Feb. 28, 1939. K. H. KINGDON 2,149,093

METHOD AND APPARATUS FOR X-RAY PRODUCTION

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Fig. 1.

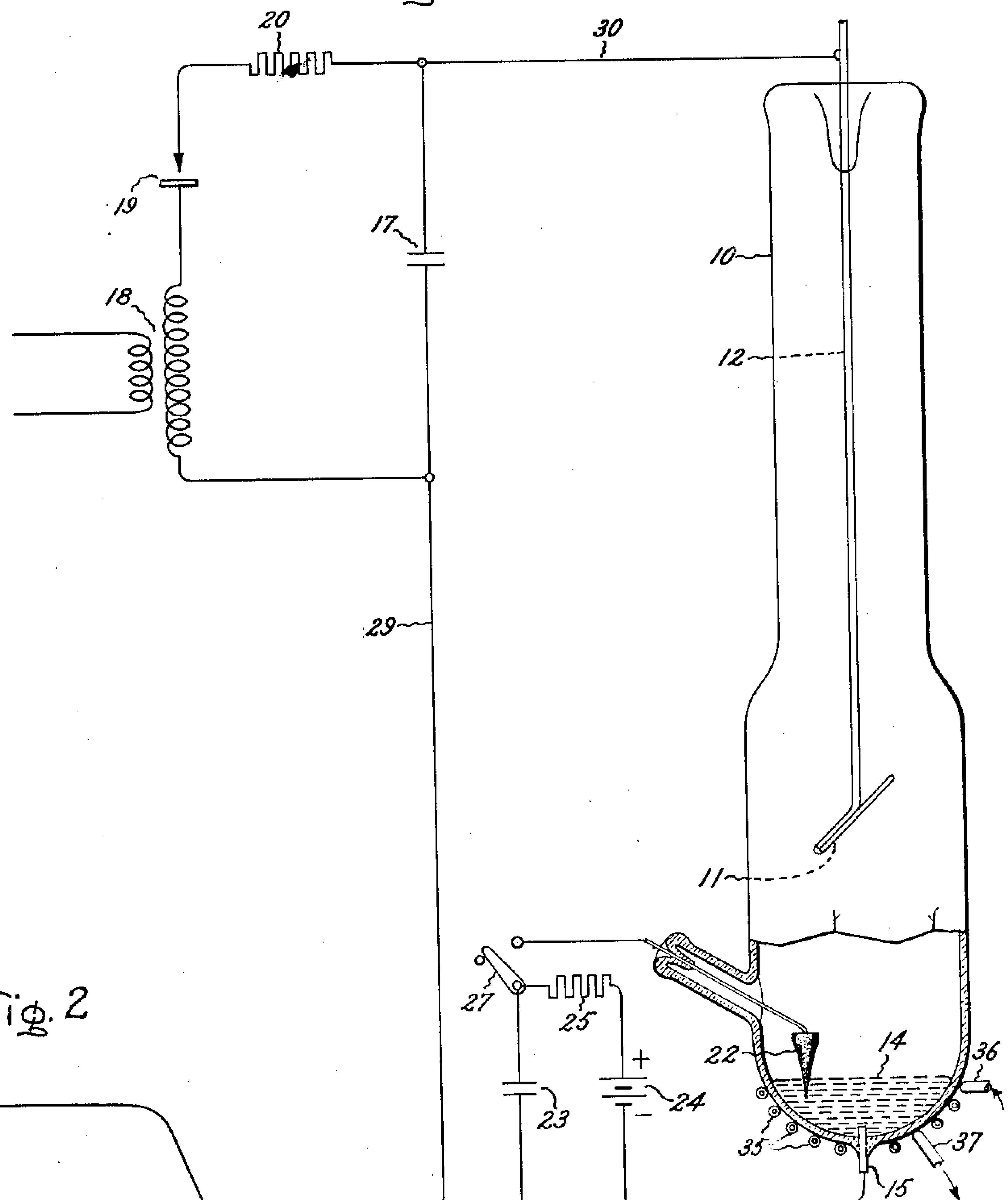
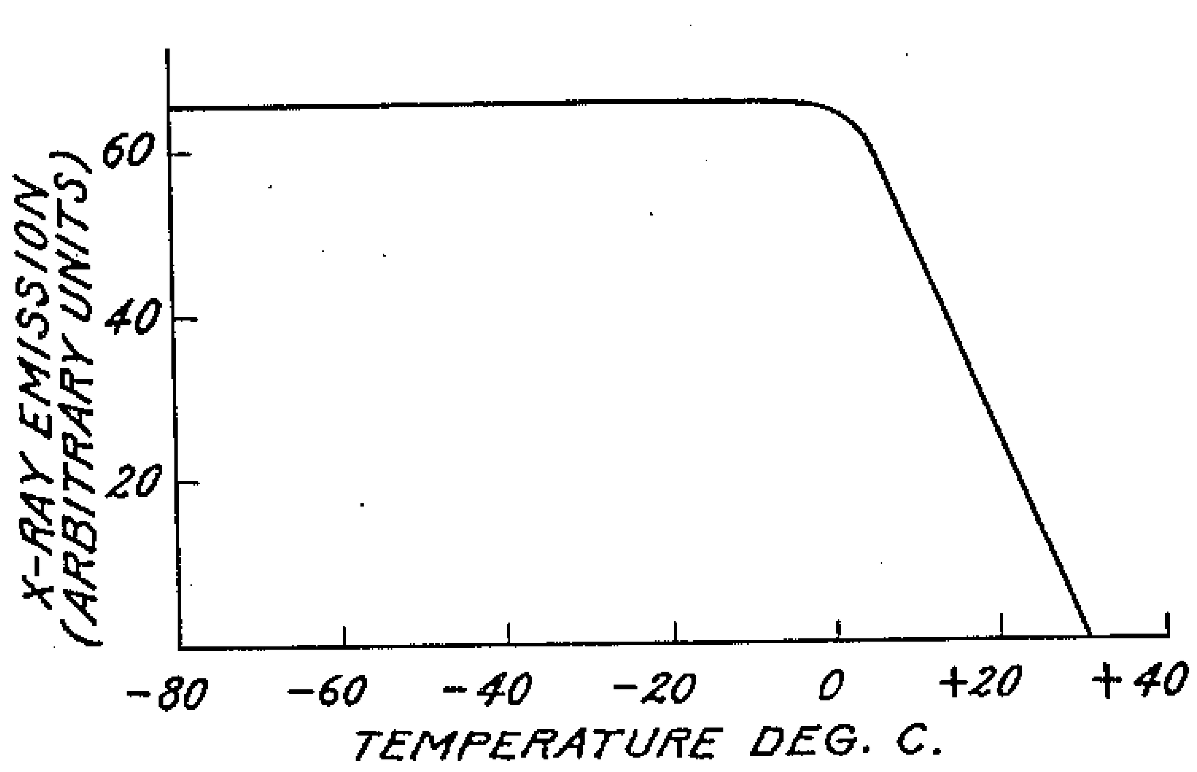


