THE FRANKLIN INSTITUTE.

Stated Meeting, Wednesday, April 20, 1898.

RECENT IMPROVEMENT IN X-RAY TUBES.

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The most important considerations in the manufacture of Roentgen-ray apparatus are those influenced by the value of the apparatus to physicians and hospitals. Now that the scientific world has recovered from the suddenness of this discovery of æther-energy, which is so closely allied with light and electricity and yet without experimental proof of the nature of its energy, investigation goes on with surer and even more-rapid strides than it did immediately after Professor Roentgen's announcement.

Investigators, both physical and medical, have become specific in their lines of research, and the large demand for apparatus has caused such competition among manufacturers that many useful improvements are the result. The manufacturers themselves, perhaps, do as much practical work in this direction as any one else. They know the faults of their own apparatus, and these deficiencies are ever before them in complaints from operators, so that it is quite a problem to furnish a good outfit capable of being easily managed by a physician or layman with satisfactory results for any length of time.

An induction coil or static machine will, with any reasonable care, last indefinitely. The manipulation of the dry plate is the same as in ordinary photography, requiring only a knowledge of developing, fixing, etc. The difficulties are chiefly met with, however, in the operation of the high-vacuum tube, in which so many factors are to be considered in achieving satisfactory work. Up to the present time I do not believe that there has been discovered a more-efficient generator of X-rays than a piece of platinum bombarded by so-called "radiant matter."

Here it may perhaps be interesting to indulge in a little speculation on "radiant matter." Faraday, who first used the

expression, defines it thus, "If we can conceive a change as far beyond vaporization as that is above fluidity, and then take into account also the proportional increased extent of alteration as the changes rise, we shall, perhaps, if we can form any conception at all, not fall far short of 'radiant matter,' and as in the last conversion many qualities were lost, so here many more would disappear." Dr. William Crookes, in 1876, made public his highly-interesting experiments with tubes carried to such a degree of exhaustion that the gases therein were in the so-called "radiant" state. In his papers he calls attention to the fact that gases are composed of an almost infinite number of small particles or molecules, which are constantly moving in every direction with velocities of all conceivable magnitudes. Owing to the great number of these molecules it is impossible for them to move an appreciable distance before they collide with one of their fellows. If the pressure of the gas be diminished, the distance which the molecule can move is proportionately increased. This average distance he calls the mean free path of the molecule. If the pressure be so decreased that the mean free path is comparable with the dimensions of the containing vessel, the matter is then in the so-called "radiant state," and the molecules are free to bound forwards and backwards across the tube. These molecules radiate from a negatively-excited pole with enormous velocity, producing many phenomena wherever they strike. Crookes constructed a number of very ingenious tubes to show the novel and characteristic properties of radiant matter, and he assigned the following properties to it: Radiant matter exerts a powerful phosphorogenic action where it strikes. It proceeds in straight lines. When intercepted by solid matter it casts a shadow. It exerts strong mechanical action where it strikes. Radiant matter produces heat when its motion is arrested.

To show this last property, he made a small tube containing a thin platinum plate placed in the focus of a converging stream of radiant matter. A weak current from the secondary of an induction coil is sufficient to heat the platinum red hot. Had Crookes gone a little further in his experiment he would have found that not only heat and phosphorescence manifest them-

selves, but also that these molecular collisions give rise to an æther disturbance of such a character as to excite phosphorescence not only inside the tube but also outside of it. It would also have been demonstrated that this disturbance radiates in straight lines, suffering no refraction, reflection, or any other of the phenomena incident to ordinary light, and that all substances are more or less transparent to it. In this way he would have antedated Professor Roentgen by more than thirty years.

Whether the X-rays are simply the result of the enormously high temperature produced by the impact of the molecules, whether they are due to oscillations set up in the charges on the discharging atoms, or whether they arise from an entirely different cause, is yet to be determined.

