A PRELIMINARY REPORT ON THE DIAGNOSTIC AND THERAPEUTIC APPLICATION OF THE COOLIDGE TUBE

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INTRODUCTION

PRINCIPLE OF THE ORDINARY TUBE

The powerful Roentgen ray tube with a pure electron discharge, designed by Dr. Coolidge, is undoubtedly the most important contribution to Roentgenology since the birth of that science. Except for slight changes made from time to time in the construction of the tube and various methods that have been devised for regulating its vacuum, all Roentgen ray tubes have been fundamentally alike, that is to say, the penetration has always been controlled by regulating the vacuum of the tube.

PRINCIPLE OF THE NEW TUBE

In the new tube, designed by Dr. Coolidge, which unquestionably should be known as the Coolidge tube, an entirely new principle is involved. The tube and the phenomena it exhibits when excited have been fully described in the December (1913) number of the Physical Review. The limitations of the ordinary tube have been overcome by devising a tube the vacuum of which is about 1000 times as great as the vacuum of the ordinary tube. The tube is capable of being excited only when the cathode is heated. When the tungsten filament, which forms the cathode, is heated by an electric current, the electrons are liberated, or as Dr. Coolidge says, "stewed out" of the cathode and propelled across the space between the cathode and anode by the high potential current from the coil, transformer, or static machine.

The penetration of the tube depends upon the rapidity with which the electrons are liberated from the cathode. This speed is controlled by regulating a low potential current from a storage battery in circuit with the tube.

THE ADVANTAGES OF THE COOLIDGE TUBE

The advantages of the new tube are manifold and include:

1. Accuracy of adjustment.
2. Stability.
3. Exact duplication of results.
4. Flexibility.
5. Tremendous output.
6. Long life of the tube.
7. Absence of indirect rays.

ACCURACY OF ADJUSTMENT

It is not until one uses the Coolidge tube that he realizes the limitations of the ordinary tube with regard to accuracy of adjustment. Self-regulating devices have proved disappointing even when the tube is used on a coil, and entirely unsuccessful when the tube is excited by the high milliamperage ordinarily used with a transformer, because the shunt of a large current through the regulator reduces the vacuum to a greater degree than is desirable. The most careful adjustment of the ordinary tube has therefore been merely guess-work, for when the tube has been reduced to a desired penetration with a small amount of current, the penetration will materially increase again when more resistance in the rheostat is cut out, and the tube excited by more current.

In the Coolidge tube the penetration is regulated *up* or down by the amount of heat generated in the cathode filament, and this in turn is controlled by regulating the amount of current from a storage battery connected with the secondary circuit from the transformer or coil, as described by Dr. Coolidge in his abstract.

