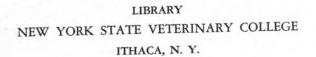
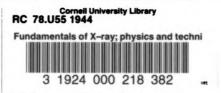
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X-RAY TECHNIQUE

INTRODUCTION

The development of X-ray machines in recent years has been characterized by great improvement as to protection from electrical hazards, increased capacity and numerous automatic adjustments. None the less carelessness may still result in disaster and knowledge is, if anything, more important than ever. There is no such thing as "fool proof" apparatus. All operators of X-ray units should be well grounded in basic principles including biological hazards.

The final report of the roentgenologist is the end result of a long chain of processes each one of which is important and subject to many difficulties. Furthermore, practically all X-ray departments are extremely busy and blunders are costly in time, inconvenience and waste of expensive material. The technician should aim at perfection in technique, a maximum of consideration for the patient and the highest degree of cooperation with the medical officer.

The X-ray or "Roentgen" Ray was discovered by Roentgen in 1895 in the course of systematic investigation of electrical discharges in glass tubes containing highly rarefied gases. His discovery formed a fitting culmination not only to his own labors but also to the work of many brilliant scientists extending back for many years, even to the invention of the vacuum pump in 1650 by Otto von Guericke.

X-ray immediately became the object of intensive study all over the world and was promptly utilized by naval and military surgeons.

The nature of X-ray was a complete mystery at first but it is now recognized that it is a form of radiant energy forming a band of very short waves in the vast family of electromagnetic waves comprising radio waves hundreds of meters in length, infra-red, visible light, ultraviolet, X-ray, gamma rays of radium and most likely the cosmic rays.

X-ray wave lengths are measured in Angstrom Units (abbreviated A^O or A.U.) This unit is 1/10,000,000 of a mm. The range of X-ray wave lengths is usually put at 0.06 to about 136 A^O but the useful rays are all less than 1 A^O . The rays generated by a tube energized by a current of 100,000 volts potential mostly fall within 0.12 and 0.15 A^O .

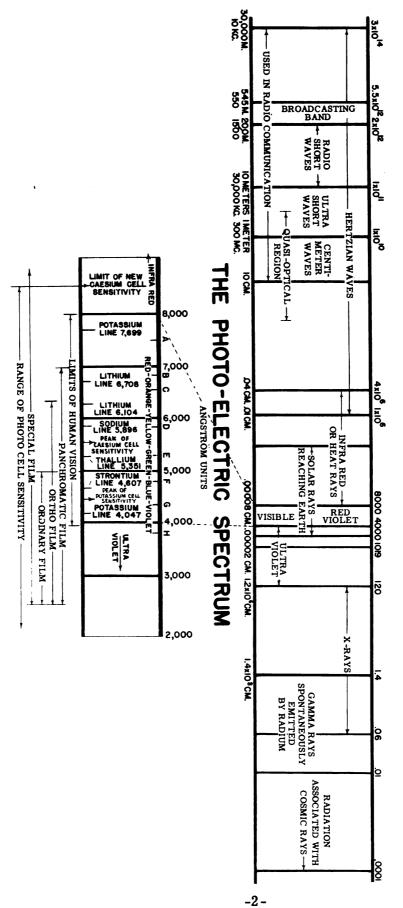
GENERAL CONSIDERATIONS

ATOMIC STRUCTURE. In order to understand the production of X-ray it is necessary first to learn something of electricity. This includes not only electrical currents and discharges but certain fundamental facts concerning the nature of matter.

Matter, as is well known, is built up of molecules which are the smallest particles of a substance which can exist and still possess the characteristic properties of the substance. The molecules in turn are made of atoms which constitute the smallest units capable of entering into the formation of a chemical compound.

