) to a higher voltage (the emitter). Now, as a result of the base current, a relatively large current will flow across the base region from emitter to collector and on down the line, through the coil of the loudspeaker.

AMPLIFICATION

In this way, the current flow through the loudspeaker will be controlled, or amplified, in exact protion to the much smaller microphone signal.

GAIN

The signal through the loudspeaker might be typically 300 milliwatts; this means that the three milliwatts of power produced by the microphone have been amplified one hundred times, and this is known as the gain of the amplifier.

$$\text{GAIN} = \frac{\text{OUTPUT POWER}}{\text{INPUT POWER}}$$

SMALLER SOUND WAVE

Now suppose a second sound wave hits the microphone. This time it is a softer sound, and produces a power output of two milliwatts. Fewer electrons flow in the control circuit, so fewer are drawn from the base region, and this time the amount of power flowing through the transistor and the loudspeaker is only 200 milliwatts. Nevertheless, it has also been amplified one hundred times.

CONCLUSION

The power in the power circuit will always be an essential duplicate of the power in the control circuit, but much amplified. We can visualize the process as the voltage traces shown below.

BUZZER

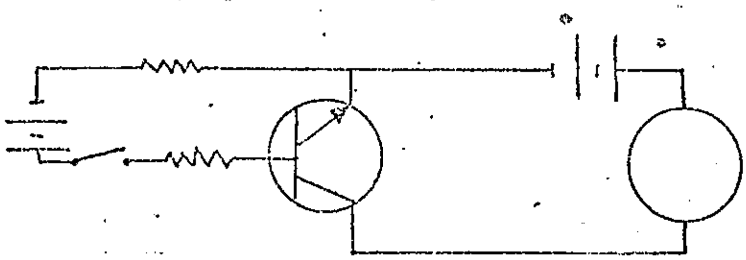
If the trace produced by the microphone looks like the tiny squiggle on the left, then the trace going to the loudspeaker will look like the big squiggle on the right - a close copy of the little one but greatly amplified.

TRANSISTOR AS A SWITCH

Sound waves fluctuate very rapidly, up to frequencies of about 30,000 cycles per second. The transistor has the capability of reacting to each of these fast fluctuations. In fact, high-frequency transistors can react billions of times per second. Now that we've seen the transistor in a regulating or amplifying function, let's look at it in a switching function.

TELEGRAPH CIRCUIT

We'll use a telegraph circuit again, as shown below.



In the control circuit, we have a switch in place of the microphone, and in the power circuit, we have a buzzer in place of the speaker. Since the switch cannot generate any power, we have a small battery in the control circuit.

RESISTANCE

The resistors in the control circuit represent the resistance to the sound, say sixty miles of wire. This resistance diminishes the control circuit power so much that not enough is left after sixty miles to actuate the buzzer. But the surviving power does provide enough energy to operate a transistor.

OPERATION

So when the transmitter key is pressed, a small current of electrons is withdrawn from the transistor base, a much greater current flows in the power circuit, and the buzzer sounds. This transistor is acting as a switch in the power circuit.

When the switch is off, the transistor is "off". When the switch is on, the transistor is "on". This allows power current to flow in proportion to the steady, unvarying control current.

CONCLUSION

Every transistor has the capability of either switching the power circuit current on and off, or throttling ("regulating") this current part-way between on and off. In the amplifier circuit, the microphone makes one transistor "regulate", and in the switching curcuit, the transmitter key and battery make the other transistor "switch". Regulating-type transistors are also known as amplifiers.

TITLE: HOW CIRCUITS MAKE DECISIONS

LECTURER:

DATE:

Previously we have discussed switching and amplifying circuits in rather general terms, but we didn't specify exactly how these circuits fit into three stages of sense, decide, and act. The fact is that circuit functions do not sense and they do not act. The sensing and acting are done by devices.

DEVICES

The microphone, for example, is a sensing device. The motor is an acting device. In any system, you might very well find switching and amplifying circuits in the sense and act stages, but they do not perform the function in either kind of stage.

SENSE STAGE

In this stage they merely translate the output of the sensing device into some form of information.

ACT STAGE

In the final stage, they provide power for the acting device in response to information from the decide stage.

So we can say that circuits do not sense and they do not act. But switching and amplifying circuits can make decisions.

DECISIONS

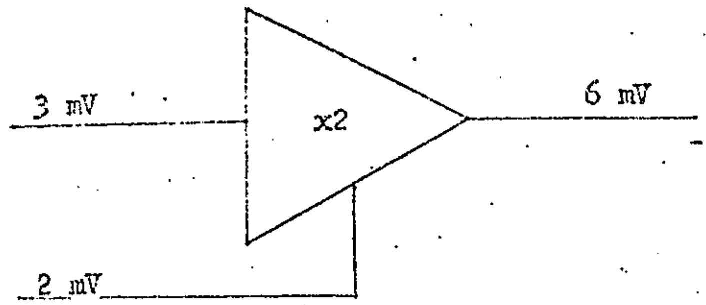
Every day in this country, in factories and offices and computer centers, literally trillions of decisions are being made by electrical circuits, every second. These decision-making circuit functions are the brains of the decide process in virtually every electronic system. This section is concerned with how circuit functions make those decisions.

ANALOGUE DECISIONS

To illustrate this we will look at our typical analogue system, which is the radio transmitter. We saw previously that the decide stage was the modulator, which also is a type of amplifier. The input is high-frequency voltage waves from an oscillator.

GAIN

A voltage signal from the microphone controls the gain of the amplifier, and earlier gain was defined as the amplification factor. The amplifier multiplies the input voltage by the gain to produce the output voltage.

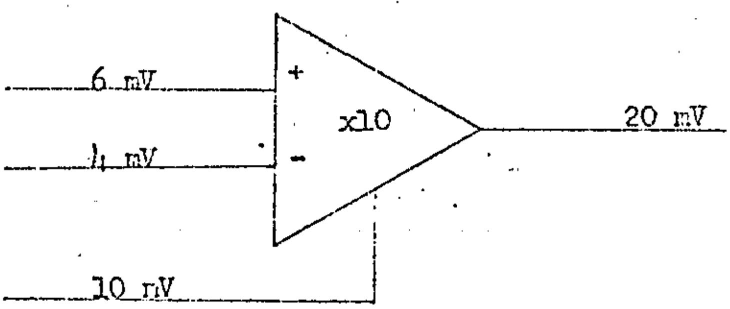


EXAMPLE:- Suppose that at a given instant, we have a gain control voltage of 2 millivolts producing a gain of 2. At the same instant, suppose the input voltage is 3 millivolts. The output, then, would be 3 multiplied by 2 to produce 6 millivolts.

This combining of input information to produce new information at the output is clearly a decision. Thus you can see that amplifiers continuously make decisions.

DIFFERENTIAL AMPLIFIER

Amplifiers can be designed to amplify in many special ways, and an example of this is the "differential amplifier". It has two inputs, and the output is an amplification of the difference between the voltages of the two inputs.



In the diagram above, the differential amplifier has inputs of 6 millivolts and 4 millivolts; it has a fixed gain of 10. Six minus 4 equals 2: times 10, it equals 20, yielding an output of 20 millivolts. Here again, we have an example of decision making - in this case, a decision that incorporates both subtraction and multiplication.

There are still other analogue circuits that perform other mathematical operations including division, finding logarithms, integrating, and differentiating. When we string these circuits together in the proper combinations, the result is an analogue computer.

DIGITAL DECISIONS

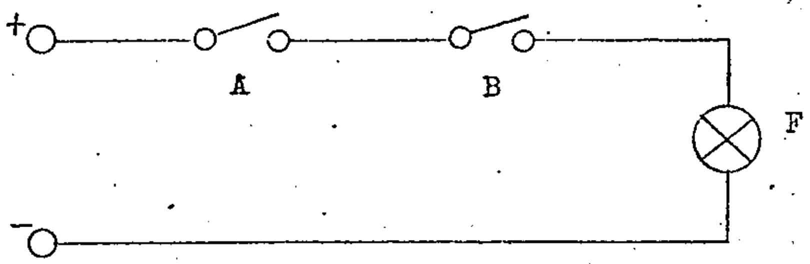
The digital computer, which is the most sophisticated type of digital system is capable of performing tremendously complex mathematical operations at blinding speed. This is achieved by thousands upon thousands of switching circuits - simple little circuits that can do no more than turn on and turn off. Thus, somehow, computer science has found ways to employ this simple on - off function of switches to solve extremely difficult problems.

GATES

The solution has been through the use of devices that are known as GATES, and they are capable of handling the binary code. The main types are the AND, OR and NOT gates.

AND GATE

Consider two switches A and B connected in series with a lamp F to a supply source as shown below.



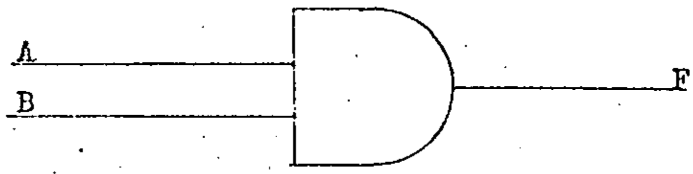
It is obvious that lamp F is on only if both switches A and B are on. Relating this to the binary code, where the on condition is represented by a '1' (known as logic 1) and an off condition is represented by a '0' (known as logic 0), then a chart known as a 'Truth Table' can be constructed to denote the lamp condition for all possible conditions or states of switches A and B.

TRUTH TABLE

A	B	F
0	0	0
0	1	0
1	0	0
1	1	1

The 'decisions' that have been made have been achieved by mechanical switching, and the AND gate connected in the right way is also capable of making these same decisions.

SYMBOL

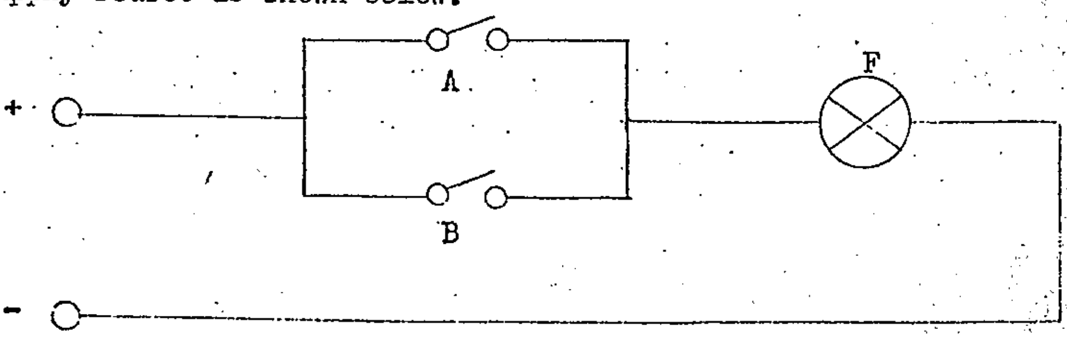


Another way of representing the AND function is to use the logic symbol for AND which is given by a 'dot'. Thus a form of shorthand with a specific meaning is available for the 'AND' gate.

E.G. A.B=F

OR GATE

Consider what happens when two switches are connected in parallel to a Camp F via a supply source as shown below.

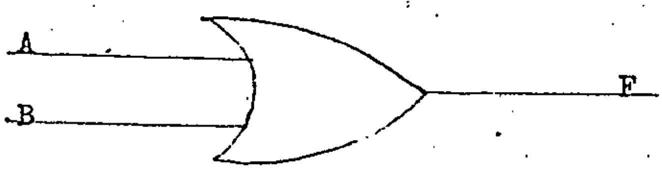


The lamp will only be ON if either switch A or switch B or both are on.

TRUTH TABLE

A	B	F
0	0	0
0	1	1
1	0	1
1	1	1

SYMBOL



LOGIC REPRESENTATION

For the 'OR' gate it is written $A+B=F$

Where the 'plus sign is the logic symbol to represent the 'OR' function.

NOT GATE

This is a gate with one input and one output. For the 'NOT' gate the output signal is the inverse of the input signal what ever the logic state of the input signal.

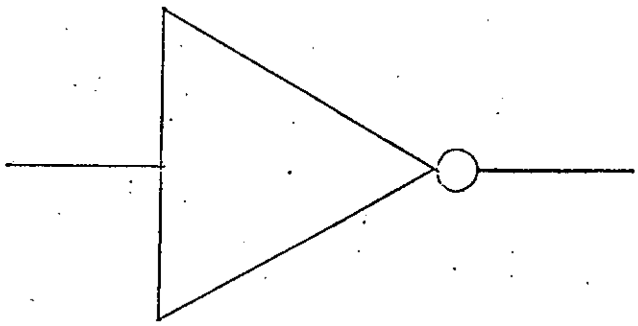
TRUTH TABLE

A	F
0	1
1	0

There are a number of words that are used to show this logical function e.g. inverse, complement and negate. The logical representation for the operation that this gate performs is written $F=\bar{A}$

In words, F is the complement of A, or F is the inverse of A, or F is the negation of A.

SYMBOL



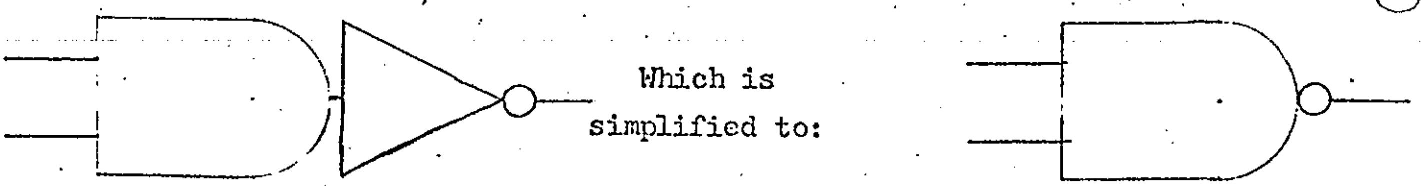
NAND GATE

Another type of gate that is made up from an AND gate and a NOT gate is the NAND gate.

TRUTH TABLE

A	B	F
0	0	1
0	1	1
1	0	1
1	1	0

SYMBOL



LOGIC REPRESENTATION $A.B=\overline{F}$

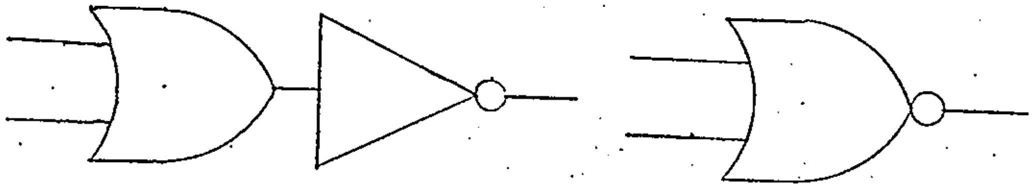
NOR GATE

This gate is made up from the OR gate and the NOT gate.

TRUTH TABLE

A	B	F
0	0	1
0	1	0
1	0	0
1	1	0

SYMBOL



Which is Simplified to:

LOGIC REPRESENTATION

$A+B=\overline{F}$

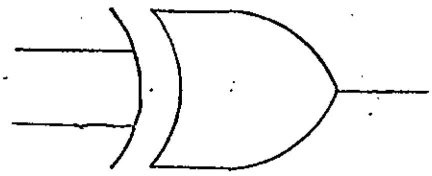
EXCLUSIVE OR

Another gate that exists, but one that is less common than the others is the EXCLUSIVE or gate. The function of this gate is that the output is OFF when the inputs are either all OFF or all ON.

TRUTH TABLE

A	B	F
0	0	0
0	1	1
1	0	1
1	1	0

SYMBOL



LOGIC REPRESENTATION

$A \oplus B=F$

ADDING BINARY NUMBERS

Now that we know how basic logic gates work, we are ready for our next step towards putting them together to solve complex mathematical problems.

BINARY CODE

We have seen previously that any number can be converted to binary code. The rules for adding binary digits are just a little different from the decimal system. The only three possibilities are shown below.

$$\begin{array}{r}0\\ \underline{+0}\\ 0\end{array} \qquad \begin{array}{r}1\\ \underline{+0}\\ 1\end{array} \qquad \begin{array}{r}1\\ \underline{+1}\\ 10\end{array}$$

As you can see, these calculations are simple enough to be done by electronic gates.

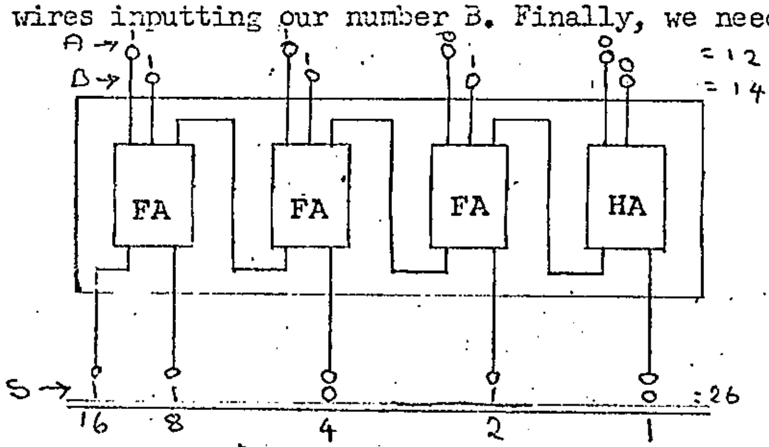
EXAMPLE:- Add two inputs A and B. A equals 12, B equals 14.

COLUMN VALUES		16	8	4	2	1		
			1					
	A		1	1	0	0	=	12
INPUTS		1	0					
	B		1	1	1	0	=	14
	SUM	1	1	0	1	0		26

Now, let's see how a computer does that same problem using gates. With the block diagram below, we have four wires inputting our first number A, and we have four wires inputting our number B. Finally, we need five output wires for our sum.

