

March 5, 1929.

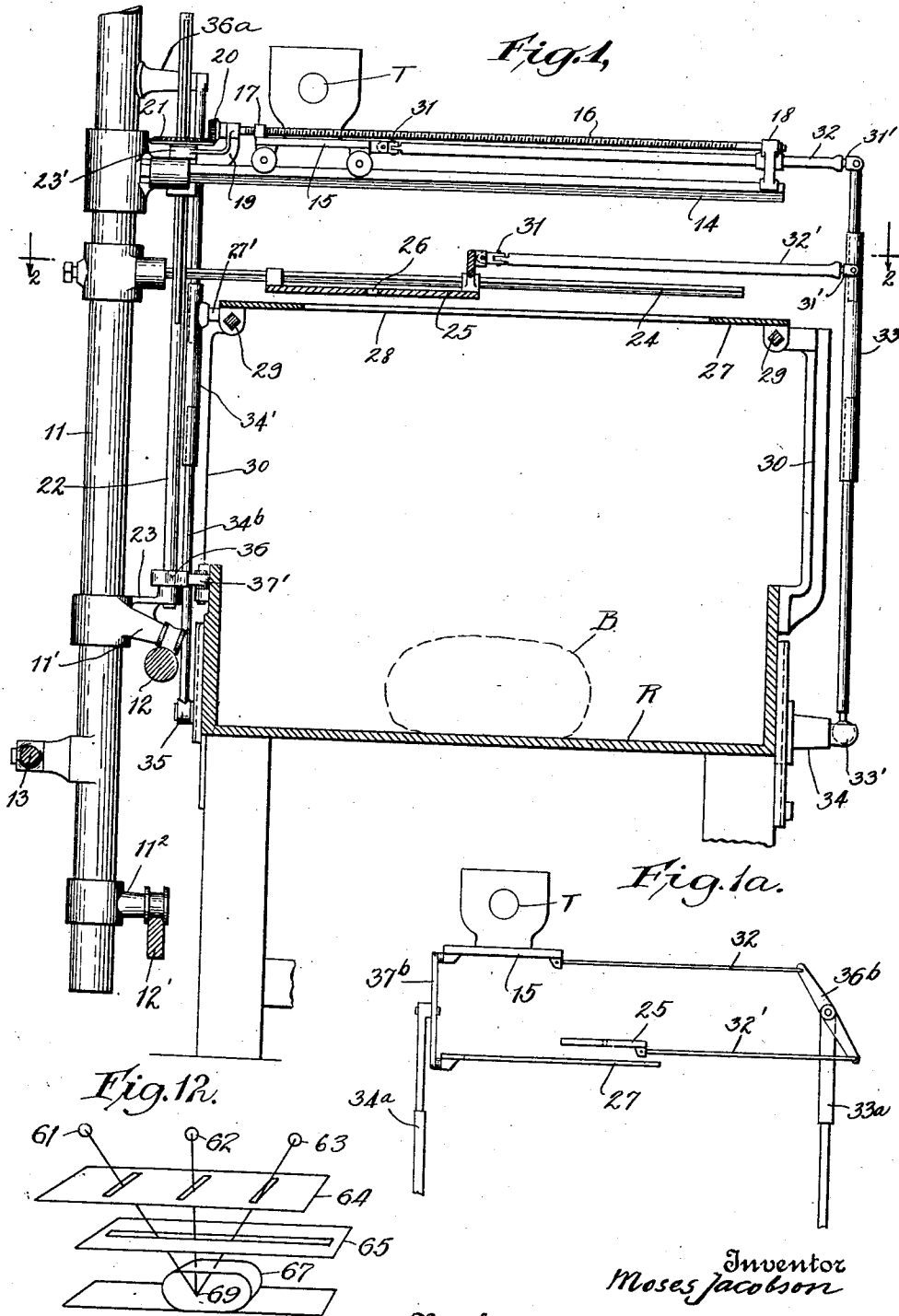
M. JACOBSON

1,704,477

METHOD OF AND APPARATUS FOR CONVERGING AND DIVERGING
 RAYS EMITTED FROM A SOURCE OF RADIANT ENERGY

Filed May 12, 1924

3 Sheets-Sheet 1



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Fig. 2,