HE ELECTRO-MAGNETIC SPECTRUM

ANGSTRÖM UNITS

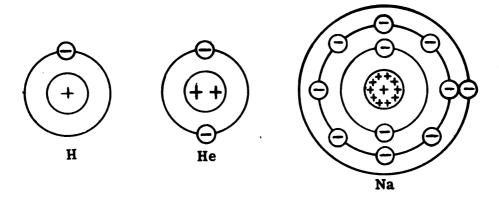


ELECTROMAGNETIC SPECTRUM

Not so long ago, the atom was thought of as a sort of undifferentiated building block, but lately it has been proven that it is a very complex structure built largely of protons and electrons. The former are heavy, positively charged and form the bulk of the nucleus or core of the atom. The electrons, negatively charged, are about 1/1800th mass of the proton and are found both within the nucleus and without.

The nuclear electrons are joined with protons to form neutrons. The outer electrons revolve in orbits much as the planets spin about the sun and so are called orbital electrons. The electrons constitute the negative particles of electricity. The number and arrangement of the various electric particles are what determine the nature and behavior of the atom and consequently each element. The number of electrons in the atomic orbits varies from one in the case of hydrogen to 92 in the case of uranium. Normally the positive charges of the protons are exactly balanced by the negative charges of the electrons and the atom is then neutral.

The following diagram will show how the orbital electrons are thought to be arranged in certain of the atoms.



ELECTRON CONFIGURATION OF SOME ATOMS

The electrons are thought to be all alike regardless of source and to possess the same negative charge. They are able to exist and move independently of the parent atom. Thus they may be torn from one body and piled on another. When such happens the atom which has lost electrons will naturally show a positive charge and the atom which has gained electrons will be negatively charged. Bodies so charged will attract each other due to the stress which seeks to restore equilibrium. If these bodies are connected by a conductor the electrons will flow back to the positively charged body. This flow constitutes the electric current.

Substances vary enormously in the ease with which they can transmit a flow of electrons. Most metals such as copper, silver, gold, aluminum and mercury are good transmitters and are called good conductors. Glass rubber, mica and various plastics are very poor conductors and are called insulators. The difference in conductivity probably depends on how firmly the orbital electrons are held. When the orbital electrons are difficult to dislodge, the substance characterized by this property will tend to block any free flow of electrons and so constitute an insulator.

When a sufficient number of orbital electrons are loosely held, the substance so characterized will possess a sort of atmosphere of electrons which are susceptible to motion under stress of an electrical charge. Such a substance will naturally be a good conductor.

A partial list of conductors and non-conductors:

Conductors	Insulators
Silver	Slate
Copper	Oils
Aluminum	Porcelain
Zinc	Dry leather and paper
Brass	Wool and silk
Platinum	Sealing Wax
Iron	Sulphur
Nickel	Resins
Tin	Shellac
Lead	Ebonite
Antimony	Mica
Mercury	Paraffin Wax
Carbon	Glass
	Various plastics

The flow of electricity in a metallic conductor is thus based on the free flow of electrons through it. Since the positive charge resides on the large heavy nuclear part of the atom, such positive charges do not move readily in solids. Consequently the flow of electricity through metals is due solely to electrons in motion, and obviously the direction of motion is from the negative terminal to the positive. This direction is exactly opposite to the convention adopted many years ago, that electrical current flows from positive to negative.

The strength or force with which the electrons seek to rush from a negatively charged body to one positively charged is called difference of potential or electromotive force (E.M.F.) and is measured in units called volts.

The amount of electrons that flow through a conducting substance is measured in amperes. The resistance of a substance to the flow of electrons is measured in ohms. These units are defined in terms of each other as follows:

A volt is the amount of E.M.F. that will cause 1 ampere of current to flow against the resistance of 1 ohm.

An ampere is the amount of current that will flow against the resistance of 1 ohm with a pressure of 1 volt.

An ohm is the amount of resistance that will require a pressure of 1 volt to cause a current of 1 ampere.

The mathematical relation between these units is expressed by Ohm's law:

E.M.F. in volts = Resistance in ohms x current intensity in amperes; or more simply E = R.I. Naturally the same law can also be expressed by R = E and E = E.