FA = Full Adder

HA = Half Adder



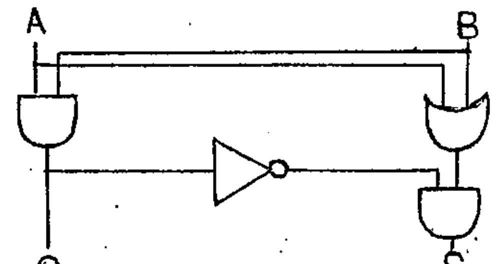
ADDERS

Within the block diagram there are four devices known as "adders". One adder is required for each column to be added. The one labeled "half-adder" merely accepts the input digits A and B; but the other three adders, called "full-adders", must add not only A and B, but also a digit carried from the previous column. Each full adder can be made from two half adders.

HALF-ADDER

The diagram below shows how the half-adder is constructed. The truth table shows that it conforms to the simple rules that we have established for adding binary digits.

A	B	C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0



C = CARRY

S = SUM

The half-adder is really the schematic of the decide section of a baby computer. It's a very limited circuit but it's functional nevertheless, because it will add two numbers.

INTEGRATED CIRCUIT

Actually, the circuit for the half adder is available in a tiny integrated-circuit.

In a later section, we will discuss memory functions, which involve integrated circuits such as flip-flops, registers and counters. But now that you know how the decide stage of a computer functions, you understand the working heart of the computer. Next, we will take the adder we have just looked at, and put it into a complete section.

TITLE: RELATING SEMICONDUCTORS TO SYSTEMS

LECTURER:

DATE:

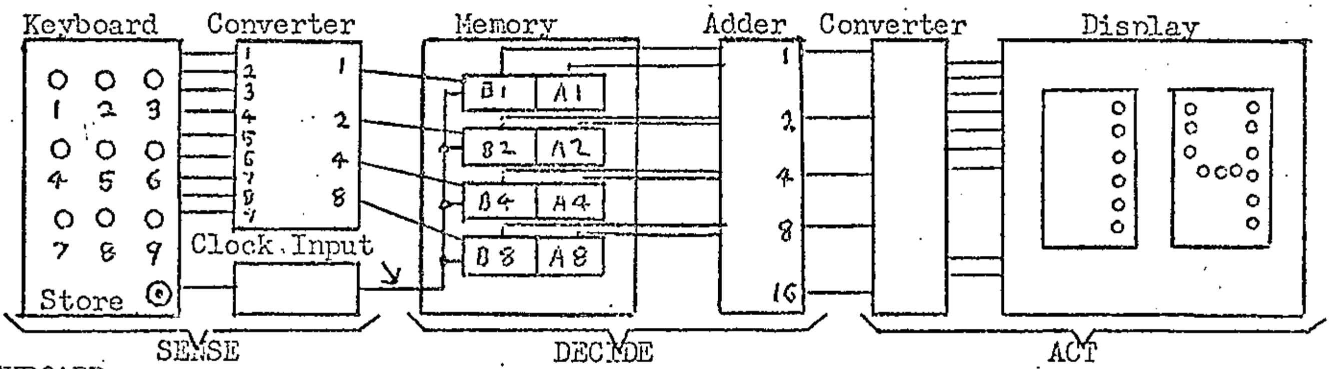
The adder that we have looked at previously, has the ability to make decisions and thereby solve simple mathematical problems. The answers it can provide are made with unerring accuracy, at fantastic speed.

HELPLESS BY ITSELF

However, it has no way of receiving instructions from the outside world. How can it be told what numbers to add? How can it communicate its answers? How can it remember (or store) the input numbers long enough to add them? This device is very much like a brain without a body. To function at all, this decision maker must be incorporated into a complete system.

COMPLETE SYSTEM

Let's take a look at what is required to make it work. The block diagram below presents a complete system incorporating the adder we looked at previously. This is a very simple system, and all it can do is add two decimal digits. But the principles involved are the same as those behind a complex electronic calculator or computer. We will need to look at each stage individually.



KEYBOARD

The first thing we need is something to sense the numbers to be added. So we use a keyboard, with a key for each of the digits one through nine. The keys are simply switches. However, the keyboard provides decimal information, and we know that the adder handles binary information.

CONVERTER

So the next thing the system must do is convert the decimal number to binary. This is done by a "decimal-to-binary-converter", this device is built from logic gates.

MEMORY

The next thing to be considered is - where does this information go? It goes to a block called the "memory", a place where information can be stored. Why must we store it? Because not all numbers can be input at the same instant, so we must hold one number until the next number arrives from the keyboard, and then they can be added.

SHIFT REGISTERS

In this simple system, the memory consists of just four sections called "shift-registers". Each register is divided into two parts or compartments. These two compartments are enough to store the two numbers to be added. Before the numbers are actually added, the digits of the first number will be stored in the far right-hand compartments labeled "A". The second number to be added will be stored in the left-hand compartments labeled "B". But we can only put the numbers in one at a time.

STORAGE

How is it achieved? Well, the shift registers do pretty much what the name implies - they register, or hold information, and they shift it. The two parts of the shift register, which we have called compartments, are actually switching circuits called "flip-flops".

FLIP-FLOPS

There are several different kinds of flip-flops, and the particular type we have here is called "D-type". Flip-flops are used in digital systems for a very important function - that of storing, or remembering data. Each flip-flop can store one bit of information - a 1 or a 0, and they only operate when the store button is pressed on the keyboard. There is nothing very mysterious about the flip-flops, they are simply switching circuits, put together in the right combination.

ADDER

The information in the memory is continually transmitted to the adder. The adder decides what the sum is, and the answer appears instantaneously at its output.

CONVERTER

The information at the output of the adder is in binary form, and we need a decimal output. So the next thing we need to do is convert the binary answer back to decimal form. So we employ another set of logic gates called, appropriately enough, a "binary-to-decimal converter".

DISPLAY DEVICES

Once the answer has been converted, it then drives the display devices. These can be in the form of gas-discharge tubes that make an illuminated display of the numbers or the system might drive printers to record answers on paper. Another method could use light-emitting diodes - little semiconductor light bulbs, arranged in a matrix so that they can be selectively lighted to form digits. These are turned on at the right time by the output converter, and the answer appears on the face of the display.

TITLE: Electric Heating

DATE:

LECTURER:

EQUIPMENT:

In wiring work the heating effect due to current in the conductor is a disadvantage and must be kept to a minimum since it represents a loss of energy.

However, the heating effect of electric current is widely used on a variety of heating appliances in domestic, industrial and commercial installations.

This is an introduction to electric heating equipment. It outlines the principles and applications of some common types of appliances.

Water and Space Heating

In general, any equipment designed for space or process heating is an energy consuming device and is therefore classified as an electrical appliance (Rule o.5.7.)

The type of appliance will determine the type of wiring and control. Low rated heating equipment not exceeding 10 amps are plunged in ordinary 240V G.P.O. Some larger portable appliances such as 4 KW air conditioners and large urns may have to be supplied by their own circuit.

If the appliance is rated at more than 10 amps it becomes necessary for the appliance plug to be of a higher rating to prevent accidential connection to a 10 A plug socket (G.P.O.).

Fixed heating appliances such as strip heaters may be permanently connected to or plugged into a circuit containing "G.P.O.". But they then become part of the number of points of such a circuit.

Before installing and wiring water heaters, rules should be carefully checked and understood (4.20.4.20.6).

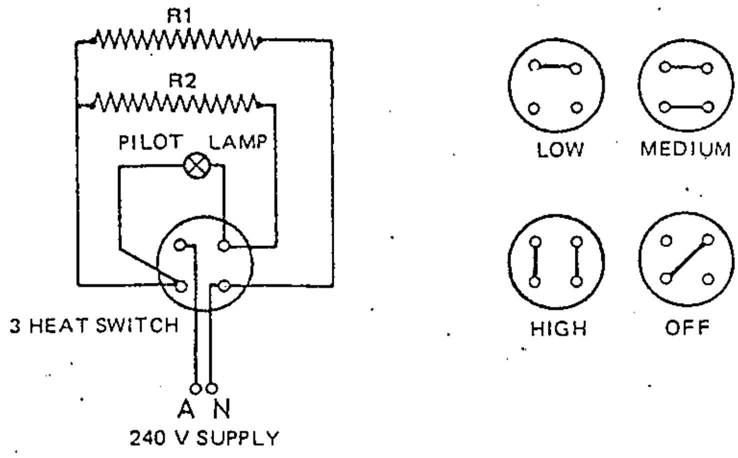
Principles of Heating Control Devices

Most heating appliances require some control over the temperature. Temperature control is achieved by:

1) Manual switching.
2) Some form of automatic control device.

1) Manual Control

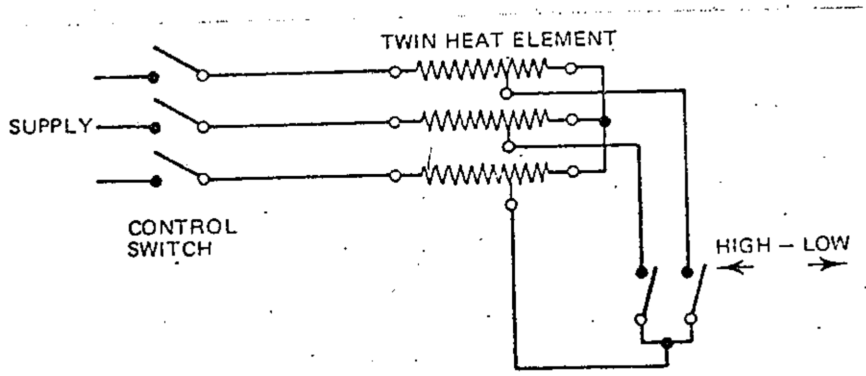
The simplest form of manual control is the switch. An improvement of this form of control is found on water urns. It is termed "multiheat" or "three heat switch".



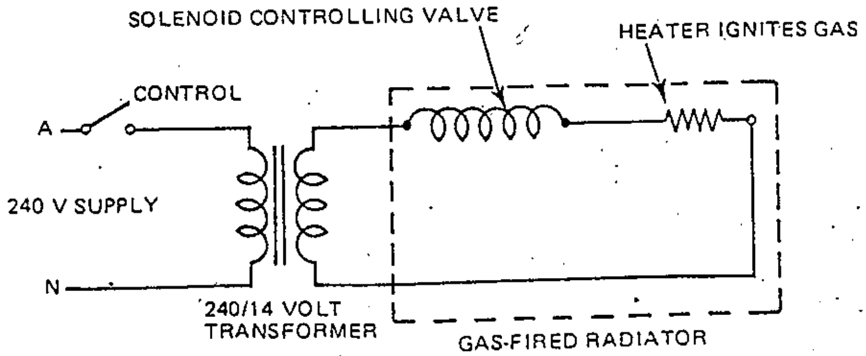
Single-pole three-heat switch with pilot light fitted

The principle of being able to select alternate heat positions, "high or low", for three phase water heaters is as follows.

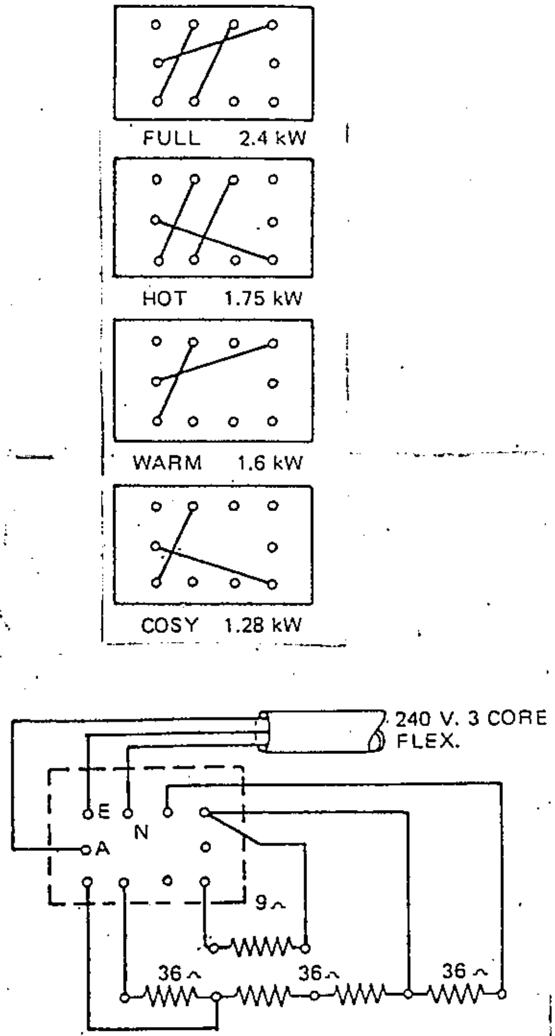
Modern domestic room heaters have a four way heat control switch. Gas and oil heaters frequently incorporate electrically operated controls.



Water heater with twin heat element



Gas radiator controlled electrically by a switch as "on-off" control



Four-heat control of a convection-typ room heater

Those controls which represent some of the many types available are "on . off" or "stepped control" and are manually set or controlled. This means that control relies heavily on the judgement of the operator. Because manual control is relatively simple and inexpensive, it is commonly used on many heating appliances.

Automatic Control

If precise temperature control is required, then automatic control devices are used. There are two main groupes of automatic control devices.

1) Thermostatic Control

Which will maintain the temperature between upper and lower limits. It will automatically switch "off" at the upper limit and back "on" at the lower limit as the thermostat senses the temperature.

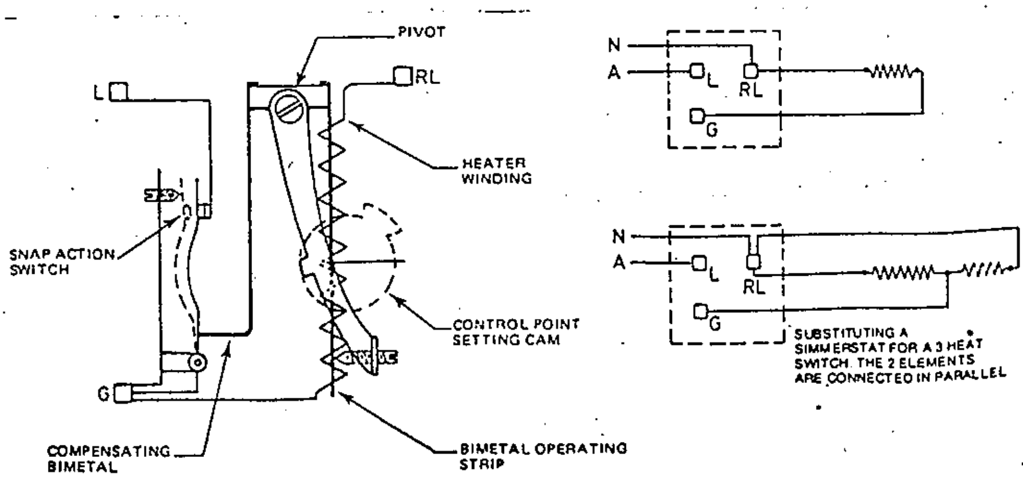
2) Simmerstat: or Energy Regulator

This is a proportional control device. Constant heat output of the electric element it controls being achieved by regulating the "on" and "off" periods in such a way that the average energy imput is maintained at the desired level.

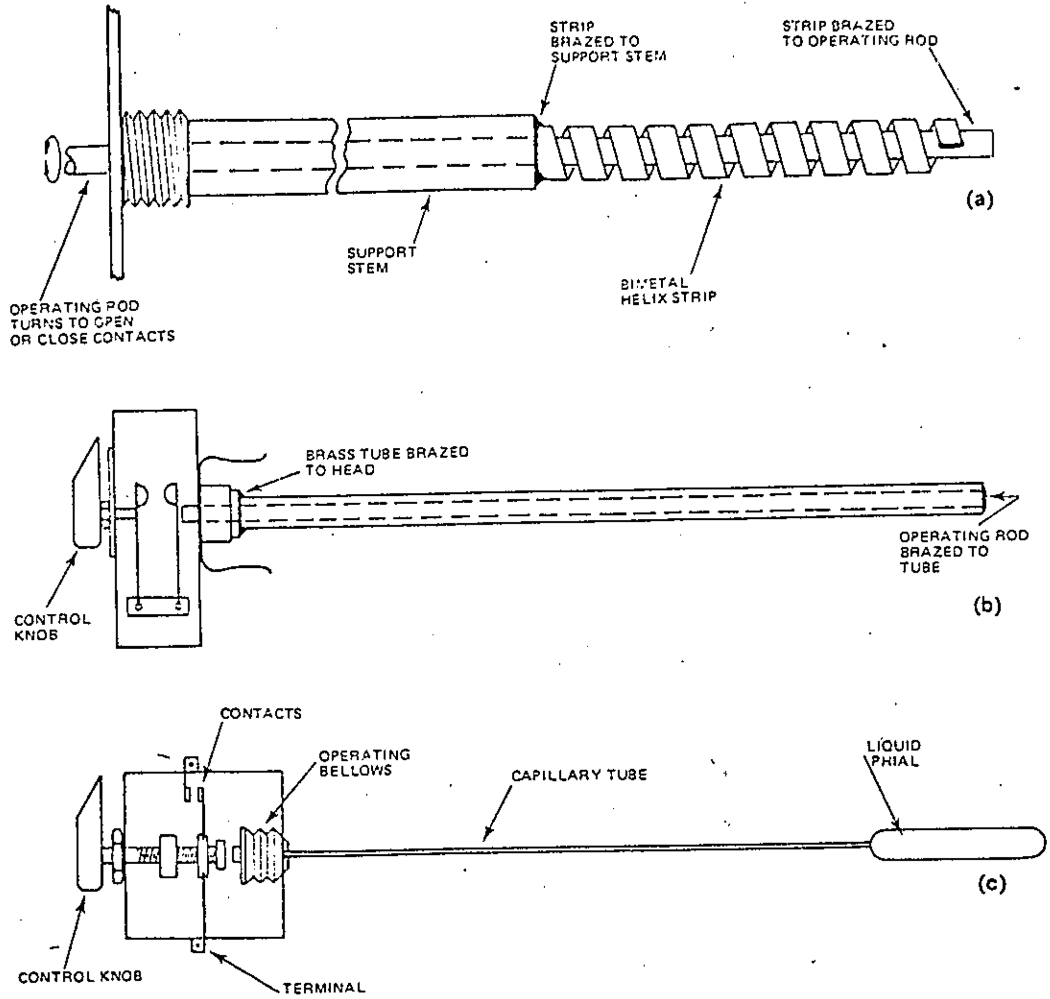
It is important to know the difference between a thermostat and a simmerstat. A thermostat senses the temperature to be controlled and controls it according to the thermostat setting. It is essentially a feed-back system.

