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STUDIES IN THE TECHNIQUE
OF X-RAY PHOTOGRAPHY

THESIS FOR THE DEGREE OF M. S.

Luther Herbert Lyndrup

1932

THESIS

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M A S T E R O F S C I E N C E

LUTHER HERBERT LYNDRUP

AUGUST 1932.

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INTRODUCTION

Several months ago Mr. V. A. Freeman, Assistant Professor and Research Assistant in Animal Husbandry at Michigan State College, in cooperation with Dr. H. R. Hunt, Professor of Zoology, requested the assistance of the Department of Physics in a study, by means of X-ray, of the variation in the number of vertebrae and ribs among pigs of different breeds. Accordingly the writer, under the direction of Associate Professor O. L. Snow of the Physics Department, was assigned the problem of repairing, assembling, and adjusting an old discarded equipment to the end that the above mentioned study involving the making of at least two hundred skiographs of pigs might be successfully pursued.

This thesis is primarily a report on the problems encountered and the lessons learned by the writer in the manipulation of available X-ray equipment in connection with this major project and a few minor projects.

The Animal Husbandry and Animal Genetics' aspect of this study of pigs will be reported in a separate thesis by Mr. Freeman at a later date.

Ill. 10000000

Several months ago Mr. V. L.

STUDIES IN THE TECHNIQUE OF X-RAY PHOTOGRAPHY

History of X-Ray

In order to more fully appreciate any contribution made by the scientific world, it is well to look at its historical background. Often a study of the history of the discovery and development of some of our simplest and most widely used conveniences reveals a story of struggles and hardships which seem more like fiction than fact. The early history of the X-ray is very interesting, showing how one man receives credit for discovering a new phenomenon, although others had unknowingly produced the same effect.

Throughout the nineteenth century extensive research work was conducted on the phenomena of electrical discharge through a tube of gas at low pressures. The first development worthy of note was Michael Faraday's discovery of electromagnetic induction in 1831. This enabled him to produce high potentials, and in 1838 he began a series of experiments dealing with electrical discharges through rarified gases. He named the positive and negative "anode" and "cathode" as we know them today. The next important step was the development of the vacuum tube by Geissler in 1857. He noticed a peculiar glow when a discharge was passing through the tube.

This vacuum tube influenced a famous physicist, Professor Hittorf of Munster, to investigate this type of tube more thoroughly. He succeeded in exhausting a tube to a much higher degree of vacuum than had Geissler. This tube offered more resistance to an electrical discharge than did Geissler's tube. Sir William Crookes discovered that he could produce a more perfect vacuum tube, and with it discovered "Cathode Rays," 1878. While conducting his research on these rays, he noticed that the walls of his tube would glow with a greenish "fluorescence. We know that this was due to the production of X-rays by the impact of the cathode rays against the glass walls of the tube. Next Hertz and his assistant, Lenard, experimented with cathode rays and unknowingly discovered more of the phenomena due to the production of X-rays. Then in 1895 Professor Wilhelm Conrad Roentgen, while duplicating an experiment described by Lenard, made his remarkable discovery.

Roentgen was experimenting with a Crooke's discharge tube which had carefully been covered with black paper to make it impossible for visible radiation to pass from the tube into the darkened room. To his great amazement he discovered that, while the discharge was passing through the tube, a fluorescent screen some three meters away glowed brightly. This screen was made up of a sheet of cardboard covered with a fresh coating of barium platino-cyanide.

It had been set up against the wall to dry. Attracted by this amazing development, Roentgen walked over to the screen to examine the fluorescence more closely. As he passed between the tube and the screen a shadow of his body appeared on the screen. His hand cast a remarkable shadow on the screen, for the bones cast a deeper shadow than did the fleshy portions. Apparently the phenomena which was producing the fluorescence on the screen penetrated flesh more readily than it did bones. Roentgen traced the emanation back to its source. The rays had as their origin the point of impact of the cathode rays on the glass walls of the tube.

Professor Roentgen completed a great deal of research on his new discovery, and then communicated his discovery to the Physico-Medical Society of Wurzburg. The scientific world was startled at the announcement of the discovery of the new X-ray which made it possible to look within opaque objects.

THEORY

Before discussing recent developments in the science of X-ray, it will be well to discuss the prevailing theory concerning X-ray radiation. Roentgen gave the new phenomena its present name because its exact nature was unknown. The pioneer research workers

in this field only knew that the rays were produced when electrons, moving at a high velocity under the influence of a strong electric field, encountered matter and suffered a change of motion. When the electrons strike an obstacle, a pulsation is sent out into the ether with the speed of light in all directions. The theory asserts that the energy of the ray is contained in a thin spherical shell. The more sudden the change in speed of the moving electron, the thinner is the shell and the more energetic is the pulse. X-rays are generally classified in that large range of wave motions which contains all forms of electromagnetic radiation. The wave length of X-rays has been found to be of order 1×10^{-8} centimeters.

PROPERTIES OF X-RAY

The following list contains the most common properties of X-ray radiation. X-rays are:

1. Produced by impact of cathode rays on matter;
2. Propagated in straight lines,
3. Invisible and pass through space without any transference of matter,
4. Unaffected by electric or magnetic fields;
5. Propagated with the same velocity as light;
7. Capable of ionizing gases;
8. Absorbed by matter;
9. Able to stimulate or kill living matter. It is now widely believed that exposure of living tissue to X-ray radiation hastens the process of evolution;

10. Capable of exciting certain chemicals to fluorescence;
11. Capable of darkening photographic plates. This property makes X-ray invaluable to the medical profession.
12. Capable of producing X-rays of shorter wave length when absorbed by matter.

DEVELOPMENT OF X-RAY TUBES

Roentgen conducted his experiments with a tube of the type shown in figure I. The operation of this type of tube and in fact any of the common type of "gas" tubes may be explained as follows:

The evacuation of the tube is intentionally never completed, but a very small amount of gas is always left in the tube. The pressure within the tube ranges from 0.001 to 0.010 mm. of mercury. Normally the number of ions present in this residual gas is very small. When a high potential is applied, the effect is to accelerate the motion of these ions toward the plates of the tube, causing them to produce many ions by collision with gas molecules. The electric field drives the positive ions against the cathode with considerable force, causing it to emit cathode rays; also, the electric field directs the cathode rays against the target with considerable velocity. The cathode rays are suddenly stopped by the target and X-rays are the direct result.

In Roentgen's tube the cathode rays were directed against the end of the glass tube. This proved very unsatisfactory because the greater part of the energy carried by the cathode rays is converted into heat when the motion is checked. Since glass melts easily, such a tube was readily susceptible to puncture while in operation. Early research workers found that metal targets could be substituted in place of the glass wall. It was also discovered that the metals of high atomic numbers gave a larger output of rays. The metals best suited for use as targets were those of high atomic numbers, high melting point—to permit sharp focusing of the cathode rays without fusing the target, and those that were good conductors of heat so that the heat would be conducted away from the point of impact of cathode rays rapidly. Platinum and tungsten are most widely used metals, with the latter being considered the more suitable. Aluminum is generally the metal chosen to serve as cathode in gas tubes.

Figure II shows the general type of gas tube. There is one bad feature connected with the operation of all gas tubes. The pressure within the tube may vary from day to day or even from hour to hour during operation. The metal parts and the glass walls of the tube no matter how carefully prepared contain small amounts of gas within them. When the tube is heated by continued operation, some of this gas may be given off. This raises the pressure within the

tube and makes it easier for the cathode rays to pass from cathode to anode and rays are produced which contain less energy. This condition is known as "softening" the tube. The metal parts and glass walls are also capable of absorbing gases and reducing pressure within the tube. Then it becomes harder to produce the necessary electrical discharge through the tube, and the tube is labelled "hard." There are remedies for both of these conditions, but they are not very accurate for one has no means of knowing exactly the condition existing within the tube. It is almost impossible to set up a standard condition of pressure under which to operate the tube and always adjust the tube to this pressure when using.

To reduce the pressure within the tube it is necessary to cause some of the gas to be absorbed by some agency. Often letting the tube be idle for some period of time will produce the desired effect. Continued heating and cooling of tube sometimes reduces pressure. Operating tube under very high potential with cathode and anode interchanged may help.

Raising the pressure within the tube is a somewhat simpler problem. The method most commonly employed is heating some substance which has been built into an arm on the tube. A spark gap is adjusted so that when the tube gets too hard, the discharge will pass across this gap and through the substance. The substance is thereby heated and gives off small amounts of gas. As soon as the tube offers less resistance

to the discharge than does the gap, then we have normal production of X-rays once again.