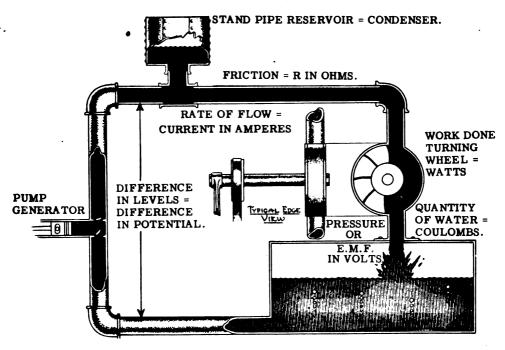
The unit for total quantity of electricity is the "Coulomb" which is 1 ampere maintained for a second. The rate of work or expenditure of electrical energy is measured in watts, one watt representing the work from 1 ampere at 1 volt E.M.F. The product of watts and time (usually in hours) gives the electrical energy consumption. At times these units are too large or too small for certain types of electrical currents so that other terms are in common use. Thus a kilovolt (Kv. or Kv. P.) is 1000 volts and a kilowatt is 1000 watts. A milliampere (M.A.) is 1/1000th ampere.

Because of the abstract nature of electric units, illustrative comparison is usually made between electricity in wire and water in a pipe.

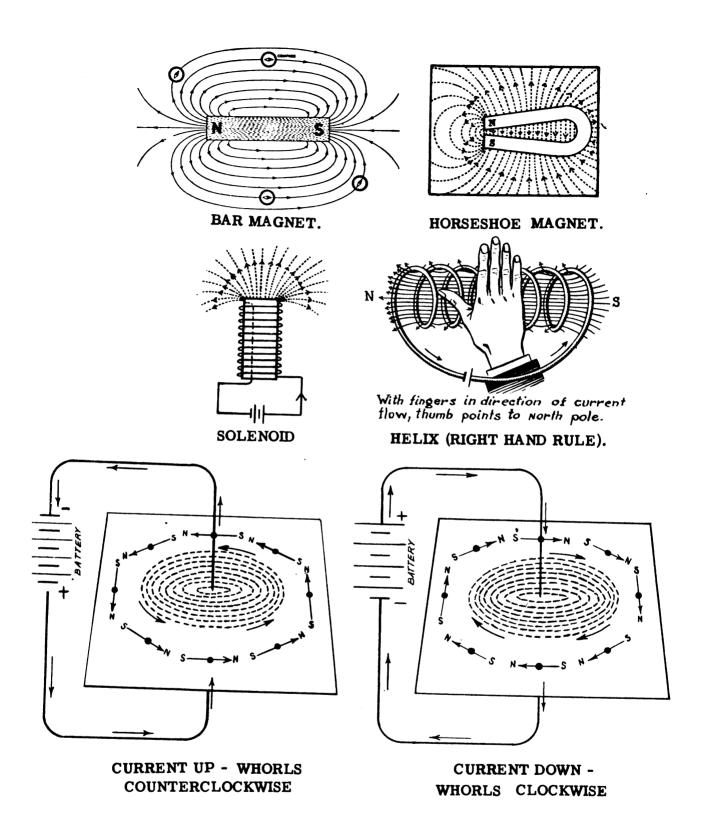
Thus:

Water pressure resembles voltage; the amount of water flow resembles amperage; the resistance to flow imposed by friction and the size of the pipe opening is analagous to electrical resistance.

This picture aids considerably in understanding many phases of electrical behavior with one important exception. In the case of water pipe there is nothing of moment that transpires about it whereas in the case of a wire conducting electric currents, electromagnetic lines of force are set up about it similar to those set up by a magnet.



WATER ANALOGY



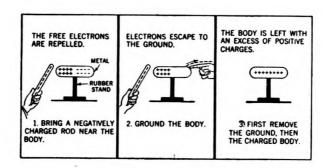
MAGNETIC FIELDS

Production of Electrical Charges and Currents.

In the nature of things atoms and the objects they make up tend to be in a state of equilibrium. If we wish to change this by producing a charge or a current, we must interfere, i.e., we must apply energy in some suitable manner as by friction, chemical reactions, and mechanical means employing electromagnetic induction.