Fig. 2



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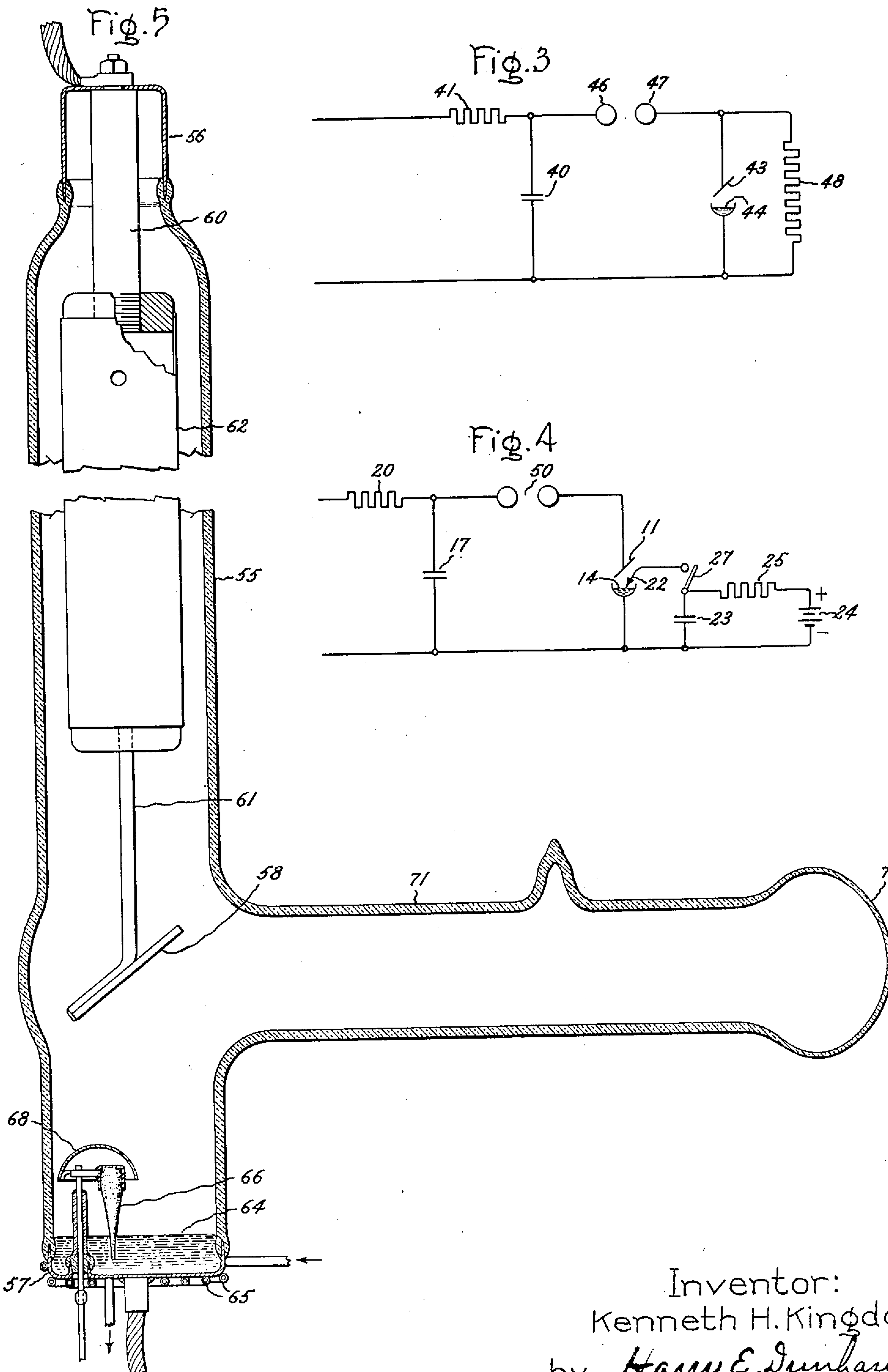

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Patented Feb. 28, 1939 2,149,093

UNITED STATES PATENT OFFICE

2,149,093

METHOD AND APPARATUS FOR X-RAY PRODUCTION

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Application June 9, 1937, Serial No. 147,287

3 Claims. (Cl. 250—143)

The present invention relates to improvements in methods and means for producing X-rays and related radiations.

It is a primary object hereof to make possible the production of X-rays at rates greatly in excess of those which have been realized in the past.

In one aspect of my invention this is accomplished by utilizing as an X-ray source a discharge device having a cathode of a type which is capable of generating almost unlimited quantities of electron emission. One example of such a cathode comprises a body or pool of mercury.

It has been almost axiomatic to those familiar with the principles of electronics that discharge devices of the mercury pool type necessarily operate at too low a voltage drop to make X-ray generation possible. This is due to the fact that the use of a mercury pool (or equivalent cathode) inherently involves the presence in the discharge space of ions of the cathode material, which ions tend to reduce the discharge voltage drop to a value approximating the ionization potential of the material. (In the case of mercury this potential is about 10 volts.)

It is an important aspect of my present invention that a discharge device of the class in question may, under certain conditions and for at least short intervals of time, be operated in such a manner as to realize potentials of X-ray-producing magnitude in the discharge space and to provide X-ray-producing currents of extremely large magnitudes. Specifically, this is accomplished in a preferred embodiment of the invention by the provision of high potential energy storage means capable of supplying extremely high-intensity current to a pool-type discharge device during an initial discharge period.

