H. C. SNOOK & E. W. KELLY.

VACUUM REGULATION.

APPLICATION FILED JULY 3, 1914.

1,143,327.

Patented June 15, 1915.

5 SHEETS—SHEET 1.

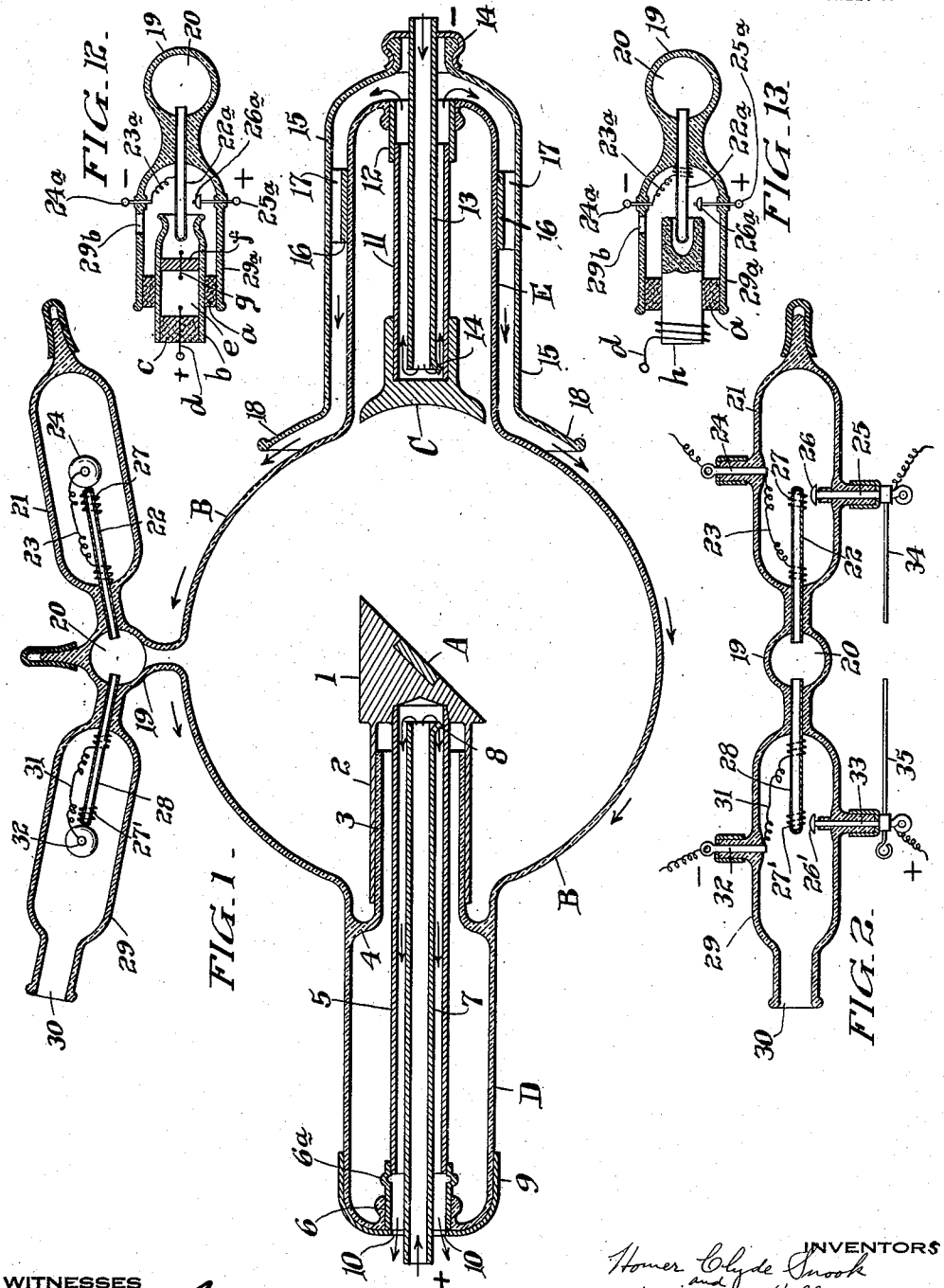


FIG. 1.