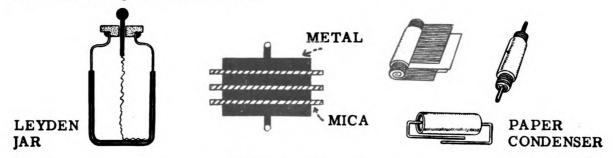
1. Friction: The ancient Greeks observed that amber (which they called elektron) when rubbed would attract light objects such as bits of paper. What happens is that when certain dissimilar substances are rubbed together electronic migrations are caused thereby producing charges. Charges thus produced are spoken of as static electricity. Glass rubbed with silk acquires a positive charge. Sealing wax or hard rubber rubbed with a dry cloth acquires a negative charge. Like charges repel each other. Unlike charges attract each other.

Induction: When a positively charged body comes close to a neutral object, electrons are pulled toward the end of the object nearest the charged body and the object thus becomes negatively charged at this end and if sufficiently light will be pulled into contact. When a negatively charged body is brought near a suitable object a positive charge will be induced by repulsion of electrons.



CHARGING BY INDUCTION

<u>Condensers</u>: These are analogous to storage tanks and consist simply of metal plates separated by insulating material such as glass or mica. They are used to store up charges to the limit of their capacity. The store of electrical energy can then be discharged when desired.



TYPES OF CONDENSERS

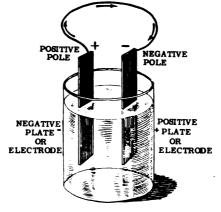
The unit for measuring condenser capacity is the Farad which is a capacity of such degree that a charge of 1 Coulomb will produce a 1 volt difference of potential. This unit is so large that in practical work the unit used most is the microfarad or 1/1,000,000th Farad.

Static electricity was formerly much used, the electric charges being generated by whirling glass plates. Since such machines are almost entirely of historical interest no discussion of them is included.

2. Chemical Generation of Electricity: When plates of two dissimilar metals such as copper and zinc are placed in dilute sulphuric acid, zinc particles will go into the solution as positively charged "ions" which repel positively charged hydrogen ions toward the Cu plate where they appear as free hydrogen atoms. The Cu plate becomes positively charged and the Zn plate negatively - due to loss of positive Zn ions.

If the Cu and Zn plates are connected by a wire a current will flow due to the difference in charges. This is the galvanic current.

A combination of suitable solution (called an electrolyte) and two metals is called a Galvanic or Voltaic cell, wet cell or wet Battery. They are not extensively used.

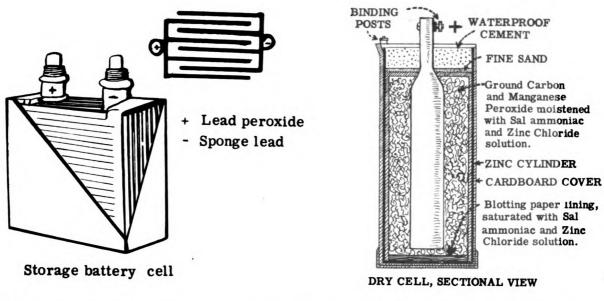


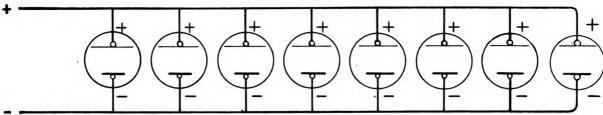
NOMENCLATURE OF A VOLTAIC CELL (Conventional Current Flow)

Dry cells consist of a zinc container filled with a paste of amonium chloride, manganese dioxide and granulated carbon. In the center is a carbon rod. The top is sealed with pitch. Terminals are placed on the zinc casing and the carbon rod. The ordinary dry cell produces about 1.5 volts, E.M.F. For some purposes large batteries of 45 or more volts are built by combining numerous cells. Dry cells are, of course, in constant use to supply current for a variety of purposes, such as door bells, signaling devices, radios, flashlights, etc.

