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The Science of Dental Radiography.

By WESTON A. PRICE, D.D.S., M.E., Cleveland, Ohio.

(Lecture and demonstration before the Third International Dental Congress, Paris, August, 1900, and reprinted from the Dental Cosmos for May, 1901.)

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The purpose of this communication is to establish a higher and more general appreciation of the splendid services the Roentgen rays can render in the various branches of dentistry, and to give a description and demonstration of the necessary apparatus and the technique of its practical application, with a report of important new developments. Owing, however, to the vastness of the subject and the shortness of the time available, our talk must be very incomplete and disconnected.

In the routine of making a practical application of the Roentgen rays in dentistry we have to deal with the following items or factors, each of which greatly affects the others,—viz: *(a)* The source of the X rays; *(b)* the exciter; *(c)* the patient; *(d)* the photographic plate or screen; *(e)* the developing and printing, and *(f)* the interpretation of the results. Of these the patient, or condition to be examined, is the fixed factor to which the others must be adapted. The science of dental radiography consists entirely in thoroughly understanding these factors and their relations to each other.

First, the *source* of the rays. For all practical purposes this may be limited to the Crookes tubes of the focus type. The Roentgen rays are emitted at all hard surfaces struck by the cathode rays produced in a high vacuum. These rays are propagated in practically straight lines from the negative pole (or electrode) of the tube; to concentrate them the cathode or negative pole is made concave, and for this aluminum is generally used. In the earliest tubes the cathode rays were allowed to strike the glass walls of the tube, but later a piece of metal (usually platinum) was placed on the anode, or positive pole, at the point of true focus of the concave cathodic stream,—for which reason the positive, when so arranged, is often spoken of as the anti-cathode instead of the anode.

The rays are emitted in all directions from the point upon which the cathode rays fall. This can be most easily demonstrated by

this lantern slide [exhibiting], which shows first the relation between the cathode *(a)* and anti-cathode *(b)*, which in this tube may or may not be in the anode, it having another pole *(c)* to which the positive wire may be connected; either connection will produce the same effect. Only a small portion of the field of X rays is shown in A in order not to hide the electrodes. The second view (B) of the same tube shows the true field of emission of the X rays.

I must take for granted that you know the principal properties of these rays, such as their invisibility and their power of penetrating opaque bodies, which last property, together with that of producing chemical action and fluorescence, gives them their value. Their property of penetration tends to be in proportion to the density and thickness of the substance through which they are passing, though no exact relation has been found between its physical and chemical properties and the amount of absorption the substance will exercise. Most investigators agree that the four chief factors influencing it are "density, thickness, molecular weight, and chemical constitution." It is a universal fact, however, that twice the thickness of any substance does not have twice the opacity, but from ten to fifteen per cent. less. It is entirely upon this property of different absorbability (for the X rays) of the various parts of the field through which they pass that all radiography depends. In ordinary radiography the differences in the densities are relatively great, the substances being flesh as compared with bone, or a foreign metallic substance as compared with bone or flesh. Very unfortunately the differences in the absorbability of the various parts from which we, in dental radiography must get contrasts, are small. This fact necessitates the most exact adjustment of the various conditions, which we shall consider later.

The penetrative power of the rays varies through a very wide range, from those that are stopped by a sheet of writing paper, or a few inches of air, to rays capable of penetrating many inches or even a foot of iron.

In any branch of radiography we can have success only by selecting rays that have just the power which renders them capable of penetrating the less opaque parts of the field and not the more opaque, according to the particular information wanted. It has been because of neglect to comply with this law that practically all the failures have been made. With tubes made under precisely the same conditions, or the same new tube under different conditions of exhaustion, it may be said that the penetrative power of the rays is in a constant proportion to the degree of exhaustion. This is not a universal law, but, according to Dr. Rollins, obtains only so long as there is an abundance of absorbed hydrogen in the cathode, the ions of which are the carriers of the electrical charges in the tubes exhausted from air containing water vapor.

It is generally the case, however, that the longer a tube is used the higher the vacuum gets, and also the greater the penetrative power of the rays. Time will not permit of an exhaustive discussion of the precise factors that are recognized as determining the penetrative power of the rays, but through a wide range it is

in a ratio with the velocity of impact on the anti-cathode. Thus a tube having a resistance which is an equivalent of one-half inch air-gap will ordinarily produce rays having very low penetration, and by putting a two-inch spark-gap in series with the tube, whether from a coil or static machine, its penetrative power will be very many times greater provided the character of the secondary discharge is right.

With a proper apparatus this use of a series spark-gap is an important factor in the adjustment of the penetration of a tube in practical work. I will throw a couple of pictures on the screen to illustrate [exhibiting]. These show the penetrative power of a certain tube with and without a series spark-gap, all other conditions being the same. They were made by placing some teeth upon a wedge made of aluminum which tapers from about three-quarters of an inch (2 c.m.) to 0.65 m.m., the whole being placed upon a sensitive film. Without the spark-gap the penetration of the tube was so low that it but slightly impressed the film through the thinnest portion of the aluminum wedge, while with the series spark-gap it penetrated it to some extent throughout its entire length, producing shadows of the teeth throughout its length.

This means of varying the penetration has not a wide enough range to be universal, and is especially limited with the ordinary sizes and forms of apparatus. We must depend chiefly upon the selection of a tube for the case in hand, adjusting it to the proper condition. This can be done by varying its temperature, the quantity and quality of the exciting current, and the nature and quantity of its contained gas. This latter is done chiefly by heating potash crystals contained in an auxiliary bulb and evaporating from them their water vapor, or by introducing gas, usually hydrogen, electrolytically. In the former the potash is usually heated by the electric current to the tube, being shunted off to a circuit containing the potash bulb, with a variable spark-gap in series. When, by the heating of the potash and consequent liberation of water vapor, the vacuum of the tube is reduced so that its resistance becomes less than that of the path through the potash, the current passes through the tube.