The simmerstat on the other hand is not a feed-back system, once set it continues to supply energy to the load irrespective of temperature.

Thermocouples and thermistors commonly used for temperature indication may be included in control circuit to form a third group of control devices but they require expensive accessories so their use is restricted to sophisticated circuitry.



Simmerstat control



Principles of typical thermostat types: (a) Bi metal; (b) Expanding tube; (c) Vapour pressure

1) Bi-Metal Thermostat

The bi-metal Helix is fixed at one end to the supporting stem but is free to move or twist within its length. The other end of the Helix is fixed to the operating rod which is also free to rotate. A change in temperature causes the Helix and the operating rod to which it is attached to twist, thus opening and closing a set of contacts.

The rod itself is made of invar which is an alloy having a negligible co-efficiency of expansion.

2) Expanding Tube

The brass tube changes in length with temperature change. As the bi-metal thermostat, the operating rod is made of invar and is attached to the tube at one end but free to move at the other, it moves and operates the contacts.

3) Vapour Pressure

The liquid in the phial attached to the end of the capillary tube is sensitive to temperature change and internal pressure within the phial varies. Pressure change is transmitted through the capillary tube to the bellows which in turn actuates the switch contacts.

The advantage of this type is that the sensor and control head may be some distance apart.

Simmerstat

Consists of a heater which causes a bi-metal strip to bend, thus closing and opening contacts with a snap action.

The load and the simmerstat heaters are connected in parallel.

The current in the heater generates heat warming the bi-metal strip which bends and opens the switch contacts. This action interrupts the supply to both load and heater.

The bi-metal cools, the switch closes and the cycle is repeated.

The rate of time "on" and time "off" may be adjusted by turning the cam which adjusts the pressure on the bi-metal.

Because the load and the heater receive the same supply voltage, any variation in supply voltage does not affect the heat produced.

TITLE: Water Heater

DATE:

LECTURER:

EQUIPMENT:

Whether the installation is domestic, industrial or commercial, water heaters may be grouped as follows:

1) Instantaneous Heaters
2) Storage Heaters

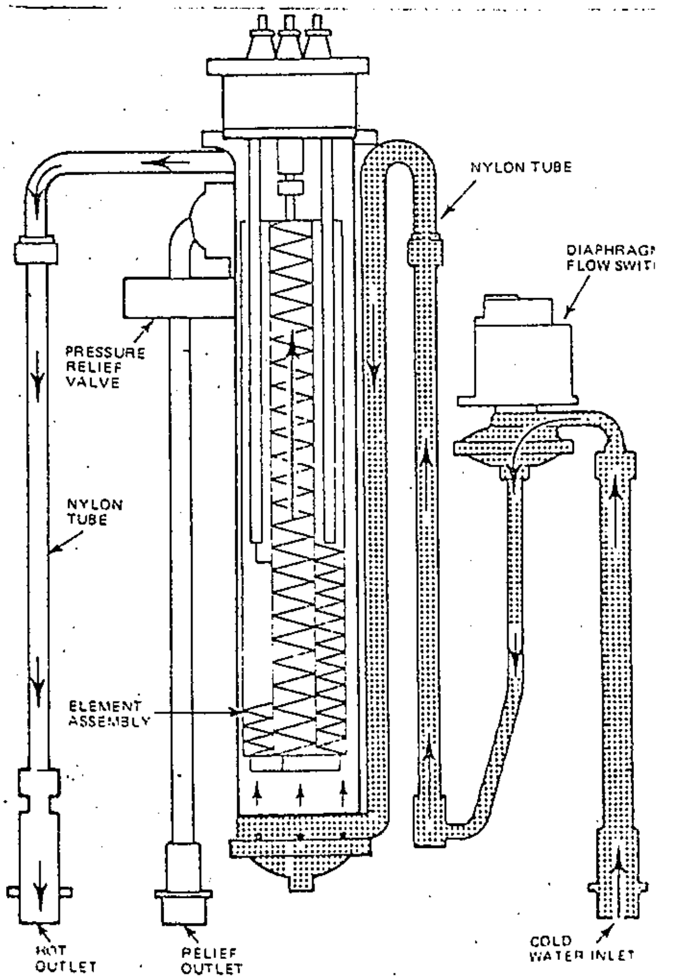
Storage heaters may be further classified according to their use and tariff rating into load groups of:

a) Continuous Water Heaters
b) Off-peak Water Heaters

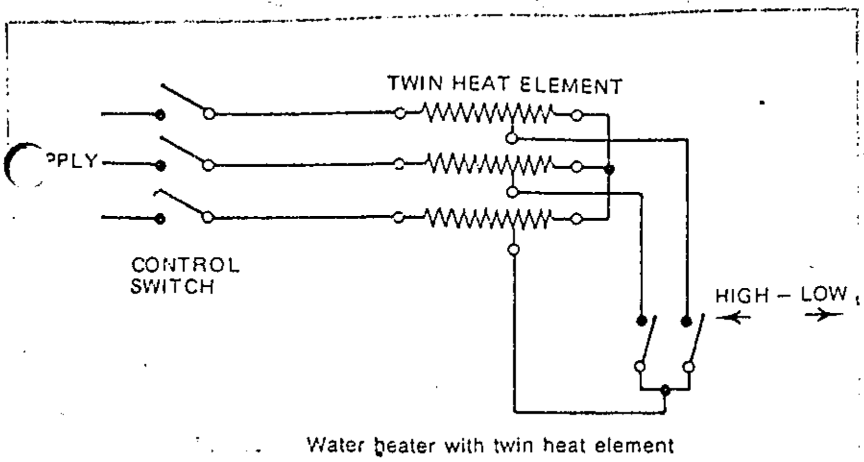
These classifications are used for maximum demand assesment.
Instantaneous water heaters only switch "on" when hot water is required.
Continuous water heaters are in circuit continuously as their name implies and have a storage capacity. Off-peak water heaters usually have a greater storage capacity than the continuous type as they are energised for only a restricted period.
Although storage water heaters are "on" for long periods, the water temperature is controlled by thermostat.

1) Instantanous Water Heaters

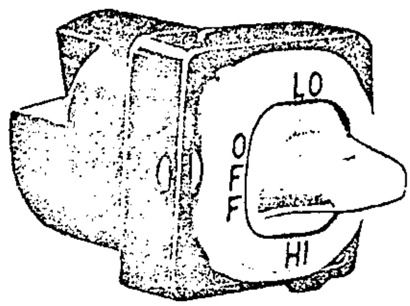
In this type the heating element is enclosed in a small copper container, making it essential to have water flowing through the heater.
The "on" and "off" controls may be manual or automatic.
Automatic control is achieved by a diaphragm "flow-switch" which is achieved by mains pressure water flow.
As the only method of regulating the water temperature is by varying the water flow, most heaters have a "high - low" switch fitted.
They are generally available as a three phase unit with element rated at 12A.15A.18A.23 Amps per phase.
Authorities discourage the installation of three phase instantaneous water heaters because of the high demand on the supply system and necessity of a three phase supply.



A three-phase instantaneous water heater. Diagrammatic section.



Water heater with twin heat element



Control of Heat by switching

Small single phase 240 volts 3.6 kw instantaneous water heaters are made, such as small over sink or hand basin types or the dux summer shower.

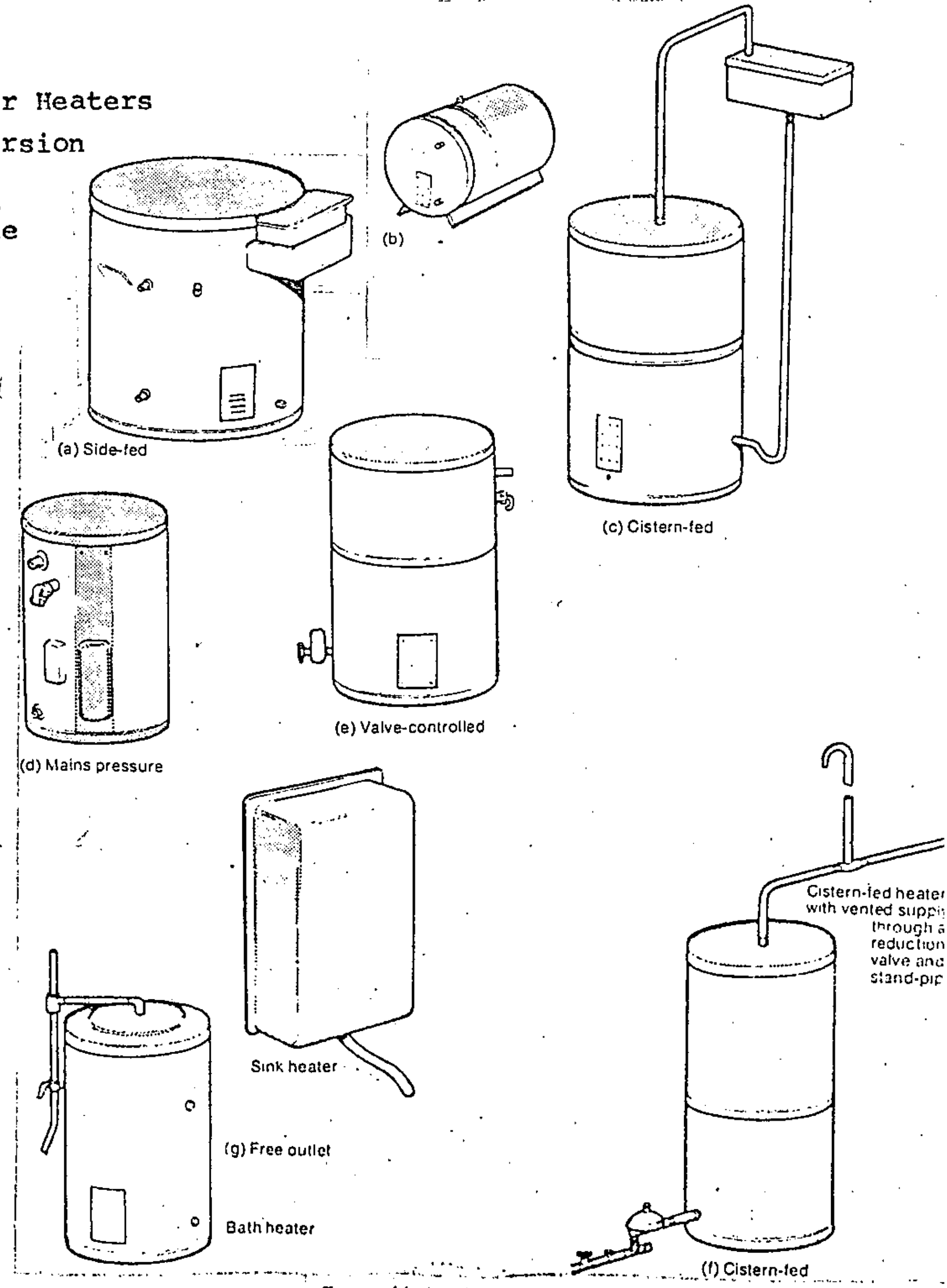
2) Storage Water Heaters

By the immersion of a bare or sheathed element in water, all the heat generated by the element of a storage water heater is absorbed by the water.

If the storage capacity is large enough and the heater supplies a multipoint installation, then the arrangement is called "Hot Water System".

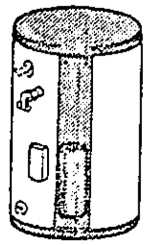
<u>Warning:</u>

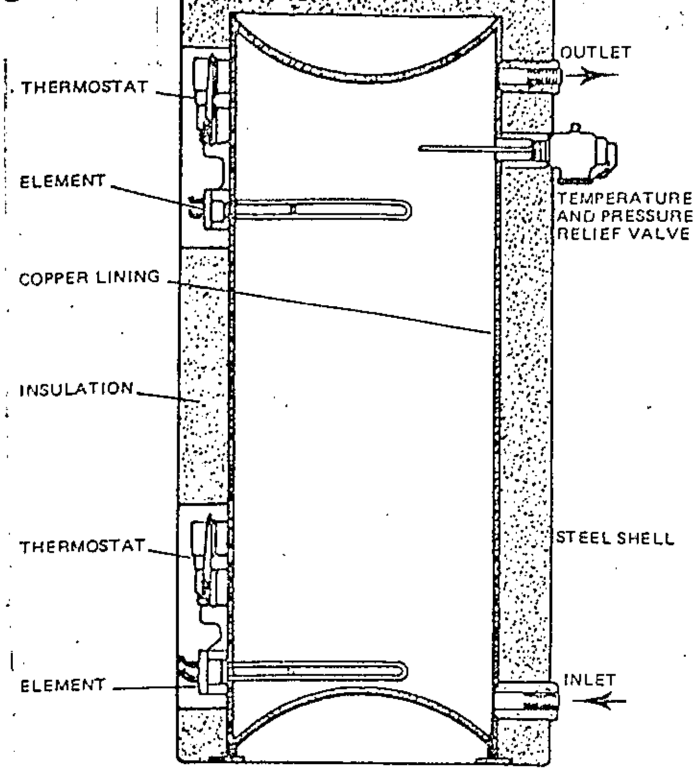
With any unvented water heater, under no circumstance should a thermostat or protective device be "bridged-out".



Types of hot water systems

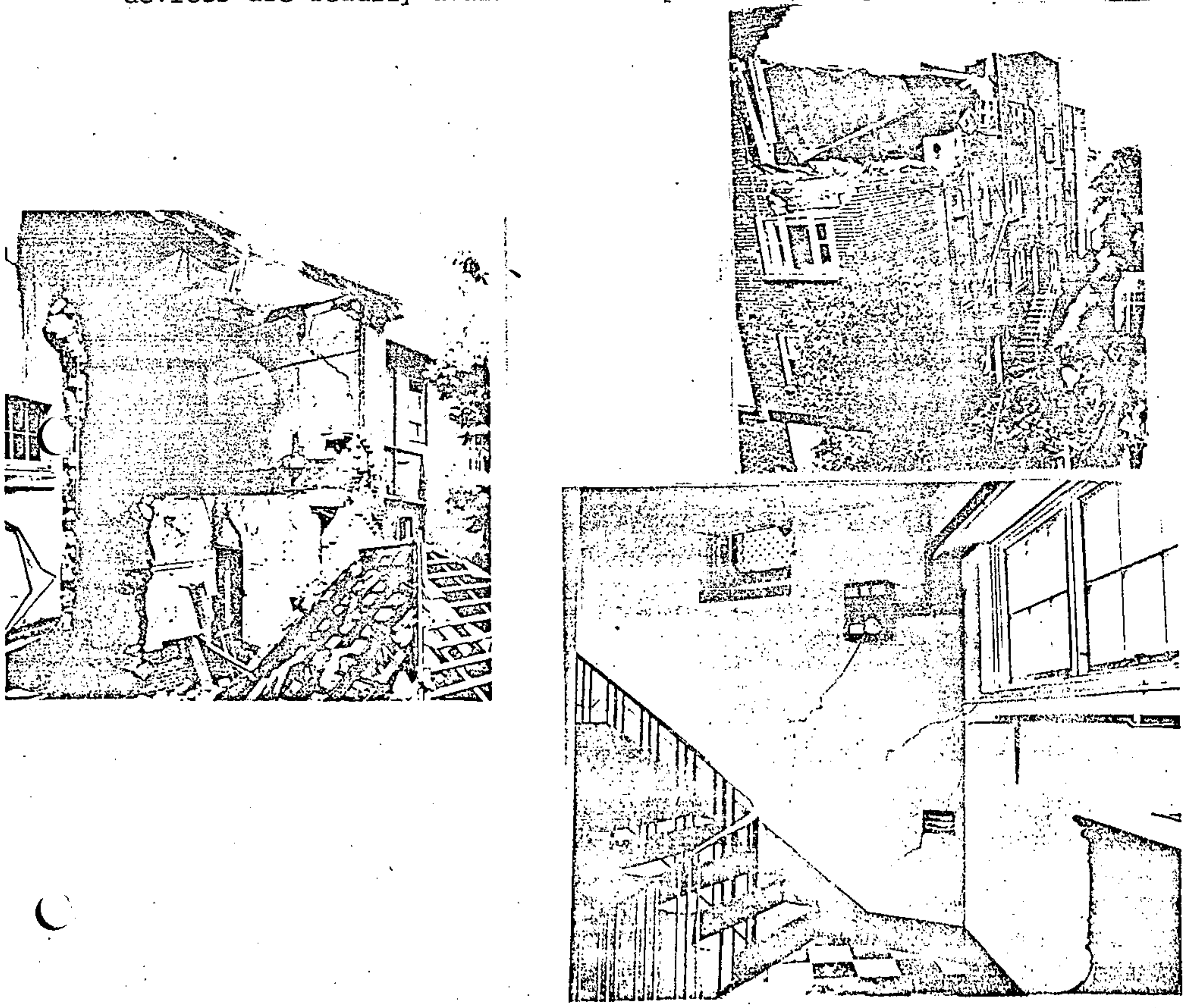
It is important to note that an unvented water heater should never be placed in service without the thermostat or protective cut-outs properly fitted and connected and the heater filled with water.





Mains pressure storage heater

Every unvented water heater shall be installed in such a manner that access to all terminals of the protective devices and safety devices are readily available for operation, inspection and adjustment.



Damage to buildings caused by explosion of unvented storage water heaters

Comparison of Commercial and Industrial type water heaters.