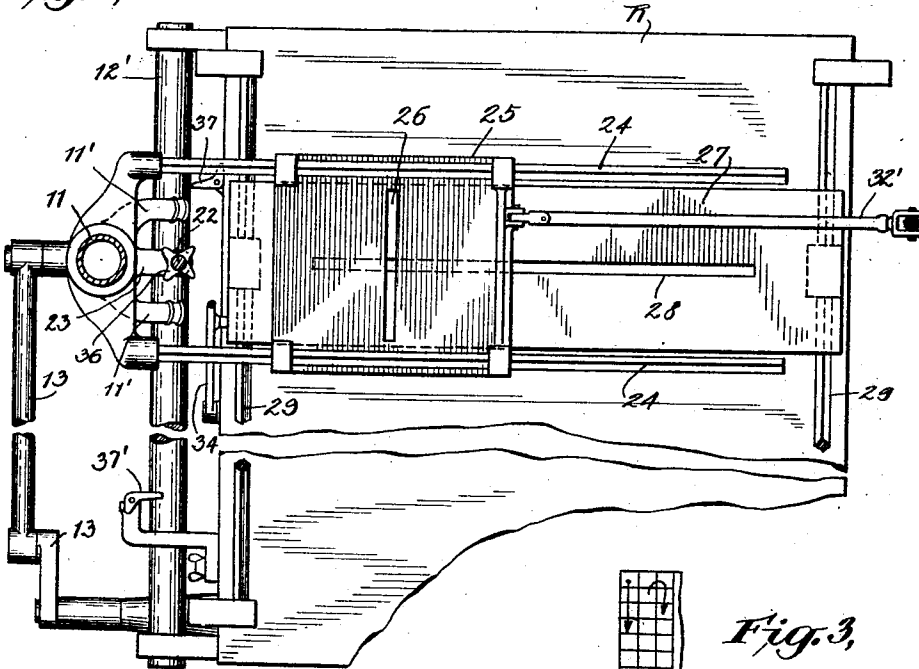


Fig. 3,

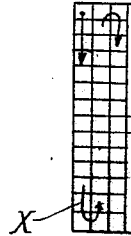


Fig. 5,

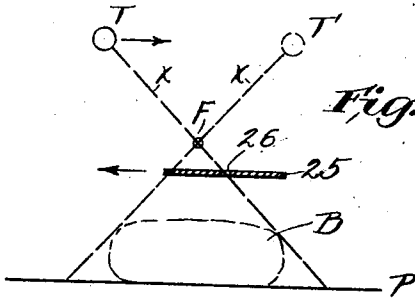


Fig. 4,

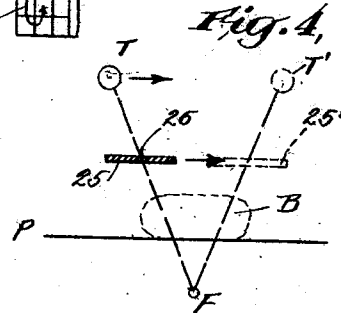
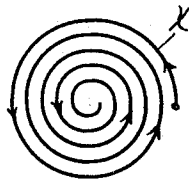