All of the many tubes employing this last principle that I have used have had two serious defects for our work: First, they are not made with a long enough spark-gap (thus not allowing of high enough penetration), and they change their vacuum very easily in operation. They doubtless are excellent for ordinary radiography, but the capacity or penetrative power of tubes for our work, particularly when working on adults, must be very much greater than for ordinary radiography; because the bone that in general surgery is required to cast a shadow (or, in other words, stop the X rays), in our work must be penetrated, and must not cast much shadow, or at least not nearly so much as the tooth, or root, or root-filling, etc., that are within it. We will return to this part of the subject later, and will now briefly consider another source of rays for radiography,—viz, those rays emitted from the newly-discovered elements, pollonium, radium, and actinium, which have been dis-

covered within recent months by M. and Mme. Currie. I had much difficulty in obtaining specimens for experimental work.

The rays are emitted continuously from the powdered salt of the metals, usually the sulfite, and have the properties of penetrating opaque bodies, of producing chemical action (as affecting a photographic plate), and fluorescence of certain salts. They act very similarly to the Roentgen rays. They have not so great penetrative power as the latter, as far as yet determined.

I have found them to behave very similarly to such X rays as are produced from an exceedingly low vacuum tube, and have made dental radiographs with them, but, as you will see by this slide [exhibiting], they do not penetrate the bone sufficiently to make contrast between it and the tooth. You will also note a very great lack of definition, which is due to the size of the emitting surface and its nearness to the photographic plate. We hope these defects can be corrected by securing greater penetrative power, which will allow of greater distance, and by a substance producing greater volume or quantity of rays, which will admit of a smaller quantity being used or a smaller emitting area.

This picture was made through a sheet of aluminum in which was placed I gram (15 grains) of the salt, and which was held close to the teeth,—two central incisors standing alone in the inferior arch. This method is so simple that we may well anxiously hope that it may develop favorably. Don't wait for it, however. I have found the rays emitted from these salts to have marked physiological effects, especially in certain skin affections, which I shall report subsequently. As yet this means of producing dental radiographs is purely experimental, and I only recommend it as such.

Returning to the Crookes tube method, we will next consider the various methods of excitation, which may be either a Ruhmkorff coil, usually called an induction coil, or a Tesla coil, or a static machine.

Time will allow of only the most general statement, both as to the methods of using them and as to their relative merits. The first, the induction coil, as its name implies, consists of a primary coil of coarse wire of a few turns wound around a soft iron core, around which is a coil of very many turns of very fine wire; and the whole is simply an ordinary transformer with a very high step, with a condenser attached to the primary. It requires about twenty thousand volts (Trowbridge) per inch to jump across any distance in air, between pointed terminals,—up to about fifty inches, or one million volts.

On account of laws of inductance and conditions of stress obtaining upon the make and break of currents passing through coiled wires, or coils passing around soft iron, it becomes necessary to have the current in the primary of the induction coil intermittent in order to produce the high tension or voltage necessary in the secondary current. In practical radiography the method and nature of this make and break of the primary is of quite as great significance as the make of the coil. A good vibrating hammer-

break is perhaps the most simple, but it is not the most efficient; the later forms are, however, greatly improved. An ideal break must give a sudden and perfect make and break without a spark, with more time for the period of make than for break.

There are many forms on the market to-day of the following types:

A revolving armature with a blast of air to break the spark, of which the Edison is the chief example, and which, considering its minor efficiency and great noise, is far from acceptable. Dr. Wm. J. Morton and Mr. Caldwell, both of New York city, have devised much more efficient interrupters of this rotary type, but, so far as I know, they are not on the market yet.

Another type is that of a metal point dipping into a mercury bath under a non-conducting liquid like kerosene or a deep layer of alcohol. These have been chiefly made in Europe, and are sometimes excellent, being capable of great variation; but as usually constructed are very noisy, owing chiefly to the cheap, poor motors used. In most of the makes on the market too small an eccentric has been used, giving the plunger too short a stroke. If the plunger is made very thin, like a ribbon spring, instead of round and stiff, it produces very much less splashing. A Ritter dental lathe motor, which so many dentists have, is superior to anything on the market for this purpose, for on it the apparatus can be constructed to run almost noiselessly and subject to the most delicate adjustment of speed.

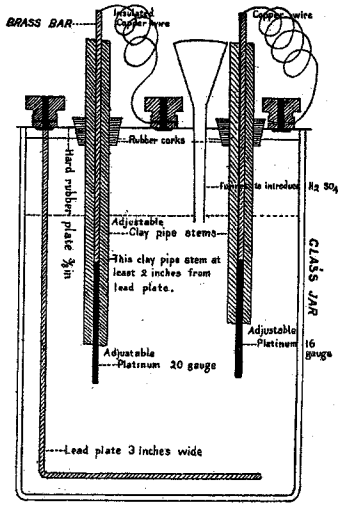
Another type of interrupter, and a very excellent one, consists of a jet of mercury thrown against revolving metal contacts. It was designed by Mr. Isenthal, of London.

In my judgment, not any of the above types of interrupters, or any others I have known of, are capable of so wide and satisfactory variation as certain particular forms of Wehnelt and Caldwell electrolytic interrupters. The former usually consists of a large electrode of lead, or preferably silver, and one of a small surface of platinum, both placed in a dilute solution of sulfuric acid. The latter consists of two lead plates or electrodes in solutions of sulfuric acid, and separated by a non-conducting partition, usually glass, through which there is a small hole or window. They greatly increase the capacity of the coil, and with them no condenser is used.