	Storage		Instantaneous
	Off-Peak	Continuous	
Operation	Providing the storage cylinder is of adequate capacity, this system will provide hot water without requiring daytime boosting. If necessary, an automatic booster element may be added to cover contingencies in demand.	Supply continuously available Higher rating elements capable of heating large quantities of water quickly are used so that similar cylinders may be employed to provide large volumes of hot water.	Cold water passes through a flow switch, automatically turning on the elements only when a hot tap is opened. The cold water is immediately heated as it passes over the elements, and none is stored. Temperature is controlled simply by a constant flow device.
Location	In the roof, on the floor, under the floor or out-of-doors if vented. If unvented, cannot be located in the roof or any unfrequented location.	In the roof, on the floor, under the floor or out-of-doors if vented. If unvented, cannot be located in the roof or any unfrequented location due to necessity to regularly operate exercising lever, but can often be closer to hot water outlets because of smaller size.	Physically small, and therefore easily located on any wall. Approximately 33 mm (13") high x 20 mm (8") wide x 10 mm (4") deep. Extremely simple plumbing.
Economy	Most economical to operate where there is a regular and fairly uniform daily demand for hot water.	More economical than off-peak in terms of space requirements, where space is at a premium.	Most economical to operate for small or irregular hot water demands.
Application	Hotels, motels, offices, shops, restaurants, factories, pavilions, or any commercial business requiring economical, reliable supply of hot water. Permits high flow rates without drop in temperature. Most suitable where ratio of maximum to minimum daily demand for hot water does not exceed about 2:1.	Suitable where regular daily use is assured or when all of the daily hot water requirements cannot be stored overnight. Mains pressure units are ideal for such applications. Falling level type boiling water units are used for tea and coffee making in commercial quantities. Capacity of boiling water units ranges from 9-450 litres (2-100 gallons) and may supply water continuously at 98°-99°C (208°-210°F).	Public showers, ablution blocks, communal laundries, and motel rooms. May be easily coupled with coin-in-the-slot meters. Used either alone or in association with other heaters for booster applications — up to 16.5 kW. The largest instantaneous heaters may take the form of electrode boilers which can be used for hot water supply and space heating in large commercial or institutional buildings, with or without hot water storage.

Table 12.1 Comparison of commercial and industrial-type water heaters.

TITLE: Space Heating

DATE:

LECTURER:

EQUIPMENT:

Space heating is a term that describes the heating of building space, to provide a comfortable and healthy environment and satisfactory temperature for goods and equipment.

Factors such as airflow, pollution and humidity have a bearing on personal comforts, appliances such as air-conditioners in some measure provide control over these.

Heat is transferred in three ways:

1) Radiation
Transfer of heat by means of electro-magnetic radiation.

2) Convection
Transfer of heat by circulation of medium (liquid or gas).

3) Conduction
Transfer of heat from one material to another by actual physical contact.

Space heating equipment is broadly classified into three main groups.

1) High temperature radiant panels or radiators.

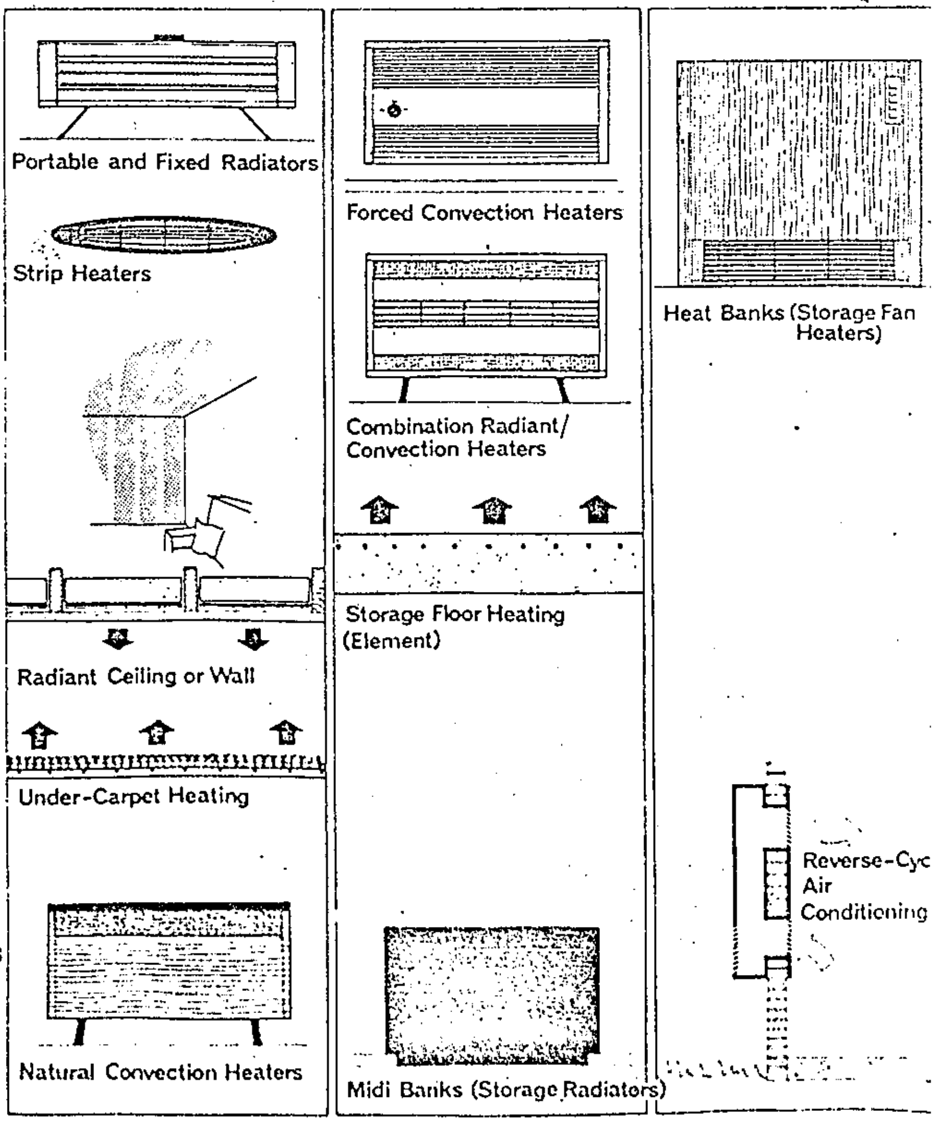
2) Low temperature panels, convectors and unit heaters.

3) Thermal storage type heaters.

The reverse cycle air-conditioner or heat-pump falls within a category of its own.

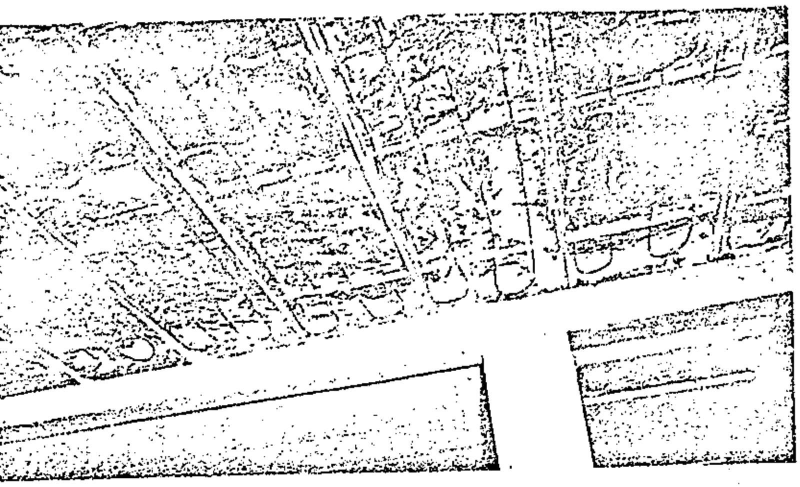
The radiators of group 1 have elements working at 1400°C . 1600°C, while operating temperature for radiant walls and ceiling panels would rarely exceed 300°C.

Under carpet heating by use of Mineral Insulated Metal Sheathed heating cable is a common form of space heating but it has many disadvantages



Some types of space heating equipment

The system is:
Expensive to install.
Relatively expensive to run since it is not suitable for "off-peak" operation.



Installing a heated ceiling

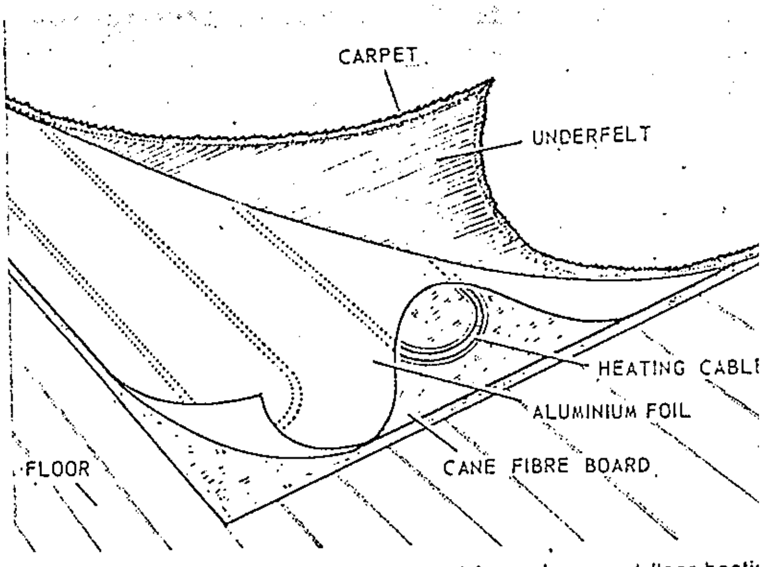


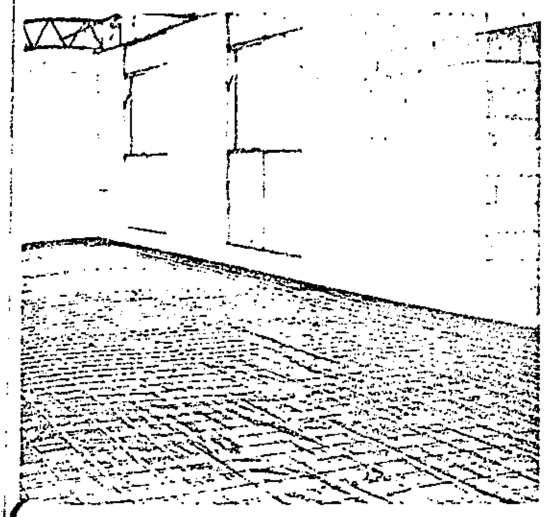
Fig. 12.17 MIMS heating cables may be used for under-carpet floor heating

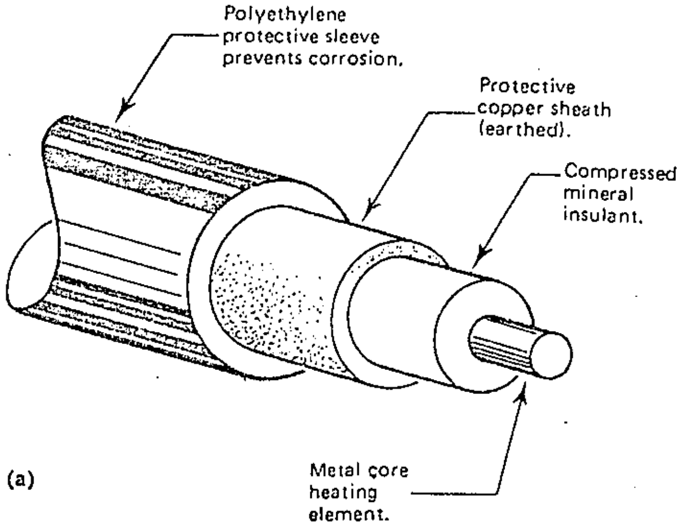
HEAT DISSIPATION PERCENTAGE
The rectangles in the table below represent the total heat output and the sections show the approximate proportions of radiation, convection, and conduction from the different heat sources.

Legend Radiation Convection Conduction

Type	Description	Application
Portable and Fixed Radiators	Rod type portable heaters from 750 watts to 2,400 watts, generally infra-red rod types with element enclosed in silica tube; permanently wired wall or console radiators for fixing to, or recessing in a surround. Up to 3.6 kW	Portable – for quick individual spot heat ing; for topping up other forms of heating during excessively cold periods; for heating in small rooms or rooms used intermittently. Heats the objects in fron of it by radiation.
Strip Heaters		As above, but particularly suitable for warming the drying area of the bathroom, out of the way heating, e.g. kitchen, children's play areas.
Radiant Wall Radiant Ceiling	Comfortably warm conditions mainly by radiation, without directly raising air temperature. Safety, automatic control (if desired), completely invisible.	Flexible, low temperature panels or fixed heating cables laid on ceiling or concealed in wall.
Under-Carpet Heating	As above, and the warmth at floor level gained by conduction is ideal where children play. Produces zero temperature gradient between floor and ceiling.	Specially insulated heating cable – mineral insulated metal sheathed – laid under floor covering, but insulated from structural floor.
Natural Convection Heaters	Cold air being drawn into the heater forces the warm air upwards, thus providing a continuous circulation without excessive air movement.	Small rooms and areas of low ceiling height where induced limited air movement is sufficient to heat all of the air in the room.
Forced Convection Heaters	More rapid circulation of air ensures quicker and more even heat distribution which is particularly useful in large areas.	Either drum or propeller fans force air over heating elements before circulation. Available as small portable units, larger capacity console heaters, or for building-in to wall or cupboard.
Combination Radiant/ Convection Heaters	(i) Two types of elements are included, one giving instant direct localised heating by radiation, the second providing heat by natural convection. (ii) Oil-filled panel and column heaters.	Generally portable, yet large enough to provide basic heating of moderate size rooms.
Storage Floor Heating Element	Heating cable embedded in concrete floor slab. Operated on low-cost controlled hours tariff and heat stored for use as required.	Central type heating – whole buildings. In new buildings with concrete floor slabs.
Midi Banks (Storage Radiators)	Heating element embedded in the heat storage core of a freestanding unit with free output characteristics. Operated on low cost controlled hours tariff.	Sole means of heating in dwellings with brick, masonry or concrete, internal walls (providing adequate heat storage capacity). Background heating where reinforced by auxiliary heating of other types in buildings of light construction.
Heat Banks (Storage Fan Heaters)	An insulated storage core to which a fan has been added (operated either manually or by thermostat) to extract heat when required. Operated on low-cost controlled hours tariff as above.	Buildings of any construction – new and existing.
Reverse-Cycle Air Conditioning	Mounted on an outside wall it pumps heat either into or out of the building. It is designed to heat a room in the winter, and by simple switching, cool it in the summer. It will also reduce the humidity on the cooling cycle. Auxiliary, direct elements may be necessary in the coldest weather.	Ideal for homes and flats giving controlled comfort in winter and summer.

Comparison of space heating equipment





(a)

Storage floor heating, which utilises heating cables installed in the concrete or tile bed prior to the finished surface being placed, has the advantage that it may be operated at the cheaper "off-peak" rate.

(b)

(a) Heating cables attached to reinforcing mesh prior to concrete pour (b) Ca embedded in the actual concrete slab. They are continually tested while concre being poured

The cables (about 5mm in diameter) consists of a central element embedded in an insulating material of compressed magnesium oxide encased in a polyethylene served copper sheathed and may be fixed to an anchoring strip or attached to the reinforcing mesh in a concrete slab.

Convection heaters may be classified as either natural convection units or forced convection using fans and pumps.

They also include free standing or built in panel or tubular types which may be water or oil filled and heated by an immersion element. They are often called radiators and do radiate about 50% of the heat produced.

All storage type heaters, if of sufficient heat storage capacity, are suitable for "off-peak" tariffs.

The use of "off-peak" tariffs is dependent upon supply authority's approval.

A modern trend is to integrate lighting, heating and airconditioning systems by using systems of ducts, fans and heat pumps on a controlled closed network, thus utilising what years ago was waste heat.

As an example, the heat dissipated from the lighting installation of a large office building (even with flourecent lighting) is sufficient to make a major contribution to the heating load.

Process Heating

Use of electrical means for producing heat is widespread because:

1) Electrical heating is clean and makes pleasant working conditions.
2) With no open flame the fire risk is lower.
3) Temperature and automatic control of the heating process is easily achieved.
4) Electrical equipment is usually more compact than equipment using other fuels, thus saving space.
5) Automation is relatively easy.
6) Higher temperatures and heating rates are obtainable.

In process heating the methods used for the conversion and transfer from electrical energy to heat energy could be roughly classified as:

a) Resistance heating using some form of element.
b) Infra-red heating from a source of infra-red radiation such as lamp or strip-heaters.
c) Induction heating by inducing "eddy-current" in the work piece or the melt.
d) Dielectric heating of non-conductive material, such as plywood or plastic by the use of an electric field to speed up molecular movement within the material.
e) Arc heating by using the heat generated in an electric arc as in an arc furnace.

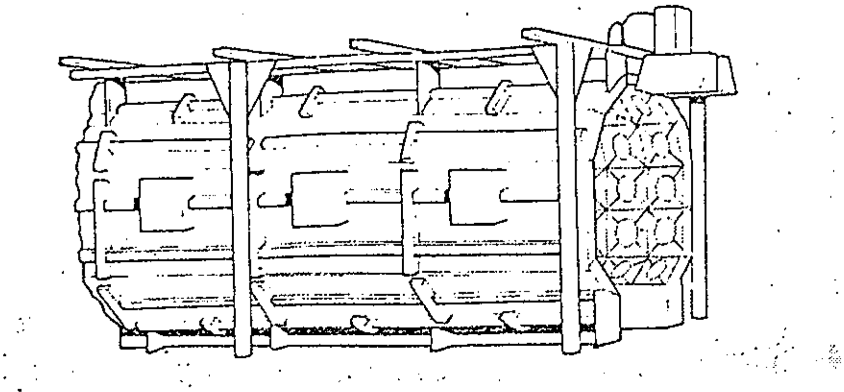
a) Resistance Heating

The heat generated in an element is transferred to the material being heated by radiation, convection, or conduction depending on the application.