Fig. 6,



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3 Sheets-Sheet 3

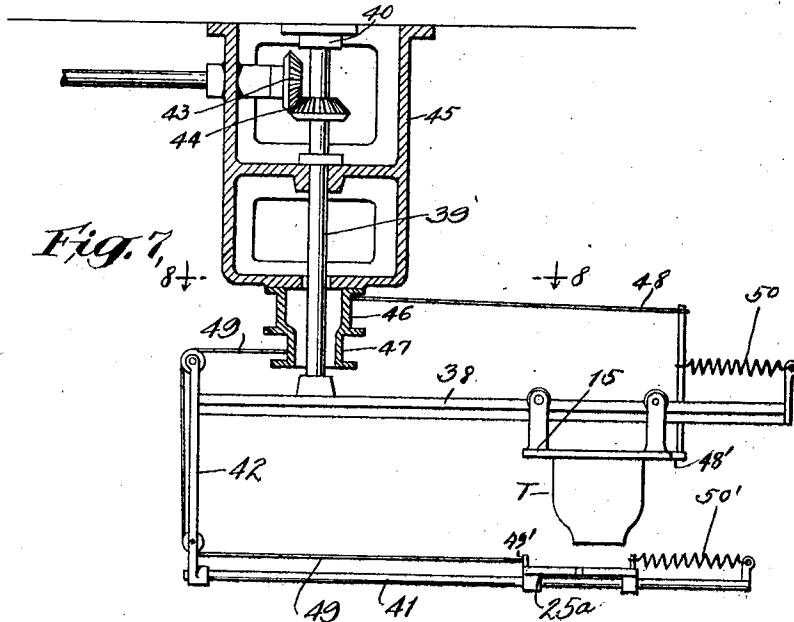


Fig. 8,

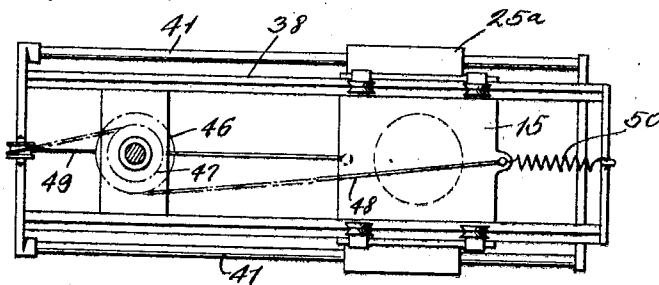
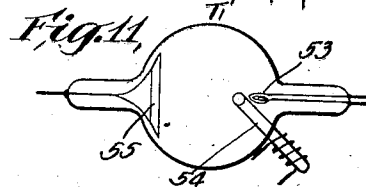
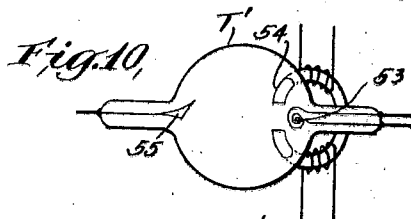
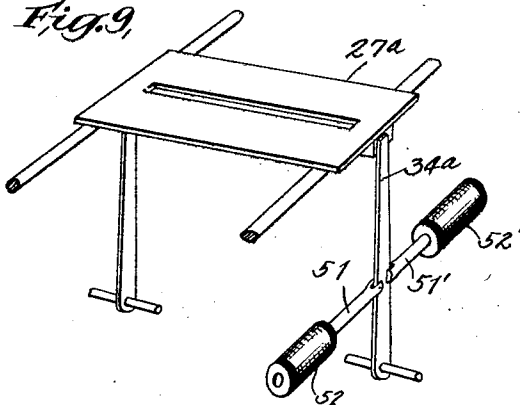


Fig. 9,



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METHOD OF AND APPARATUS FOR CONVERGING AND DIVERGING RAYS EMITTED FROM A SOURCE OF RADIANT ENERGY.

Application filed May 12, 1924. Serial No. 712,889.

X-rays, rays from radioactive substances and the like emitted from a source of radiant energy, as is well known, spread out in all directions from the source and do not show regular reflection or refraction and hitherto it has not been possible to properly concentrate or disperse them. This, however, is frequently required in order, for instance, to enable the concentration of the rays to the exact spot within the body of the patient to be treated and thereby avoid injury to other parts not requiring treatment, or for obtaining enlarged or diminished photographic or fluoroscopic pictures of the internal parts of the human body, machines or the like, or for making enlarged pictures of microscopically small opaque subjects.

The object of my invention is to provide a comparatively simple method of and means for converging or diverging such rays for the purposes mentioned or other purposes, where the same may be required.

While in the following I will describe and illustrate my new method and apparatus as applied to X or Roentgen rays, I wish it to be expressly understood that my invention is just as well applicable to rays from radioactive substances and also to visible, ultraviolet and infrared rays and to electro-magnetic and acoustic waves in all cases where the use of lenses or mirrors is too expensive or results in too much absorption or is undesirable for any other reason.

It must also be expressly understood that the method and apparatus hereinafter described and shown are only some embodiments of my invention and that since various modifications may be made by those skilled in the art without departing from the principle thereof, I do not wish to restrict myself to the details described and shown.

My invention will be more fully understood by reference to the accompanying drawing illustrating means for carrying out my method and in which Fig. 1 is a vertical section of an X-ray apparatus equipped with my new means; Fig. 1^a is a diagrammatic view of the same apparatus changed to perform movements somewhat different from those of Fig. 1, when it is desired to make the rays divergent; Fig. 2 is a cross section on line 2—2 of Fig. 1; Figs. 3, 4, 5 and 6 are diagrams illustrating the principle on which my invention is based; Fig. 7 is a modification of the

apparatus; Fig. 8 is a cross section on line 8—8 of Fig. 7; Fig. 9 is a modification of means for transmitting motion to one of the diaphragms; Figs. 10 and 11 are diagrammatic views at right angles to one another of a modified X-ray tube, and Fig. 12 shows an arrangement for directing rays from a plurality of sources upon a single point.