Gas tubes glow with a weird greenish light while producing X-rays. This fluorescence is not caused by any action of the X-ray on the walls of the tube. The fluorescence is produced by cathode rays which miss the target and are sent against the glass of the tube.

The Coolidge tube was developed to give the operator practically complete control of the conditions within the tube during any period of operation. In this type of tube the gas is exhausted to such a low pressure that it plays little or no part in the actual production of X-rays. Coolidge, inventor of this tube, became interested in applying the phenomena of thermionic emission of electrons as a source of cathode rays in an X-ray tube. He is directly responsible for the production of the modern "hot cathode" tubes which are rapidly replacing gas tubes. The cathode consists of a spiral of tungsten wire which is heated to incandescence by means of an electric current. Large quantities of thermions are liberated, the number liberated depending directly upon the temperature of the wire. After these electrons have been produced, the operation of the tube is similar to that of the gas tube.

The Coolidge tube can be operated on either alternating or uni-directional potential. Besides serving as a source of electrons the filament, cathode also serves as one of the terminals of the tube.

X-RAY TUBES----- -GAS TYPE TUBE

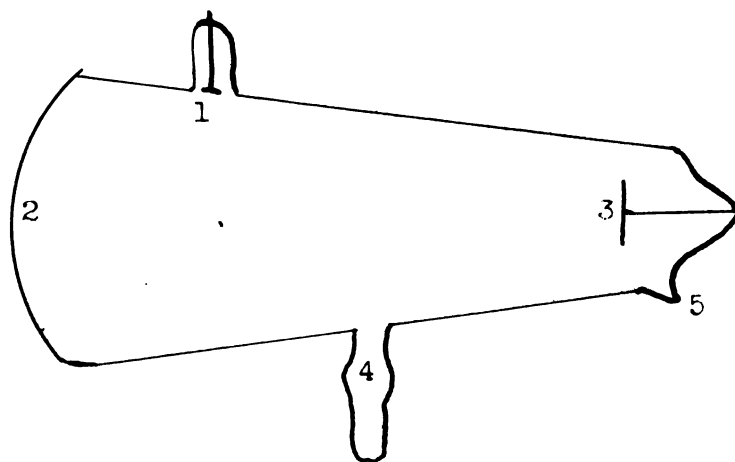


Fig. I

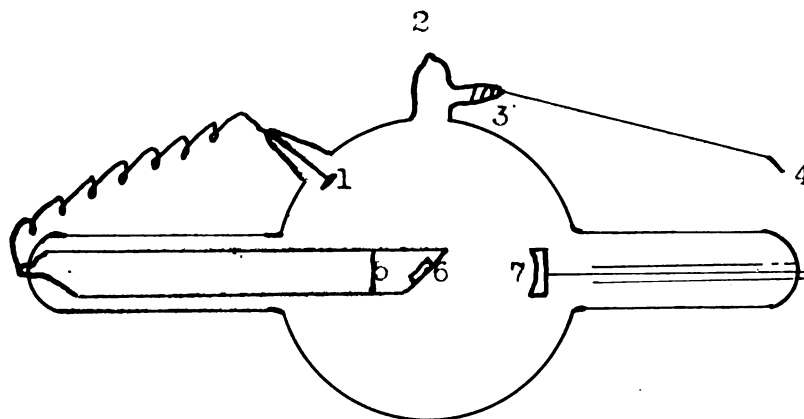


Fig. II

KEY TO FIGURE I

1. Anode
2. Glass wall which served as target
3. Cathode
4. Glass rod for supporting tube
5. Sealing tip.

KEY TO FIGURE II

1. Auxiliary anode
2. Sealing tip
3. Softening material
4. Adjustable gap for softening
5. Copper block
6. Tungsten or platinum button
7. Aluminum cathode.

COOLIDGE X-RAY TUBES

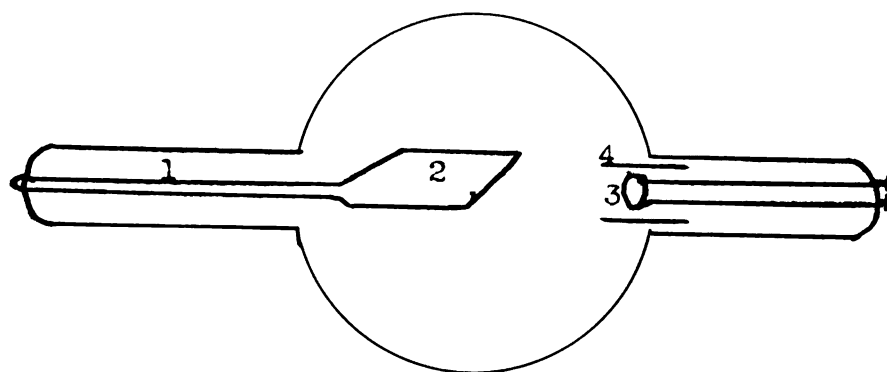


Fig. III Universal Type Tube

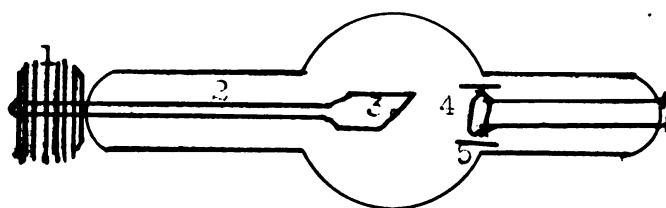


Fig. IV Radiator Type Tube

KEY TO FIGURE III

1. Molybdenum stem
2. Anode, Tungsten target
3. Cathode, Spiral of Tungsten wire
4. Device for directing cathode rays

KEY TO FIGURE IV

1. Cooling or radiating fins.
2. Molybdenum stem
3. Tungsten target
4. Cathode
5. Device for directing cathode rays.

When alternating potential is applied, it is alternately charged positively and negatively. When positive, no electrons leave the cathode and we have no other source of electrons. Thus on this half of the cycle there is no discharge. However, if the target becomes heated to a high temperature, it may emit electrons. This would produce a cathode ray bombarding the fragile cathode and the vital part of the tube would soon be destroyed. The target must be kept at a low temperature if alternating potential is used.

All tubes of the hot cathode type are commonly called Coolidge tubes. There are many special designs of this type of tube for special lines of work. These types are built with fine, medium, and large focal spots, depending upon the use of the tube in question. To get the sharpest and the clearest pictures, it is necessary to have almost a point source of X-rays. This condition is affected by special shaping of the cathode spiral. A hemispherical spiral placed close to the target gives a small focal spot. Such a fine focus tube has its disadvantages because the cathode rays bombard only a very small area, and considerable energy is released at a point. The target becomes badly pitted and distortion results in pictures if tube is operated for long periods of time. For work where less sharpness is desired, broad focus tubes can be used. The broad focus type of tube does faster work than the fine focus tube.

The Westinghouse Electric Company have developed a tube which differs markedly from the ordinary X-ray tube in construction. This new tube has target arranged perpendicular to the path of the cathode rays. The X-rays are sent back over the same path the cathode rays travel and right on through the cathode. By suitably arranging the focal area on target, the rays can be made more nearly parallel than in tubes where the target is inclined forty five degrees to the path of the cathode rays. Figures III and IV show schematic diagrams of Coolidge tubes. Figure IV shows a tube with an external device to aid in radiating heat away from the target.

DEVELOPMENT OF HIGH POTENTIAL APPARATUS

The Induction Coil is a device for transforming low potential current from a battery into high-potential current suitable for the operation of an X-ray tube. It consists essentially of a few turns of wire around an iron core, outside of which thousand of turns of fine wire are wound. The iron core becomes magnetised when the switch is closed and the battery send current through the few turns around the core. This magnet attracts a small metal arm which act breaks the battery circuit, and the core loses its magnetic properties, releasing the metal arm which is pulled back into its original position by a small spring.

This "makes" the circuit again, and the whole process is repeated. As the circuit is thus alternately "made" and "broken," an alternating current is induced in the coil surrounding the primary. It is desirable to employ a direct potential across the terminals of the tube. Therefore a condenser is placed in circuit, as shown by Figure V, so that it is charged when the primary circuit is closed and discharges rapidly when the circuit is broken. This demagnetizes the iron core rapidly. The induced potentials in the secondary are much feebler at the "make" than at the "break" of the primary circuit. The current induced on the "make" is known as "inverse" current and is very nearly suppressed in a good coil. This method of generating high potentials for X-ray work is not very widely used in United States but finds considerable use abroad. It is often employed in semi-portable outfits.

