

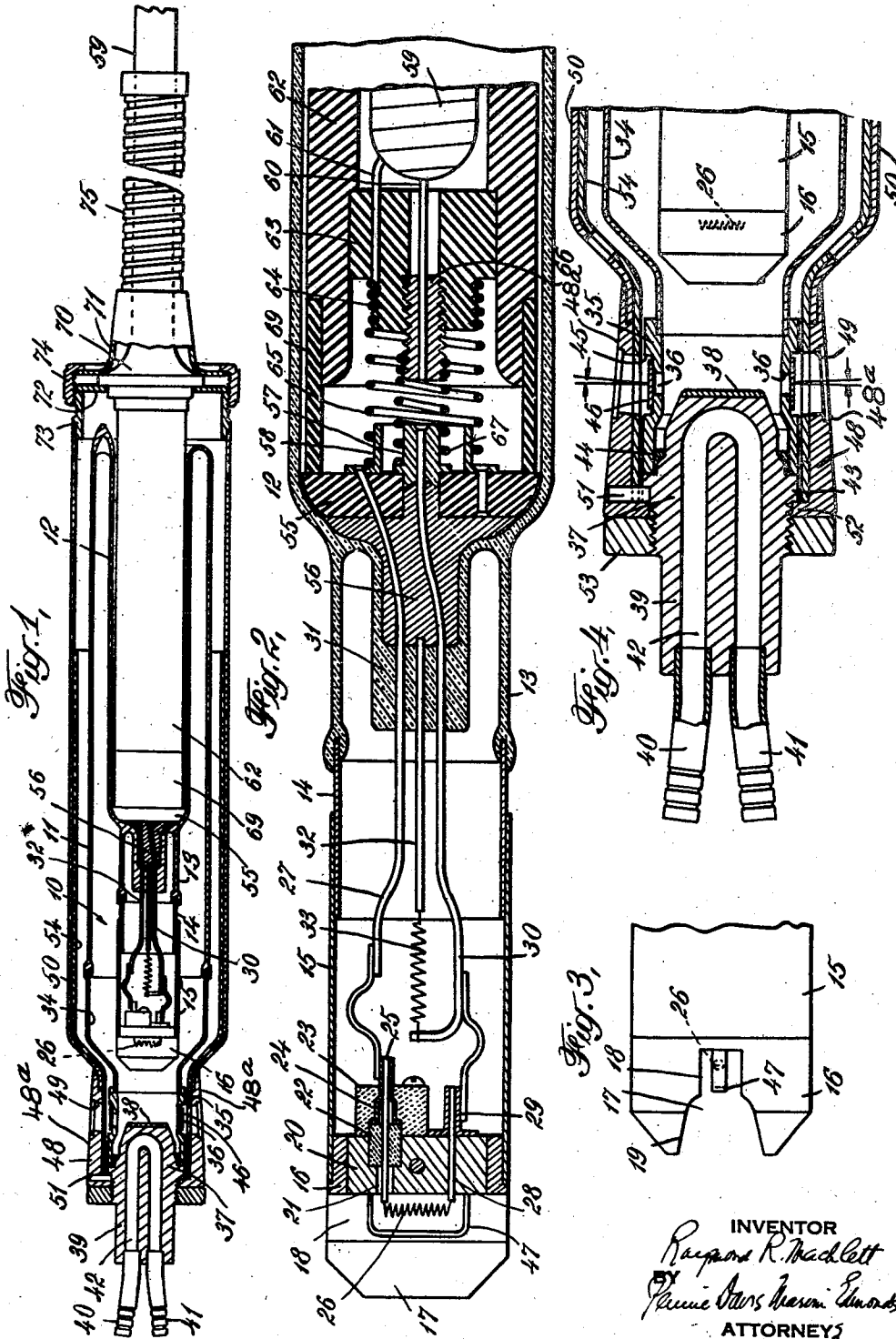
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X-RAY TUBE