The features of novelty which I desire to protect herein will be pointed out particularly in the appended claims. The invention itself, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the drawings, in which Fig. 1 represents a discharge device suitable for the practice of the invention in combination with an appropriate circuit for energizing the same; Fig. 2 is a graphical representation useful in explaining the invention; Figs. 3 and 4 illustrate alternative modes of applying the invention, and Fig. 5 is a sectional view of an alternative form of discharge device in connection with which the invention may be applied.

Referring particularly to Fig. 1, I have shown a discharge device comprising an elongated glass envelope 10 which encloses a plurality of cooperating discharge electrodes including an anode, a cathode and a starting electrode. The anode, indicated at 11, may suitably comprise a plate or disk capable of X-ray emission upon bombardment by high velocity electrons. It is preferably constituted of a refractory metal such, for example, as tungsten and may be supported within the tube by a conducting member 12, for example, of molybdenum. In accordance with the present invention, the cathode indicated at 14 is of such nature as to be capable in its normal or steady-state operation of developing electrons at a sufficient rate to permit substantially unlimited energy to be transmitted through the discharge device. Such a cathode is typically exemplified by a pool or other self-reconstructing body of a readily vaporizable ionizable material, such as mercury.

It is characteristic of discharge devices of the class described that while they are capable of transmitting substantially unlimited energy, as previously specified, they inherently operate at low (non-X-ray-producing) potentials. Such operation is a result of the fact that in a steady-state or non-transient condition sufficient of the cathode material becomes vaporized to permit the occurrence of substantial ionization in the discharge space. Such ionization neutralizes space charge and permits the passage of a discharge at potentials on the order of those which characterize an arc. Because of the apparent impossibility of developing high electron velocities within such devices, it has heretofore been considered impracticable to generate X-rays by their use.

I have found that while the normal or steady-state characteristics of discharge devices of the class under consideration are as stated in the foregoing paragraph, such devices may nevertheless exhibit during their initial starting periods a brief transient state in which entirely different conditions obtain. During such a starting period, high potentials, sufficient for X-ray production, may under proper conditions be established in the discharge space. The conditions necessary for accomplishing this result are set forth in the following.

Referring again to Fig. 1, I have illustrated apparatus which is adapted to realize the method of operation described in the foregoing. Thus, directly connected to the lead-in connections 12 and 15 of the anode and the cathode, there is provided an energy storage means exemplified as a condenser 17. During inoperative periods of the discharge device, this condenser may be charged to an X-ray producing potential by means of a high voltage transformer 18 in combination with a rectifier 19 and a current-limiting resistor 20. It will be understood that the rectifier 19 may be of any known type, for example, a thermionic vacuum tube.

As a means for initiating a discharge through the discharge device there is provided a starting electrode 22 suitably comprising a body of semiconducting material having a portion thereof in contact with the cathode during the normal operation of the device. If this electrode is subjected to a properly directed potential at a time when the anode 11 is positive with respect to the cathode 14 a discharge will be caused to take place between the anode and cathode. Particular means for impressing such a potential are illustrated as comprising a condenser 23 in combination with a battery 24 for charging the same and a current-limiting resistor 25. A manually operable switch 27 controlling the electrode 22 makes it possible to initiate the discharge at desired intervals.

For the desired mode of operation to be realized, it is necessary that the condenser 17 be of relatively high capacity and capable of being charged to X-ray-producing potentials. (In a particular case I have employed with good success a condenser having a capacity of 0.015 microfarad and charged to an operating potential of 100,000 volts.) It is also necessary that the circuit connections 29 and 30, which connect the condenser to the anode and cathode terminals of the discharge device, be of extremely low inductance and resistance in order that they shall not constitute a limitation on the rate at which current may be delivered to the discharge device. In connection with the discharge device itself, it is desirable to have the surface of the electrodes clean and free from contaminating impurities which might tend to modify the breakdown characteristics of the device.