The Tesla coil is in a way a double induction coil. Figure VI is a sketch showing the principles of operation. An alternating current is applied to the primary of the first coil and is stepped up to a high voltage by the secondary. This induced current is then sent to the terminals of a circuit including a condenser, coil and spark gap. The current is oscillating rapidly as it leaves the condenser. A high frequency, high-potential current is delivered at the terminals of the secondary coil. The use of the Tesla coil is usually confined to small portable outfits because an X-ray tube especially adapted to high frequency potential must be used.

The Influence Machine has also had some use in generating high potentials. Two sets of conductors are rotated in opposite directions. One set of conductors becomes charged by friction or some other method and this charge induces charges on the other set of conductors. Brushes are arranged to pick up these charges which are stored in Leyden jars until the potential difference across the terminals of the machine becomes sufficiently high for the desired use. A properly operating influence machine produces a beautifully steady potential for X-ray work. However, it is very difficult to keep such a machine operating properly. Many plates must be rotated at a high velocity which involves considerable danger to the attendant.

The method most commonly used for the production of the high potentials required for X-ray work is stepping up a low alternating voltage by means of a closed iron core transformer. The primary and secondary windings are both wound about the iron core. The whole set-up is generally immersed in oil which has a very low carbon content. The resultant high potential will bear the same ratio to the impressed voltage as the number of turns in the secondary winding bears to the number of turns in primary winding.

Some tubes are built to operate under an alternating potential, but the tube is twice as efficient when full wave uni-directional potential is applied.

HIGH POTENTIAL APPARATUS

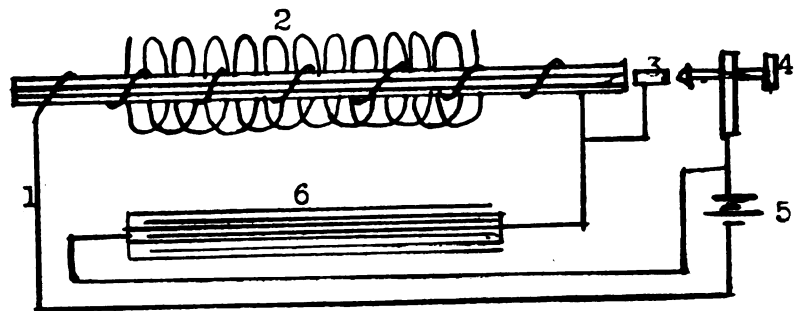


Fig. V Induction Coil

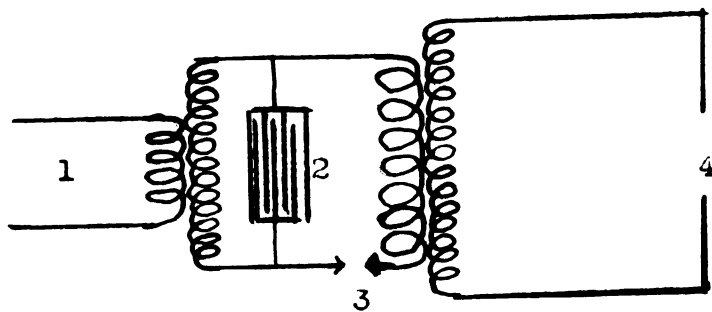


Fig. VI Tesla Coil

KEY TO FIGURE V

1. Primary circuit
2. Secondary circuit
3. Metal arm, primary circuit interrupter
4. Frequency adjuster
5. Battery
6. Condenser

KEY TO FIGURE VI

1. Alternating potential applied to primary
2. Condenser
3. Spark gap
4. Secondary terminals

The method for producing high voltages by transformer produces an alternating current. Maximum efficiency of operation is obtained when the alternating electromotive force is rectified, converted into direct e. m. f. The methods most commonly employed for rectifying high potential alternating current are: the kenetron tube circuits and the mechanical rotating disc.

The kenetron tube is so constructed as to allow current to flow through it in one direction only. Figure VII pictures a circuit employing one kenetron tube and giving half wave rectification. Only one half of the voltage cycle is effective in producing X-rays. Figures VIII and IX picture circuits using two and four kenetron tubes respectively. These circuits give full wave rectification, that is, the one half of cycle is reversed in direction and the resulting potential is uni-directional.

Figure X gives a schematic drawing of the mechanical rotating disc rectifying switch. A large disc made up of mica or other suitable insulating material is driven by a synchronous motor. The disc is driven at 1800 revolutions per minute, and in exact synchronism with alternating potential delivered to brushes 1 and 2 shown in diagram. Metal conductors A and B are mounted on the periphery of the mica disc. When brush 1 is negative then 4 is also negative (from Fig X and 3 and 2 are positive. When

one half of a cycle is completed, terminal 1 has become positive, but the disc has rotated through ninety degrees and conductor B now joins brushes 1 and 2. Therefore 2 is always positive and brush 4 is always negative and uni-directional potential is applied to terminals of the tube.

Figures XI and XII show the voltage curve before and after rectifying. Although the rectified potential is unidirectional it is of pulsating form as shown in diagram. The shaded portions represent voltage wasted in the process of rectifying and in heating the tube.

The methods are commonly employed for controlling the kilovoltage applied to the terminals of the X-ray tube. A variable resistance is often connected in series with the primary winding of the transformer. This method is not very dependable where accuracy is desired because the resistor becomes heated during the operation of tube. Due to atmospheric conditions the heat may not be radiated from the resistor at the same rate on two successive days for any one setting. A more accurate method is to place an auto-transformer in the primary circuit so that the voltage applied to the primary coil of the transformer can be easily and accurately adjusted.

DEVELOPMENT OF OTHER X-RAY PHOTOGRAPHIC EQUIPMENT

The first X-ray photographs required long exposures to the rays. The films used were not very sensitive to the X-rays, and intensifying screens had not yet

HIGH POTENTIAL RECTIFYING APPARATUS

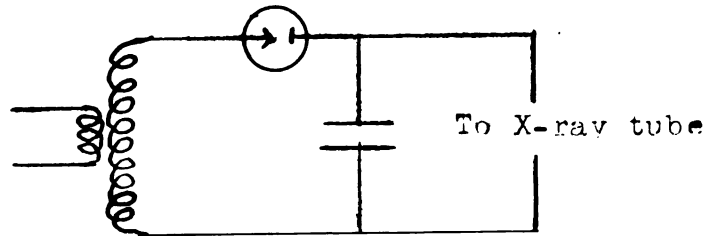


Fig. VII Kenetron Tube half wave rectifying circuit.

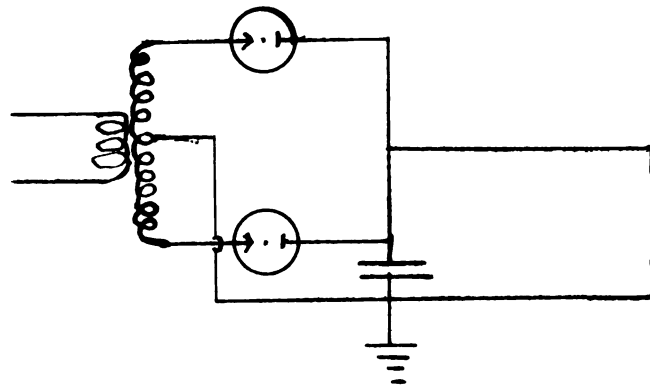


Fig. VIII Two tube rectifying circuit, full wave.