After much experience, I must strongly advise against the use of a platinum point fused into a glass tube, for it is only a certain very definite amount and shape of surface of platinum that will give the maximum results with each particular tube and coil; besides, the quality of rays can be varied considerably from the same tube by having a perfectly adjustable platinum electrode.

The Wehnelt interrupter works best on an alternating current, and produces almost a undirectional current in the secondary when properly adjusted. The form I presented before the Ohio State Dental Society last December (see February, 1900, DENTAL COSMOS, and the *Ohio Dental Journal,* 1900) still proves to be the best I can find. It consists of three independent platinum points,

and is made by soldering pieces of platinum wire of three or four inches in length and size about Nos. 16, 20, and 24, respectively (B. W. gauge), to copper or silver rods the same size, and placed inside clay pipe-stems or, better, glass barometer tubes, in which they are easily adjustable and which are not disintegrated by the heat or acid. The pipe-stem or glass tube is placed in a perforated rubber cork, through which it is easily adjustable into the bath containing the lead electrode. Owing to difficulty of finding clay pipe-stems of small enough bore, I have recently been using in the same way, and with perfect success, pieces of glass barometer tubing, well annealed, which work excellently; it can be gotten with small bore, of varying sizes, and very thick walls. I here show this good



Electrolytic Interrupter.

working form of Wehnelt interrupter as I have arranged it. Use a glass battery jar of about two gallons capacity, and make the top of hard rubber or paraffined wood. A single focus tube is used, and the definition seems quite as sharp as when the continuous current is used. I regret that the distance to travel prevented my bringing a complete set of various forms of interrupters, and also the other apparatus which I have found best suited for our work.

The Caldwell interrupter is usually made by perforating a large test-tube, placing a lead electrode within it, and placing the whole in a larger vessel containing dilute sulfuric acid and another lead electrode. The interruption takes place in the small hole. It works best on the continuous current, and in the best forms the size of the hole is regulated by means of an adjustable tapered glass point. It must be remembered that every interrupter must be adjusted to the particular coil with which it is to work, and both of them to the tube and the quality of rays desired. A variable

resistance or rheostat should be used in the circuit of the primary with all interrupters.

The static machine may be any of the many forms of rotating glass or hard rubber or mica plates, but must be of very large capacity, and hence large size. Different forms have advantages and disadvantages, such as being greatly influenced by moisture or not at all so, changing of polarity, relatively enormous size, and inability to light tubes of high penetration unless of very great size. I shall judge from the standpoint of a dentist and his peculiar needs in radiography, and what I have to say regarding static machines for lighting X ray tubes does not apply to the general physician's use of it, which is entirely different. It has but one strong point in dental radiographic work, and that is the steadiness of the glow of the tube for fluoroscopic work, which is not, as I will show later, a strong argument for its use in dentistry, since of necessity we shall use that method rarely; besides, it does not produce a noticeably more steady glow than can be secured with a Wehnelt interrupter. And, again, it only produces that steady glow when the resistance of the tube is very low, and consequently its penetration feeble, or otherwise when the capacity of the machine is enormous, which requires great size. True, tubes of so-called high penetration can be lighted by many of them by means of the series gap or Leyden jars, but this immediately produces the slight flickering we were giving it the credit of obviating. Moreover, the penetration required for our work, to produce the best results, is so very great that not one static machine in many hundred will light the tubes. I speak advisedly, for I have visited very many operators and manufacturers, both in America and Europe, to investigate these matters. Some very few operators in general radiography are getting really excellent results, but they have very large machines.

The various forms of Tesla coils or oscillators have much merit for exciting X-ray tubes, but time does not permit of their explanation further than to say that the nature of the current they produce is always alternating, and is of very high tension and frequency. Their current illuminates a tube beautifully and abundantly, and consequently they are capable of producing pictures with short exposures. I do not consider it such an instrument as I should advise for dental use, for the following reasons: On account of its very high tension, much more danger occurs of puncturing the tube. Most forms are not so easy and simple to regulate as a coil, and it is a very noisy generator. The first two objections are overcome by the skilled physicist, and hence it becomes an instrument better suited for the physical laboratory than for the lay operator.

In the *patient,* or rather the condition, to be radiographed we have the most exacting conditions, to which all else must be adjusted and adapted, and I say frankly that no physician, or physicist, or layman can possibly do dental radiography very successfully unless he be also a skilled dentist. By skilled dentist I mean most thoroughly acquainted with all the minute anatomy of all the adjacent parts, and particularly their relative densities and thickness. He must also know thoroughly all the general operations and the den-

sity of the materials commonly used, and also must know thoroughly all the pathological conditions that may be present to be looked for or recognized, especially within the teeth and bone. It is only by correctly judging the relative densities of the various parts in question and adjusting the penetration of the rays so that they will penetrate the less dense and not the more dense parts that we get any information, for our information is only obtained from the shadows produced. Without this information the operator is as certain of failure as a hunter going out to hunt game with his eyes blindfolded and not knowing anything about his ammunition, which is of the greatest possible variety.