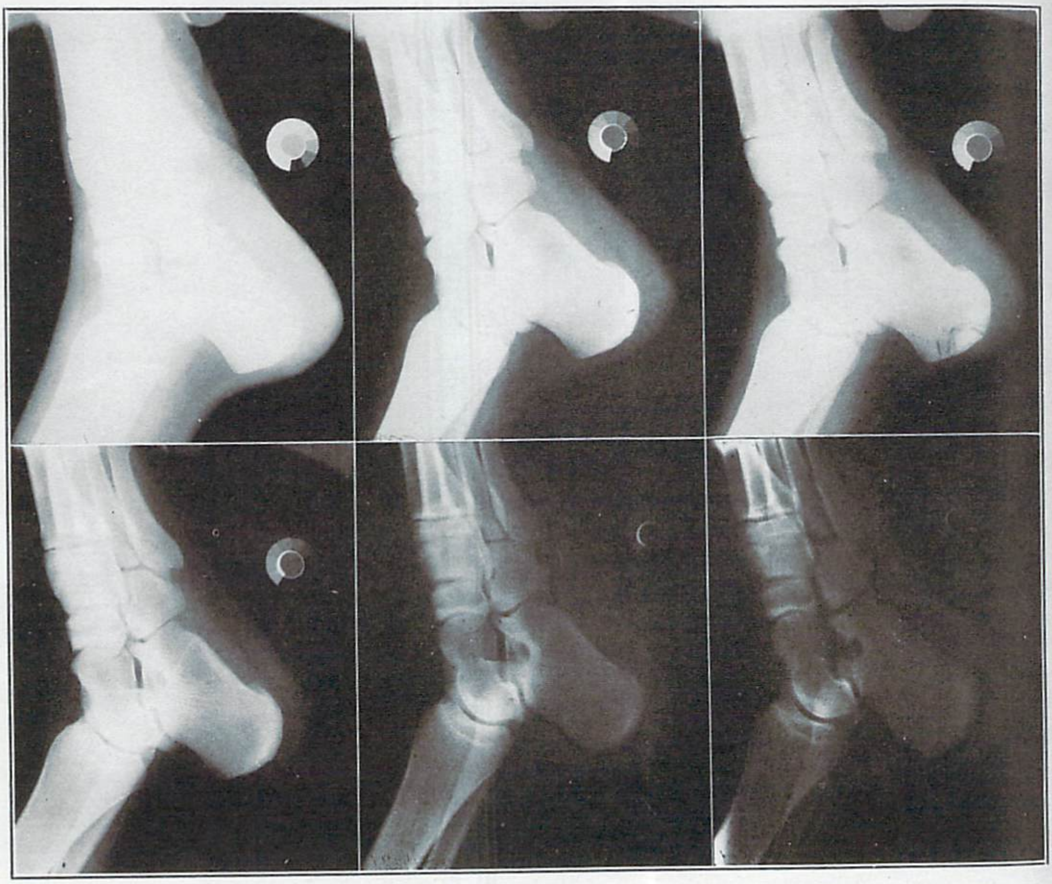
STABILITY

The stability of the tube is no less remarkable than the accuracy with which it may be adjusted. Dr. Coolidge states that the present tube, crude as it is, may be excited continuously with 25 milliamperes for 50 minutes without perceptibly changing the

(Foot, Walter Bell. Test Plate No. 1)
Fig. 1.
Detail in soft tissues. No structure of bone visible.
Parallel Gap, 2 ins.; Current, 10 m. a.; Exp., 5 secs.; m. a. secs., 50; Benoist reading, 2.

(Foot, Walter Bell. Test Plate No. 2)
Fig. 2.
Structure in soft parts shows very distinctly. Some detail begins to appear in the structure of the bone.
Parallel Gap, 3 ins.; Current, 10 m. a.; Exp., 5 secs.; m. a. secs., 50; Benoist reading, 4.

(Foot, Walter Bell. Test Plate No. 3)
Fig. 3.
Exact duplicate of roentgenogram illustrated in Fig. 2, showing the ability to produce exactly the same characteristics in two different roentgenograms.



(Foot, Walter Bell. Test Plate No. 4)
Fig. 4.
Structure of soft parts disappearing. Increasing detail in structure of bone.
Parallel Gap, 5 ins.; Current, 10 m. a.; Exp., 5 secs.; m. a. secs., 50; Benoist reading, 8.

(Foot, Walter Bell. Test Plate No. 5)
Fig. 5.
Soft tissues almost entirely obliterated. Very minute detail in structure of bone.
Parallel Gap, 6 ins.; Current, 10 m. a.; Exp., 5 secs.; m. a. secs., 50; Benoist reading, 9.

(Foot, Walter Bell. Test Plate No. 6)
Fig. 6.
Soft parts entirely obliterated. Structure of bone beginning to be obliterated.
Parallel Gap, 7 ins.; Current, 10 m. a.; Exp., 5 ins.; m. a. secs., 50; Benoist reading, 10.

penetration. For Roentgenographic work such prolonged stability is unnecessary; but stability for the length of time required to make an exposure of any part of the body produces Roentgenograms with a uniformity of excellence which has been the hitherto unattained ideal of every Roentgenologist. Having determined the amount of penetration required for any given part of the body, the tube is readily adjusted for that degree of penetration, and may be excited with any desired milliamperage from 1 to 200 milliamperes, for a sufficient length of time to make a correct exposure. The number of milliamperes multiplied by the length of exposure gives the milliampere seconds. The few tests that I have made indicate that it is immaterial whether one uses 1 milliampere for 50 seconds or 50 milliamperes for 1 second. If this be true, and one can accurately control the penetration during the entire exposure, then it is a very simple matter to obtain uniform results in all roentgenographic work by following a scale of the milliampere seconds required for each part of the body. During the short time that we have been privileged to test this tube the different degrees of penetration required for the various parts of the body were perfectly sustained during every exposure.