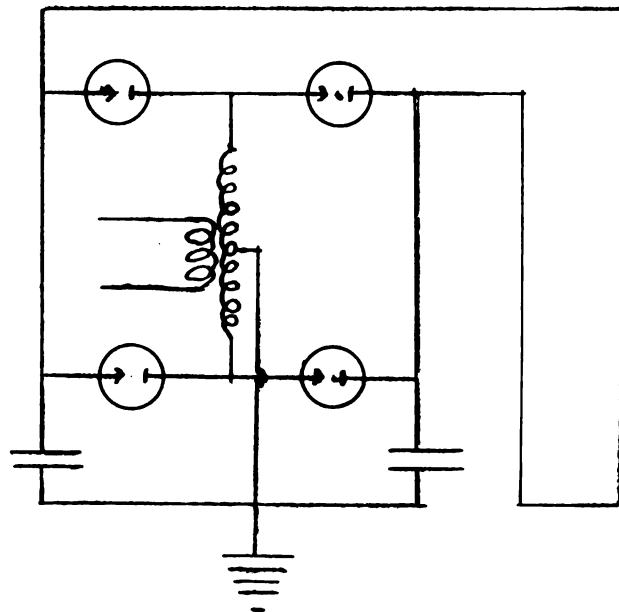


Fig. IX Four tube full wave rectifying circuit

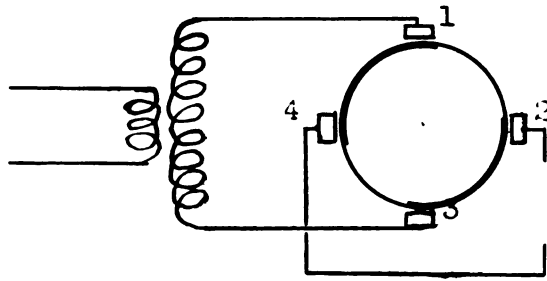


Fig. X Mechanical rectifying device

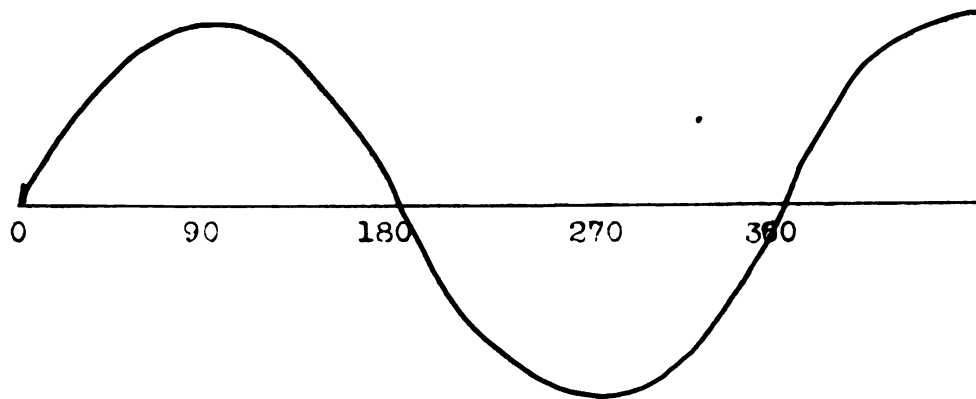


Fig. XI Alternating voltage sine curve

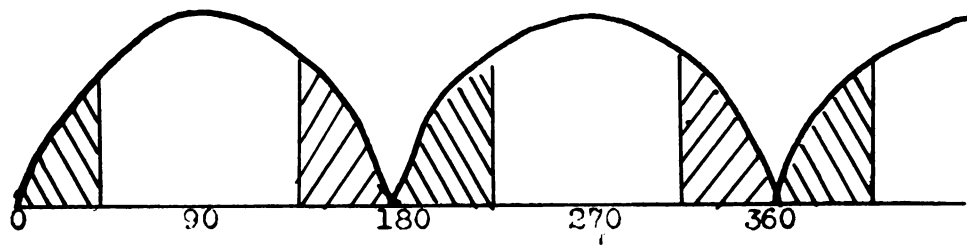


Fig. XII Rectified voltage curve.

been invented. However, scientists who noticed that the X-ray was capable of causing certain chemical compounds to fluoresce with visible light conceived the idea of placing such a screen against the film during the exposure. Since the film was more sensitive to visible light than to X-ray, this should produce a good picture. The results were satisfactory and the idea was developed. The usual type of intensifying screen is now made up of a fluorescent material consisting largely of calcium tungstate which fluoresces with a light of wave length about 3000 angstrom units. This is the wave length for which the emulsion is most sensitive.

Only a very small portion of the ray is absorbed by the film. If the plate is backed up by a lead sheet more of the energy is utilized. The Eastman Kodak Company manufacture a film for X-ray photography which is heavily coated with sensitive emulsion on both sides of the film. This cuts the time for exposure in half. The intensifying screens, one placed on each side of such a film reduces the time to about one eighth the time for ordinary exposure with Eastman's duplitized film.

TECHNIQUE OF X-RAY PHOTOGRAPHY

The operator should try to become thoroughly familiar with his machine before trying to produce perfect pictures. He should try to work out a technique for different sizes, objects, using different settings

been invented. However, scientists who noticed that the X-ray was capable of causing certain chemical compounds to fluor

of the switches. A proper procedure in handling tube and machine is indispensable. A method should be adopted which will save time and tube, render reproduction of results possible, apply to any machine, require a minimum of instrument reading when tube is operating, and indicate the working range of the machine. X-ray apparatus is expensive, handle with care. Never close the operating switch while some person is too close to a high tension wire. Never test your tube and apparatus with patient in position. Never close the main switch before you know that current is flowing through the filament of a Coolidge tube. Do not try to take pictures of thick dense objects with low power, not try to use excessive power for thin objects. Develop a good darkroom technique.

It will soon become apparent to an X-ray operator that the rays produced by higher potentials have considerable more penetrating power and more energy than the rays excited by lower potentials. The lower potentials show more detail in a picture while higher potentials tend to penetrate and obliterate details. The effect of the ray on a plate is proportional to the square of the voltage exciting the ray. This statement deals with a constant potential or with the effective voltage.

Variation in the tube current also produces a decided effect on the exposed plates. If the potential is kept constant, the effect on plate varies directly with the tube current. However, (at least with our machine), as you lower the tube current, the applied potential raises. Thus the effect of lowering tube current may not produce direct variation in blackening of plate unless constant potential is maintained.

The blackening of the plate varied indirectly as the square of the distance from the plate to the target of the tube. The distance chosen should be great enough so that distortion of image does not result.

If the operator has plenty of time in which to make the exposure, he should choose a technique involving low enough potential to give good detail, a large enough plate to target distance to give no marked distortion, and the tube current should be moderate. Intensifying screens may be used or omitted as the operator chooses. If fast work is required, the following conditions should be met: very large current, high voltage, fast plates and intensifying screens, and if necessary, small target-plate distance. Most machines are equipped with automatic timing devices but the operator can time his exposure by a stop watch or by counting off seconds. "One thousand one, one thousand two, one thousand three," is a convenient system with which one can acquire a great deal of accuracy with a little practice.

Darkroom technique is also very important in the production of good X-ray pictures. Several important rules follow:

Never handle the films with wet or greasy fingers before or after exposure;

Learn how to handle the plate without touching the emulsion;

Do not expose film to any light at any time until the film is almost fully developed;

A weak red light may be used in darkroom to view developing plate; this is best done by using reflected light.

Wash all negatives thoroughly before and after fixing,

Leave the films in the fixing bath for a few minutes after they seem fully cleared up;

Do not leave films in the developer or ~~hydro~~ too long as this is harmful to the plate and poor pictures will surely be the result;

Try to have the darkroom well ventilated;

Arrange the materials in an orderly fashion and learn the arrangement so that you can find things in the dark;

Do not leave any boxes open when you leave the room; X-ray films are expensive and a small amount of light renders them useless;

Do not leave fixed negatives in the water for long periods of time, for the emulsion will soak off.

WAPPLER KING MODEL X-RAY MACHINE

Figure XIII on following page shows a schematic wiring diagram of the Wappler King model X-ray machine with which the writer's work was carried out. This machine is rather old and not very dependable. The first problem was to make the machine run for it had not been used for some time and ^{was} decidedly out of adjustment. The rotating disc is really driven by two motors. An induction motor serves as a starting motor, but this is left running even after the synchronous motor reaches full speed. Alternating current is delivered to the one end of the armature of the synchronous motor. Direct current is taken from the other end by means of a commutator and brushes. This direct current is used to excite the field and was also intended to operate the automatic timing device, but we used a separate source of direct current. The synchronous motor offered considerable trouble before it was finally made to run at the right speed. After considerable delay the machine was finally made to run and a few good pictures were obtained, Print number 1 was made at this time.

Before attacking any problem, the operator must first become familiar with the peculiarities of his machine and work out a suitable technique which will cover all phases of his problem. It is very helpful to know what voltage the transformer is delivering for each setting of the switches. A calibrated spark gap was used to record these voltages.



Print Number I Showing Wrist Structure

The terminals of the gap were connected to the terminals of the tube, and the readings were taken while the tube was operating. The potential control was a variable resistor in the primary circuit. On it were nine fins to aid in radiating the heat. These fins were numbered 0, 1, 2,—8. With the arm on fin number 0, no resistance was in the circuit. All the resistance was in the circuit when the arm was set on fin number 8 etc. There were also various settings of the primary convolution switch for which the voltages were calibrated. These settings as indicated on wiring diagram of the machine, were for various number of turns in the primary of transformer. A table of values appears on separate sheet. Values of potential given in each case represent peak voltages and not the effective value of the potential.

SPECIAL PROBLEM

With the above information and knowledge we were ready to begin taking X-ray pictures. The Animal Husbandry Department was interested in the variation in the number of ribs and vertebrae which existed among pigs. They desired to make X-ray photographs of all the young pigs born in the Michigan State College experiment station at East Lansing during the spring farrowing season. The X-ray offered an easy way to make a count of the vertebrae and then feeding tests were to be conducted to determine if these variations were of any economic importance.