According to my invention, I separate from the rays, for instance, X-rays, emitted from the target of one of the usual X-ray tubes, a narrow beam by means of one or more diaphragms. Changing the position of the diaphragms relative to the source of rays and of both diaphragms and source together relative to the body or object which is to be radiated through, the said narrow beam is caused to follow predetermined directions on its path to and through the body. In order to make the rays converge toward a desired focal point or diverge from a focal point, different from that of the natural source of emission, the source of rays and one or more diaphragms are moved in space relative to one another and to the body and to the photographic film or fluoroscopic screen in such a way that the point of emission of the rays and the passage left open by all diaphragms remain always on a straight line swinging around a fixed point as a center, so that the beam of rays passing through is always directed toward or from said focal point. These movements are so controlled as to direct the beam of rays successively and continuously through all parts of the body to be radiated.

To radiate through bodies of big dimensions, a plurality of equidistant and equal sources of rays may be used connected each with its own system of moving diaphragms and moved simultaneously in such a way that all beams of rays shall be directed towards one common focus.

All movements are designated as relative movements. That means that instead of moving the source of rays and the diaphragms and keeping the body and the recipient of the energy (film, screen, etc.) at rest, exactly the same results may be obtained by moving say the body and the diaphragms, and keeping the source of rays and the recipient at rest, or by moving the source of rays and the body, and keeping the diaphragms and recipients at rest. To obtain a divergence or convergence of the rays, at least two of the said ele-

ments must be moved, but there can be also combinations of movements of more than two of them giving the same relative motions.

The principle of my invention best illustrated in the diagrams, Figs. 3, 4, 5 and 6, is as follows:—

Let T (Fig. 4) be the target of an X-ray tube, a radioactive substance or generally a source of radiant energy; P a photographic plate, film, fluorescent screen or other recipient of energy or rays; 25 a diagram of suitable material through which the rays could not pass except through its opening 26 (for X-rays or radium rays the material of the diaphragm may be lead) and finally let B denote the body to be treated or radiographed. It is obvious that if the tube T is moved from T to T' and the diaphragm 25 is moved at the same time to position 25', so that its opening 26 always remains with the target on a straight line turning around the point F as on an axis, the narrow beam of rays will gradually cover the entire triangle T T' F, and that this will be the same result as when the rays are made to converge toward F by a lense or a spherical mirror. If the diaphragm 25 is moved in the same direction as the target T, the focus F is below or behind the diaphragm, as in Fig. 4, and the rays are thus made to converge. If the target T and the diaphragm 25 are moved in opposite directions according to Fig. 5, and the focus F is located between the target T and the diaphragm, the rays are caused to diverge. The first named arrangement may be used when it is desired to effect concentration of the rays to a single spot of the body treated or to obtain reduced photographic or fluoroscopic pictures, while the second arrangement will be used when it is desired to cover a large area, as for instance to stimulate seeds by X-ray treatment or to produce enlarged photographic X-ray pictures. The divergence of rays by my method is preferable to the natural divergence of the rays when emitted from the target, because by my method, I can adjust the focus to be much sharper than the natural focus and thus can produce a much sharper enlarged picture, and also can bring the focus much nearer to the body and have a cone of rays with a much wider angle. It is obvious that to radiate through bodies having three dimensions, the described movements of the passed beams of rays must be carried out not in one plane, but in two directions, preferably at right angles to each other. This can be accomplished, as will be hereinafter shown, by using two separate diaphragms with slits moving at right angles to each other and in such a manner that after each stroke of one diaphragm and the source the other and the source are advanced a certain distance. The X-rays will then describe a zig-zag line, as shown diagrammatically in

Fig. 3. Or the same result may be accomplished by having a diaphragm together with the source revolving in concentric circles around a common axis and at the same time moving in radial direction, thereby describing a spiral as shown diagrammatically in Fig. 6.

In the apparatus shown in Figs. 1, 1^a and 2, I assume the X-ray or Roentgen tube T to be of the well known construction, comprising the usual target from which rays are emitted in well known manner. I further assume that the apparatus here shown is of the kind used for medical treatment or for taking X-ray pictures or the like. Such apparatus ordinarily comprises a table or rest R above which is adjustably supported the X-ray tube T by means of a post or standard, which is arranged at one side of the table.