EXACT DUPLICATION OF PREVIOUS RESULTS

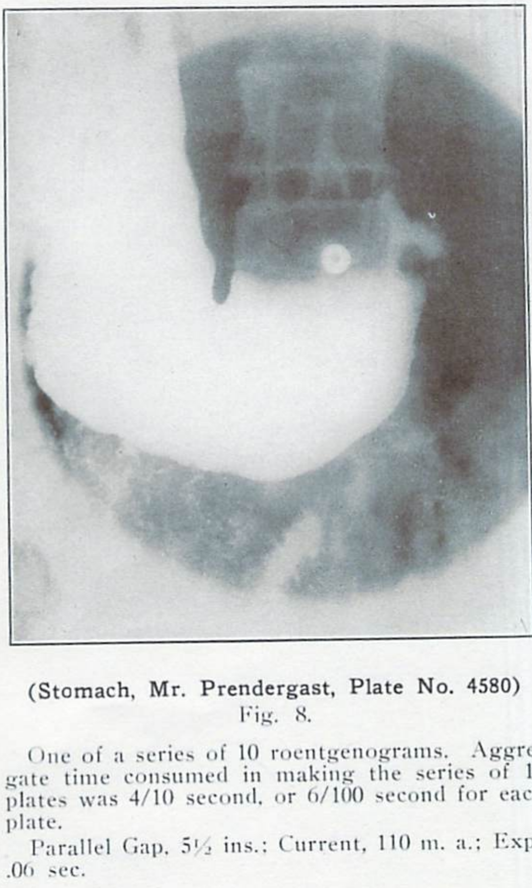
It is the experience of every operator that occasionally he obtains a roentgenogram of admirable brilliancy, but personally I have never been able to obtain such results with any degree of certainty. On a few occasions I have made roentgenograms showing really remarkable detail. My experience with the Coolidge tube leads me to believe that these exceedingly brilliant roentgenograms, hitherto obtained only occasionally, may be made quite uniformly with the new tube, as soon as we have determined the exact penetration required and the amount of milliampere seconds necessary for each part of the body. The apparatus can be set for a given penetration, and by using the same milliamperage through the tube, a hundred roentgenograms can be made so nearly alike that it is impossible to tell them apart.

FLEXIBILITY OF THE TUBE

Flexibility as a characteristic of Roentgen tubes has been an almost unknown quantity. Raising the vacuum has never been successfully accomplished. It has been possible

(Arm, Leone Cottrell, Plate No. 39721)
Fig. 7.
Bones, muscles, blood in veins, and even small lobules of fat show distinctly.
Parallel Gap, 3½ ins.; Current, 70 m. a.; Exp., ¼ sec.

to reduce the vacuum and therefore the penetration to any desired degree, but the instability of the vacuum made results very uncertain. In the Coolidge tube flexibility is one of the strong points. The tube may be operated one instant at a penetration so slight as to show the anastomosis of the blood vessels of the extremities and the next instant, without leaving his seat in the operating booth, one may operate the tube at a penetration far exceeding anything possible with the ordinary tube. Therefore the same tube may be used for all kinds of roentgenographic and therapeutic work.



(Stomach, Mr. Prendergast, Plate No. 4580)
Fig. 8.

One of a series of 10 roentgenograms. Aggregate time consumed in making the series of 10 plates was 4/10 second, or 6/100 second for each plate.

Parallel Gap, 5½ ins.; Current, 110 m. a.; Exp., .06 sec.