22



KEY TO FIGURE XIII

1. Filament transformer
2. Filament current control
3. Coolidge X-ray tube
4. Auto-transformer, supplies 220 volts to
motors and primary of transformer.
5. Automatic timing device
6. Ammeter
7. Time switch
8. Main switch
9. Key to aid in setting timing device
10. Polarity reversing switch
11. Spark gap
12. Variable resistance potential control
13. Primary convolution switch
14. Rotating rectifying disc
15. Primary transformer winding
16. Secondary transformer winding
17. Tube current milliammeter

THE UNIVERSAL TUBE

PEAK VOLTAGES

<u>Tube current</u> <u>m. A.</u>	<u>Res. Rho.</u> <u>Setting</u>	<u>Potential</u> <u>Prim. Con. #4</u>	<u>Potential</u> <u>Prim. Con. #3</u>
25	0	80	Not determined
25	1	78	" "
25	2	74	" "
25	3	68	" "
25	4	43	" "
25	5	34	" "
25	6	**	" "
20	0	88	57
20	1	81	55
20	2	75	50
20	3	72	42
20	4	58	32
20	5	44	18
20	6	10	**
15	0	90	60
15	1	88	60
15	2	84	56
15	3	83	56
15	4	78	46
15	5	65	40
15	6	38	**
10	0	94	65
10	1	93	64
10	2	90	62
10	3	92	62
10	4	84	58
10	5	70	57
10	6	57	50
10	7	28	**

Radiator Tube (all readings taken on Prim. Con. #4)

10	0	105
10	1	100
10	2	98
10	3	96
10	4	88
10	5	84
10	6	70
10	7	52
5	0	106
5	1	104
5	2	102
5	3	98
5	4	96
5	5	90
5	6	86
5	7	76

A permanent record was desired, so it was necessary to invent some system of numbering the film and the individual pig, so that they could both be accurately identified in the future. Marking the film was an easy matter because a small thickness of lead stops X-rays. We used lead wire numbers and letters indicating the breed, sex, litter, and individual pig number. The pigs were marked by means of notches in their ears. Notches in a certain position represented a definite number, those on one ear representing the litter number and those on the other ear representing the individual pig number. A notation on the film of YS207 would be interpreted as Yorkshire sow, litter 20, pig #7.

PHOTOGRAPHING THE PIGS

Due to the trouble in repairing the machine, a late start was made. Several litters of pigs had already come into existence and were rapidly growing too large for us to handle. There were about two hundred young pigs to photograph. This involved much work besides the actual photography, for the pigs had to be caught, loaded into a truck, and transported over to the Physics building, and then returned to the pastures. We wanted to film as many as possible at the age of one to two weeks. The technique set up was not one that produced perfect negatives, but our object was to get readable pictures of as many of the pigs as possible. Our machine would not take good pictures of pigs which were thicker than five inches through the chest and was absolutely stopped at eight inches.

One of the difficulties encountered in photographing pigs was keeping them from moving during exposure to the rays. Whether due to static electricity, noise of the machine, or the effect of X-rays, the pigs would begin to squirm when the main switch was closed. Several methods for holding the pig were invented. Only two were successful and one of these was discarded as being too dangerous to attendants. In this latter method two men held the legs of the pig, but this was apt to result in over exposure of their hands. The most satisfactory method consisted in rolling the pig tightly in a heavy fabric cloth which did not absorb an appreciable amount of the rays. Rubber bands were stretched about the bundle over the pigs legs.

Two or three pigs were rolled up and placed on a small wooden frame. Long wooden boards were placed between the walls of the frame and the pigs to hold them firmly in position. Between the pigs were placed boards with lead strips on bottom to mark division between pigs on film. The "patients" were laid on their backs. Numbers and letters to identify each individual were mounted on a thin strip of wood and placed beneath the pig to which it referred.

The wooden frame was built to allow the loaded cassette to be placed beneath it. The cassette was 10 x 12 inches and was equipped with two intensifying screens.

The time of exposure varied with the size of the pigs. Due to our many difficulties, we were not able to take the pictures of all the pigs while they were of a certain age. Pigs ranging in age from eight days to ten weeks were dealt with. The time of exposure was decided by the operator, one picture was taken and developed, and from the resulting negative, the operator determined a suitable time. The actual exposures were from one to eight seconds. The general fault of our technique was over-exposure. All pictures were taken at a target-plate distance of 36 inches.

Two tubes were used for this work. The first employed was a Coolidge tube of the universal type. This tube was rather old and performed erratically. It was a fine focus tube, and the target was rather badly pitted. Its performance became more and more erratic until it had to be discarded. This tube was operated at sixty to eighty Kilovolts potential and twenty-five milliamperes tube current. The above tube was employed because the time necessary for an exposure was less than with our Coolidge radiator tube which was designed for only ten milliamperes tube current. The latter tube was employed in the latter half of the experiment with much better results. Toward the end of the experiment the transformer became erratic, probably due to a break in the insulation of the secondary circuit.

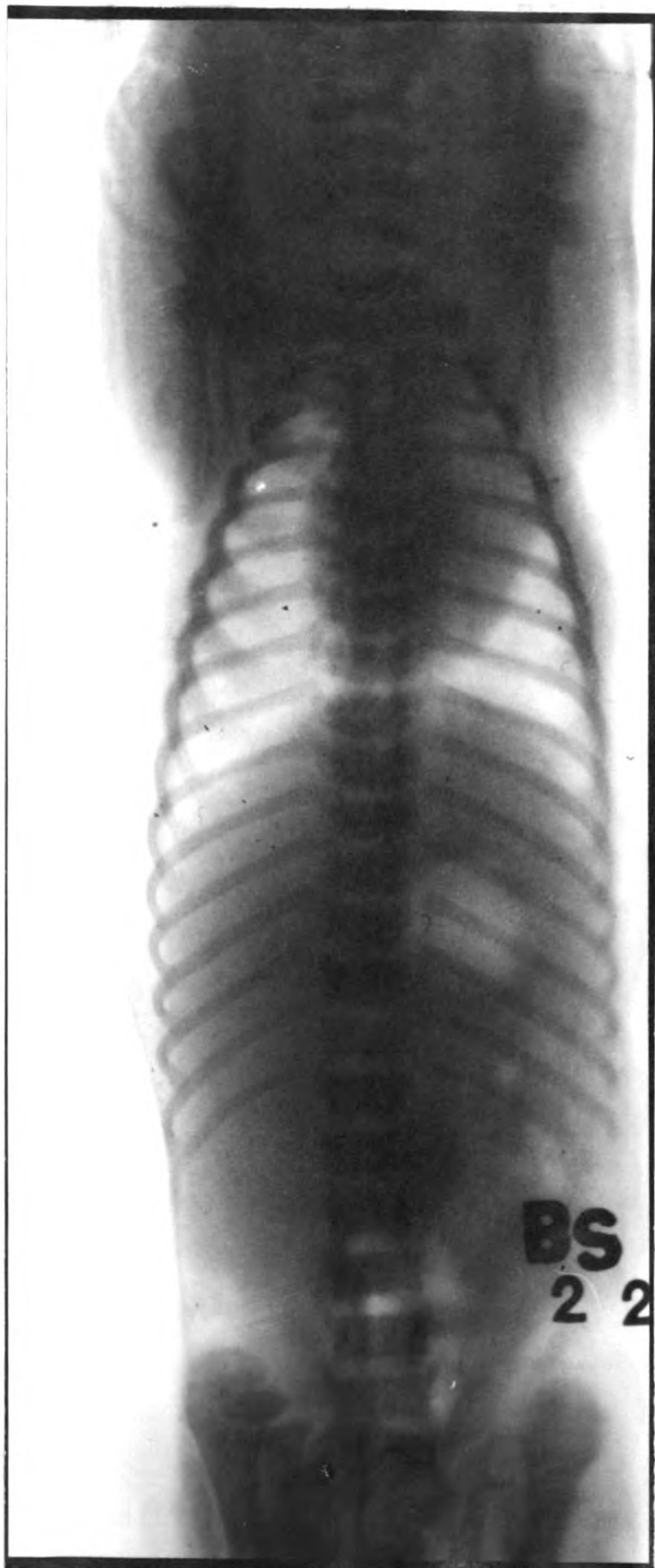
Prints 2, 3, and 4 show some of the variations found.