Elements may be wire strap or a solid such as silicon carbide.

b) Infra Red Heating

This is a direct radiant heat method where the source of infra-red may be lamps with internal reflectors, metal sheathed strip elements in reflectors or silica sheathed elements or quartz tube lamps in reflectors.



An infra-red oven

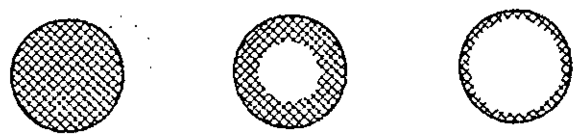
Electricity Supply Association of Au

c) Induction Heating

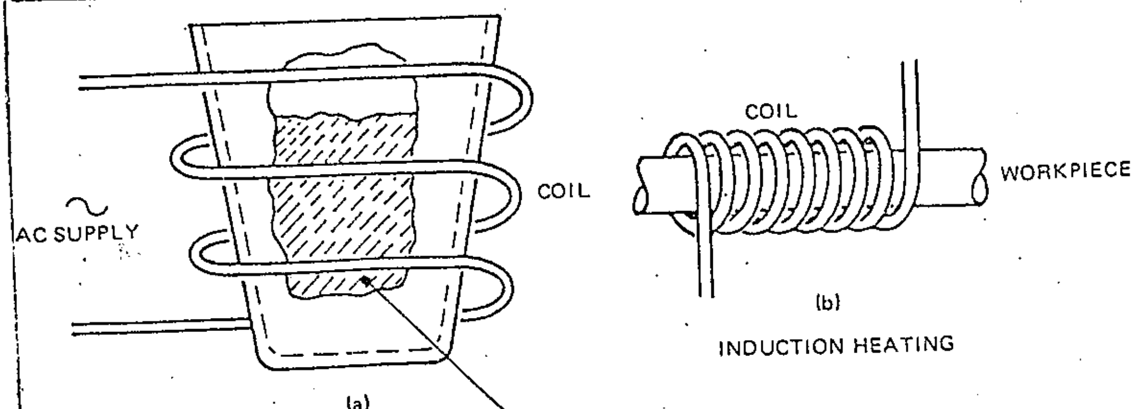
In this system, the metal workpiece of the material being heated becomes the "core" of a coil which is energised from an A.C. source.

Eddy currents are included in the conductive workpiece due to the alternating magnetic field of the coil. The heat generated will depend upon the magnitude of the current, the time, the resistivity of the material frequency of 50 HZ up to 5 MHZ are used depending upon this application.

This system was originally to melt metals. It's uses are now spreading to heating, welding, brazing, soldering and case hardening.



Skin effect of a.c. utilised in case hardening of metals



Principles of induction heating

d) Dielectric Heating

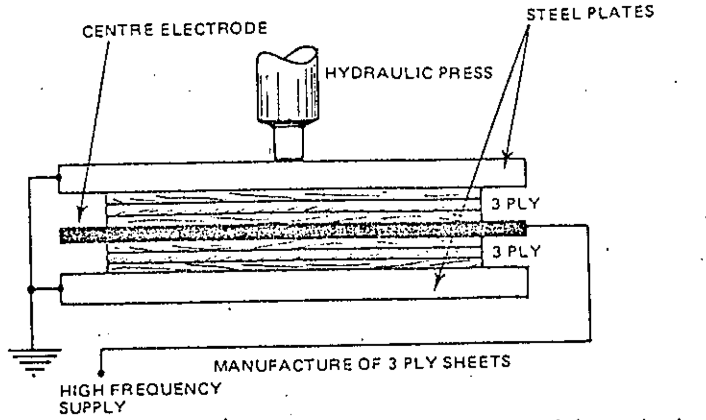
If a non conductor such as wood, glue or plastic is placed between two electrodes and A.C. supplied to the electrodes, the electrostatic field produced speeds up the movement of the molecules in the dielectric between the electrodes and heats it.

This method is extensively used for the heating of thermosetting sinthetic glues and the welding of plastic. It is also used in the food-stuff industry for defreezing, sterilization and disinfecting and drying of breakfast cereals.

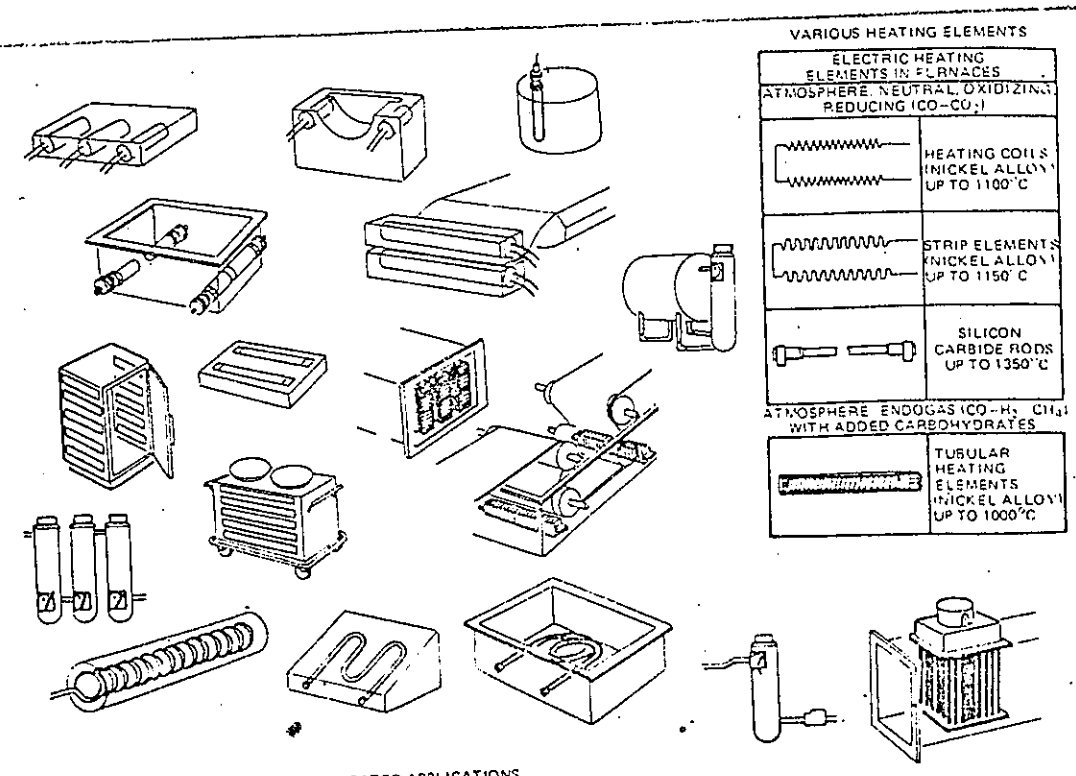
c) Electric Arc

Direct arc type furnaces are used in the steel industry, this type having a melting capacity of 150 t are called direct arc types. The arc takes place between electrodes and the melt or the charge. In the indirect arc type or the rocking arc furnace, the charge is heated by an arc established between horizontally opposed graphite electrodes connected to single phase supply and heat transfer is mainly by radiation.

The furnace rocks continuously to ensure thorough mixing. It's capacity is from 2.25 kg to 45 kg.



Dielectric heating applied to the manufacture of three-ply shee



Resistance heater applications and furnace eleménts

CHEMICAL EFFECTS OF AN ELECTRIC CURRENT

ELECTROLYSIS

Conductors or electric current may be divided into two classes:-

(a) Metallic or Electronic conductors, e.g. Copper, Aluminium, zinc, graphite.

(b) Electrolytic Conductors or Electrolytes. (An electrolyte being any liquid capable of allowing a current to pass through it.)

Typical of this latter class are aqueous solutions of acids, alkalies, and salts; and substances such as lead chloride, cryolite, and caustic soda, when in the fused or molten condition. In both these classes of conductors the current produces the well-known heating and magnetic effects, but there is this fundamental difference. The passage of a current through electrolytes is accompanied by certain chemical changes at the places where the current enters and leaves the liquid. These chemical changes which are brought about by the electric current are termed "Electrolysis."

Pure water is almost a non-conductor of electricity, and the addition of substances such as sugar, glycerine and alcohol does not promote conduction, but when a small amount of sulphuric acid, common salt, or bicarbonate of soda is dissolved in the water, the solution becomes a moderately good conductor. Conductance is therefore a function of the solvent, (in this case water) and of the dissolved substance.

EXAMPLES OF ELECTROLYSIS

The following experiment illustrates the chemical changes which are brought about by an electric current. Four cells are arranged and connected with a battery.

(b) They Contain:-

(i) pure water (expressed in chemical symbols as H_2O),
(ii) silver nitrate ($AgNO_3$),
(iii) copper sulphate($CuSO_4$), and
(iv) sodium chloride (NaCl) common salt solutions.

The parts of the conductor which bring the current into and lead it from the liquid are called ELECTRODES.

For most experiments these are made of platinum because this material is unaffected by the acid or alkaline solutions, practically all other metals being eaten away.

The electrode (a) at which the current enters is charged POSITIVELY, and called the "anode", and that by which it leaves (c) is charged NEGATIVELY and is known as the "cathode."

A vessel so equipped, and containing an electrolyte, is an ELECTROLYTIC CELL, and if gases are being evolved they can be collected and measured by inverting test tubes filled with the liquid over the electrodes as in the first cell. By closing the switch S the circuit is completed, but it will be found that practically no current passes.

The reason is that the pure water of cell (i) is an extremely bad conductor. The addition of a very small amount of sulphuric acid will, however, make it a conductor and the current will then pass and give rise to the following changes: -

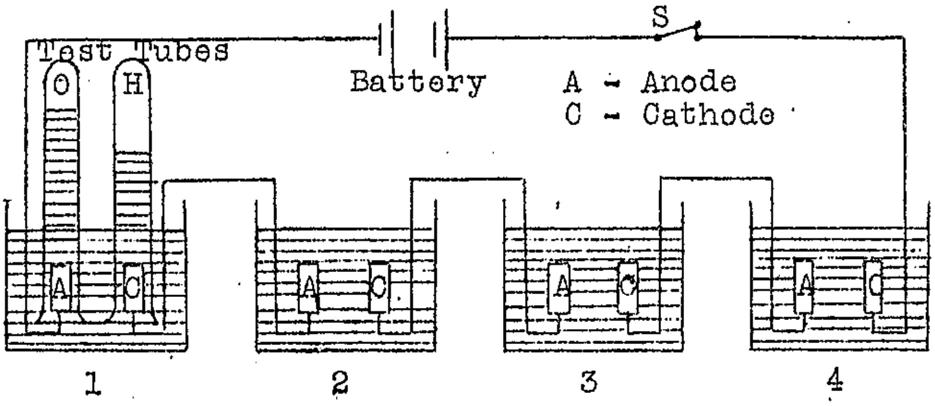


Figure 1

At the Anode (+)	At the Cathode (-)
Cell (1) One volume of Oxygen liberated Sulphuric acid also concentrates at this electrode.	Two volumes of Hydrogen liberated.
Cell (ii) Oxygen liberated. Nitric acid concentrates at electrode.	Silver is deposited on electrode.
Cell (iii) As in Cell (i).	Copper is deposited on electrode.
Cell (iv) Chlorine is liberated and some oxygen, the relative amounts depending on the strength of the solution.	Hydrogen gas is evolved and caust: soda (NaOH) concentrates at the electrode.

These are typical examples of chemical changes brought about by the aid of electrical energy, and as a general rule Hydrogen and the metals are liberated at the cathode or negative pole and are said to be electro-positive. The hydrogen comes away as a gas and can be collected.

The metals like silver, copper or nickel are deposited (this being the principle of electroplating, etc,), as a film on the surface of the electrode. The metals sodium (Na) and potassium (K) cannot be usefully obtained in this way, for they immediately react with the water, producing caustic soda or potash and hydrogen by ordinary chemical action.

MECHANISM OR OPERATION OF ELECTROLYSIS

According to theory which is now generally accepted, when a substance such as sulphuric acid or silver nitrate is dissolved in water, the molecules may split up into sections which are electrically charged, some positively and others negatively. These charged portions are known as IONS and the process of breaking up the liquid into these electrified particles is called IONIZATION.

The extent of this ionisation depends on the nature of the substance, and also on the degree of dilution. Thus if equivalent amounts of sulphuric acid, and acetic acid are dissolved in the same volume of water, the former will produce far more ions than the latter, Sulphuric acid is a "strong" electrolyte and the acetic is said to be "weak". If water be added progressively to these solutions the number of dissociated molecules increases until all have broken up into ions. Naturally actual number of ions per unit volume of solution will be reduced by the dilution. For a strong electolyte such as sulphuric acid the amount of water which must be added to bring about the complete ionization of the molecules will be far less than in the case of a weak electrolyte like acetic acid. Some substances such as sugar do not ionise when disolved in water and hence do not produce electrolyte

In ordinary concentrations of solutions, molecules and ions are "wandering" in all directions. Some of the ions may be uniting to reform molecules and some of the molecules breaking up to produce more ions, but a balance is maintained and the average number of each is constant for a given concentration of solution. The positively charged ions are called cations, (pronounced "cat-ions"), and the negatively charged ions, anions (pronounced "an-ions").

From what has been previously stated, it may be reasonably assumed that the cations will be atoms of hydrogen, copper, silver, and other metals bearing a positive charge or charges. The residue of the molecule will take up the negative charge or charges. An ion may therefore be defined as an atom, or group of atoms carrying electrical charges. According to the electron theory the cations are atoms or groups of atoms minus one or more electrons. The anions will be atoms or groups of atoms with the addition of one or more electrons

Some typical ionisation equations-

$$H_2O \longrightarrow H^+ + OH^-$$
Water

$$H_2SO_4 \longrightarrow 2H^+ + SO_4^{--}$$
Sulphuric Acid

$$CuSO_4 \longrightarrow Cu^+ + SO_4^-$$
Copper Sulphate

$$NaCl \longrightarrow Na^+ + Cl^-$$
Common Salt

The ions move freely in the solution in all directions. When the circuit is completed with two electrodes and a battery, an electric field is produced in the electrolyte and the positively charged particles, the cations, are attracted to the negative electrode or cathode. It is because they are always trying to move to the cathode that they are called cations. The anions behave in a similar way, but move in the opposite direction. There will, therefore, be a stream of cations (+) moving in one direction towards the cathode, (-), and a stream of anions (-) making for the opposite pole or anode (+). This constitutes the electric current in a solution, and the ions are the carriers of the electricity. When the ions reach the discharged elements assume their ordinary properties.

Thus silver, copper, and nickel ions lose their positive charges at the cathode, becoming ordinary metallic silver, copper and nickel, and are deposited or "electro-plated" on the electrode as a thin film. Hydrogen ions when first discharged yield atomic hydrogen, but one atom of hydrogen cannot exist as such, it unites with a second atom to form the molecule (H_2), and escapes as a gas.

The electro-negative groups of atoms, when their charges are neutralised at the anode react with the water, or the material of the electrode, or are liberated as gas.

If the anode is a metal such as silver or copper which can be attacked by the anion, the metal gradually dissolves, forming a salt which dissolves in the water and produces a fresh supply of metallic ions. The concentration of the metallic ions in this case remains undiminished and this is an important factor utilised in electroplating and copper refining. Thus, when copper sulphate is electrolysed using copper electrodes, pure copper is deposited on the negative pole, whilst the positive pole, which may even be the impure copper, is attacked by the sulphuric acid produced so giving a fresh supply of copper sulphate in solution.

ELECTROPLATING

This is the commonest application of electrolysis, and consists in depositing silver, gold, nickel, copper, zinc. etc., upon baser and more corrodible metals, or even upon non-conducting materials such as wood, plaster of Paris, wax, etc. Which can be rendered conducting by coating them with a layer of graphite. The object to be plated is immersed in a suitable solution or "bath" containing a salt of the metal which is to be deposited, and a current passed in such a direction that the object acts as the cathode.

In order to maintain the strength of the solution, the anode is usually a plate of the metal that is being deposited.

The essential parts are:-

(a) A vat of wood, slate, iron or lead, depending on the type of metal to be electroplated.

(b) A solution containing an electrolyte which holds in solution the metal solution constant.

(d) Metallic object to be plated, and which forms the cathode.

(e) A source of D.C. supply from 3 to 7 volts, and a current flow of 3 to 40 amps. per square foot. of surface of object to be plated.

The vat has three heavy copper rods laid along it, the outer pair being connected to the + supply lead while the centre one is connected to the - lead. The anodes which are to be eaten away to replace the metal taken out from the solution are connected to these outer rods while the objects to be plated are hung by wires from the centre rod or cathode. The placing of the + electrodes on either side of the plated objects is to ensure even distribution of metal on objects to be plated.

The objects are first cleaned in a caustic or acid solution to free them from dirt and grease. In some cases they are actually put in a plating tank and used as anodes so stripping or eating their outer surface away to a greater extent than a plain chemical bath could do.

The current is adjusted so that a satisfactory coating is obtained in a reasonable time. Too heavy a rate of deposition often results in a rough or discoloured coating.

Metals which are commonly deposited by electroplating are copper, brass, nickel, chromium, silver, lead, zinc, gold and other precious metals. In the case of chromium an anode of that metal cannot be used. Instead a lead or iron anode is employed and the chromic acid in the electrolyte must be constantly replenished.

ELECTROLYTIC REFINING OF METALS

FUNDAMENTAL PRINCIPLES

In electrolytic refining of metals the starting material is a highly concentrated alloy or mixture of metals, and the purpose is to remove the last impurities and to recover not only the principal metal in pure form, but also the foreign metals, especially the precious metals. The impure metal is made the anode, and the fundamental principle of the process is that by the electrolytic action the metal to be refined is dissolved from the anode and passes into the electrolyte.

At the cathode the pure metal is deposited alone. This cannot be satisfactorily accomplished, except with a comparitively pure, high-grade anode; in practice of copper refining the impure copper anode is generally 98% - 99% pure.