TREMENDOUS OUTPUT

The tremendous output of Roentgen rays from the Coolidge tube, the penetration of which is accurately adjustable and absolutely stable for an unlimited time, and moreover can be exactly duplicated at any subsequent time, places in the hands of the roentgenologist a diagnostic and therapeutic agent of immeasurable value.

LONG LIFE

The life of this tube is estimated by Dr. Coolidge to be at least a thousand hours of constant running. In fact he says that instead of wearing out, the tube is more likely to meet its fate by being dropped or accidentally broken in handling. He believes it will not be punctured by any ordinary usage.

INDIRECT RAYS

Indirect rays, generated in the wall of the anterior hemisphere of the tube by secondary or deflected cathode streams, have played a villainous role in the ordinary tube. The indirect rays are not only useless for Roentgenography, but they are positively detrimental, for they blur the image and generate secondary rays in the tissue of the body interposed. A long time ago I determined that one-half of the radiation from the ordinary tube emanated in the form of indirect rays. Other observers have made this percentage much higher. Although various screens and hoods encircling the anode have been devised, the most practical method for eliminating their disturbing influence has thus far been to cut them off with a diaphragm outside of the tube, without trying to prevent their generation. In the Coolidge tube indirect rays do not exist, as is indicated by an absence of green fluoresence of the anterior hemisphere, and as has been proven by the pin point camera obscura tests. Their absence eliminates the necessity for a small diaphragm and compression blend near the tube, with the result that the compression blend may be located independently of the tube-holder, and is used only for compression and localization of the area of the body to be exposed.

APPLICATION OF THE NEW TUBE TO ROENTGENOGRAPHY AND ROENTGENOTHERAPY

Having briefly referred to the remarkable practical advantages of this tube, let us consider its application to Roentgenography and Roentgenotherapy. A comparison of roentgenograms of various parts of the body made with known sustained penetration and milliamperage and with different lengths of exposure, has enabled us to compile a table or scale, which is based on penetration of the tube and milliampere seconds. This scale undoubtedly will be improved by refinement in gradation of penetration, and amplified for patients of various sizes. However, as it has proved a great help in the routine work of the office and has enabled us to duplicate results with great accuracy, the following crude table is submitted as a guide to those who may wish to use the tube as soon as possible.*

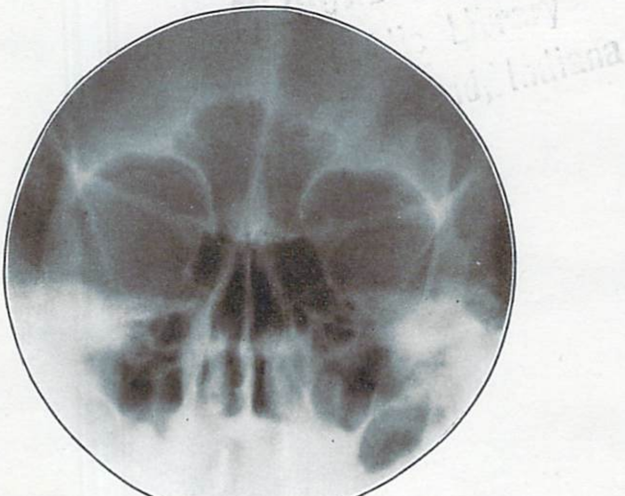
Part of the body.	Length of sparks gap in inches.	Milliamperage.	Time in seconds.	Milliamperage seconds.
Hand—Soft parts....	1½–2	25	2	50
Hand—Bone	2	25	2	50
Foot—Soft tissues, lateral	2	25	3	75
Foot—Bone, lateral..	3	25	3	75
Knee—Soft parts....	3	25	4	100
Knee—Bone and soft tissues	4	25	4–5	125
Knee—Bone only....	4½	30	5	150
Shoulder—Soft tissues	4	30	8	240
Shoulder—Bone	4½–5	30	10	320
Hip—Bone	5	30	15	450
Kidney	4	30	15	450
Spine—Bone detail...	5	30	15	450
Head—Lateral	5	30	15	450
Head—A. P..........	5½	40	15	600
Lungs	3	40	10	400
Stomach (screen)....	5	100	.06	6

From our experiments, the number of milliampere seconds seemed to be greater than the amount we have been accustomed to use with the ordinary tube. To test this, an exposure was made with the ordinary tube with as nearly a stable vacuum as possible. The same procedure was then repeated with a Coolidge tube. The result was that no variation could be detected in either density or detail between the two exposures. It therefore appears that the increased crispness obtained with the new tube is due, at least in part, to a full exposure, without variation, in vacuum and without fogging by indirect rays.