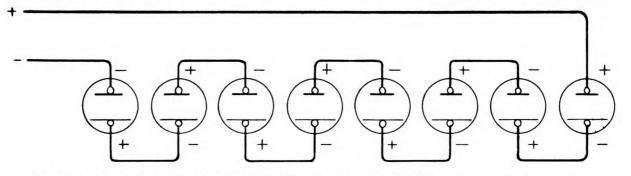
When a number of cells must be connected together to obtain the desired current, it is necessary that they be connected correctly. When a group is connected carbon to zinc they are said to be in series and the resulting voltage will be the sum of the voltages of all the cells. The maximum amperage is that of one cell. When they are connected zinc to zinc and carbon to carbon, they are said to be in parallel. In this case the voltage is that of one cell and the maximum amperage will be the sum of all.

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EIGHT CELLS CONNECTED IN PARALLEL FOR MAXIMUM CURRENT

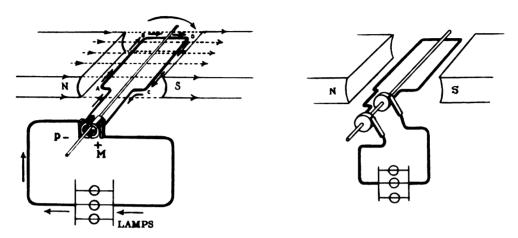


EIGHT CELLS CONNECTED IN SERIES FOR MAXIMUM VOLTAGE

A storage battery is a group of special type cells (usually three) connected in series. The plates are usually of lead and certain of its compounds; the electrolyte, dilute sulphuric acid. They can be charged by devices operating on line current whenever necessary, and furnish a low voltage current of high amperage.

3. <u>Mechanical generation:</u> This is made possible by electromagnetic induction.

About all magnets and about wires carrying electric currents there are electromagnetic lines of force. When a wire loop forming a complete circuit cuts through such lines of force an electric current will be induced. By using powerful electromagnets and specially wound coils of insulated wires which rotate rapidly in the magnetic field, huge outputs of electric current are obtainable in either direct or alternating forms. The apparatus used to accomplish this is called a dynamo. As we all know dynamos are the main source of electrical currents used in our daily lives.



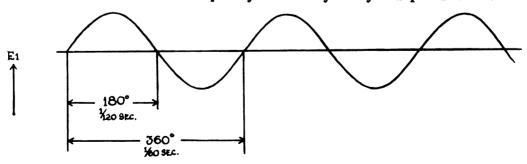
When the current from a dynamo is collected from a slip ring device it will be alternating. To obtain direct current it is necessary to employ a segmented ring, each segment insulated from the other. This device is known as a commutator.

SIMPLE A.C. GENERATOR.

SIMPLE D.C. GENERATOR

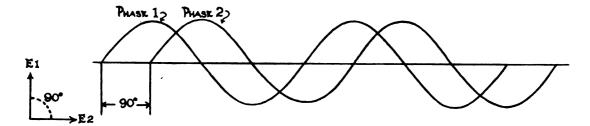
It is to be remembered that the D.C. current from a dynamo is not entirely even like that from a battery. It will show a number of minor fluctuations corresponding to the number of segments on the collecting ring. In other words, there are unidirectional pulsations producing a finely rippled wave form.

Possibilities do not end here as alternating current may be varied as to number of phases. To make this clear, let us consider first ordinary A.C. current from a simple dynamo; this will be "single phase" and is conventionally diagramed as the so-called sine wave. Frequency is usually 60 cycles per second.

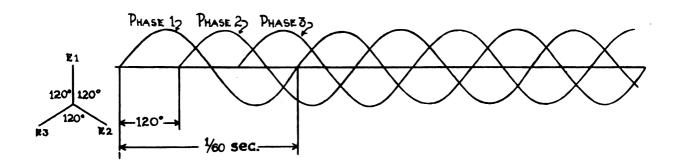


SINGLE PHASE 60 CYCLE A.C.

By appropriate design of the armature it is possible to start one or two additional waves of A.C. currents at different points in the original cycle, thus producing two or three phase current as the case may be.



TWO-PHASE A.C.



THREE-PHASE A.C.