COPPER REFINING

The electrolyte is a copper sulphate solution containing free sulphuric acid. The copper content usually is between 3 and 3.75% and the free sulphuric acid is between 15 and 18%. (Usually a very small amount of a soluble chloride, like NaCl, is added to precipitate as chloride any silver which may dissolve and to slime antimony as oxychloride.)

An anode of typical composition contains 99 to 99.3% copper, up to 110 oz. silver per ton, up to 7 oz. gold per ton, and up to 0.07% arsenic. The cathode copper is exceedingly pure, usually running about 99.93% copper, with hydrogen as the chief impurity. In order to have arsenic and antimony (the amount should be but a few thousandths of a percent.); in order to prevent brittleness, the cathode copper must be free from tellurium and lead. Since the electric conductivity of copper indicates its purity, it is commonly used as a measure of the purity.

It is customary to circulate the electrolyte from tank to tank and this is more important the higher the current density. The current density varies in different refineries, usually between 16 and 28 amps. per sq. ft. The question of what current density to use is largely one of energy cost. A heated electrolyte is used, and soluble sulphates of impurities in the anode pass into the solution which therefore needs purification at intervals.

ELECTROLYTE CORROSION

Chemical attack on metals usually forms reaction products which retard further attack unless the product is liquid volatile, porous or flakes off or cracks. Probably the most destructive corrosion results from indirect electro-chemical attack, frequently thought of as chemical in nature.

The best known galvanic or electrochemical corrosion occurs when two dissimilar metals are in contact in the presence of an electrolyte. In this case a galvanic couple is created and is short circuited on itself through the electrolyte. The metal of higher potential will become the anode, tend to go into solution in the electrolyte and therefore, corrode. An almost indentical condition is obtained in an alloy which is not perfectly homogeneous or in a metal of which different parts have been subjected to different heat treatments or mechanical stresses.

Under these conditions, certain parts will have a higher potential than others, and in the presence of an electrolyte, a galvanic couple is formed. The part of higher potential will tend to go into solution and corrode. The electrolyte need only be rain water with impurities dissolved from the air or from the surface of the metal itself.

When different parts of a metal have unequal access to oxygen, the parts more greatly exposed acquire on their surfaces thin films of oxide or hydroxide. The part protected from oxygen then has a higher potential, tends to become an anode, and corrodes in the presence of an electrolyte. An example of this is the corrosion of a steel sheet or bar partially immersed vertically in brine. Corrosion occurs much more rapidly on the lowest portion than on the part immediately below the surface of the liquid where oxygen has greater access to the metal. Because of the lesser oxygen content at that level, the lowest part becomes anodic and corrodes - the portion just below the liquid level becomes cathodic and is protected. Another example is in the corrosive behaviour of a drop of brine on the surface of a piece of steel or iron. Corrosion is much more pronounced under the centre of the drop, where oxygen is at a minimum, than around the edges.

It will be appreciated that should an acid flux be used for soldering the joints of an electrical circuit and then not wiped clean or neutralised, there is every likelihood of a chemical reaction (corrosion of wires) taking place on the passage of an electrical current. This may cause open circuits in fine wire in transformers and motors.

Also the use of wax or varnish which is acidic may not only ruin the insulating properties of compenents such as condensers, but may also cause corrosion in fine copper wires.

PRODUCTION OF AN E.M.F. BY CHEMICAL ACTION

CELLS

Two different electrodes immersed in an electrolyte will set up an E.M.F. A necessary condition for this is that one of the electrodes (usually metals) is acted on chemically by the electrolyte.

The table given below shows how various metals develop a difference in electrical potential when placed in some active electrolyte which is usually dilute sulphuric acid (H_2SO_4). Exceptions to this normal electrolyte are given in the actual descriptions of the different types of cells.

Each metal has been placed in such an order that the first is always positive to that of any others following. Obviously the greatest difference in potential will be developed between the first and the last, namely carbon and zinc, hence its use in modern dry cells.

1. Carbon
2. Platinum
3. Gold
4. Silver
5. Copper
6. Antimony
7. Bismuth
8. Nickel
9. Iron
10. Lead
11. Tin
12. Cadmium
13. Zinc

PRIMARY CELLS

SIMPLE VOLTAIC CELL

If a rod of copper and a rod of pure zinc are partially immersed in dilute sulphuric acid, no action occurs until the free ends are connected by a conducting wire, in which case a current is found to pass from the copper to the zinc along the wire. The zinc rod gradually dissolves and it is found that it forms zinc sulphate in solution, whilst hydrogen gas is liberated in the neighbourhood of the copper rod and not at the zinc rod. A difference of potential is set up between the two metals which is known as the electro-motive force of the cell. Other pairs of metals and other electrolytic fluids may be used, but it is necessary that one of the two metals shall be acted upon chemically by the fluid.

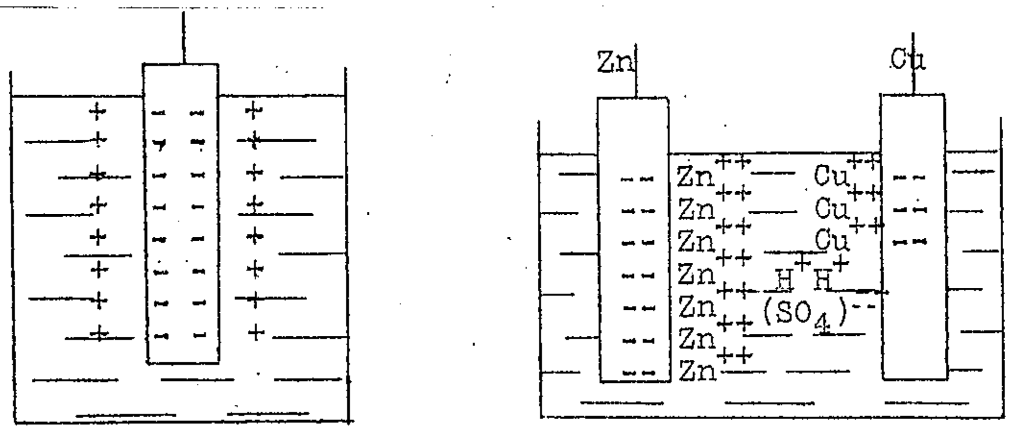
The theory of action of primary cells is quite complex, but a fairly good picture of what occurs can be drawn if the assumption is made that the ions of metals immersed in an electrolyte have a tendency to leave the metal and enter the electrolyte in the immediate vicinity. (Figure 2.) This, as metallic ions carry a + charge, leaves an excess of electrons on the metal itself, the attraction between the charges preventing the ions from wandering away and ultimately balances the tendency for more to leave the metal. In the simple cell with zinc and copper in sulphuric acid solution, the acid ionises thus the tendency of the metal ions to

$$H_2SO_4 \longrightarrow 2\,(H)^+ \qquad (SO_4)^{--}$$

enter the solution (termed the "solution pressure") is greater in zinc than in copper, and the number of zinc ions that enter the solution, before the attraction between the charges balances the solution pressure, is larger. Also the positive charge in the solution in the vicinity of the zinc is higher than that near the copper, thence the negative $(SO_4)^{--}$ ions tend to move towards that region and the positive $(H)^+$ ions move in the opposite direction.

This movement does not begin till the zinc and copper rods are joined by a conductor. There are more electrons on the zinc rod, by virture of the escape of more $(Zn)^{++}$ ions, then on the copper and the tendency is to equalise the charges by flow of electrons from zinc to copper. (Figure 2.) This frees some $(Zn)^{++}$ ions, which combine with the $(SO_4)^{--}$ ions to form the compound $ZnSO_4$, zinc sulphate. The solution pressure now being unbalanced, more $(Zn)^{++}$ ions can leave the metal and the process goes on as long as the rods are joined. The $(H)^+$ ions move to the copper rod, which having gained electrons from the zinc one, has actually withdrawn $(Cu)^{++}$ ions from the solution and now gives up electrons to the $(H)^+$ ions. These, being neutralised, become ordinary hydrogen atoms, and bubbles of this gas soon form on the copper plate. The copper having lost electrons, is able to draw more from the zinc and so the process goes on. Note that electrons flow from zinc to copper through the wire and from copper to zinc through the solution being carried on the $(SO_4)^{--}$ ions.

This theory is included here for the sake of completeness and to help students to understand the action of primary cells in general but it is not necessary to memorise it.



+ ions have left the metal which now carries a - charge.

Ions in a simple cell.

Figure 2.

POLARISATION IN CELLS

The simple copper-zinc voltaic cell is of little practical use, since its current weakens rapidly when working. This defect is due to the layer of hydrogen bubbles which adhere to the surface of the copper plate, thus, in the first place, reducing its effective area, and since the hydrogen is a thin insulating film the internal resistance of the cell is increased. Moreover, since hydrogen collects at one electrode, a new voltaic cell is produced with hydrogen as the active element which gives an E.M.F. in the reverse direction. This is a typical case of chemical polarisation in which new "poles" are produced by the substances liberated, thus diminishing the original E.M.F. of the cell. To overcome this difficulty the hydrogen must be removed, either mechanically or (preferably) by chemical means.

LOCAL ACTION IN CELLS

Common zinc contains many impurities, such as iron, lead, arsenic, etc.; these together with the zinc, being in contact with the acid give rise to a number of small local cells all over the surface of the plate, the result being that the latter is consumed without any advantage being gained therefrom. This "local action" is prevented by AMALGAMATING the plate, i.e., coating its surface with mercury. The mercury dissolves the zinc, forming a uniform amalgam, which covers up the impurities; as the zinc is consumed the impurities fall to the bottom of the cell. Local currents between portions of the plate differing in hardness are also prevented by this device.

TYPES OF CELLS

LECLANCHE CELL

This cell is an improvement on the simple cell because means are taken to overcome polarisation. In this cell the electrodes are carbon and zinc and the electrolyte is sal ammoniac (ammonium chloride, NH_4Cl). These products an E.M.F. of 1.5 V.

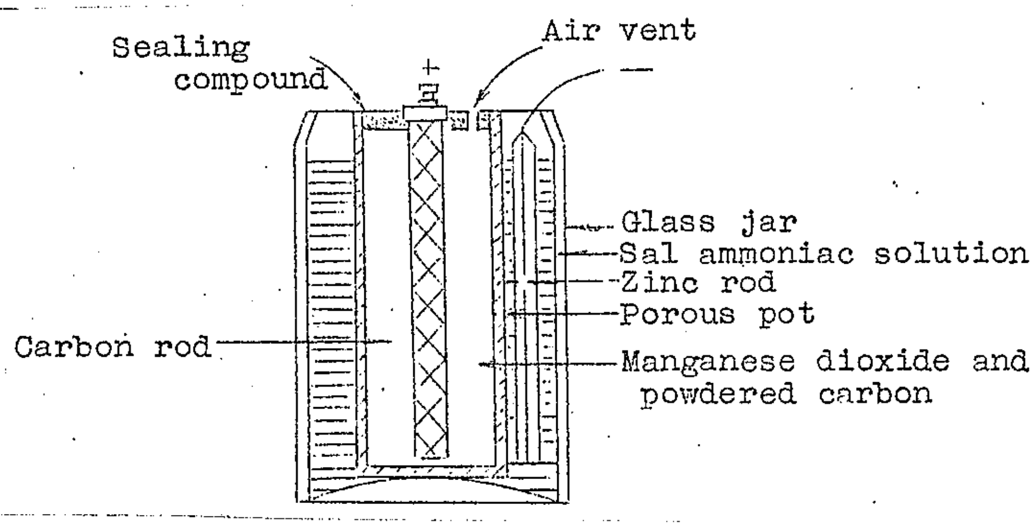


Figure 3.

The carbon rod is placed centrally in a porous pot and pressed tightly around it is a mixture of the Manganese Dioxide and graphite. The action of the Manganese dioxide is to give some of the oxygen which it possesses in chemical combination to the hydrogen bubbles to form water, thus tending to overcome polarisation. The graphite does not act as a depolariser. Its purpose is to act as a conductor of electricity since Manganese dioxide is a non-conductor. The pot must be porous to allow the penetration of ions. The pot is contained in a glass jar holding the electrolyte. The zinc rod Zn is also placed in the electrolyte and the cell is complete.

The Leclanche Cell is only useful for intermittent work, such as operating electric bells. Should a continuous current be taken from it, the depolariser, (manganese dioxide) cannot oxidise the hydrogen bubbles quickly enough and the cell is rendered useless by polarisation. If, however, the cell is left for a time, it will recover itself.

DRY CELL

The dry cell is an improvement on the Leclanche cell because in it, the electrolyte is made in the form of a paste and the outer glass jar is replaced by a zinc can which also serves as the negative electrode. The porous pot is replaced by a linen bag. Thus the cell is made portable and compact. The name DRY cell is really incorrect because if the cell is dry it is useless. The carbon rod is packed tightly about with a mixture of Manganese dioxide and graphite and is then tied firmly in a linen bag. This is then centrally placed by means of spacers in the zinc can, the inside bottom of which is protected from corrosion by waxed cardboard. Into the zinc can is then placed a paste of water, flour or starch, salammoniac and some mercuric chloride (the mercury which serves to amalgamate the zinc and prevent to a certain extent, local action). The whole is then boiled and the paste forms into a thick glue-like substance. The top is then covered off with sealing wax and the cell provided with a card-board cover.

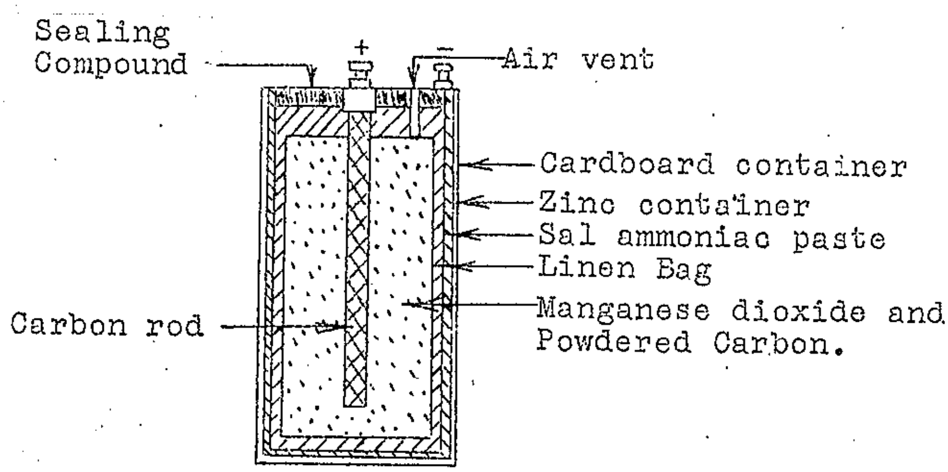


Figure 4.

The E.M.F. of a dry cell is 1.5 Volts. This decreases as the cell ages because the electrolyte gradually dries up. For this reason the internal resistance of the cell increases as the cell ages. The normal current drain from a cell is determined by its size.

Too great a current should not be taken from a dry cell. The depolariser would not be able to do its work quickly enough, and the cell would be affected by polarisation. Also the heat developed by the excess current would quicklydry up the electrolyte and be detrimental to the cell.

SHELF LIFE OF CELL

By this is meant the length of time a cell remains useful even though it is not being used. This determined by two factors within the cell:-

1. The drying up of the electrolyte.
2. Local action.

The drying up of the electrolyte, which is the main factor, is determined in turn by local conditions and on how a cell is stored. It should be kept upright in a cool, dry place.

THE EFFECT OF INTERNAL RESISTANCE OF CELLS

When a cell is driving a current around a circuit, some of its voltage or pressure will be used up in pushing the current through the inside of the cell.

We should regard a cell as combination of two things:-

(a) A source of E.M.F.

(b) A conductor, with resistance.

Suppose we have a dry cell of E.M.F. 1.5 Volts and internal resistance .1ohm and its terminals are connected by a resistance of .4o ohm.

The total resistance of the circuit = .5 ohm

Current = 3 amps.

P.D. across external load = 1.2 V.

This P.D. is sometimes referred to as the working voltage, external voltage, load voltage, terminal P.D. on closed circuit, or simply as the P.D. of the circuit = 1.2 V.

The E.M.F. may be referred to as the no load voltage or terminal voltage on open circuit, and may be very closely determined by connecting a high resistance voltmeter directly across the terminals of the cell.

Thus there is .3 volts required to drive the current through the internal resistance of the cell, and this may be simply referred as the "internal voltage".

Notice that the more current we take from a cell, the greater will be the internal voltage, and of necessity, the less is the terminal voltage.

Normally the internal resistance from one electrode or plate to the other in a cell is disregarded because it is very low compared with the resistance of the circuit it is supplying but in some cases it is specified, and such problems must be dealt with accordingly.

CELLS IN SERIES AND PARALLEL

1. SERIES

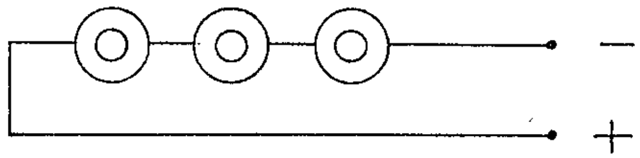


Figure 8.

Cells in series are connected as shown in the diagram. The E.M.F.'s of cells in series are additive. Thus if we have three dry cells in series, each of E.M.F. 1.5 V, the E.M.F. of the combination will be 4.5 V.

The internal resistance of these cells are also connected in series and if each internal resistance is .12 ohm, the combined internal resistance will be .36 ohm.

If we assume the normal current flow from a dry cell of this type is to be, ¼ amp, we can still only take a ¼ amp from the three cells in series.

2. CELLS IN PARALLEL

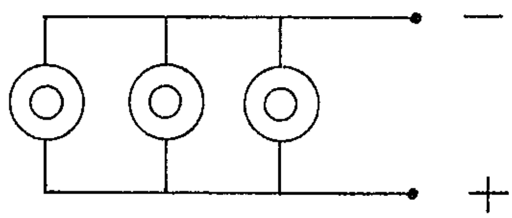


Figure 9.