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X-RAY TUBE

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This invention relates to X-ray apparatus functioning with low inherent filtration of the X-radiation and is concerned more particularly with a novel apparatus of the specified type which offers many advantages over prior similar apparatus in various applications. The new X-ray unit may be constructed in a form permitting operation at high beam intensity without liability of mechanical or electrical injury to the equipment and it may be shockproof and rayproof so that danger to the operator or patient is eliminated. In addition, it is of small over-all dimensions so that it is compact and can be easily manipulated. These desirable results are obtained by the use in the unit of a tube containing a number of novel features which, among other things, make possible a close spacing of the X-ray port or window to the center of the focal spot on the target surface of the anode. The tube also includes provision to prevent contamination of the spectrum of the beam by condensation on the target surface of material vaporized from the cathode filament and the means employed for the purpose assists in focusing and simplifies the manufacture of the cathode structure.

The new unit is supplied with high tension energy through an insulated cable and it includes a novel connection between the cable and the tube which can be quickly made and broken and, although occupying little space, is so constructed that current leakage and difficulties arising from corona are avoided. This connection and various features of both the tube and housing therefore are of wide application in the X-ray field, as will be evident from the following detailed description.

The new apparatus is of especial utility in diffraction analysis of crystals, stress measurements, and contact therapy. For these purposes, operation at high beam intensity is desirable and in crystal analysis in particular, low absorption of the X-radiation is highly important. Heretofore, diffraction tubes have commonly been provided with windows of low absorption material, such as aluminum and Lindemann glass, the use of aluminum ordinarily being confined to tubes operating under continuous pumping. Lindemann glass, as used for windows in prior tubes, must be spaced a substantial distance from the focal spot, because otherwise the glass would be under heavy secondary electron bombardment with accompanying danger of gas liberation and possible melting of the glass. Windows of glass

become negatively charged during operation and their mechanical and electrical fragility is such that the camera equipment must be kept a considerable distance from their exterior because of the danger of electrical puncture or mechanical damage. Various shielding means have been suggested to reduce the amount of secondary bombardment to which such windows are subjected, but these expedients do not make possible a close approach of external objects to the source of X-rays.

In the new apparatus, the tube used is provided with one or more windows of a metallic substance having the desirable characteristics of beryllium and the windows are vacuum-tight and mounted on a grounded section of the tube envelope. When such material is used for the windows, the long dimension of the focal spot is the limiting factor with respect to the diameter of the discharge chamber and to the spacing of the windows from the center of the focal spot, which spacing may be of the order of about the longest dimension of the spot and as low as that dimension. The metallic window material employed is a fair heat and electrical conductor and it is not as fragile as glass. When mounted on a grounded section of the tube envelope, it does not become charged by secondary electron bombardment, and its use in the construction described, accordingly, eliminates the electrical and mechanical hazards encountered with glass ports. In the operation of a tube of such small diameter at the window, the elimination of the hazards mentioned permits a close approach to the focal spot by external grounded objects and a great increase in useful beam intensity is obtained, the intensity improving as the square of the reduction in the distance. The provision of the metallic windows, accordingly, makes the new unit highly advantageous for diffraction analysis and also for contact therapy.

In crystal analysis and similar work involving the use of camera equipment, it is important that the collimator employed with the camera have a precise relation to the focal spot. In the new apparatus, the tube is housed in a casing which is formed with one or more surfaces which have a fixed relation to the plane of the focal spot and serve as reference planes for proper mounting of the camera equipment. The provision of such surfaces, accordingly, simplifies the use of the new apparatus.

The beryllium windows, as used in the new tube, have considerably less absorptive capacity than either aluminum or Lindemann glass. The new

equipment can, therefore, be employed to advantage in the production of soft X-rays employed in certain types of therapy.