Fortunately, dentin has a slightly greater opacity to the X rays than bone, and enamel more than dentin, and gutta-percha root-fillings, cement and metal fillings, or broken steel instruments still more than enamel. At the same time the density or opacity of the bone increases rapidly with age,—much more rapidly than that of the dentin; consequently in making radiographs for adults or old people very much more care must be taken to use rays of just the proper degree of penetration. In like manner, since the opacity is in nearly direct proportion to the thickness, such variations as are caused by the presence of a pocket in the bone, from whatever cause, will be shown in the most minute detail if rays of just the proper penetration have been used. So also natural cavities, such as the antrum and inferior dental canal, must be familiar to the operator in every detail,—as normal position and possible complication. A splendid radiograph of bone will show large bloodvessel and nerve canals, and will also show minutely the cellular structure of the bone, even its minute histology.

The proper *development* of the negative, after a proper exposure has been given, is a matter of the greatest skill and exactness, and it can only be done by one who knows just what information is desired. Too much or too little development will very often obliterate or fail to bring out the particular information desired. Suppose, for example, you were radiographing to find the actual size of a pulp-chamber, and you (or your photographer) developed until you brought out in good definition the tooth and its root or roots; on fixing, you would have no trace of the pulp-chamber; while, if it were developed to the proper point to show the pulp-chamber most distinctly, the outline of the tooth would probably appear to be seriously injured, and by all but the one knowing just what information was wanted the negative would be thought to be spoiled. And so also with most cases it is imperative, for best results, that the operator be his own photographer, and that he be a good one.

The conditions make a flexible photographic plate desirable, which suggests a celluloid film such as that used for kodaks. Since, however, we require great depth of detail, and since the rays have the power of producing almost an equal action on a great number of films placed one behind the other, it is clearly to our advantage to use a greater thickness of emulsion than the ordinary kodak films carry, and also a heavier celluloid, on account of convenience

in handling and developing, as it does not curl. I have had special film made with as many as four layers of the sensitive emulsion, one upon the other, but have gotten the best results with three layers. M. A. Seed & Co., of St. Louis, have assisted me in producing an excellent special film, and I cheerfully recommend them as careful manufacturers.

The best method I have found of preparing film for use is to take a piece of, say, four by five inches and lay a piece of bromide paper of the same size upon it with the emulsion sides or faces together. Then stick the edges of two pieces of unvulcanized black dental rubber together after taking the paraffined linen from one side of each. On this lay the piece of film and bromide paper, and over all put another side of the black rubber, allowing the edges of the rubber, where they pass beyond the film, to unite,—which they will do, as you know, very firmly by simply allowing them to touch. Of course the above must be done in a totally dark room, or with the most subdued ruby light. Dark rooms suitable for ordinary photography would fog this film almost instantly.

This piece of covered film can now be cut through with shears in any direction into pieces the proper size for practical cases, and part of it can be left for cutting at a moment's notice for a special case. Prepared in this way, they do not need to be cut the exact size and shape required for the case in hand, but can instantly be made any desired shape by simply bending a corner or end over and allowing the rubber to touch itself, which will secure it firmly and make a very smooth round corner to place against sensitive tissue. I have done much experimenting to see if anything better could be found for the coloring-matter of the rubber, but the lampblack generally used is as transparent to X rays and as opaque to ordinary light as most substances that are also suitable, and the ordinary black rubber can be had from any dental dealer. Red and pink dental rubbers are exceedingly opaque to the X rays, and make most excellent screens for various purposes, such as shields and for covering the tube to cut off stray X rays and fluorescent light in fluoroscopic work, and have the advantages of lightness, easy adaptability, and non-conducting or insulating properties. It is an advantage to have the manufacturer of your dental rubber cut you some black about five by six or six by nine inches. The latter folds easily over a four- by five-inch film.

I have carried on some extended experiments with the treatment of photographic plates and films, with the view to increasing their sensitiveness to X rays and thereby shortening the time of exposure, particularly with such chemicals as would tend to make them orthochromatic or sensitive to the rays of the lower part of the spectrum, on the theory that the emulsion changed the order of some of the ether waves. My experimenting has been with quite satisfactory results, the sensitiveness of the film being increased from thirty to fifty per cent. with some treatments. In brief, the best found consists in dipping the film into a solution of erythrosin for about two minutes and allowing to dry in total darkness. After this is done, it cannot be exposed to even a ruby light, and must be

used within a fortnight. I have recently, however, made such improvements in my own radiographing apparatus as to so far reduce the time that this means was not necessary or desirable.

When X rays fall upon certain salts they cause them to fluoresce; the chief of the salts so affected are calcium tungstate and barioplatinum cyanid; the latter is usually considered the better. When this salt is evenly distributed upon a card or board, and the rays are allowed to strike it, the illumination or fluorescence is very bright, and any opaque object placed in the path of the rays will produce a shadow. This you all know as the fluoroscope. It is, I think, applied best in dentistry by placing a small screen of it, made in the shape of a large mouth-mirror with the face turned the opposite way, into the mouth behind the condition to be examined, and then viewing the shadow cast upon it direct or with a mouth-mirror. These are good forms and simple [demonstrated]. When using this method the X-ray tube should be covered with something to entirely shut off its white light. A heavy black cloth will do, but the rubber spoken of is better. Use black over the part where the rays come through, and red elsewhere over the entire surface of the tube. This method of using the X rays requires a totally dark room, and that the eyes of the operator be well accustomed to the darkness. A large fluoroscope held against the outside of the face, with the tube on the other side, will sometimes show something, but comparatively faintly; besides, the shadows of the teeth of the opposite side seriously interfere. This last objection is overcome by placing a tube inside the mouth, of which I shall soon speak.