With these conditions fulfilled and with the condenser 17 charged as indicated, if the switch 27 is closed, a discharge will be caused to take place between the anode 11 and the cathode 14. If the energy storage means is capable of delivering energy to the discharge device at an adequate rate then X-ray emission will occur as a result of the bombardment of the surface of the anode 11. Due to the relatively great electron emission of a cathode such as that described (even during the initial discharge period) the rate of X-ray production may be greatly in excess of that heretofore realized with cathodes of other types. I have actually obtained X-radiations at apparent instantaneous rates equivalent to one million Roentgen units per minute, and much greater rates are theoretically possible. This offers a remarkable contrast to the radiation rates realizable with present commercial apparatus which radiation is on the order of 50 Roentgen units per minute. It is anticipated that the great intensities of X-radiations which my invention makes possible may be of great benefit in biological and therapeutical applications.

In connection with the use of a mercury pool cathode for the purposes indicated, it has been found that the amount of X-ray radiation obtainable is a function of the temperature at which the mercury is maintained. This is presumably due to the effect which variations in the cathode temperature have on the residual concentration of mercury vapors in the discharge space. Presumably, with higher vapor concentrations the newly started discharge reaches its steady-state arc-like condition more rapidly than when substantially no mercury vapor is initially present.

The precise character of the variations obtained is illustrated in Fig. 2, in which it appears that the amount of X-radiation obtainable with a mercury pool cathode falls off rapidly at temperatures above about 0° C. For this reason, I prefer to operate at mercury temperatures below this value, and in Fig. 1 I have shown an exemplary means for maintaining the mercury temperature within the desired range. As shown, such means comprises a cooling coil 35 having an inlet 36 and an outlet 37 and arranged in heat-exchanging relation with the cathode 14. At zero degrees centigrade the vapor pressure of mercury is about 0.16 micron.

In Fig. 3 I have illustrated an alternative means for utilizing the phenomena discussed in the foregoing. In the arrangement shown the energy storage means is of the same character as that previously described and comprises a condenser 40 adapted to be connected to a high potential source (not shown) through a current-limiting resistor 41. The discharge device, however, differs from that previously described in comprising only an anode 43 and a cathode 44, the starting electrode being omitted. In series with the discharge device and between it and the condenser 40 there is provided a spark gap comprising spaced spheres 46 and 47, such spheres being separated by a distance which permits breakdown between them only upon application of a voltage of X-ray producing magnitude. In order that the entire voltage of the energy storage source may be concentrated across the spark gap during inoperative periods of the discharge device, the device is shunted by a high resistance 48 (say, 50,000 ohms).

In order to initiate a discharge between the anode 43 and the cathode 44 with the arrangement illustrated two procedures are possible. In the first, the spheres 46 and 47 may be maintained in fixed spatial relationship and the voltage across the condenser 40 allowed to build up until breakdown of the spark gap occurs, whereupon substantially the full voltage of the condenser will be impressed across the discharge device. In the second, the condenser 40 may be charged to a desired voltage and the spacing of the spheres decreased until a discharge occurs. In utilizing either of these methods X-radiation of the character previously described may be obtained provided the rate of current supply to the discharge device during its initial discharge period is sufficiently great.

In the still further modified arrangement shown in Fig. 4, I have combined a spark gap as just described with discharge-initiating means of the type illustrated in Fig. 1. In this arrangement, in which parts corresponding to those shown in Fig. 1 are similarly numbered, the main distinction consists in the fact that a spark gap 50 is included in the circuit connections between the energy storage means and the discharge device. Under these conditions, before a discharge occurs and during the inoperative period of the discharge device a portion of the voltage will exist across the spark gap and another portion across the discharge space between the anode 11 and the cathode 14. As soon as the starting electrode 22 is energized, however, the decrease in the drop across the discharge space will raise the potential gradient across the spark gap and result in its immediate breakdown. This having occurred, the entire voltage of the energy storage means will be impressed between the anode 11 and the cathode 14, thus producing a steep wave front discharge. It is an advantage of this arrangement that it permits using the ignitor method of starting the discharge in a tube which would break down at a more or less random time if the full voltage of condenser 17 were applied to it without the series spark gap 50. Instead of the ignitor, any other of the customary means of initiating a mercury arc cathode spot may be used.