*The milliampere seconds may be obtained with any amount of amperage or any length of exposure, but a moderate milliamperage and an appreciable length of exposure is desirable if the part to be roentgenographed can be kept at rest.

ADVANTAGES FOR ROENTGENOGRAPHY

The tremendous amount of milliamperage that may be used for a short time is of great advantage in gastroduodenal roentgenography. By the use of a time switch we were able to determine accurately the aggregate time required to make ten roentgenograms of the stomach of a moderate-sized man. The aggregate time required for the ten exposures was 4/10 second, making the time required for each exposure about .06 second, and the contrast and detail is all that could be desired. This rapidity is especially valuable for Roentgencinematography, and may make possible the production of cinematographs direct from the fluorescent screen.



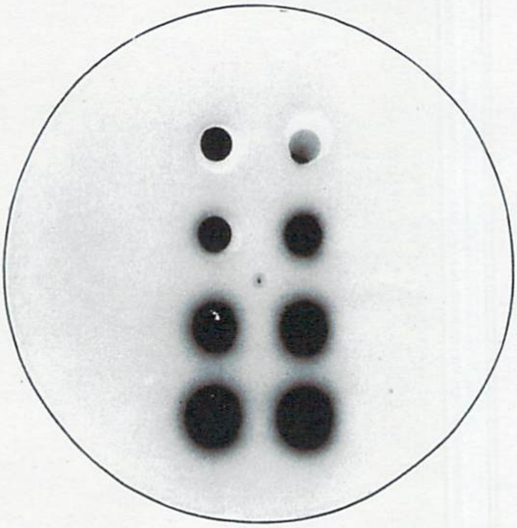
(Frontal Sinuses, Hazel Hill 39593)

Fig. 9.

Parallel Gap, 5⅛ ins.; Current, 30 m. a.; Exp., 15 secs.

ADVANTAGES FOR FLUOROSCOPY

For fluoroscopy, the Coolidge tube offers great advantages also, because any degree of penetration can be obtained with a minimum amount of milliamperage, generated from the same source, which at the next moment can be used through the same tube for making instantaneous roentgenograms of the gastro-intestinal tract. It will be seen, therefore, that its value is incalculable for combined serial and Cinematographic Roentgenography and Roentgenoscopy, which is the ideal method for gastro-intestinal examination.



(Walter Penetrometer, Test Plate No. 10)
Fig. 10.

Roentgenograph of Walter Penetrometer, showing a plus reading of an 8 Walter, and the fact that the rays readily passed through the lead screen surrounding the platinum discs.

Parallel Gap, 7½ ins.; Current, 10 m. a.; Exp., 10 secs.

APPLICATION OF THE COOLIDGE TUBE TO ROENTGENOTHERAPY

The great demand for a more efficient Roentgenotherapeutic tube caused me to urge Dr. Coolidge to announce the success of his tube while it was still in what he considered a crude form. At that time only three roentgenograms had been made with the tube, and its therapeutic value was wholly untried. Nevertheless, laboratory tests, showing the stability of the tube during its excitement with a tremendous milliamperage, had already suggested its usefulness in the field of Roentgenotherapy, and certain experiments recently carried out are a proof of the extraordinary therapeutic efficiency of the Coolidge tube compared with standards to which Roentgenologists are accustomed. For these experiments, the Kienboeck and Hampson radiometers were used.