No part of the work requires truer skill than *interpretation* of the negative or the positive it produces. A most intimate acquaintance is absolutely necessary, not simply with the anatomy of the parts, but with the relative densities. The normal positions and relations must be known, and, as important as anything else, the angle of incidence of the rays; also the relative positions of the film and parts radiographed, to each other and to the rays, particularly the point from which they are emitted. This makes it necessary that the operator keep a complete record of the distance of his tube from the film, and the direction or angles; also a record of the relation of the film to the parts.

By having a systematic method of charting, this becomes very simple, as I will show in this slide [exhibiting]. You will easily understand it, unless it be the plan of recording the angles. In the first the heavy black line represents the long axis of the tooth, and the dotted line its perpendicular. The line marked *a* represents the plane of the photograph film, and the other, with the arrow sign, the angle of the rays to the tooth and film. The second shows the lateral angle of incidence of the rays, the dotted line representing a perpendicular upon the natural plane of the tooth, which is the heavy line, and the pen line the true angle at which the rays struck this plane,—in this case about fifteen degrees to the right. Imagine yourself looking down upon it.

We have now come to the most interesting and practical part, the technique of actual application. I should like to have been able

to devote my whole time this afternoon to this part of the subject, for much of what I have given could be gotten elsewhere, but it was necessary in order for an understanding of this more practical part.

First of all, have the patient comfortable. This is very desirable and perfectly practicable. Probably half of our patients will be children, and everything possible should be done to make the operation seem as harmless, insignificant, and simple as possible. My best judgment and experience is to place patients in the dental operating chair, make them as comfortable as possible, and leave them so, except the natural tipping of the chair or rotating of their head.

Now adjust your apparatus to the patient, which is exceedingly simple.

Secure a small plate-glass-top table the length of the base of your coil and about ten inches wider, and of ordinary height, with a glass shelf midway below. The table must be mounted on rubber-tired wheels not less than four inches in diameter. On the shelf place your ammeter. On the top place the induction coil, which for our work should produce a ten- or, better, twelve- or sixteen-inch spark, also the tube-stand and a timepiece marking seconds. Place the timepiece so you can at the same time see through the glass top to watch the ammeter below, which is an indispensable part of the apparatus. Such a table can be had from or made by any maker of hospital furniture. Cast a heavy lead ring to load the base of the tube-stand if it be not already heavily loaded. Have a tube-stand that is itself a non-conductor and compact. It does not need a very long extension.

Wrap some unvulcanized dental rubber around the stem of the X-ray tubes to clamp on to; it holds the tube firmly, without danger of crushing. Use very heavy wire with all good connections for the primary circuit; for the secondary to the tube a light wire will do, but it must be well insulated and, better, without any free points. This high-potential secondary current leaks off very rapidly from a bare wire or from exposed points or around a short tube. With a static machine half the energy may be lost from a few feet of bare wire or from an exposed point. The coil or interrupter, or both, could be elsewhere in the room, as on a bracket on the wall, except for two reasons: First, the desirability of having both within easy adjustment while operating, and, secondly, the difficulty of conducting the high-potential secondary current without loss. The wires carrying the secondary current can be best insulated with what is known as high-pressure gum tubing, which has very thick walls, such as I have here. Lead fuse wire inside makes an excellent and very flexible conductor.

Nothing whatever, besides the operator's fingers, is necessary to hold the sensitive film in place in the patient's mouth, and with this arrangement of apparatus the operator can hold the film with the fingers of his right hand, with the thumb and hand steadied against the face, by which he can detect the slightest displacement of the film; and with the left hand he can control and regulate every part

of the apparatus and see everything. Every desirable angle can be secured in this way with perfect convenience to both the operator and patient. When radiographing either left or front superior or inferior conditions, roll the table to the left side of the chair and stand behind the patient. For the various positions of the right side of the patient, place the apparatus on the right or slightly back of the patient, with the operator standing forward on the right.

With the movements of the dental chair, tube-stand, and table, every possible dental condition can be radiographed with perfect ease for both patient and operator. For radiographing anterior superior conditions, it is especially convenient to tip the chair back to the reclining position and place the apparatus behind, with the tube above the patient's forehead.

This slide [exhibiting] shows the apparatus in position for a left-side exposure.

To have the apparatus working *quietly* is a very important item for the comfort of the patient. The two chief sources of noise are the interrupter of the primary circuit and the series or parallel spark-gaps of the secondary. It is a most lamentable fact that many forms of apparatus are put on the market that make as much racket and demonstration when running as a small foundry or nail-factory. They frighten women and children exceedingly, which is entirely unnecessary. First, do not use any but a comparatively quiet interrupter; and, secondly, place it on a sawdust or inclose it under glass or place it in a tight box.

Using a large mass of liquid in a Wehnelt or Caldwell interrupter and covering it in this way, or in one or two tight boxes, it makes scarcely more noise than a boiling tea-ketttle, if heard at all. When a heavy spark from the secondary takes place in the air it makes a report like a pistol, and hence a spark-gap in series with the tube is very noisy. It is also very often desirable to test the internal resistance of a tube, which is most easily done by adjusting a spark-gap parallel with the tube, gradually closing it until the current will jump across rather than go through the tube. This also makes much noise. This is not, by the way, a constant expression of the resistance of the tube, nor even relatively, unless a constant volume of current is used which is impracticable. It is, however, very useful, and the noise from it, as also from the series-gap, can be almost entirely done away with by having it occur within a heavy glass tube (suggested by Professor Andrews).

Since these secondary series-gaps aid so much in regulating the penetration of the tube, it is desirable to be able to change them while the tube is glowing. But we cannot put our hands near them on account of getting a shock. I have overcome these difficulties by mechanical appliances, one of which I have here to show you. They cause the spark to take place within the glass cylinders attached to the heads of the coil, and both positive and negative series-gaps and the parallel gap are under perfect control close beside the switches of the primary current, all of which are within easy reach of the left hand while holding the film with the right. This is a material improvement.