In Fig. 5 I have shown another form of discharge device which may be substituted for that described in connection with Fig. 1. In this embodiment there is provided an elongated glass envelope 55 which is closed at its ends by means of metal members 56 and 57 sealed into the glass. The upper metal closure member acts as a support for an anode 58 to which it is connected by means of a conducting structure including shaft portions 60 and 61. These two shaft portions are connected by means of a conducting cylinder 62 which is of a diameter only slightly smaller than that of the envelope itself and which provides a long narrow space between the cylinder and the envelope whereby the possibility of a discharge reaching the closure member 56 may be effectively avoided. The lower closure member 57 acts as a receptacle for a quantity of cathode material 64, suitably of mercury, and is provided externally with cooling means in the form of a cooling coil 65 as previously described.

In contact with the cathode material 64 there is provided a starting electrode 66 comprising a tapered body of semi-conducting material. In order to avoid the danger of an unwanted discharge occurring between the electrode 66 and the anode 58, there is provided a metal shield 68 interposed between them. The shield 68 is preferably provided with a rounded and polished surface whereby the danger of its acting as a point of breakdown is reduced to a minimum.

It has been found that in operating an X-ray device of the type described there is a tendency for tungsten or corresponding anode material sputtered from the anode surface to coat the envelope wall and to decrease the passage of X-rays therethrough. In order to avoid this difficulty, I have provided an X-ray-transmitting wall portion or "window" 70 which is supported at the extremity of a tubular extension 71 projecting from one side of the discharge envelope. The fact that the window 70 is relatively remote from the target surface necessarily tends to prevent atoms of sputtered tungsten from reaching its inner surface. Furthermore, the mercury vapor which is ordinarily present within the extension 71 as a result of the partial vaporization of the pool 64 effectively reduces the amount of tungsten which is able to find its way to the outer end of the extension.

While I have in the foregoing referred primarily to mercury as a suitable cathode material, it should be pointed out that many other materials may be substituted therefor. For example, I have used tin satisfactorily for this purpose, and one may employ alternatively gallium, cadmium, or other similar metals. Cathodes comprising these materials are generically referred to herein and in the following claims as "pool-type cathodes", by which term I intend to designate a pool or other substantial body of the materials in question. In the use of all such materials for the purposes stated there should be present a source of a readily ionizable gas. This may comprise either a vaporized component of the cathode material itself, or a residual gas such as argon provided in the discharge envelope.

While I have shown particular embodiments of my invention, it will be understood that many modifications may be made by those skilled in the art without departing from the invention, and I aim by the appended claims to cover all such modifications as fall within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a discharge device comprising an anode constituted of a material which is capable of effective X-ray emission upon bombardment by high potential electrons and a pool-type cathode serving as a source of ionizable vapor, a condenser, circuit means for connecting the condenser to the anode and cathode terminals of the discharge device, said circuit means having a substantially negligible impedance during discharge periods of the device, and means effective during inoperative periods of the device to charge such condenser to an X-ray producing potential.

2. In combination, a discharge device comprising an anode constituted of a material which is capable of effective X-ray emission upon bombardment by high velocity electrons and a pool type cathode cooperatively associated with the anode, said cathode being capable in its normal or steady state operation of developing electrons at a sufficient rate to permit substantially unlimited current to be transmitted between the anode and cathode at non-X-ray-producing potentials, a condenser, circuit means for connecting the condenser to the anode and cathode terminals of the discharge device, said circuit means having a substantially negligible impedance during discharge periods of the device, means effective during inoperative periods of the device to charge such condenser to an X-ray producing potential, and means for initiating a discharge through the device at desired intervals.

3. In combination, a discharge device enclosing an anode and a mercury pool cathode, means for cooling said cathode sufficiently to maintain the normal vapor pressure in the envelope below about 0.16 micron of mercury, a condenser, circuit means for connecting the condenser to the anode and cathode terminals of the discharge device, said circuit means having a substantially negligible impedance during discharge periods of the device, means effective during inoperative periods of the device to charge such condenser to an X-ray producing potential, and means for initiating a discharge through the device at desired intervals.

KENNETH H. KINGDON.