FIG. 2.

FIG. 12.

FIG. 13.

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FIG. 3.

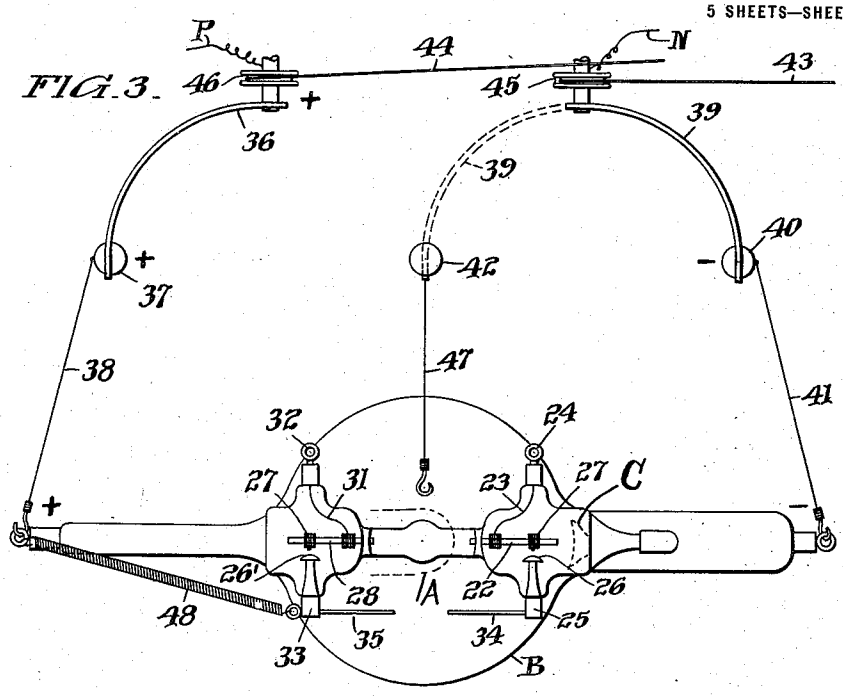
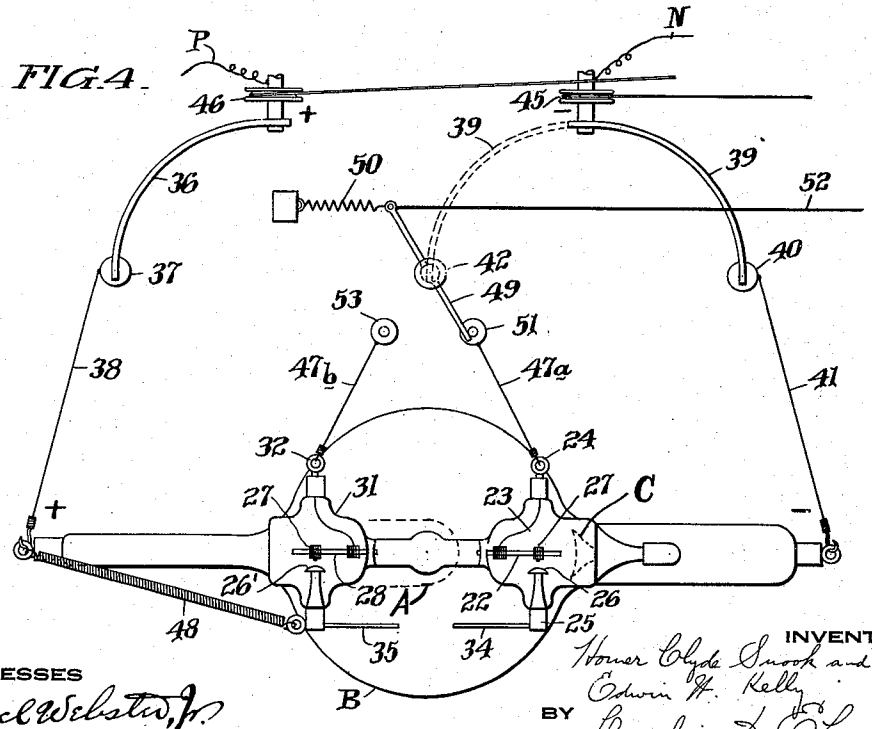


FIG. 4.