The length of exposure is dependent upon the volume and quality of the X rays, the sensitiveness of the film, the information wanted, and, most important, the distance of the tube from the film. Some early investigators suggested, upon the theory of radiant propagation, that the time should be inversely as the square of the distance, as with light. Vandevyver (*Journ. de Phys.*, 1897, page 23) and others have stated it to be inversely as the distance instead of the square of the distance. As this point is exceedingly important, I made many experiments to establish it, and I think this one slide [exhibiting] does so, as do others made with tubes of different degrees of penetration.

This shows three sections of a plate exposed separately to the same tube under the same conditions except distance and time. No. 460, the section to the left, shows the action on the plate with the tube six inches away and a ten-second exposure. The center section shows the result with the time adjusted to the distance inversely as the distance, which was six times the first, or thirty-six inches, and hence the time sixty seconds. You observe that the action on the plate is very much less than the first. The third section to the right shows the result with the time inversely as the square of the distance, or thirty-six inches and six minutes, which is as nearly as is appreciable identical with the first exposure; from which we may conclude that approximately the time should be inversely as the square of the distance.

By far the most difficult part of the technique of application is the securing of rays of proper penetration. Unfortunately, there never has been any standard adopted, and we have no way of expressing rays of various qualities, which would be a matter of very great advantage. Roentgen discovered that the ratio of absorbability of different substances was not proportional to their thickness, and was different for different substances. On this hypothesis he made a radiometer of platinum foil 0.0026 m.m. thick, with fifteen circular windows. In each of these he placed one additional number of disks or panes of aluminum foil of 0.0299 m.m. On passing the rays through this the penetrative power of the rays was determined by noting the number of windows in which the absorbability was the same in the platinum and aluminum. This idea is excellent, but, since we require rays of such high penetration as to pass with great ease through half an inch of aluminum, this method becomes impracticable. Besides, it is very hard to read accurately, and has not a wide range unless made very large. I have used with good success a wedge of aluminum eight inches long and one inch wide, and built up of layers each 0.65 m.m. thick and each layer one-fourth of an inch shorter than the last. One edge of the wedge is covered with lead plate overlapping the faces one-fourth of an inch, and each step numbered with lead figures. A radiograph of it has already been shown. With it and the fluoroscope one can judge as to the penetration of the rays with great accuracy, from the distance to which it is transparent as compared with the opaque lead backing. This gauge has a great disadvantage in size.

The conditions demand that we have a gauge which we can not

only use with the fluoroscope, but also with each practical case, and both test our work and also secure an accurate history of the rays used in each case,—preferably upon the negative itself. We can not judge one case accurately by another, for it is scarcely possible to get two cases with the conditions identical.

I am glad to be able to recommend to you a radiometer which answers largely all these desirable features, and at the same time is very cheap and easy to secure in a pure form. It is made of pure copper rolled accurately to 0.1 m.m. thickness and built up in twelve steps,—the first being one inch wide and any length, say six inches, and each succeeding layer one-twelfth inch narrower and the same length. Put a piece of lead or fuse wire in the thick side. Flood each side with rubber cement or glue, and wrap with a turn of thin, strong paper and dry. From one end cut with shears some small gauges, about one-eighth inch wide, which can be laid on the end of the film where it extends beyond the teeth when radiographing. From this you will secure, on developing, a correct record of the actual rays used and their suitability for this case,—which is the short road to success, for from the information thus gained, and a larger scale or gauge made in the same way, and the fluoroscope, you can tell when you have secured the proper rays for the next similar case.

I have tabulated the opacity of the various structures as compared with this standard, determined with the fluoroscope and photographs from a number of skulls, as well as from practical cases, and find the thickness to make considerable difference, as expected. Dry skulls have much less opacity than in life, and teeth give much greater contrasts. Watch for this in all exhibition radiographs, for it is easy to get good pictures of teeth in dry bones.

The bone of the inferior maxilla of children in life has an opacity about equal to 0.15 to 0.3 m.m. pure copper, adults 0.2 to 0.4 m.m., and old people 0.2 to 0.5 m.m.

The bone of the superior arch of children, from 0.2 to 0.35 m.m., adults 0.25 to 0.45, and old people 0.3 to 0.6 m.m.

The opacity of dentin is difficult to determine, because the thickness varies so much, but is usually about equal to 0.05 to 0.1 m.m. more copper than the bone of children, and 0.05 with adults, and 0.05 to nearly zero in old people. Of course, the bone being thinner through the inferior maxilla, the contrast is greater between it and the dentin of the roots.

The opacity of the enamel of all ages is equal to from 0.1 to 0.4 m.m. greater than that of the dentin.

Gutta-percha root-fillings are, fortunately, quite as opaque as enamel, and fillings of the cements and the metals more so. Broaches are much more opaque than enamel. This slide (Fig. 1) shows a standard of 0.1 m.m steps, also dry bone, dentin, enamel, a root-socket, a Donaldson broach, a white and a pink gutta-percha point, the pulp-chambers, the dental canal, and the cellular structure of the bone.

In practical work select the rays that will not penetrate the more

opaque structure, but will the less so; and the more accurately this selection is made the more distinct will be the shadow. You will all understand now why pictures taken with rays that are not penetrating enough fail entirely to show contrast or definition. Fortunately, tubes give out a mingled variety of rays as regards their penetrative power, though a majority will have approximately the same. This is to be seen in any of the slides showing a radiometer gauge (see Fig. 1). This characteristic is not an unmixed advantage, for, indeed, it is usually a disadvantage. Happily, it can be remedied somewhat by regulating the nature of the secondary discharge. It is only because there are some (though relatively few)

FIG. 1.



rays of high penetrative power emitted from tubes of really low power that, by allowing the apparatus to run long enough, a picture—though a poor one—is possible.