A piece of beef two inches thick was placed with its surface 5½ inches from the focal point of the tube. Three millimeters of aluminum was interposed between the tube and the beef. A Hampson pastille and Kienboeck strip were placed on the surface of the beef, a second pastille and strip were placed one inch below the surface, and a third pastille and strip were placed behind the two inches of beef.

Experiment I: The tube was regulated so that it backed up 7⅜ inches on the parallel gap. The Bauer penetrometer read far beyond the registered scale. The Walter penetrometer registered 8+.* An exposure of 3½ minutes was made. During this time the milliamperage varied from 10 to 8 and back to 9. The Hampson pastille on the surface read 12 H, or 3 times an erythema dose. The Kienboeck strip on the surface was spoiled. The Hampson pastille one inch deep read 6 H or 16 K, or 1½ erythema dose. The pastille two inches below the surface read 3 H and 8 K, respectively, or about ¾ of an erythema dose.

A second experiment was made, repeating the previous test.

Experiment II: The same degree of penetration was maintained in the tube, i. e., the gap remained at 7⅜, the Bauer penetrometer read off the scale, the Walter penetrometer registered 8+, and the milliamperage varied from 8 to 10. Three millimeters of aluminum was interposed. A series of four one-minute exposures and one two-minute exposure was made.

After the first exposure of one minute, the pastille and strip on the surface read 4 H and 12 K, respectively. The pastilles and strips one inch and two inches deep were not read.

*Note—A later experiment showed that when the Walter pentrometer was laid on a plate and roentgenographed, the rays readily passed through the thickest aluminum disc, and even through the surrounding lead.

After the second exposure of one minute, making a total exposure of two minutes, a new pastille and strip on the surface read 4 H and 18 K. The pastille one inch deep, exposed for a total of two minutes, read 3 H. The Kienboeck strip was not read.

After the third exposure of one minute, a new pastille and strip on the surface read 4 H and 15 K. The pastille one inch deep, exposed for a total of three minutes, read 4 H. The Kienboeck strip was not read.

After the fourth exposure of one minute, a new pastille and strip on the surface read 4 H and 15 K. The pastille and strip one inch deep, exposed for a total of four minutes, read 6 H and 15 K, respectively. The pastille two inches deep read 3 H. The Kienboeck strip two inches deep was not read.

After a fifth exposure of two minutes, the surface pastille read 8 H. The Kienboeck strip was black. The pastille and strip one inch deep were not read. The pastille and strip two inches deep read 4 H and 15 K.

The following table is a condensed form of the above experiments:

Spark Gap.	Milliamperage.	Length of Exposure in Minutes.	Filter.	Reading (Hampson and Kienboeck).
7⅜	Varied from 10 to 8 to 9	3½	3 mm. of aluminum	Surface: 12H-K (spoiled) 1 in. deep: 6H-16K 2 in. deep: 3H-8K
"	9	1	"	Surface: 4H-12K 1 in. deep: not read 2 in. deep: not read
"	8½	1 (total 2)	"	Surface: 4H-18K 1 in. deep: 3H-K (not read)
"	9 to 8½ to 8	1 (total 3)	"	Surface: 4H-15K 1 in. deep: 4H-K (not read)
"	9 to 8½ to 8 to 9½	1 (total 4)	"	Surface: 4H-15K 1 in. deep: 6H-15K 2 in. deep: 3H-K (not read)
"	10 to 8	2 (total 6)	"	Surface: 8H-K (black) 1 in. deep: not read 2 in. deep: 4H-15K

The above tests indicate that through six ports of entry one may obtain a full erythema dose two inches below the surface in six minutes. With this tremendous amount of highly penetrating rays, any amount of screening desirable may be used and yet the treatment need not be prolonged beyond a reasonable time. Dr. Coolidge believes that with a large focal point on the anode these milliamperages may be increased up to 2000, and transformers or other exciting apparatus may be designed which will increase the penetration.

With these forces under control, there is no limitation to the amount of ray at our command, and with the cross-fire method of application, and the screen materially increased, there is every reason to hope that we may be able to apply to internal cancers the same amount of X-Ray which, when applied to superficial cancers, has caused their immediate disappearance.