For a better understanding of the invention, reference may be had to the accompanying drawing in which

Fig. 1 is a longitudinal sectional view through an apparatus constructed in accordance with the principles of the invention and intended primarily for diffraction analysis purposes;

Fig. 2 is a similar view on an enlarged scale through the cathode end of the tube and the cable connection;

Fig. 3 is an elevational view of a portion of the cathode taken at right angles to Fig. 2; and

Fig. 4 is a longitudinal view on an enlarged scale through the anode end of the tube.

The unit illustrated in the drawing includes a tube, generally designated 10, which comprises a glass envelope 11 having a re-entrant portion 12 at one end. Projecting inwardly from this end is an extension 13 of the envelope wall in the end of which is sealed a metal tube 14 carrying the cathode structure.

The cathode includes a tube 15 telescoped over the tube 14 and spot-welded thereto. Tube 15 carries a metal focusing block 16 in its free end and the block has a transverse channel 17 in its outer end. The bottom of the channel is defined by opposed walls 18 lying parallel to the axis of the tube and extending outwardly from the outer end edges of the walls 18 are divergent walls 19.

The block 16 has a central recess in its rear face in which is mounted a metal block 20 having a bore 21 therethrough. This bore is of enlarged diameter at its outer end and in that end of the bore is seated an insulating cylinder 22, preferably of ceramic material. A portion of the cylinder 22 lies outside the block 20 and is received in a recess in an insulating block 23, also preferably of ceramic material. The block 23 has a passage therethrough in which is seated a flared metallic tube 24 held in place by its flare between cylinder 22 and block 23. A filament lead 25 extends through tube 24, a passage in cylinder 22, and the bore 21 in the block 20, the cylinder 22 thus serving to space the lead from the walls of bore 21.

One end of the lead is connected to one end of the coiled filament 26 lying between the parallel walls 18 of channel 17 in block 16 and the other end of the lead is connected to the cylinder 24 which is in turn connected to a conductor 27. The other end of the filament 26 is connected to a lead 28 passing through a bore in block 16 and into a flanged cylinder 29 mounted against the rear face of block 20. A conductor 30 is connected to the cylinder 29 and thus to lead 28. The conductors 27 and 30 extend through and are sealed in the portion 31 of the wall of the envelope and the exposed portions of the conductors lie within the re-entrant end portion of the envelope. A third conductor 32, likewise sealed through the portion 31 of the envelope, is connected through a resistance 33 to the conductor 30. Energy is supplied to the resistance 33 only during the processing of the tube and, when the tube is completed, conductor 32 is cut off close to the outer surface of the envelope.

The glass section 11 of the envelope terminates somewhat to the rear of the focusing block of the cathode and in the end edge of the glass section is sealed a collar 34 of an alloy having

expansion characteristics closely similar to those of the glass used. The collar has a portion of reduced diameter starting close to the end of the cathode and the end of this portion enters a channel in the inner surface of one end of a metallic barrel 35. The barrel has a pair of openings 36 on a diameter parallel to the axis of the filament 26 and into its other end projects a hollow anode structure 37 provided with a target disc 38 which lies parallel to the axis of the filament and in such relation to the windows that the central rays taken at 6° from the face of the target will emerge through the centers of the windows. The target disc is made of various metals, depending on the purpose for which the apparatus is to be used, those commonly used including molybdenum, iron, copper, and cobalt.

The anode is of copper and it includes a shank 39 projecting out of the envelope and provided with an inlet 40 and an outlet 41 by which cooling liquid is introduced into and carried away from the passage 42 extending through the anode and at one place lying close to the rear of the target disc. At the end of the barrel, the shank is provided with a circumferential flange 43 against which the end of the barrel abuts and the anode is secured to the barrel as by brazing, indicated at 44. The barrel is similarly secured to the end of collar 34. The anode and barrel are grounded and the cooling fluid conduits may be conveniently employed for the ground connection.