Strive to produce in the tube as limited a variety of rays as possible, and adjust for the majority.

I must speak of the methods of *making radiographs by placing the tube within the mouth.* This sounds formidable, but is thoroughly practicable, and was done first by Dr. Wm. Rollins in 1897. There are two chief methods. The first is by the placing of a very small tube in the mouth, or one with a large auxiliary bulb outside, and attaching the negative wire from a mild static current to the cathode terminal and the positive to a pad on the back of the patient's neck or elsewhere. The connection is made to the positive terminal, which is inside the bulb in the mouth (and which carries the anti-cathode) by means of a metal tip on the end of the bulb, which makes contact with the soft tissues of the mouth. It is not very painful, though very disagreeable. The other method is similar, except that the patient is in electrical contact with one side

of a condenser of large capacity or the earth, the discharge taking place through the tube. The current from either a static machine or an induction coil can be used. The positive wire is grounded, and has an adjustable spark-gap and is connected to a metal handle, which supports the tube and which is held by the patient. The metal of the handle is connected to an aluminum sheath which covers the bulb to prevent accident from breakage, and also to make connection with the positive pole. A specially complete arrangement of this method has been presented by Dr. Bouchacourt, of Paris. Compared with the ordinary methods, it is very disagreeable to the patient; and, in fact, I think few children could be induced to tolerate it.

However, neither of these methods is practical as compared with the more simple method, since the point of emission is so close to the object to be radiographed. Suppose the tooth to be radiographed is a second bicuspid, one inch long, and the point of emission of the rays is inside the mouth one inch from the crown, and on a line even with its morsal surface. The nearest the photographic plate or fluoroscope could get to the tooth outside would be about three-fourths of an inch, then the shadow of the tooth would be one and three-fourths inches long, as shown by this diagram at A [demonstrating]; and nearly all this distortion would be of the root, the only part wanted. Imagine the distortion of an abscess at the apex of the root. As a matter of fact, the shadows of the apex of the root and an abscess, if there were one, would have to pass through the anterior portion of the zygomatic arch, a dense bone, and would be lost on account of the dispersion. The same tooth radiographed with the tube outside and ten inches from and at right angles to the film, which would be placed against the arch on the inside and would necessarily bear away from the root, would produce exceedingly slight distortion, as shown at B [demonstrating]. The latter, on account of its length, has the extension lines cut off.

By keeping a record of the lateral and elevation angles and distance, the exact position of any part can readily be determined. It is also well to keep for comparison a complete record of the case and conditions when radiographed. Since it is practically impossible to identify negatives or prints when they get mixed up, especially when you get a lot, it is a great advantage to have a simple means of numbering them. The best way I have found is to place a small metal number upon the outside of the film on the part extending beyond the teeth. This number will be radiographed upon the negative, and will appear, as you observe, upon all prints made from it. The number is put into the record at the time of making the exposure. (These numbers are very easily made of fine lead fuse wire and stuck with paste on a sheet of paper, which is afterward cut, so that they may be readily torn off as needed.)

There are a great many practical points that should be brought out, like tricks in developing the negatives, controlling the vacuum of tubes, etc., but time forbids. Those interested can get more detail in a book, by the speaker, on "The Applications of Electricity in Dentistry," which is nearly ready for publication.

Develop slowly with a weak developer, one that will not stain, and aim for detail, not contrast. The thickly-coated films referred to I leave in the developer from one to two hours.

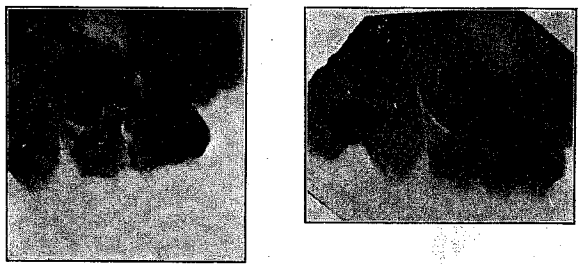
I will now show a few slides of practical cases, which represent only a small portion of the field of application.

The first slide (Fig. 2) shows the method of using the radiometer, which here was much larger than need be, and had steps 0.1 m.m. thick. This is a case of delayed dentition in a boy of seven-

FIG. 2.



FIG. 3.



teen years. You see the enamel sheath of the unerupted canine distinctly from the dentin, and it has never formed properly at the tip. This tooth has advanced one-eighth of an inch in one year.

The next slide (Fig. 3) shows the small amount of correction nature has made in three months in a deformity due to but one bicuspid forming, and that the first. It developed backward against the first permanent molar and locked. The superior arch on this side was greatly depressed, causing an intruded bite.

Nature was making practically no advancement in correcting the deformity of the position of the bicuspid, which was rotated about half around, as you see. The deciduous molar was extracted and an appliance adjusted to place the canine in its proper position to permit the bicuspid to advance, which, as you see by the next slide

FIG. 4.

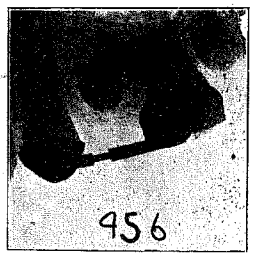


FIG. 5.





FIG. 6.



FIG. 7.