THE RESULTS OF INVESTIGATION

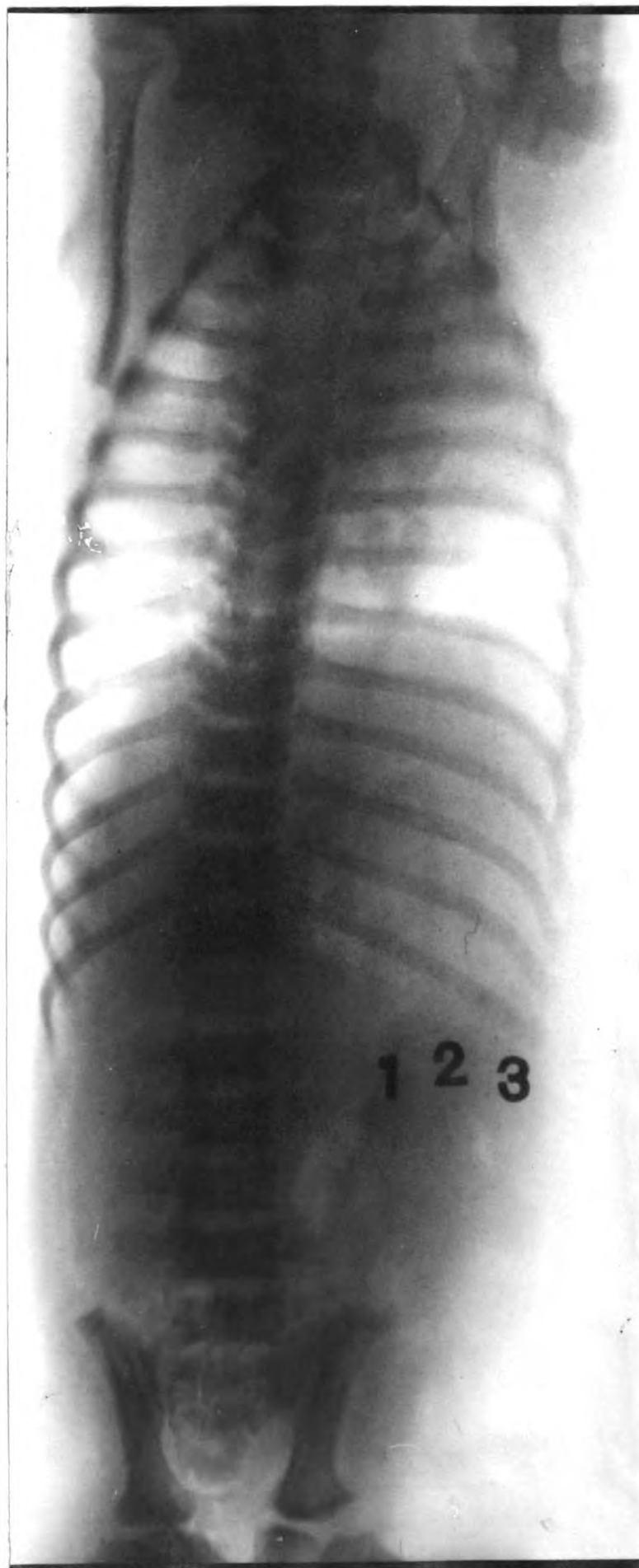
A complete record of the results of our experiment is not yet compiled, but since this paper is not concerned with genetic importance of the experiment, the following table of results will satisfactorily show the variations found.

<u>Breed</u>	<u>No. of Pigs</u>	<u>20 Vt.</u>	<u>21 Vt.</u>	<u>22 Vt.</u>	<u>23 Vt.</u>
Chester White	36	1	25	10	0
Duroc	27	6	18	3	0
Poland China	25	2	16	6	1
Berkshire	28	0	9	17	2
Yorkshire	56	0	47	9	0
	—	—	—	—	—
	172	9	115	45	3

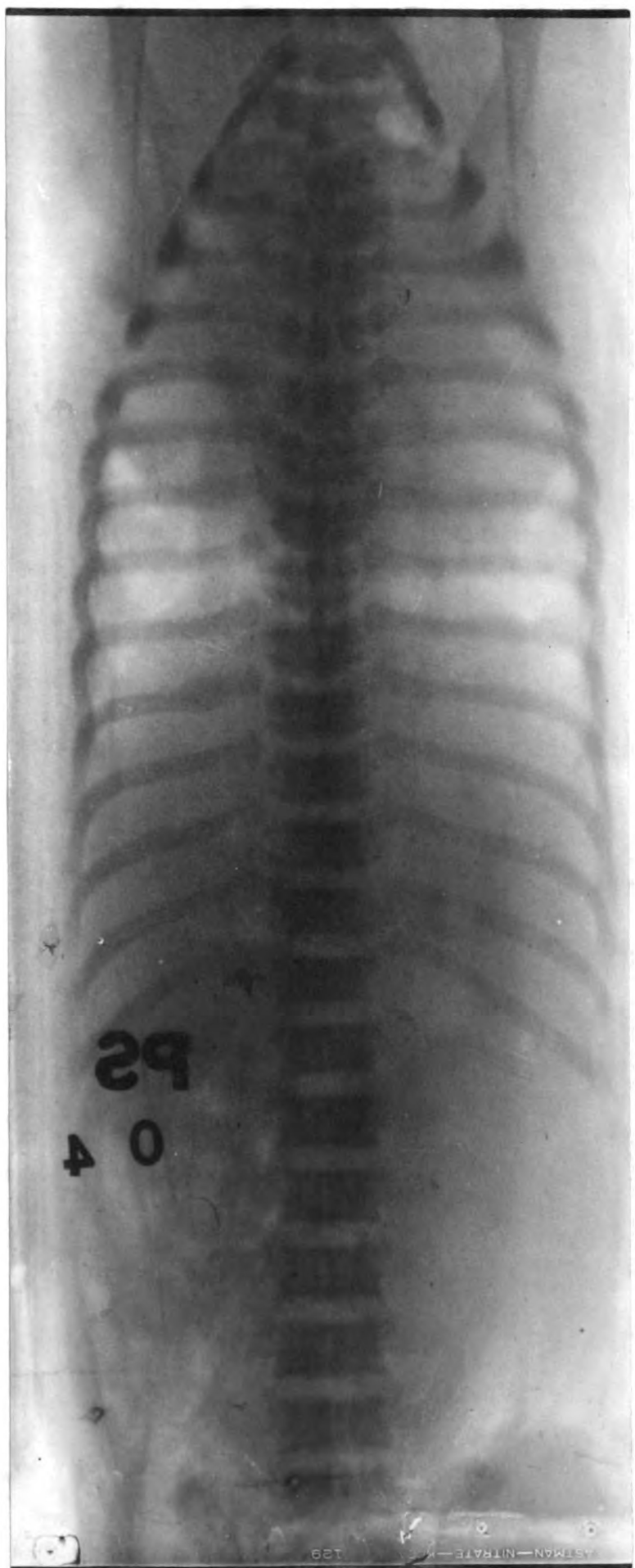
Prints 2, 3, and 4 show some of the variations found.



Print II 16 Pr. ribs and 21 Vertebrae



Print III 14 Pr. ribs and 20 vertebrae



Print IV 15 Pr. ribs and 22 vertebrae

CRYSTAL STRUCTURE AND X-RAY DIFFRACTION

After completing the immediate task of taking pictures of all the pigs available the writer, desiring to get further experience in the manipulation of other available X-ray equipment, elected to make a study of the equipment especially designed by the General Electric Company for Crystal structure analysis by the X-ray diffraction method. The discussion following is a report on this study.

During the seventeen years following Roentgen's discovery of the X-ray considerable research work was carried on to prove or disprove that X-rays and light were similar in nature. Nearly all experiments failed to produce any definite proof. Not until 1912 was the truth definitely established. During that year Prof. Laue of Munich published a paper asserting that the regularly spaced planes of a crystal should produce diffraction of X-rays if the latter were a wave phenomena. He calculated mathematically what effects would be produced on a photographic plate when a monochromatic beam of X-rays was passed through a crystal of zinc blends. Friedrich and Knipping put his argument to test experimentally and obtained the results prophesied by Laue, definitely establishing the fact that X-ray radiation is wave phenomena similar to light.

X-ray diffraction by crystals interested other scientists and was soon being applied to identifying crystal structures and determining the wave length of X-rays. The chief difficulty encountered was in finding perfect large crystals of compounds. Only a few crystalline substances yielded suitable crystals for this type of research. Debye and Scherer, and Hull advanced a new method for producing X-ray diffraction. The method consisted in sending a fine beam of monochromatic X-rays through a mass of finely powdered crystalline material, the particles of which are arranged at random so their axes are oriented in all directions.