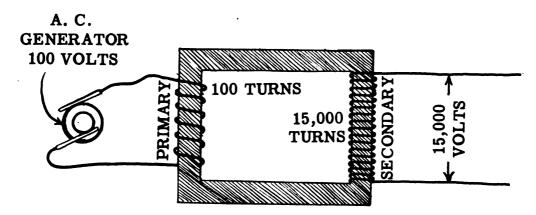
The purpose of multiple phase current is smoother flow of power and in the case of X-ray, as will become apparent later, a closer approach to "constant potential".

So much for sources of electric current. In order to obtain the various voltages needed, induction is again made use of. If a bar or ring of soft iron has two different coils wound on it, one coil consisting of a few turns of thick wire and the other of many turns of fine wire, then when alternating or rapidly interrupted direct current is sent through one coil, a current will be induced in the other, the voltage of which will be in the same proportion to the original or primary current as the number of turns of wire in the respective coils. These appliances are called transformers.

The iron core plays a most important part and is an absolute essential. Without it a coil of wire becomes a simple helix through which a current will flow with practically no resistance except inherent ohmic. When an iron core is in place however, impeding counter currents are set up which act to stop or choke the flow in the primary circuit and produce fluxes of electromagnetic lines of force. These serve to divert the electrical energy into the secondary. Without the presence of the counter E.M.F. or impedance it is obvious that we would have largely "short-circuit" effects and comparatively little induction.

In general induction occurs as the lines of force are built up and collapse with the "making" and "breaking" of the circuit in the case of interrupted direct current or with the reversals of alternating current.

It might also be noted that the impeding or choking effect mentioned above is made use of in regulating current strength. A simple coil with a movable iron core is placed in the circuit. By varying the position of the core the amount of current will be altered. When the core is completely within the coil comparatively little current will pass due to impedance. When the core is largely withdrawn the current strength will be increased due to lack of impedance. This type of coil is known as a "choke coil" and is used most frequently to regulate filament currents.



A STEP-UP TRANSFORMER

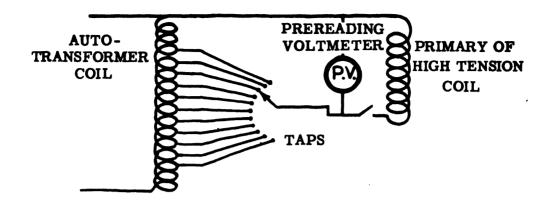
To change D.C. to A.C. current, motor generators or rotary converters are used. To change A.C. to D.C. rectifying vacuum tubes are commonly used, though converters may also be used.

In use of apparatus it is always important to know the type of current it is designed for. Apparatus designed solely for A.C. will not operate on D.C. and may be ruined by it. Furthermore A.C. apparatus must be operated on the frequency for which it is designed.

The transformers used in X-ray apparatus are of three types. (1) Step-up, (2) Step-down, (3) Autotransformers. The step-up transformer has already been illustrated. The step-down transformer is simply the reverse of the step-up type; the primary coil has numerous turns and the secondary few so that a reduced voltage is obtained.

Transformer windings must be well insulated and in the case of high tension types the entire transformer is usually submerged in a tank of dehydrated oil.

The autotransformer is another means of obtaining varying voltages from the incoming current. It has but one winding which serves as both primary and secondary. The windings are tapped at a number of points so that a varying number of turns may be utilized for the secondary circuit. The ratio of these turns to the entire number of turns will determine the voltages in the secondary. Thus by means



DIAGRAMMATIC SKETCH OF AN AUTOTRANSFORMER

of the autotransformer, various voltages may be applied to the high tension step-up transformer and so regulate its output. The autotransformer taps are connected to studs of a multiple point switch. Between each of these studs a "dead" or unconnected stud is always present to prevent the switch from shorting out two line studs, thus causing a short circuit which may burn out the autotransformer or do other damage.