The original tube used by Roentgen was similar in construction to one I now show you. In this, the bombardment is on the glass at the spherical end of the tube. The efficient X-rays resulting are few, because it is impossible to bombard the glass very hard without cracking or melting it; a considerable portion of the rays are absorbed in traveling through the thick glass at the end of the tube, and, to get a sharp picture, the light must be considerably cut off by a diaphragm. Practically all forms of tubes were tried by the early investigators, the one finally found most efficient was discovered at King's College, London, in 1892. It was the Crookes hot-platinum tube. This is the fundamental form of tube used by various makers throughout the world to-day, though with considerable modifications as to detail arrangement. It was not long, however, before a great difficulty manifested itself in the use of high-vacuum tubes for X-ray work, and that was the rise in vacuum subsequent to their constant use. Many attempts were made to remedy this defect, but they all lacked success from the very fact that the vacuum was in too a fickle a state for the human hand to manage. The vacuum in a Roentgen-ray tube can vary only over very small limits, and, being also dependent on the temperature of the tube, it is in a very unstable position. Thus, if a tube starts to heat when running, the vacuum lowers and the tube takes more current, due to the

increased conductivity of the gas therein, lowering the vacuum still more; a reversed condition of affairs takes place if the tube starts to cool. It will, therefore, be seen that it is very difficult and often impossible to keep the temperature of a tube constant, and to manage a non-automatic regulating device. The ideal regulating device should possess the following qualities:

- (1) It should act immediately.
- (2) It should be independent of the temperature of the tube.

C, cathode terminal ; *A*, anode terminal ; *S*, adjustable spark point ;
c, cathode auxiliary tube ; *t*, communicating tube ;
B, potash bulb.

- (3) It should maintain the desired vacuum unvaryingly.

Having these difficulties in mind and the qualities desired, I designed for Queen & Co. a tube, which I fully described before the Electrical Section of the Institute about a year ago. It is unnecessary in this connection to do more than refer to the principles involved in its construction. Its operation depends upon two phenomena, viz., the variation of the electrical re-

sistance of the gas in the tube due to different degrees of vacuum, and to the fact that certain salts will give off vapor on being warmed, re-absorbing it on cooling.

A reference to the figure will make the operation of the tube clear. A small bulb containing a substance which gives off vapor on being heated and re-absorbs it as it cools is directly connected to the main tube and surrounded by an auxiliary tube, which is exhausted to a low Crookes vacuum. In the auxiliary tube the cathode is opposite the above-mentioned bulb, so that any discharge through it will heat this bulb. This cathode is connected in an adjustable spark point, which can be set at any desired distance from the cathode terminal of the main tube. In operation, the induction coil is connected as usual to the main bulb. On starting the coil, the vacuum of the main tube being high, its resistance is also high, and the current takes the path of least resistance through the auxiliary tube, thereby heating the substance in the small bulb. This will continue for a few seconds, until a sufficient amount of gas has been evolved to bring down the resistance of the main tube. After this only an occasional spark will jump across the gap sufficient to maintain the tube at the same vacuum. As the spark point is adjustable, the vacuum may be set high or low by varying the distances between it and the main tube.

Practical work has demonstrated that a tube must possess the following characteristics in order to secure efficient results:

(1) The vacuum should be adjustable to permit the ready employment of the tube in various kinds of work.

In a radiograph of the hand, it is desirable to use a low vacuum in order to secure good contrast between the bones and the flesh, while a high vacuum is necessary to locate foreign metallic bodies in the denser muscular or bony tissues.

(2) It should require a minimum amount of attention from the operator during the operation.

(3) It must be able to hold its vacuum continuously for an indefinite period.

(4) It must be able to carry a large current in order to generate powerful X-rays, thereby consuming as little time as possible in making the exposure.

(5) It should have sharp definition, *i. e.*, the source of X-rays should be as small as possible without interfering with the efficiency of the tube.

In designing the tube shown in the figure, and which I shall now put in operation, all the foregoing points received careful consideration. The principle of self-regulation is identical with that first employed in the original design. This tube is made in two sizes, one with a larger bulb and heavier platinum suitable for powerful currents. In the larger tube the platinum is reinforced by welding an extra thickness underneath, the platinum being very thick immediately under the focal point of the cathode stream. The cathode is made of aluminum, hand-hammered to prevent rapid deterioration. It is ground and polished to a curve of a radius of one inch. It may seem curious, but it is a fact, that the rays focus at a point, the distance of which from the cathode is dependent on the height of vacuum. After once having come to a focus, they seem to continue in the form of a pencil until they strike the platinum. The cathode rays do not cross each other at all. This is not true, however, for very low vacua in which they do cross.

The small bulb containing the gas-producing substance is made with a conical side towards the bombarding cathode, in order that the heat shall be well and evenly distributed over its surface. This allows the substance to get the full benefit of the heat generated without the liability of the bulb cracking, due to an excessive current. The conical point of the bulb is protected by sealing in it a little piece of platinum wire welded to a piece of foil of the same material.