Cells in parallel are connected as shown in the diagram. The E.M.F. of cells in parallel is just the same as that of one cell, i.e. putting cells in parallel doesn't increase the E.M.F. of the combination. Thus if we had three dry cells in parallel, each of E.M.F., 1.5 V, the E.M.F. of the combination would be still 1.5 V.

The internal resistances of these cells are also connected in parallel and if each internal resistance is .12 ohm, the combined internal resistance would be .04 ohm.

If we assume the normal current flow from a dry cell of this type to be ¼ amp we could take a normal current of 3/4 amp from the three cells in parallel.

When cells are arranged in series, the number of amps multiplied by hours of use remains the same as for one cell since the same current is discharged through all cells.

If cells are arranged in parallel, the number of amps. multiplied by the hours of use increases above that of one cell by every other one added in parallel.

SECONDARY CELLS

STORAGE BATTERIES

A storage or secondary cell (sometimes called an accumulator) involves the same principles as a primary cell, but the two differ from each other in the manner in which they are renewed. The materials of a primary cell which are used up in the process of delivering current are replaced by new materials, whereas in the storage cell, the cell materials are restored to their initial condition by sending a current through the cell in a reverse direction. There are but two types of storage cells in common use, the lead-acid type and the nickel-iron-alkali type. In both of these cells the active materials do not leave the electrodes.

THE LEAD ACID BATTERY

The principle underlying the lead cell may be illustrated by a simple experiment. Two plain lead strips are immersed in a glass of dilute sulphuric acid. These are connected in series with a rheostat, and supplied from direct-current mains, or from a battery Figure 3. When a current flows through this cell, bubbles of gas will be given off from each plate, but it will be found that a much greater number come from one plate than from the other. After a short time one plate will be observed to have changed to a dark chocolate colour but the other will not have changed its appearance. A careful examination, however, will show that the metallic lead at the surface of the latter plate has started to change from solid metallic lead to spongy lead.

When the current is flowing as shown the voltmeter connected across the cell indicates about 2.5 volts. If the current be interrupted by opening the switch, the voltmeter reading will fall to about 2.1 volts, and the cell will now be found to be capable of delivering a small current, but the amount of energy that such a cell can deliver is very limited. As the cell discharges, the voltage drops off slowly to about 1.75 volts, after which it drops more rapidly until it becomes zero and the cell is apparently exhausted. The colour of the dark brown plate will now have become lighter. After a short rest the cell will recover slightly and will gain deliver current for a very brief period.

The plate, which is a dark chocolate colour in this experiment is a positive plate or anode, and the one which is partially converted to spongy lead is the negative plate or cathode. The bubbles which were noted came mostly from the negative plate and were free hydrogen gas. When current is passed through such a cell, the metallic lead of the positive plate is converted into lead peroxide, whereas the negative plate, though not changed chemically, is converted from solid lead into the spongy or porous form. When the cell is discharged, the lead peroxide of the positive plate is changed to lead sulphate, so that plates tend to become the same chemically.

The principle of the cell is the same as that of the primary cell. When the two lead plates are the same chemically, that is, when both lead sulphate, there is practically no electromotive force. When the positive is converted to the peroxide and the negative to spongy lead by the action of an electric current, the two plates become dissimilar and an electro-motive force results. This electromotive force is about 2.1 volts, the excess of 0.4 volt observed in charging the cell being necessary to overcome the internal resistance and the polarisation effects.

This simple experiment illustrates the principle underlying the operation of lead storage cells.

The chemical reactions which take place in a storage cell are as follows Figure 4:-

Battery Charged		Battery Discharged	
$PbO_2 + 2H_2SO_4 + Pb$	$\rightleftharpoons$	$PbSO_4 + 2H_2O + PbSO_4$	
Positive Plate	Negative Plate	Positive Plate	Negative Plate

It will be noted that, when the battery is being charged, the change that takes place in the electrolyte is that water is converted into sulphuric acid. This accounts for the rise of specific gravity on charge. On discharge, the sulphuric acid is dissociated and reacts with the lead peroxide to form water. There, the specific gravity of the electrolyte decreases when the cell is discharging. When charging, free hydrogen is given off at the negative plate and oxygen at the positive plate. Because of the explosive nature of hydrogen, no flame should be allowed to come near a storage battery while it is charging.

It would not be practicable to construct storage cells of plain lead sheets, such as were used in this experiment. The capacity of the cell would be so small that it could not deliver currents of commercial value for any length of time, unless it were made prohibitively large in order to secure the necessary plate area.

PLANTE PLATES

There are two methods of increasing the active plate area, the Plante process and the Faure process. In the Plante process, the active material on the plates is formed from the metallic lead by passing a current through the cell first in one direction and then in the reverse direction, which procedure changes the lead on the surface of the plates into active material.

The surface area may be increased by the design of the plate (Figure 35.)

The Manchester Plate (Figure 33) is made by this process. A grid is made of lead-antimony alloy and the active material consists of a corrugated lead ribbon, which is coiled in spirals and pressed into the perforations of the grid. The peroxide has a greater volume than the lead from which it is derived. Hence, when the cell is charged, these spirals expand and become more firmly embedded in the plate.

FAURE OR PASTED PLATE

This type of plate consist of a lead-antimony lattice work into which lead oxide is applied in the form of a paste. The battery is then charged. The pasted on the positive grid is converted into peroxide and that on the negative grid into spongy lead. (Figure 36-38).

The chief advantage of the pasted plate is its high overload capacity, especially for short periods, together with its lesser size, cost, and weight for a given discharge rate. It is therefore, very useful where lightness and compactness are necessary, such as in electrical-vehicle batteries, ignition and starting batteries. The pasted type of positive has a much shorter life than the Plante type, due to a more rapid shedding of the active material.

In all batteries there is one more negative than positive plate. This allows all positives to be worked on both sides. Were any of the positives to be worked on one side only, the expansion of the active material which occurs when it is converted to the peroxide on charge, would be unequal on the two sides of the plate and buckling would result.

Storage batteries are divided into two general classes, stationary batteries and portable batteries.

STATIONARY BATTERIES:

The plates of this type of battery may be either of the Plante type or of the pasted type, depending on the nature of the service. For merely regulating duty, involving only moderate though continual charging and discharging, the Plante plate is preferable. Where a battery is installed for emergency service, to carry a heavy overload for a very short period during a temporary shutdown of the generating apparatus, the pasted plate, because of its high discharge rate, is preferable. As such batteries are usually located in congested city districts where floor area is very valuable, the high discharge rate of the pasted plate is of great importance.

TANKS:

The containing tanks for stationary batteries are of three general types: glass; earthenware, and lead-lined wooden tanks. Glass jars are used only for cells of small capacity, as they are expensive and have not the requisite mechanical strength in the larges sizes. Earthenware tanks have been used more as an experiment and will probably not come into general use. Wooden tanks are lined with sheet lead. The seams of the lead lining must be sealed by burning the lead with a non-oxidising flame.

Solder should never be used. The wood should be painted with an acid-resisting paint, such as asphaltum. Wooden boxes lined with rubber have been used in submarines to reduce fragility.

When glass jars are used, the plates are suspended by projecting lugs which rest on the edges of the jars. In the lead-lined tanks, the plates are similarly suspended on two glass slabs, which rest on the bottom of the tank. The plates of like polarity are burned to a heavy lead strip or bus-bar to which the current-carrying lug is either burned or bolted. There should always be a liberal space between the plates and the bottom of the tank to allow the lead peroxide to accumulate without short-circuiting the plates. All types of stationary batteries should have a glass cover to reduce evaporation and to intercept the fine acid spray which occurs during the charging period.

SEPARATORS

To prevent the positive and negative plates from coming in contact with one another, several types of separators have been tried. Glass rods inserted between the plates have been used as separators and thin perforated hard rubber is also occasionally in small cells.

ELECTROLYTE

Th eléctrolyte should be chemically pure sulphuric acid. When fully charged, the specific gravity should be 1.210 for Plante plates and not higher than 1,300 for pasted plates. This solution may be made from concentrated acid (sp.gr. 1840) by pouring the acid into water in the following ratios:

Specified Gravity Required	Parts Water to One Part Acid	
	By Volume	By Weight
1.200	4.3	2.4
1.210	4.0	2.2
1.240	3.4	1.9
1.280	2.75	1.5

The liquid should be cooled to room temperature before use, and the S.G. adjusted to the value required by adding water or acid. A large amount of heat is evolved when acid and water are mixed. This results in the generation of a large amount of steam if the water is added to the acid. This should be avoided as it may scatter the acid, break the container, and may cause personal injury.

The specific gravity of the solution must be determined directly, when it has cooled, by the use of a hydrometer. This consists of a weighted bulb and graduated tube which floats vertically in the liquid whose specific gravity is to be measured. The specific gravity is read at the point where the surface of the liquid intercepts the tube.

Such a tube may be left floating permanently in stationary batteries in a representative cell called a "pilot cell."

The small amount of liquid, and the inaccessibility of vehicle and starting batteries, make use of such a hydrometer impossible. To determine the specific gravity with such batteries the syringe hydrometer is used. The syringe contains a small hydrometer and when sufficient liquid is drawn into the syringe tube, the small hydrometer floats and may be read directly.

SPECIFIC GRAVITY

When the battery is charged, hydrogen is given off at the negative plate and oxygen is given to the positive plate to convert it into the peroxide. The electrolyte gives up water, which means that the solution becomes more and more concentrated. The specific gravity will rise from the complete discharge value of 1.140 to 1.280 when fully charged (Figure 16). At the gassing point, the specific gravity drops slightly due to the presence of hydrogen bubbles in the electrolyte. On discharge, the specific gravity decreases even after the battery has ceased to deliver current, as the dilute acid in the pores of the active material diffuses into the soltuion. The specific gravity is such a good indicator of the state of charge of the battery that the hydrometer reading is generally used to determine how nearly charged or discharged the battery is at the time. The condition of the plates can be determined by measuring the voltage on heavy loads. A special meter with a low resistance across its terminals is used for this purpose.

As the hydrogen and oxygen which escape from the battery during the charging and discharging periods are, ordinarily, only dissociated water, nothing but water need be added to replace the electrolyte. Acid need be added only when an actual loss of electrolyte takes place, such as occurs with a leaky tank. As a rule, distilled water is used to replace the evaporation of the electrolyte. As hydrogen and oxygen mixtures are explosive, naked lights should never be used near batteries under charge.

The freezing temperature of the electrolyte is considerably reduced with increasing specific gravity. For example, the freezing temperature is $-6^{\circ}F$ when the specific gravity is 1.180, and $-90^{\circ}F$ when the specific gravity is 1.280. Hence, there is little danger of a battery's freezing in the temperate zone, if it is well charged.

INSTALLING A STATIONARY BATTERY

When installed for service, a stationary cell should rest in either a glass tray, or a wooden tray, painted with asphaltum and filled with dry sand. The tray should be set on insulators. Before the battery is ready for service, the active material on the plates, which is more or less converted into lead salts during exposure to the atmosphere, must be reduced electrically. Therefore the battery should be given an initial charge at the normal charging rate for about 40 hours or more.

If the battery stands for a long time without being used, the active material becomes more or less converted into inactive lead sulphate. Therefore a battery if idle, should be charged occasionally.

VEHICLE AND STARTING BATTERIES (Figure 17 - 38).

In the design of batteries for propelling vehicles and for automobile starting, it is necessary to obtain a very high discharge rate with minimum weight and size. Therefore, pasted plates are used for both positives and negatives. These are made extremely thin and are insulated from one another by very thin wooden separators. They are then packed tightly into a hard rubber jar, This jar is sealed with an asphaltum compound to the jar which is closed with a cap. This permits the replenishing of the electrolyte. A vent in the cap allows the gases to escape.
Because of the high discharge rates which occur where this type is used, the specific gravity of the electrolyte is as high as 1.280 to 1.300. Further, the amount of electrolyte is very small and it is necessary to work it between wide limits, the lower limit being 1.185 and the upper 1.280 to 1.300.

The individual cells are mounted beside one another in boxes or crates and are connected together on top by lead connectors which may be burned or held by lead nuts. The number of cells in such a unit depends on the voltage which is desired.

As the space for the electrolyte is very limited in vehicle batteries, the level of the electrolyte falls quite rapidly so that frequent additions of water are necessary.

CHARGING

There are three methods in general use for charging storage batteries. When batteries of comparatively small capacity, such as starting and ignition batteries are to be charged, and direct current service is available, the battery may be connected across the line in series with resistance. Carbon filament lamps are desirable for the series resistance, since they indicate visually the approximate current, are not expensive, and are readily renewed. This method, although convenient, is inefficient from the energy point of view and only suitable for small cells with low charging current.

A separate generator may be used for charging. The generator voltage may be controlled by its field rheostat, and thus the current to the battery can be adjusted to its proper value without using series resistance. Since the battery voltage rises during charge, the current will decrease unless the generator voltage is raised from time to time. This method of charging is commonly employed in farm-lighting units. A magnetic switch called a cut out, is used, to prevent the current flowing back through the generator if the engine fails.

The terminal voltage of a cell rises on charge. The terminal voltage is about 2volts at the beginning of charge and rises slowly to about 2.4 volts, after which it rises very rapidly to 2.6 volts. This last rise occurs in the gassing period. This final rise of voltage also indicates that the cell is nearing the completion of charge.

The charge rate is adjusted depending on the capacity of the battery in ampere hours. Thus if a 40 amp. hr. battery is charged at 5 amps., it should take 8 hrs. This rate would be referred to as the 8 hr. rate.

With batteries of the pasted-plate type, the current may be maintained at either the 5 or the 8-hour rate until gassing begins, when the rate should be reduced. The charging rate with Plante plates is usually in excess of these. The charge may be started at the 3 hour rate and end at the 8 hour rate. The rate should always be reduced when gassing begins, as gassing represents a waste of energy and causes active material to become loosened from the positive plates.

A battery cannot be charged from alternating-current supply without the use of some rectifying device. The battery must be connected so that current enters its positive terminal from the positive line. If doubt exists as to the polarity of either the line or the battery use a voltmeter, if one is available. If a voltmeter is not available, dip the ends of two wires which are connected to either the battery or the circuit into slightly acidulated water. Bubbles form about the negative wire.

THE NICKEL-IRON-ALKALINE BATTERY

Instead of using acid as an electrolyte the Edison cell uses an alkali, consisting of a 21 per cent potassium-hydrate solution. The positive plate consists of nickel pencils about ¼ inch diameter and 4½ inches long, filled with green nickel oxide. As the nickel oxide is a very poor electrical conductor, very fine metallic nickel flakes are mixed with it to produce sufficient conductivity. The negative plate consists of flat perforated nickel-plated steel stampings, containing iron in a very finely divided form. These flat pockets are mounted on a nickel-plated steel frame for support. (See figure 39).

The chemical reaction in the cell is complex, but its nature is indicated by the following chemical equation:

Positive Plates — Negative Plates

$$8KOH + 6NiO2 + 3Fe \rightleftarrows Fe_3O_4 + 2Ni_3O_4 + 8KOH$$

The equation, read from left to right, indicates discharge, and read from right to left indicates charge. It is to be noted that the same quantity of potassium hydrate solution (OH) appears on both sides of the equation. This indicates that ultimately all the reaction occurs between the electrodes themselves, and also that now water is formed. Hence the specific gravity of the solution does not change during charge or discharge.

The plates all have a perforated lug by which they are fastened together with a steel bolt and to a binding post. The positive and negative plates are insulated from one another by hard-rubber grids. The positive and negative assembly is placed in a corrugated, nickel-plated, welded steel tank. In the top is a valve which allows the gases to escape during the charge, and through which water may be added to the electrolyte. This valve should never be allowed to become so encrusted with a potash deposit that it sticks, because the internal pressure may become sufficient to cause the sides of thecontainer to bulge. The valve is needed to keep out air, which would change the electrolyte chemically.

The individual cells are usually mounted in wooden racks, the cells being connected together by nickle-plated steel connectors.

CHARGE AND DISCHARGE

The Edison cell is rated on the basis of a 5-hour charging rate. The average voltage on load is about 1.2 volts per cell. As the specific gravity of the electrolyte changes but slightly, it cannot be used to indicate the condition of charge, as with the lead cell. Moreover, there is no sharp voltage rise near the completion of charge. If doubt exists as to the condition of charge, it is advisable to give an overcharge in order to be on the safe side.

The electrolyte in an Edison cell changes to potassium carbonate very readily, so that only freshly distilled water should be used in replacing the electrolyte, as tap water usually contains carbonates in solution. The electrolyte should be replaced by fresh electrolyte every 250 complete cycles of charge and discharge.

The Edison cell has many advantages. It is light, rugged, and can safely stand for a long time in a discharged condition without being given an occasional charge. The plates do not buckle and the active material does not "flake" or drop from the plates. It is however expensive, and has a higher internal resistance than lead cells.

APPLICATIONS

Edison cells are used for vehicle lighting and ignition, and are also much used in motor boats and in various types of electric trucks. In automobiles they are not used for starting, as their comparatively large internal resistance does not permit a sufficiently high discharge rate.

CAPACTIY OF A CELL

The term 'capacity' refers to the amount of electrical energy which may be taken out of a cell from the beginning of discharge until the gradually diminishing electromotive force value, which has been arbitrarily fixed and which is reached long before all of the active material is reduced to lead sulphate, and zero voltage attained. This arbitrarily fixed voltage to which a cell should allowed to fall is usually 1.8 volts.

DEFINITION OF UNIT OF CAPACITY

The capacity of a cell is measured in ampere-hours. One ampere hour (symbol A.H.) is the amount of electricity conveyed by a current of one ampere in a time period of one hour, i.e., capacity is the product of the rate of flow in amperes and the number of hours the current rate is maintained until the final voltage is reache

EXAMPLE

A fully charged cell is discharged at a constant rate of 7.5 amperes and, when the cell potential difference has dropped to 1.8 volts, it is found that 10 hours of time has elapsed. Therefore, the cell has a capacity of 75 ampere hours at the 10 hour rate of discharge.

The discharge current of 7.5 amperes is referred to as the 'normal' value of discharge current in accordance with capacity if the time period has to be maintained. However, if the discharge current is variable, the capacity is the sum of the products of each of the various rates multiplied by its duration in hours.