It will occur to many here that a coil of high resistance wire with a sliding contact could also be used to cut down the primary current for X-ray purposes. This type of apparatus is called a rheostat and, of course, could be used. The draw-back is that the rheostat wastes energy by marked heat production and where considerable reduction of incoming voltage is necessary, both the loss of energy and the production of heat are too serious. Ordinarily a rheostat is used only to supplement the autotransformer for the purpose of fine gradation.

The high tension transformer for X-ray apparatus often has about a 1000 to 1 ratio. Each volt of the primary would thus result in 1000 volts in the secondary. Amperage is correspondingly reduced. If 10 amperes flow in the primary, 0.010 amperes (or 10 milliamperes) will flow in the secondary. It can thus be seen that a transformer produces no energy, it merely changes its form. As a matter of fact some energy is always lost due to electrical resistance and various factors.

The voltages used in usual clinical radiography range from about 30 to 90 K.V.P. Industrial radiography of metal castings, etc. calls for voltages up to 400 or more K.V.P. X-ray therapy usually calls for range of voltage from about 100 to 200 K.V.P. However, voltages of from 400 to 1,000 K.V.P. are being used.

The step-down transformer is used to produce voltages of from 10 to 18 for filaments in X-ray and valve tubes.

X-RAYS AND X-RAY MACHINES:

With the foregoing in mind we are in a better position to take up the actual production of X-rays.

First let us consider what happens in the earliest type of tube. These tubes contain a very small amount of gas and so are spoken of as gas tubes. When a high tension E.M.F. is applied to such tubes, the stress of this very high voltage liberates electrons from the atoms of gas. Due to the extreme repulsion consequent upon the high voltage, these electrons are hurled from the cathode in a heavy, high velocity stream which is called the "cathode ray" and thereby forms an electric current through the tube. These electrons necessarily are suddenly stopped by the wall of the tube or an interposed target and just as marbles thrown on a drum head will cause sound waves, so these electrons will set up an analogous disturbance in the form of the very short waves which we know as X-rays. In the earliest tubes the electrons simply hit the glass wall of the tube in a large spot and produced feeble scattered X-rays. When much energy was used the glass would heat, soften and give way ruining the tube. This was largely because, unfortunately, only a small amount (possibly less than 1%) of the energy of the electrons is converted into the energy of X-ray, the rest appearing as heat. Thus in a short time platinum and later tungsten targets were interposed and these targets were conveniently used also as the anode. The cathode was made convex so as to focus the electrons on the target both to prevent waste by scattering and to have a smaller spot from which X-rays emanated. The smaller the spot the sharper the radiograph. Gas tubes were used for a long time and good work was done with them. However, they were exceedingly "cranky" as minute variations in gas content caused marked changes in current and hence X-ray characteristics. The less the gas, the lower the milliamperage, the higher the voltage and the shorter the wave length of X-ray, the greater is its penetration and vice versa.

The modern "hot cathode" type of tube is based on the fact that when metals are heated to incandescence they give off clouds of electrons much as a kettle of boiling water emits steam. Thus it is possible to use a heated filament in the cathode as a source of electrons to carry current across a tube instead of relying on electrons from highly rarefied gas. Further, since the current intensity that can be sent through the tube depends on the free electrons available and since these in turn vary with the degree to which the filament is heated, we can readily control the tube current merely by varying the current which heats the filament. A prerequisite is a practically complete vacuum; otherwise the gas will complicate matters and interfere with control and focus of the cathode stream. A hot cathode tube that has accidentally acquired gas is spoken of as "gassy" and more than an exceedingly minimal amount of gas will ruin such a tube. These tubes were developed by Coolidge and are often spoken of as "Coolidge Tubes".

The capacity depends very largely on ability to disperse heat, since, as already noted, nearly all the electrical energy is converted into heat. Thus a fundamental feature of all tube design is some means of disposing of the excess heat.

In the old universal Coolidge tube with a solid tungsten target, heat radiation from the target is depended on. The target, under condition of heavy radiation, becomes heated to the point of glowing and thus radiates heat effectively. A large glass envelope is used to aid in cooling and also prevent breakage from heat; it is thus a constant feature of these tubes.

A glowing anode is, of course, most objectionable with unrectified current as