This post, according to the present example, is movably supported by arms 11', 11^a on suitable guides 12, 12' and is adapted to be reciprocated longitudinally of the table by means of a crank arm 13 driven from a suitable source of power (not shown). Projecting across the table and suitably fixed to an upper part of the post is a horizontal frame or guide 14 on which is movably mounted the X-ray tube or other source of rays T by means of a carriage 15 or the like. This carriage, for purposes to be hereafter described, may be fed transversally of the table on its guide 14 through a screw spindle 16, which works in a nut 17 provided at and fixed to one end of said carriage. The screw spindle is rotatively borne in bearings 18, 19 provided at the ends of the guide 14 and is operated through the medium of bevel gears 20 21. The bevel gear 21 is fixed on a vertical spindle 22 rotatively supported at its ends in brackets 23, 23' (Figs. 1 and 2).

Fixed to and projecting from the post 11 below and parallel to frame 14, is another frame or guide 24 extending above and across the table R and on which is slidably supported a screen or diaphragm 25 of suitable opaque material through which the rays will not pass, such as lead in case of X or radioactive rays, and which is provided with a slit 26 extending transversally thereof. This slit forms a passage for the rays emitted from the tube, as will be hereinafter described and may be made adjustable in size in any suitable manner (not shown).

Immediately below the screen or diaphragm 25, I provide a second screen or diaphragm 27 arranged parallel to the former and extending transversally of and substantially over the entire width of the table or rest R. This screen is provided with a slit 28 extending at a right angle to the slit 26 and substantially throughout the length of the diaphragm and is slidably supported on guide rails 29 fixed by arms 30 to the table R. In order that the rays be directed in a

converging or diverging manner, according to the method hereinbefore described and illustrated in the diagrams Figs. 3-5, the movements of the diaphragms must be coordinated with the movements of the source of rays in such a way, that the passage of the rays will constantly lie on a straight line swinging around the desired focal point. To this end, according to the present example, the following construction is used:—

The diaphragm 25 and the carriage 15 of the tube T are operatively connected by vertical joints 31 to parallel arms 32, 32', which in turn are connected by universal joints 31' to a telescopic pendulum 33 fulcrumed by a ball or other universal joint 33' to a vertically adjustable bracket 34 projecting from one side of the rest R. On the opposite side of the rest R, a second telescopic pendulum 34^b is adjustably fulcrumed with its lower end at 35 and connected to a bracket 36^a projecting from the post 11. An intermediate telescopic section 34' of said pendulum is connected at 27' to said second diaphragm 27. It is obvious that due to this pendulous connection of the diaphragms 27 with the post 11, during the forward and backward movements of said post longitudinally of the table R, the tube T and the diaphragm 27 will move synchronously but through different distances, as shown in Fig. 4, and so that the beam of rays passed through the rectangular intersections of the slits 26 and 28 will always be directed towards a point located on a continuation of the axis of the fulcrum 35. The particular position of the focal point on this line depends on the initial relative position of the source of rays T and the diaphragm 25, which, according to Fig. 1, would be nearly in the center of the table. The to and fro movement of the diaphragm 25 together with the post 11 and the source of rays T, as carried out in a direction parallel to the length of its slit 26, gives the same result, as if this diaphragm would be stationary during the to and fro movement. It is introduced only for purposes of convenience, inasmuch as it permits the employment of a smaller diaphragm. During one stroke of the to and fro movement, the beam of rays remains in one plane and only a narrow layer of the body is radiated through.

In order to pass through the whole body, after every stroke of the to and fro movement, steps must be made by the source of rays T and the diaphragm 25 in a direction at right angles to the pendulous motion in accordance with the diaphragm shown in Fig. 3. These intermittent displacements of the source and diaphragm are accomplished according to the present example through the medium of the screw spindle 16, which is adapted to advance the carriage 15 transversally of the table at the end of each stroke a small distance. To

this end, the spindle 22 from which motion is transmitted to the screw spindle 16 through the bevel gears 20, 21 carries at its lower end a star wheel 36 or the like and projecting from the corresponding side of the rest R and near each end thereof is a finger or pawl 37, 37' projecting into the longitudinal path of said wheel. As the star wheel, during the reciprocation of the post 11, reaches the finger at either end, it receives a short turn, which it transmits to its spindle 22 and thence to the screw spindle 16 as a result of which the tube T will make a short advance transversally of the table R at the end of each stroke. This short displacement of the tube will cause the pendulum 33 to swing on its fulcrum 33' and as a result thereof, the diaphragm 25 will be pulled in the same direction synchronously with said tube, but a distance shorter than that of the tube displacement, in proportion to their distances from the fulcrum, and thus the rays passing the slit 26 will again be in a plane going to the previous focal point.