The outer surface of the barrel is formed with recesses 45 to which the openings 36 lead and a window 46 made of a thin disc of a material having certain of the characteristics of beryllium is seated in each recess to close the opening. In order to serve the intended purpose, the beryllium material must be of high purity, vacuum-tight, and capable of being hermetically secured to the barrel of the tube. The material preferred for the purpose is the alloy containing more than 98% beryllium which is disclosed in the United States patent to Claussen, No. 2,306,592, issued December 29, 1942, since that alloy has the desirable characteristics of beryllium and, in addition, can be rolled into thin sheets suitable for use as windows in the present tube. Because of the characteristics of the beryllium window material, great care must be taken in the mounting of the window in order that a vacuum-tight construction is obtained. Accordingly, a material is selected for the barrel which has expansion characteristics similar to those of beryllium and the window is secured to the barrel by brazing. Low carbon steel or pure nickel may be used for the barrel and I prefer to employ the brazed construction disclosed in the co-pending application of Claussen Serial No. 450,859, filed July 14, 1942.

The distance between the windows of the new tube and the focal spot is much shorter than that necessary when glass windows are employed. In practice, the focal spot is a rectangle about 1.2 mm. wide and about 12 mm. long and it is square in projection when viewed at an angle of about 6° from the target surface. These dimensions are the optimum values for maximum specific loading capacity of the focal spot, which is an important factor in determining the beam intensity in view of the small apertures usually found in the collimators employed with diffraction cameras. In the new tube, the diameter of the barrel at the focal spot may be as low as twice the

longest dimension of the focal spot, so that the distance between each window and the center of the focal spot may be of about the order of the longest dimension of that spot and as low as that dimension. This close spacing of the windows to the focal spot, together with the elimination of the hazards encountered in the use of ports of glass, makes possible operation with external objects in close proximity to the windows and at correspondingly increased beam intensity.

The advantage of using the beryllium material for the windows in the minimization of inherent filtration will be readily understood from the following table giving the absorptive coefficients of beryllium, aluminum, and Lindemann glass.

Wave length (Angstrom units)	Absorption coefficient			Ratio Al/Be	Ratio LG/Be
	Be	Al	Lind. gl.		
.710 (K α for Mo)...	.583	14.1	2.24	24.2	3.85
1.54 (K α for Cu)...	2.96	132.0	19.5	44.7	6.6
1.934 (K α for Fe)...	5.64	252.0	38.4	44.8	6.8

Windows made of aluminum for use in X-ray tubes are very thin, but the use of that metal has ordinarily been limited to pump-connected tubes and the necessity of continuous pumping is an objectionable feature of such apparatus. Most commercial diffraction tubes of the sealed-off type have heretofore included Lindemann glass windows of a thickness varying from .005" and .010", but the glass windows have the disadvantages above mentioned. The beryllium windows employed in the present tube have a thickness of the order of .010" and the tube is sealed-off. The reduction in absorption resulting from the use of beryllium, as indicated by the data above, together with the possibility of employing the beryllium windows in a sealed-off construction, offer great advantages, as will be apparent.

In tubes employed for diffraction work, it has long been recognized that vapors originating from the tungsten filament and condensing on the surface of the target may, in time, produce radiation of a troublesome character and difficulties from that source are overcome in the new tube. For this purpose, an electrostatic focusing shield 47 is mounted in the channel 17 so as to lie between the filament and the target face and this shield may take the form of a flattened wire of about the same dimensions as the cathode helix.

Tungsten vaporized from the cathode helix tends to move in straight lines outward from its point of origin under the influence of the electrical field within the tube. The shield acts to intercept the vapor and, in effect, casts a shadow on a portion of the anode occupied by the focal spot and substantially eliminates the contaminating effect of the vapor. The shield serves a further purpose in that it assists in focusing.