Special apparatus was developed for this type of research. Figure XIV shows a schematic diagram of the X-ray Diffraction Apparatus, Type VWC, form E, manufactured by the General Electric Company. Item #5 on diagram, Victor Stabilizer, is designed to control the filament current and thereby regulate the tube current. When the desired adjustment is obtained, the stabilizer will automatically maintain these conditions. In the filament circuit of the tube is an automatic water pressure switch which breaks circuit if water pressure falls below fifteen pounds per square inch. The tube is a Coolidge type tube with a water cooled molybdenum target, permitting the application of unrectified potential. This metal produces very nearly monochromatic X-rays at a potential of 30,000 volts. Detailed description and instructions for operation are furnished with the apparatus.

X-RAY DIFFRACTION APPARATUS

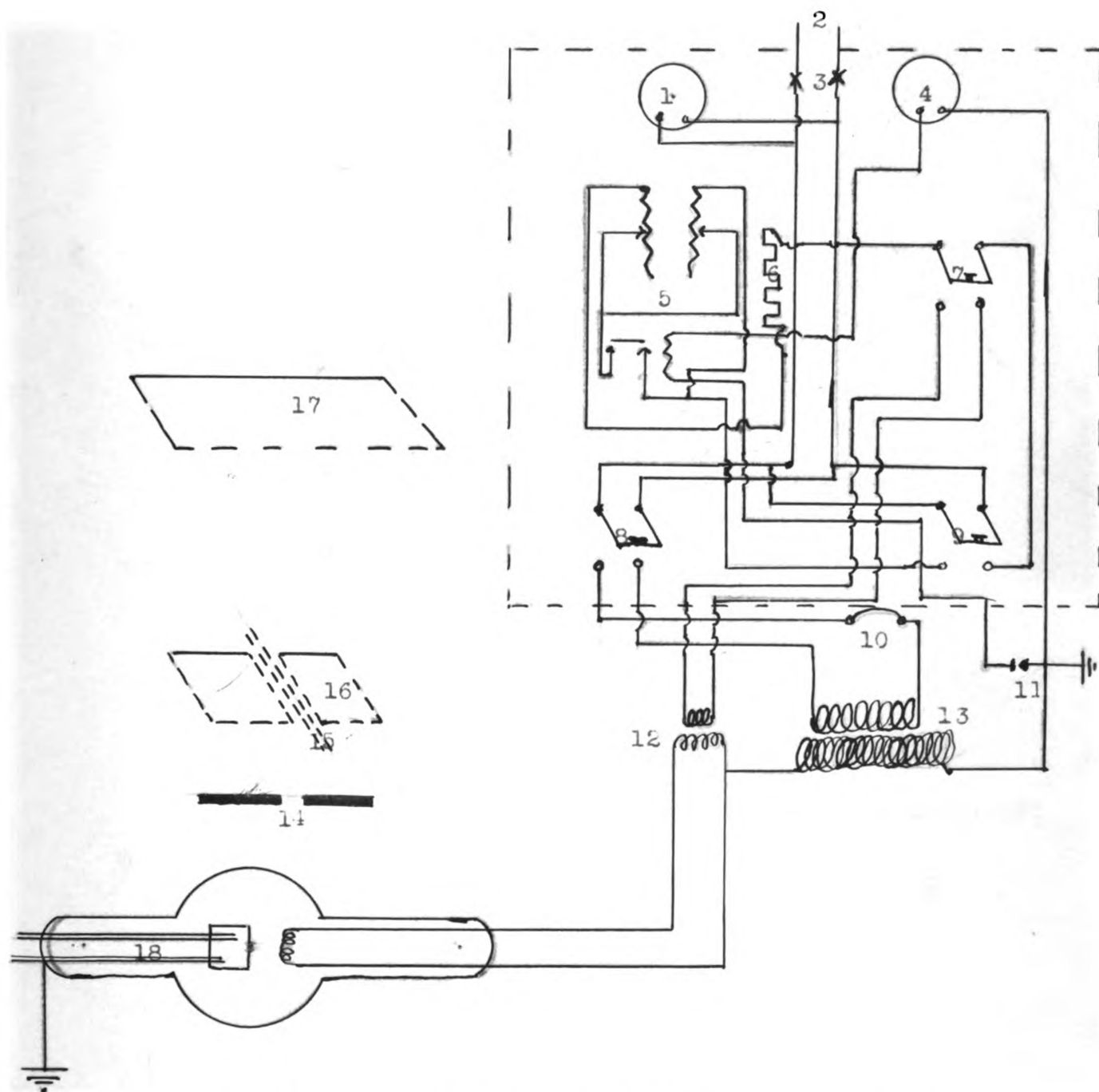


Fig. XIV General Electric Diffraction Apparatus.

KEY TO FIGURE XIV

1. Voltmeter, line voltage
2. 110 volts alternating e. m. f.
3. Fuses
4. Milliammeter, tube current
5. Victor stabilizer
6. Cage type resistance
7. Automatic water pressure switch
8. Switch
9. Switch
10. Safety break on door of can
11. Safety breakdown spark gap
12. Filament transformer
13. High potential transformer
14. Slit
15. Powdered specimen in glass tube
16. Slit
17. Film
18. Water circulating system of cooling target

THEORY OF CRYSTAL STRUCTURE

Crystallographers had produced the prevailing theory of crystal structure before X-ray diffraction by crystals was developed. However the latter did much to confirm the theory. It is believed that crystals are made of atoms, arranged in perfectly definite geometric pattern. Every atom is contained a set of parallel, equally spaced planes. There are several such systems of planes, but we will think of three sets of parallel planes corresponding somewhat in general directions to the planes making up the rectangular system of coordinates so commonly used to locate points in space. Each set of planes are equally spaced but the spacing in one set need not equal that in either of the other sets. We can refer such a structure to a coordinate system by taking any point of intersection of three planes as the origin and the three lines formed by intersection of pairs of planes as the coordinate axes. Parallelopipeds are formed throughout the crystal by the intersection of the three sets of planes. Each of these parallelopipeds is a unit crystal. The length of the edges of the unit cell becomes the unit of length on the corresponding axis.

All crystals can be classified into six systems:

CUBIC SYSTEM. Crystals referable to three equal rectangular axes;

TETRAGONAL SYSTEM. Crystals referable to three rectangular axes, two of which are equal, the third being a tetragonal axis.

HEXAGONAL SYSTEM. Crystals referable to three equal oblique axes making equal angles with each other;

ORTHORHOMBIC SYSTEM. Crystals referable to three unequal rectangular axes;

MONOCLINIC SYSTEM. Crystals referable to three unequal axis one of which is perpendicular to the other two;

ANORTHIC SYSTEM. Crystals referable to three unequal oblique axes and possessing a center of symmetry.

Figures XV, XVI, and XVII show three types of crystals belonging to the cubic system. Figure XV pictures a simple cubical lattice. Figures XVI and XVII picture face centered and body centered cubical lattices respectively.

There exists a method for numbering the various planes which consists in labelling the plane with the reciprocals of its intercepts on the coordinate axis. In figure XV the method would be applied thus:

Plane GLAF---100 plane
 Plane CEDG---001 plane
 Plane BDGF---010 plane
 Plane ACB---- 111 plane
 Plane CBEF--- 011 plane
 Plane DBAE--- 110 plane

X-RAY WAVE DIFFRACTION

Wave Diffraction phenomena may be explained by aid of diagram XVIII. We learned that one of the properties of X-rays is the power to produce a secondary radiation of rays when absorbed by matter. The diagram