The diaphragm 25 has its slit adjusted to such a width, that the displacement of the diaphragm after every stroke will be equal exactly to this width and so all consecutive layers of the body without any interruption and overlapping will be step by step radiated through.

From the foregoing, it will be seen that by the described combined movements of the tube and of the two diaphragms 25 and 27, the diaphragms moving in the same direction as the tube, the rays will be made to converge toward a focal center located between the diaphragms and the table R as per diagram (Fig. 4), which focal center can be adjusted by the vertical adjustment of the fulcrums 33, 35.

In order to cause the rays to diverge, the movement of the diaphragms 25, 27 must be made to proceed in opposite directions to those of the tube T. To accomplish this, according to the present example shown somewhat diagrammatically in Fig. 1^a, the pendulum 33^a has fulcrumed to its upper end a double armed lever 36^b the free end of one arm of which is connected to the arm 32 of the tube carriage 15 and the free end of the other arm of which is connected to the arm 32' of the diaphragm 25. The diaphragm 25 being initially positioned near the side of the table R opposite to that at which the tube T is arranged, the arm 32' is made in this case correspondingly shorter. On the other hand, the telescopic pendulum 34^a of the diaphragm 27 has its upper end pivoted centrally to an arm 37^b whose ends are connected to the tube carriage and the diaphragm 27. It will be seen that while the tube T reciprocates longitudinally, the diaphragm 27 will move in opposite direction longitudinally of the table and when the tube is displaced

transversally at the end of each stroke, the diaphragm 25 will move in a direction opposite thereto.

In Figs. 7 and 8, a modification is shown whereby the covering of a surface by the rays is effected by simultaneous circular and radial movements of the tube and of a diaphragm, resulting in a spiral motion, according to the diaphragm in Fig. 6. To this end, the carriage 15 of the tube T may be slidably suspended from a horizontal frame 38, which is fixed to a vertical spindle 39 journaled in the ceiling, as at 40. A second frame 41 for the slidable support of a diaphragm 25^a arranged parallel to and below said frame 38 is rigidly suspended from the latter by rigid arms 42. The spindle may be rotated from a suitable source of power (not shown) through gears 43, 44 or the like. On a support 45 or the like also fixed to the ceiling are fixed centrally relative to the spindle 39 two pulleys 46, 47 of different diameters to one of which is attached one end of a cord 48 or the like connected, as at 48' to the carriage 15 of the tube and to the other of which is attached one end of a cord 49 connected to the carriage of the diaphragm 25^a, as at 49'. Both carriages may be under the influence of springs 50, 50' or the like. When the spindle 39 and consequently the frames 38 and 41 are revolved, the tube T and diaphragm 25^a will be moved in circles around the axis of said spindle. Simultaneously the cords 48, 49 will be caused to wind around the two pulleys and thereby the tube T and the diaphragm 25^a will describe spirals with different radial velocities, according to the ratio of the diameters of the two pulleys. In order to radiate through the whole body without intermissions or without overlapping of the neighboring circles of the spiral, the width of the diaphragm slit in radial direction must be equal exactly to the difference between the circumferences of the pulleys 46 and 47 ($2\pi(R-r)$, if R and r denote the radii of said pulleys). When the diaphragm 25^a moves radially in the same direction as the tube, the rays will be caused to converge towards a point located below the diaphragm. For causing the rays to diverge from a focal point located above the diaphragm, the diaphragm will have to radially move in opposite direction to that of the tube T. This can be readily accomplished by connecting the cord leading to the diaphragm to the right side of the latter over two pulleys on the right side of the frames 41 and 38 (not shown), so that while the tube will move towards the axis, the diaphragm will move away from it.

It is also obvious that the swinging movement of any of the pendula 33 and 34^b may be effected by electro-magnets, and so all movements of the tube T and of the other diaphragm 25, as in the modification shown

in Figs. 1 and 2, may be obtained in a purely electro-magnetic way. Thus, according to Fig. 9, the pendulum 34^a, which causes the reciprocation of the diaphragm 27^a may be attached to the rods 51, 51' sliding in the inside of two coils 52, 52' arranged at opposite sides of the pendulum near the axis of the latter. When direct current is used, the rods 51, 51' preferably will be made from soft iron and the current by means of a suitable commutator passed through the two coils not simultaneously but alternately. When alternating current is used, the rods 51, 51' may be permanent magnets or electro-magnets fed by direct current. By such arrangement, the construction and the reversing of the movements of the diaphragms are considerably simplified.