With the usual line-focus construction, great difficulty is encountered in accurately controlling the size of the focal spot and the loading thereof, as the anode-cathode spacing is increased, and in the new tube, that spacing is considerably greater than that usually employed in line-focus tubes. The focusing difficulty arises from the fact that two separate electron bundles originate at the helical filament, one at the front face and one at the face farther removed from the target. The electrons emitted from the rear face of the fila-

ment must completely change direction in order to emerge from the focusing channel and they thus enter the anode field at a lower speed than those emitted from the front face. They are, therefore, more greatly influenced by electrostatic forces than those of the bundle originating at the front face and, when the anode and cathode are spaced a considerable distance, the focusing of the two different electron bundles on a spot of predetermined size on the anode requires a degree of accuracy in the making of the cathode structure which is extremely difficult, if not impossible, to achieve. The use of the shield tends to make electrical conditions influencing the electrons originating at the cathode helix more nearly uniform and thus permits long anode-cathode spacings without loss of accuracy in the focusing and also simplifies the manufacture of the cathode structure.

While the tube may be employed in the open air, the new apparatus is preferably made shock-proof and rayproof and, for this purpose, the tube is enclosed within a grounded rayproof housing. The housing comprises a metal block 48 having planed surfaces 48a on opposite sides lying at an angle of 6° to the axis of the cathode structure and through these surfaces are drilled passages 49 for the emergence of X-rays. The block 48 telescopes over the small end of a metal member 50 conforming in shape to the tube and extending lengthwise beyond the re-entrant end thereof. The block is welded to the member 50 and it is drilled to receive a pin 51 which enters a bore in the flange 43 of the anode, the bore being so disposed that when the pin is in place, the openings in the block are in registry with the tube windows. The block has an inwardly directed flange 52 of smaller internal diameter than the diameter of the flange 43 on the anode and the flange 52 is clamped against the outer face of the anode flange by a nut 53 threaded on the anode shank. Within the block and member 50 and extending part way of the length of the latter is a lead shield 54 for rayproofing purposes.

In order to supply energy to the cathode, the conductors 27 and 30 extend out through the end portion 31 of the envelope and through passages in a block 55 of a suitable insulating material which is seated in the bottom of the re-entrant portion of the envelope and held in place by a body of cement 56. The cement fills the space between the block and the envelope wall and serves not only to hold the block in place but also to exclude air which would otherwise become ionized in operation.

Mounted on the outer surface of the block 55 and extending into a central bore through the latter is a terminal 57 to which the conductor 30 is electrically connected, this terminal having a circumferential flange lying against the outer face of the block around the bore. A second terminal 58 is mounted on the outer face of the block concentrically with the terminal 57 and terminal 58 has a cylindrical portion extending coaxially of the block and a circumferential flange lying against the face of the block and connected to the conductor 27.

Energy is supplied to the tube through a cable 59 containing a pair of conductors 60, 61 enclosed within insulation. The cable is provided with the usual metallic grounding sheath (not shown) and its end is enclosed within an insulator 62 which fits loosely into the re-entrant end portion of the tube. The conductors 60, 61

pass through bores in a block 63 of insulation seated within the end of the insulator 62 and the block 63 has an externally threaded extension 64 from its outer face. One end of a spring terminal 65 is mounted on the extension and connected electrically to the conductor 61. The bore through which conductor 60 passes through the block 63 is of considerably greater diameter than the conductor and threaded into the outer end of the bore is a metal cylinder 66 into which the end of the conductor 60 extends to make an electrical connection. A spring terminal 67 is mounted on the exposed end of the cylinder 66 and lies concentrically within terminal 65. The terminals 65 and 67 are of such diameters that, when the end of the cable with the insulator in place thereon is inserted into the re-entrant end portion of the tube, the terminals telescope over the cylindrical portions of terminals 58 and 57, respectively, and bear against the circumferential flanges thereof to establish electrical contacts.