(Fig. 4), it has done marvelously in sixty days' time, and it has rotated. In this you see a radiometer in place. The same one can be used indefinitely.

Fig. 5 shows the movement of teeth in orthodontia, roots and all, keeping the long axes of the teeth parallel. These teeth were normally touching.

Fig. 6 shows a delayed bicuspid in a boy of fourteen years. The

deciduous molar is very firm, and you see the reason: the distal root is not absorbed.

Fig. 7 shows another retained deciduous molar, which is also very solid. Its successor is forming, but it is malposed; it is erupting lingually at about forty-five degrees, and is not producing absorption of the deciduous molar.

Fig. 8 is a case of delayed dentition (age fifteen), but in this case the permanent laterals have never formed.

Fig. 9 shows the teeth of a baby at fourteen months, when none of the deciduous set had appeared. Not only are they to be seen,

FIG. 8.

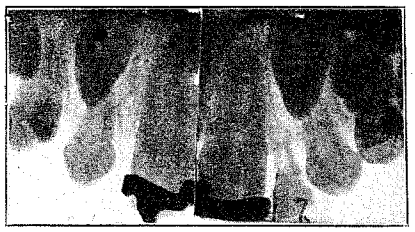


FIG. 9.

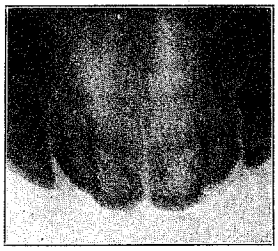
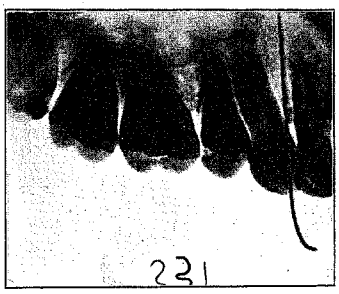


FIG. 10.



FIG. 11.



but also the tips of the forming crowns of the permanent centrals and the crypts of the laterals. This is of special interest, since the child's father has not his permanent laterals; and even before the baby has got a temporary tooth we know he will get the permanent teeth which his father lacks.

Fig. 10 shows a supposed abscess having a fistula, which proves to be a so-called pyorrhea pocket. It was treated by root-amputation.

Fig. 11 shows that the missing bicuspid is not causing this obscure abscess, in the fistula of which a lead wire was placed for radiographing. The bicuspid has never formed. The abscess clearly comes from the lateral, the apex of which is much absorbed. Note how plainly the floor of the antrum shows, and its most dependent point.

Fig. 12 shows the cause of an aggravated case of obscure neuralgia, which is an abscess from a putrescent pulp; the tooth furnished no abnormal symptoms.

FIG. 12.



FIG. 13.



FIG. 14.



FIG. 15.

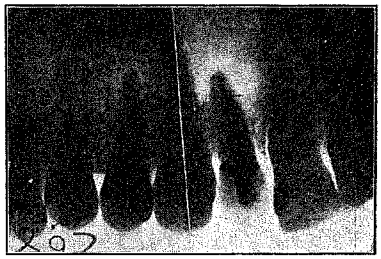


FIG. 16.

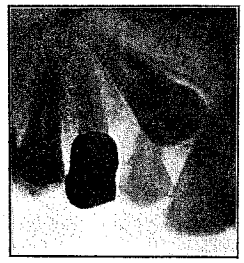


FIG. 17.

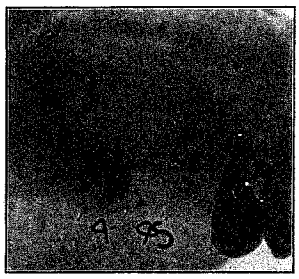


Fig. 13 shows a very large abscess of the inferior maxilla, which it has cut quite half in two.

Fig. 14 shows the extent of absorption of the bone from an abscess which made its demonstration and fistula beside the second bicuspid. The radiograph showed it to come from the lateral,

which was treated accordingly by the amputation of its apex and the abscess thoroughly drained at its most dependent point, marked x. Repair was very rapid, and the next slide (Fig. 15) shows the extent to which the bone was redeposited in three months.

Fig. 16 shows the position of a retained canine of a lady aged eighteen. The clinical evidence was very strong against its having formed. On extracting the deciduous canine and attaching an extruding appliance it came to proper position in a very short time.

Fig. 17 shows the antrum of a lady about sixty. She had suffered with acute empyema for some years. The radiograph reveals a root penetrating the antrum, but entirely buried. This is the only picture that has been retouched a particle, and in it the root was intensified, the negative being weak.

Fig. 18 shows an impacted lower third molar. It was treated by first extracting the second molar, and then the third, after which the roots of the second were filled and it was replaced. Apparently excellent results.

FIG. 18.



FIG. 19.



Fig. 19 shows a case that was operated upon unsuccessfully for the extraction of a supposed impacted third molar which had a fistula externally. The radiograph shows that no third molar has ever formed, and also shows an abscess at the apex of the second molar, which later proved to be the cause of the external fistula.

Another radiograph [exhibiting], which is the last, shows the great service of the rays in opening into a blind abscess. In this case there was a blind abscess connected with the superior central incisor, and this abscess was developing back around the lateral. When drilling through the process to get to it to make an artificial fistula, which became necessary, I could not be sure of the accuracy of the course or distance. When I thought I had reached it, I placed a piece of lead wire into the artificial fistula and made a radiograph, which showed that I had not quite reached it, though in the proper course. The second picture shows the next test, which proved the success of the work.

I forgot to mention before that the piece of bromid paper placed with the film would develop in a few seconds, giving you a very quick picture, though not a splendid one as compared with the negative.