A further simplification of my method and apparatus, when applied to X-rays, may be obtained by the following construction:—

Since the source of the rays in the case of X-rays is the spot where the beam of the cathode rays (electrons flying from the cathode) strike the target of the anticathode, the movement of the source of rays may be effected by alternate deflections of the cathode rays. To this end, the tube T' may be so constructed that in front of the cathode 53 (Figs. 10 and 11), (or the filament in the case of a Coolidge tube), an electro-magnet 54 is provided with the magnetic field in a vertical direction. Opposite the cathode, I provide an elongated anticathode 55. On energizing the electro-magnet by an alternative current, the cathode rays will perform a pendulous motion in the horizontal plane so that the impact spot of the cathode rays, which is the source of the X-rays, will be caused to oscillate. This will replace the mechanically effected reciprocating movement of the tube T heretofore described. The corresponding movement of the diaphragms can be in such case accomplished by means of an electromotor moving synchronously with the same period as the alternating current feeding the electro-magnet 54 or by means of an electromagnetical device like that which is shown in Fig. 9, fed by the same alternating current. On the other hand, the transversal displacement of the tube and diaphragms may be effected by the same means as heretofore described and illustrated by Figs. 1 and 2.

Fig. 12 illustrates a plurality of equidistant and equal sources of rays 61, 62, and 63 shown with a system of diaphragm plates so arranged that all the beams of rays are directed to one common focus 69. Owing to the fact that the upper plate 64 is provided with three slots a separate set of diaphragm plates for each beam of rays is not necessary in this particular modification.

This same Fig. 12 also shows the focal point located within the body being irradiated, that is, within 67, and illustrates the use of

the invention for treatment of internal pathological conditions rather than for the photographing of such conditions. Assume some abnormality located deep within a body 67 and located at point 69. Should it be desired to destroy or treat the abnormality with powerful rays and at the same time avoid injury of the surrounding healthy tissue the arrangement suggested by Fig. 12 would prove very effective.

What I claim is:—

1. Apparatus for controlling rays of radiant energy, comprising a source of rays, means for obstructing said rays, said means being shaped to provide a restricted passage for a beam of said rays, and means connected to said obstructing means to actuate the latter in such a manner that said beam is directed upon an object and falls successively upon each part thereof till the whole of said object has been subjected to said rays.

2. A method of focalizing rays emitted from a source of radiant energy to a predetermined focal point consisting in moving relatively to each other a source of rays, one or more perforated plates serving as a diaphragm, and the recipient of the rays at such ratios of speed that said source and the passage left by the plate or plates will always be on a straight line extending through the predetermined focal point.

3. A method of focalizing rays emitted from a source of radiant energy to a predetermined focal point which consists in operatively connecting for relative movement a source of rays, one or more plates collectively forming a diaphragm and the recipient of the rays, so that when one of these elements is moved, the others connected to it will move at such ratio thereto that the source of rays and the passage through the plate or plates forming the diaphragm will always remain on a straight line extending through the predetermined focal point.

4. A method of focalizing rays emitted from a source of radiant energy to a predetermined focal point consisting in moving the source of said rays and a system of plates with elongated openings forming a diaphragm transversely to the path of the rays in two directions at an angle to each other and at such ratios of speed that the source and the openings in the plates will always remain on a straight line extending through the predetermined focal point.

5. A method of focalizing rays emitted from several sources of radiant energy to one predetermined focal point consisting in providing for each source of rays a set of narrow openings in a system of diaphragms coordinated thereto to pass the rays emitted by said source, placing said sources and diaphragms in such relative positions that all rays passing through the diaphragms will be directed to the predetermined focus and in moving

said sources and systems of diaphragms synchronously and at such ratios of speed that every source and the opening in the system of diaphragms coordinated with that source shall always remain on a straight line passing through the predetermined focus.

6. A method of focalizing rays emitted from a source of radiant energy to a predetermined focal point consisting in moving the source transversely to the path of the rays and in two directions at an angle to each other and in coordinating with said source two superposed diaphragms provided with slits intersecting each other at an angle and arranged in the path of said source, moving each diaphragm transversely of its slit synchronously with a corresponding movement of the source but at such ratio of speed that the passage formed by the intersecting slits will always lie on a straight line connecting the source with the predetermined focal point.