Mounted at the end of insulator 62 and extending outwardly therefrom is a sleeve 69 of yielding insulating material, preferably synthetic rubber of the type known as "neoprene." When the insulator is in place with the contacts engaged, the sleeve bears against the face of block 55 to confine the space within which the contacts are established and thus reduce corona. The terminals are preferably treated, as by silver plating, to inhibit corrosion resulting from corona and the space within the end of the insulator and sleeve 69 may be filled with an insulating material, such as "Vaseline," if desired.

At the outer end of the insulator is a metallic flare 70 which is connected to the metallic sheathing on the cable and consequently grounded. Beyond the flare is a flared clamping collar 71 which is used as a means for holding the end of the cable in the re-entrant portion of the tube, with the terminals in contact. For this purpose, the flare 70 is seated against a washer 72 bearing against a sleeve 73 mounted on the end of the portion 50 of the housing. The sleeve is externally threaded and a clamping nut 74 mounted on the sleeve and bearing against the collar 71 holds the parts in the desired position. The collar 71 further acts as an anchor for the spring 75 mounted on the cable as a guard against kinking.

From the foregoing, it will be apparent that the new apparatus is superior in many respects to prior equipment employed for similar purposes. It not only functions with low inherent filtration so that it may be employed in applications for which X-radiation issuing through ports of material of high absorptive capacity is not desirable, but also it may be operated safely at higher beam intensity than has heretofore been permissible. For analytical purposes, the provision of means for preventing impairment of the spectrum is important, and the means used for the purpose is advantageous in other respects in that it simplifies the construction of the cathode in those details which affect focusing. The new connection between the cable and the tube is simple in both construction and use and the tube housing is so constructed that removal of the tube for replacement is easy. These are highly desirable features in apparatus used for diffraction purposes in which tubes having targets of different materials may be employed,

depending on the nature of the object being subjected to examination. The provision of the reference planes 48a on the block 48 also facilitates use of the new apparatus with camera equipment.

Although illustrated in connection with an X-ray unit having specific characteristics, it will be apparent that the new housing and tube connection and also the focusing shield are not limited in their utility to the particular apparatus described.

I claim:

1. In X-ray apparatus, an X-ray tube comprising an envelope enclosing an anode and a cathode, the envelope including a metallic section having an opening and the anode having a shank extending out of the envelope, a member mainly of beryllium closing the opening in the envelope and forming a window for emission of X-rays, a casing enclosing the tube and having an opening through which the anode shank projects, the casing having a second opening, and means for holding the casing on the shank with the second opening aligned with the window.

2. In X-ray apparatus, an X-ray tube comprising an anode having a flat target surface and a cathode including a helical filament disposed with its axis parallel to the plane of the target surface, the envelope including a metallic section having an opening, a window pervious to X-rays disposed to close the opening, and a casing enclosing the tube and having a flat external surface formed with an opening through which rays issuing through the window may pass, the flat external surface of the casing lying at such an angle to the target surface of the anode that when the focal spot is viewed along a line normal to said flat external surface, it appears to be square.

3. In X-ray apparatus, an X-ray tube comprising an anode having a flat target surface and a cathode including a helical filament disposed with its axis parallel to the plane of the target surface, the envelope including a metallic section having an opening, a window mainly of beryllium closing the opening, and a casing enclosing the tube and having a flat external surface formed with an opening through which rays issuing through the window may pass, the flat external surface of the casing lying at such an angle to the target surface of the anode that when the focal spot is viewed along a line normal to said flat external surface, it appears to be square.

4. In X-ray apparatus, an X-ray tube comprising an anode having a flat target surface and a cathode including a helical filament disposed with its axis parallel to the plane of the target surface, the envelope including a metallic section having an opening, a window mainly of beryllium closing the opening and lying spaced from the center of the focal spot a distance not substantially greater than the longest dimension of the spot and in the direction of such dimension, and a casing enclosing the tube and having a flat external surface formed with an opening through which rays issuing through the window may pass, the flat external surface of the casing lying at such an angle to the target surface of the anode that when the focal spot is viewed along a line normal to said flat external surface, it appears to be square.

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