EFFECT ON CAPACITY WITH VARIOUS DISCHARGE CURRENT VALUES

The capacity of a cell is dependent upon the surface area of the active materials, and in well formed plates the porosity of the materials generally increases the effective area exposed to the acid.

When rates of discharge current higher than normal value are taken from a cell, the growth of lead sulphate on the surface of the plates is very rapid and this will not allow the diffusion of the acid to take place at the required rate to maintain the cell voltage. Therefore, the voltage falls comparatively rapidly and in consequence the capacity is decreased below that when normal discharge current is taken.

When rates of discharge current lower than the normal value are taken from a cell, the growth of lead sulphate on the surface of the plates is comparatively slow and does not restrict the diffusion process to the extent it does when normal discharge current is taken.

Therefore, the acid will be in contact with the plate materials for a longer time, thus maintaining the cell voltage and with it current output. This extension of time for which the current can flow will give an increase in the capacity of the cell.

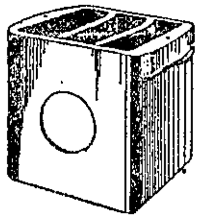


FIG. 19.
Hard Rubber
Container

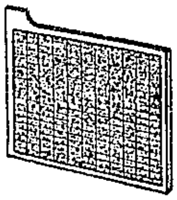


FIG. 20.
Positive Plate
(Chocolate Brown)

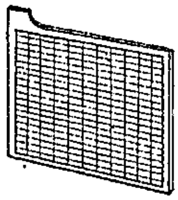


FIG. 21.
Negative Plate
(Grey)

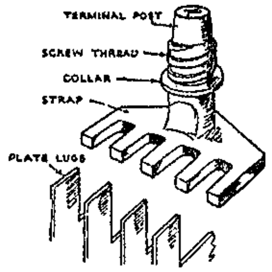


FIG. 22.
Terminal Post
Assembly

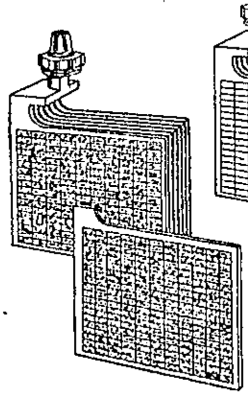


FIG. 23.
Positive Group
Assembled

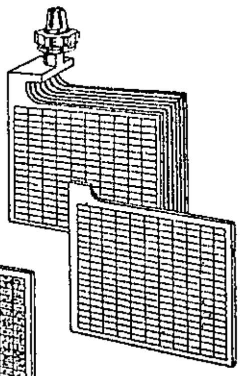


FIG. 24.
Negative Group
Assembled

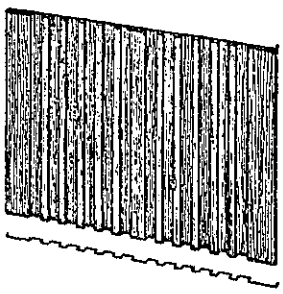


FIG. 25.
Wood Separator

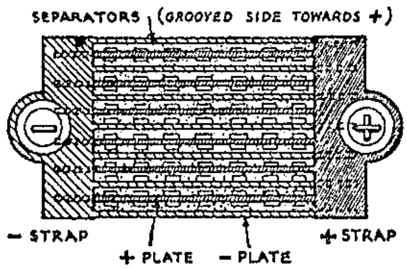


FIG. 26.
Plan of Assembled Battery

FIG. 27.
Cell Covers

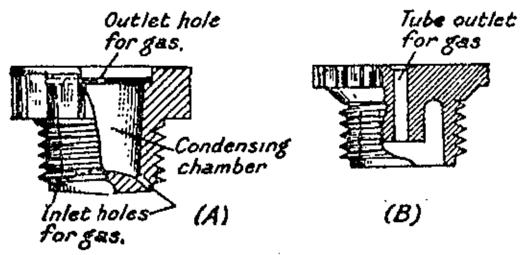


FIG. 28.
Vent Plugs

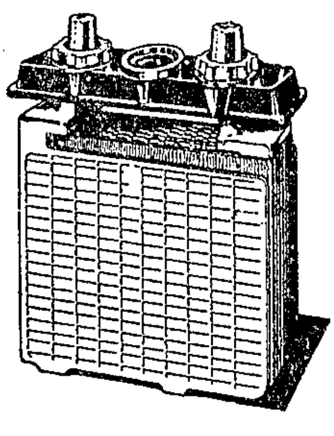


FIG. 29.
Battery Element Assembled

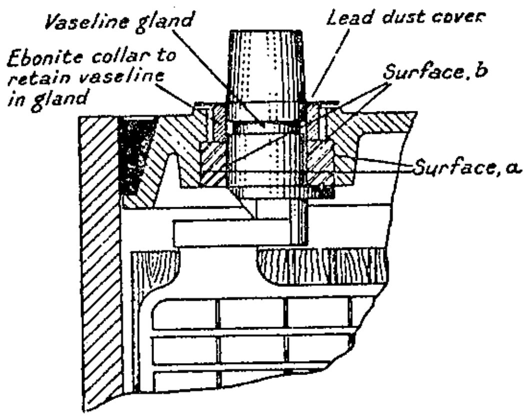


FIG. 31.
Terminal Post (Section)

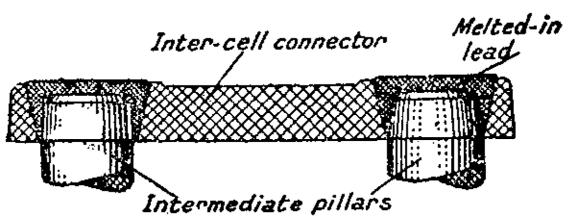


FIG. 30.
Cell Connectors

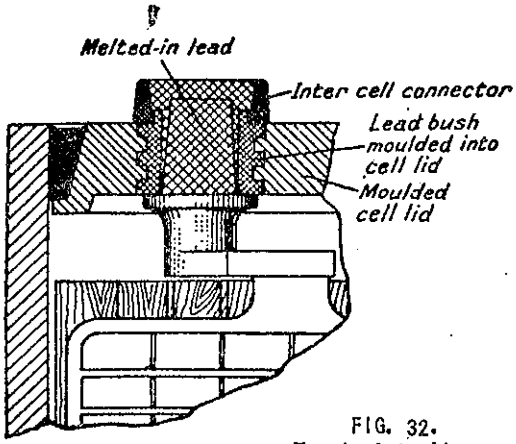


FIG. 32.
Terminal Sealing

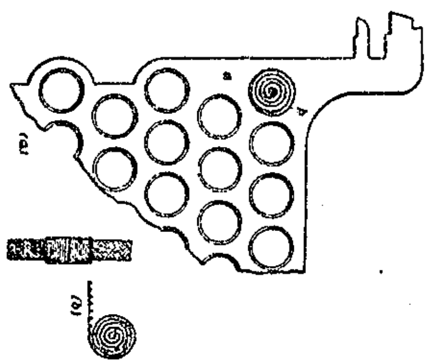


FIG. 33.
Manchester Positive Plate

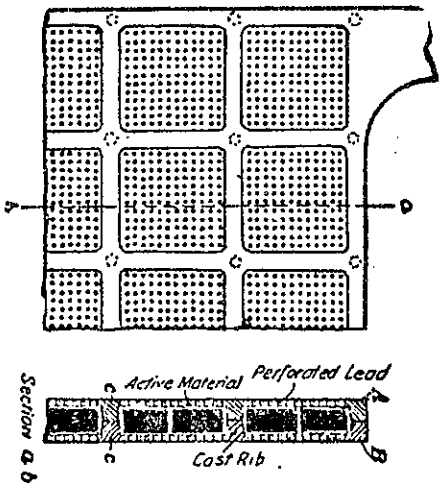


FIG. 34.
Box Type Negative

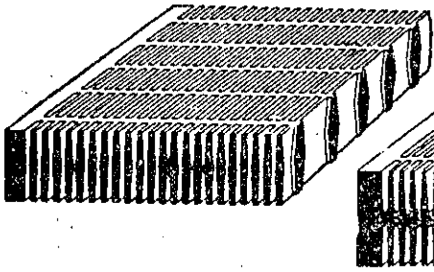


FIG. 35 (a).

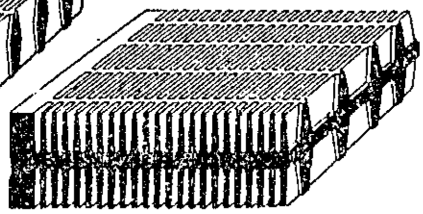


FIG. 35 (b).
Plante' Plates (Section)

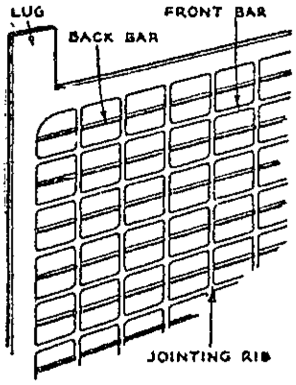


FIG. 36.
Lead Grid

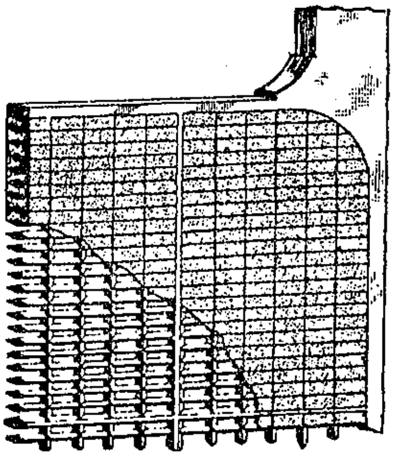


FIG. 37.
Lead Grid (Pasted)

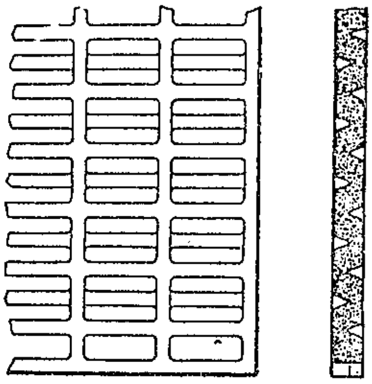


FIG. 38.
Pasted Plate

A—Negative Pole.
B—Valve.
C—Filler Cap.
D—Positive Pole.
E—Copper wire swedged into steel pole.
F—Cell cover welded to container.
G—Stuffing box.
H—Gland ring.
I—Stuffing box gasket.
J—Weld to cover.
K—Spacing washer.
L—Connecting rod.
M—Positive grip.
N—Grid separator.
O—Seamless steel ring
P—Positive tubes (nickel hydrate and nickel in layers).
Q—Suspension boss.
R—Cell bottom (welded to sides).
S—Solid steel container.
T—Side insulator.
U—Pin insulator.
V—Negative Pocket (iron oxide).
W—Negative grid.
X—Cell cover.
Y—Hard rubber gland cap.

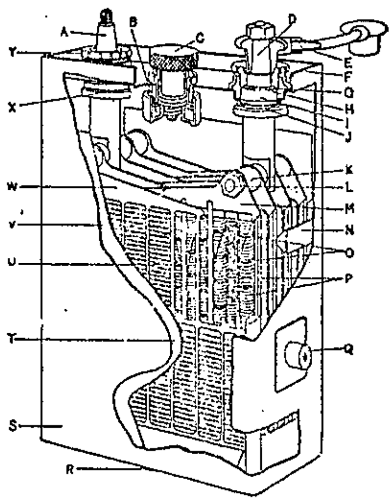


FIG. 39.
Edison Cell

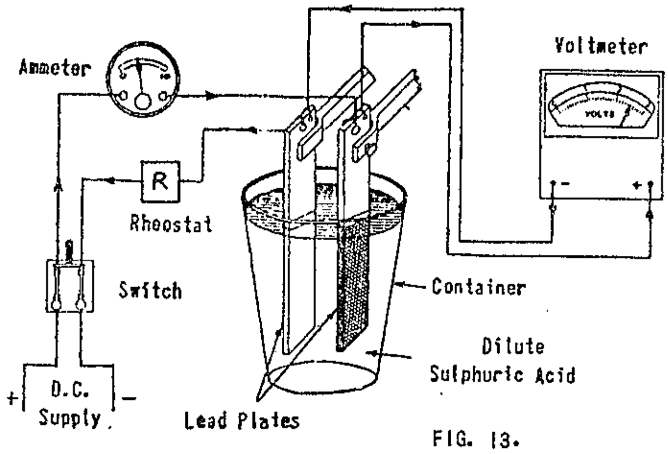


FIG. 13.

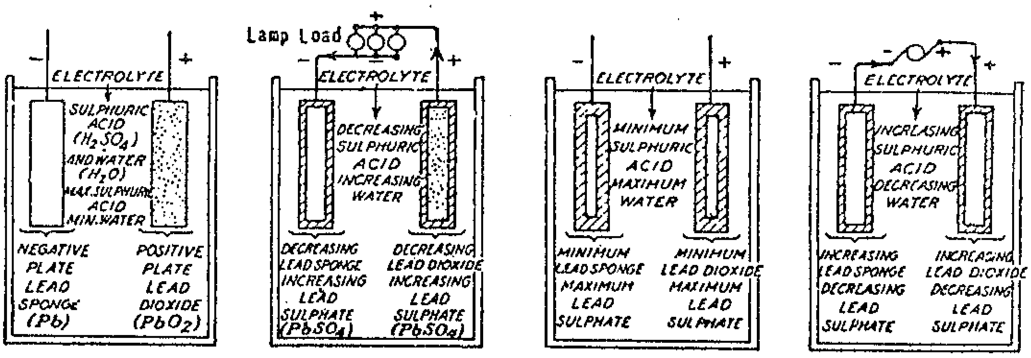


FIG. 14. Chemical Action in a Lead-Acid Cell.

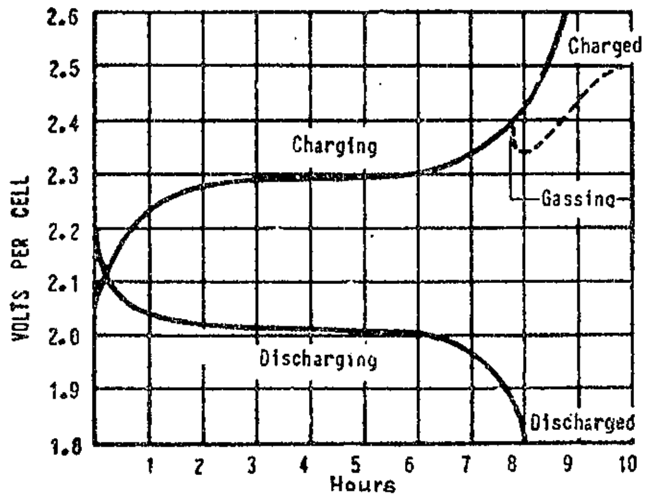


FIG. 15. Variation in E.M.F. on Charge and Discharge.

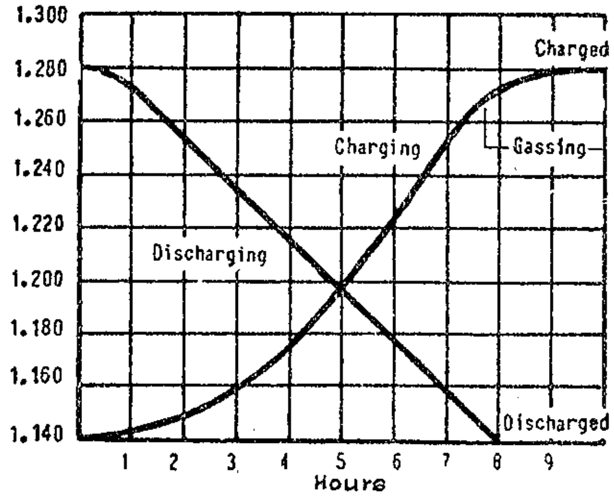


FIG. 16. Variation in S.G. on Charge and Discharge.

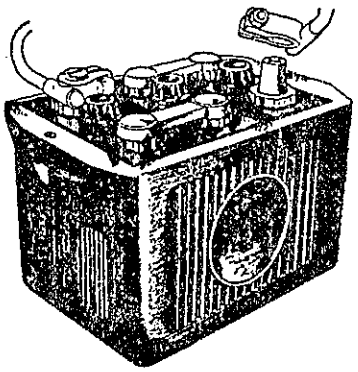


FIG. 17. Automobile Battery.

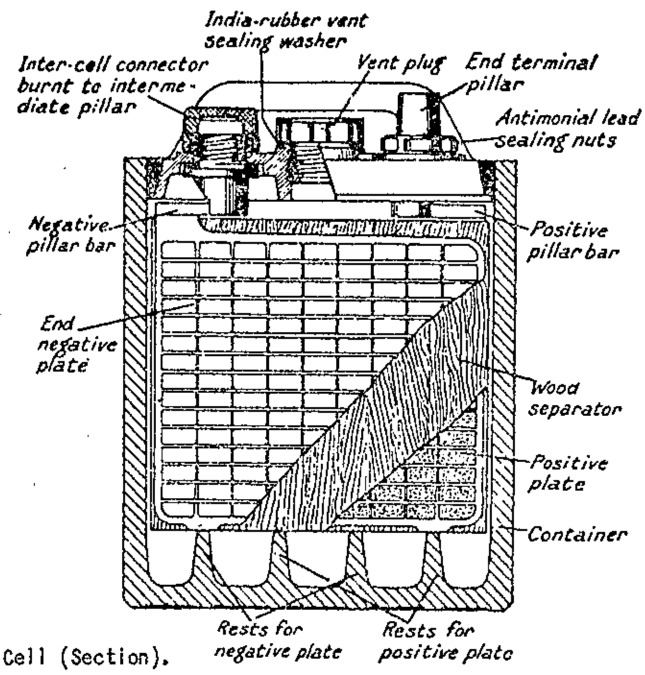


FIG. 18. Storage Cell (Section).