7. A method of focalizing rays emitted from a source of radiant energy to a predetermined focal point consisting in imparting to the source a step by step movement and also a movement at right angles thereto, both movements taking place at different times with respect to each other, and in moving a system of diaphragms having openings therein synchronously and substantially parallel to the movements of the source but at such ratios of speed that the opening left by the system of diaphragms, and the source will always be on a straight line passing through the predetermined focal point.

8. A method of focalizing rays emitted from a source of radiant energy to a predetermined focal point consisting in imparting to the source a step by step movement and also a movement at right angles thereto, both movements being transverse to the path of the rays and taking place at different times with respect to each other, and in moving a system of diaphragms having openings therein synchronously and substantially parallel to the movements of the source but at such ratios of speed that the opening left by the system of diaphragms, and the source will always be on a straight line passing through the predetermined focal point, the openings left by the system of diaphragms being equal to the steps made by one of the diaphragms.

9. An apparatus for using rays of radiant energy, comprising a source of rays, means forming a passage arranged in the path of said rays and means for moving said source and said passage forming means synchronously and relatively to one another, so that the rays passing from said source through said passage will be caused to focalize into a focal center.

10. An apparatus for using rays of radiant energy, comprising a source of rays, diaphragms with slits therein arranged in the

path of the rays emitted from said source, the slits in said diaphragms intersecting one another, at least one of the diaphragms and said source being operatively connected to move synchronously relatively to the body to be irradiated and one of said diaphragms to move also relatively to the other diaphragm in a direction at right angles, so that the rays passing through the passage formed by the intersection of said slits will be focalized to penetrate in many directions through different paths crossing at a predetermined part of the object to be irradiated.

11. An apparatus comprising a source of radiant energy, means for moving said source, and a movable slitted diaphragm system operatively so connected thereto that when the source is moving, said diaphragm system will move synchronously with and relatively to the latter and the transmitted energy will be guided towards a predetermined focal center.

12. An X-ray apparatus comprising a tube, means for reciprocating the tube over a stationary energy recipient and for moving it at the end of each stroke in a direction transversely of said reciprocating movement, and two superposed diaphragms each having a slit therein, said slits intersecting one another, means for connecting said diaphragms to said tube to move synchronously with said two movements of the latter, said connecting means comprising means for changing the amplitudes and velocities of the diaphragms in a desired ratio, whereby, when the tube is moved, the passage left by the intersecting slits will move relatively to the source and the direction of the transmitted rays will change in a desired manner.

13. An apparatus for using rays of radiant energy, comprising a source of rays, means for reciprocating and moving the source at the end of each reciprocation in a direction transversely of the reciprocating movement, two superposed diaphragms of opaque material arranged in the path of said rays and each having a slit said slits intersecting one another, means for transferring said reciprocating movement with changed speed and amplitudes to both said diaphragms and

means for transferring said movement at the end of each reciprocation to one of said diaphragms with changed speed and amplitude.

14. An apparatus for using rays of radiant energy, comprising a source of rays, a carrier therefor capable of reciprocating and moving at the end of each stroke transversely of the reciprocating movement, two superposed diaphragms of opaque material arranged in the path of said rays and each having a slit, said slits being arranged at a right angle to one another; means connecting said diaphragms to said source carrier including pendula with adjustable fulcrums and whereby said two diaphragms will be caused to participate in the reciprocating movement of said carrier and one of said diaphragms will also be caused to participate in the transverse movement of said source carrier, so that the passage formed by the intersecting slits will always remain on a straight line with said source swinging around a focal center predetermined by the positions of the fulcrums of said pendula.

15. In an apparatus for focalizing rays the combination with a support for an energy recipient, of a movable source of radiant energy, movable slitted diaphragms in the path of the energy radiating from said source, means for moving said source, means for moving said diaphragms and means for coordinating the speed and amplitudes of said movements to pass the radiant energy to the recipient at desired angles of incidence.

16. An X-ray apparatus comprising a tube, means for reciprocating the tube over a stationary energy recipient and for moving the tube at the end of each stroke in a direction transversely of said reciprocating movement, a diaphragm system between said tube and recipient, having a clear passage for rays in said system and means for transferring said movements of the tube to said diaphragm system with a different amplitude and velocity, whereby when said tube is moved, said passage left by said diaphragm system for the rays will move proportionately to the source and the transmitted rays will change their direction continuously and in a desired manner.

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