CUBIC LATTICES

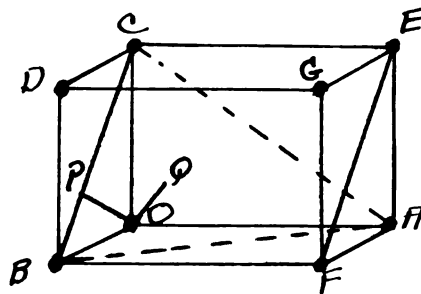


Fig. XV

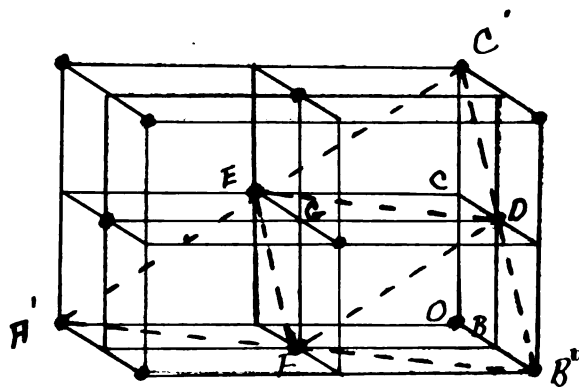


Fig. XVI

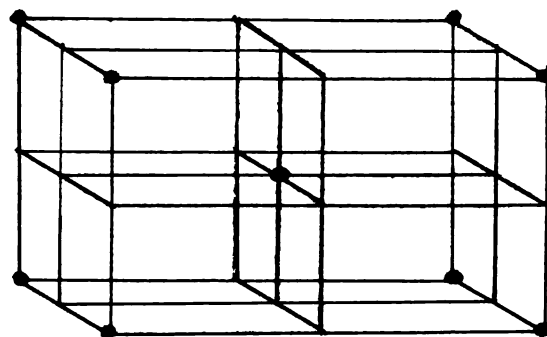


Fig. XVII

X-RAY DIFFRACTION

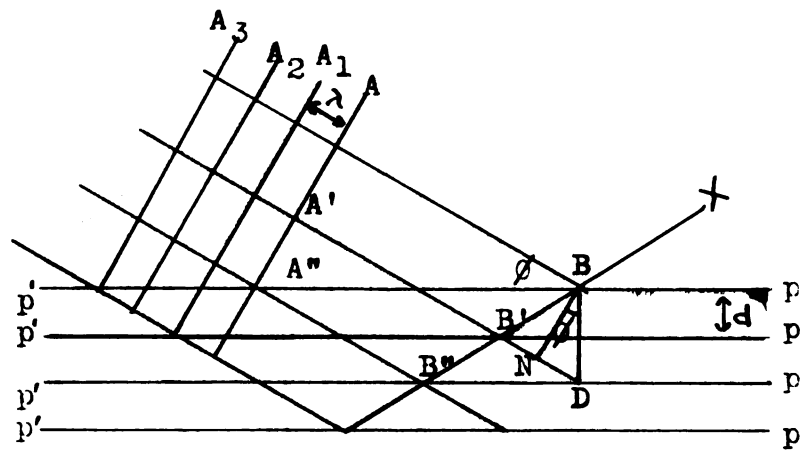


Fig. XVIII

represents a two dimensional figure, but the lines pp' represent planes in the crystal which are thickly studded with atoms. Let $A-A'-A''$, A_1 , A_2 , A_3 , etc. represent wave fronts of a train of X-ray waves striking the planes pp' at angle ϕ . Since the secondary radiation is sent in all directions, we may consider any part of the secondary ray which is sent out in a direction making angle $180 - 2\phi$ degrees with the incident beam. Then we can consider this a phenomena of reflection. The atoms at B , B' and B'' all tend to send radiation out in this direction. If the waves from each of these separate sources reach point X in phase, constructive interference is the result and a dark line or spot would be formed on a photographic film. The conditions necessary for such a result can be worked out readily. Let λ be the wave length of the original X-ray. Produce $A'B'$ to next plane, calling point of intersection D . Then $B'D$ is equal to $B'B$. The difference in path for ray AB and $A'B'$ equals $B'B - B'D$. But by correct substitution this remainder is equal to ND . ND can be expressed as a function of the angle ϕ and the distance between parallel planes pp' .

$$ND = 2d \sin\phi = n\lambda$$

For constructive interference ND must be $n\lambda$ where n represents integral values. If the waves are not exactly in phase the resulting radiation from the many layers approaches zero intensity and the film is not affected. Other systems of planes will have different angle of reflection and hence the dark line for this

system of planes will appear in different position on the film. Knowing the distance of the specimen from the film the angles of diffraction can be measured from the spacing between lines on the negative. For another set of planes the above formula becomes: $2d' \sin \theta$.

The powdered specimen is placed in a small glass tube about one thirty-second of an inch internal diameter. The ends of the tube are plugged with cotton so that no chemical change shall take place during the long exposure. The specimen is held in place by the cassette which holds the film. This cassette is in the shape of a quadrant of a circle of eight inch radius. The bands resulting on the negative are in reality arcs of circles though they appear to be straight lines.

The spacing between planes can be read directly from the negative by means of a scale furnished by the General Electric Company. They also furnish graphs containing curves drawn from data about hundreds of crystal substances. If a paper with spacing on film indicated on logarithmic scale is moved up across graph, always keeping the paper strip parallel with the abscissa, an exact fit of curves with lines on paper can be found. This will then identify the crystal structure of the substance dealt with.

To check results the spacing between the (100) planes of the crystalline substance can be calculated mathematically from the following formula:

$$P = \frac{NM \times 1.649 \times 10^{-24}}{(d \times 10^{-8})^2}$$

P = density of substance

d = side of elementary cube, parallelopiped,
equals distance between the (100) planes.

M = molecular weight of substance

N = number of points associated with unit cell

n = 1 for simple cubic lattice

n = 2 for body centered cubic lattice

n = 4 for face centered cubic lattice

n = 8 for diamond cubic lattice.

Similar formulas have been developed for tetragonal and hexagonal crystals but these involve corrections for axial ratios and the hexagonal formula involves side of triangle rather than edge of cube.

EXPERIMENTAL RESULTS

The following substances were examined and their crystalline structure identified in our laboratory:

<u>Substance</u>	<u>Structure</u>
Sodium chloride	Face centered cube
Potassium chloride	Simple cube lattice
Sodium Bromide	Face centered cube
Sodium Iodide	" " "
Aluminum	" " "
Nickle	" " "
Antimony	" " "

Other substances were studied but the results were of no value due to impure samples. Print number V on following sheet shows a typical film of diffraction Pattern.

PRECAUTIONS TO BE OBSERVED BY OPERATOR

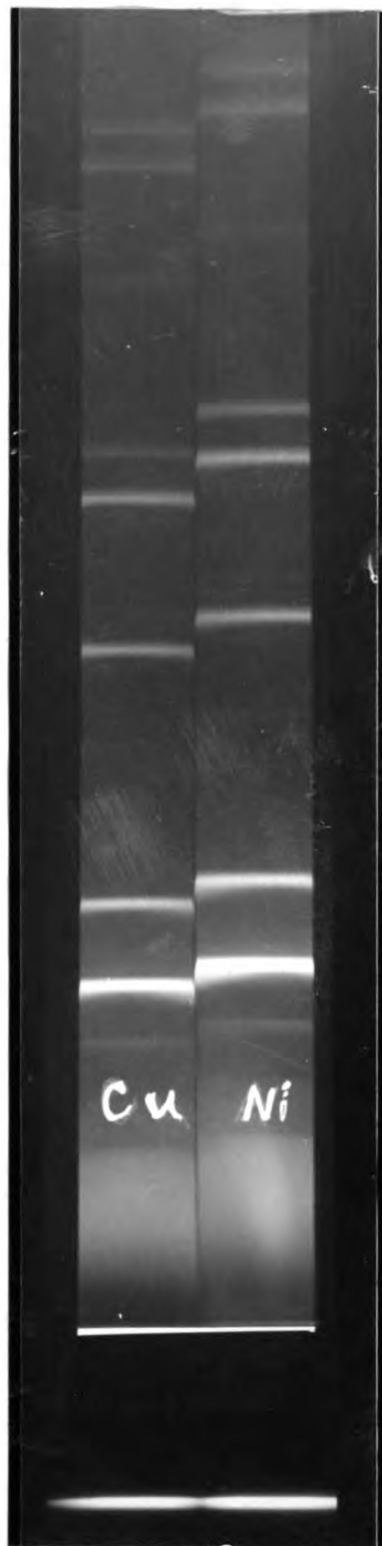
There is considerable danger connected with the operation of an X-ray machine if special care is not taken to avoid undue exposure to the rays. The body absorbs the rays from day to day. The effects are cumulative and may not appear for a week or two after the operator has been exposed. Severe and painfully slow healing wounds may result on surface of the body, and sterilization is often produced by too much exposure to the rays.

The danger can be greatly reduced if the operator will observe the following rules:

1. Use lead glass shield about the tube;
2. If possible, stand behind a lead barrier when operating machine;
3. Never use your body for fluoroscopic or photographic demonstrations if you are constantly operating an X-ray machine;
4. From time to time test the position in which you stand at controls for intensity of exposure; This can be done with a fluoroscope.
5. If doubtful about the amount of exposure your body undergoes, carry a dental film in pocket; Develop it after a week. If the film is blackened appreciably, use more care in shielding the body.

6. It is a good plan to keep an accurate record showing when and how long your body was directly exposed to X-rays;

7. Take good care of the high potential apparatus and wires. Be sure that all high tension leads are well away from control switches and from the patient.



Print V Diffraction Pattern

CONCLUSION

The writer has gained invaluable experience from his contacts with X-ray photography. He has learned to apply the principles of X-rays to practical problems to obtain desired results. A proper technique of handling costly apparatus has been developed. He has been taught that each problem should be carefully analyzed and the method of attack planned carefully before one tries to obtain a solution. Above all, this work has taught him to appreciate the importance of setting up a suitable technique for reaching a desired goal whether the problem deals with the phenomena of X-rays or other branches of science.

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