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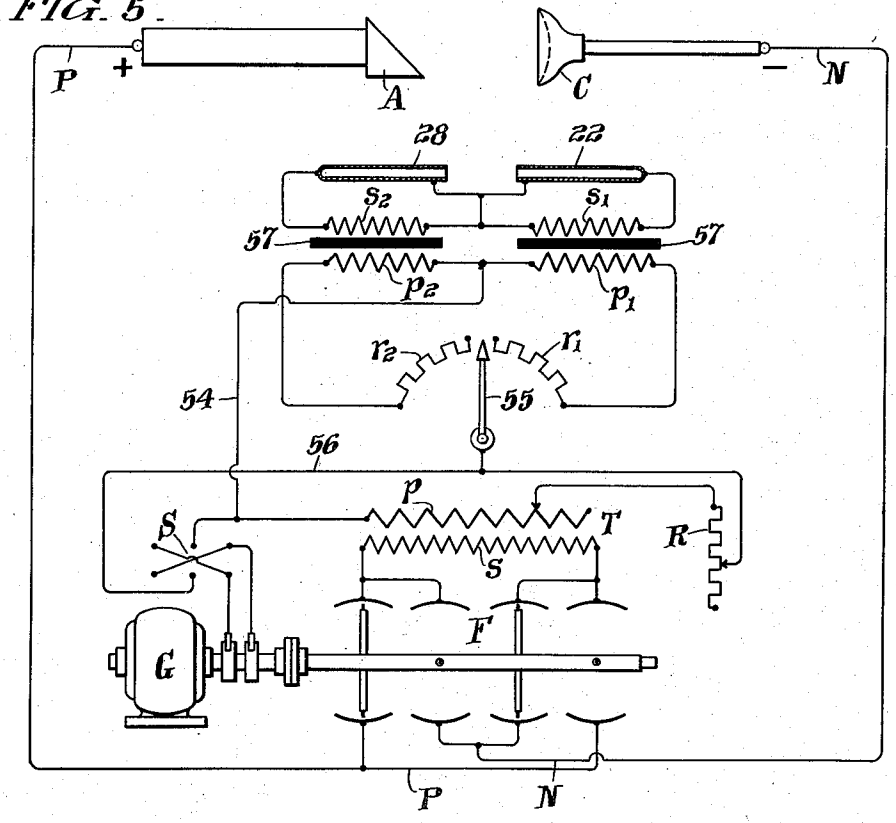
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5 SHEETS—SHEET 3.

FIG. 5.



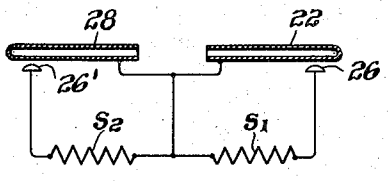
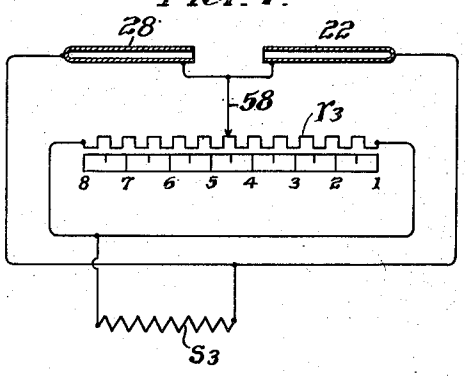


FIG. 6.

FIG. 7.



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5 SHEETS—SHEET 4.

FIG. 8.

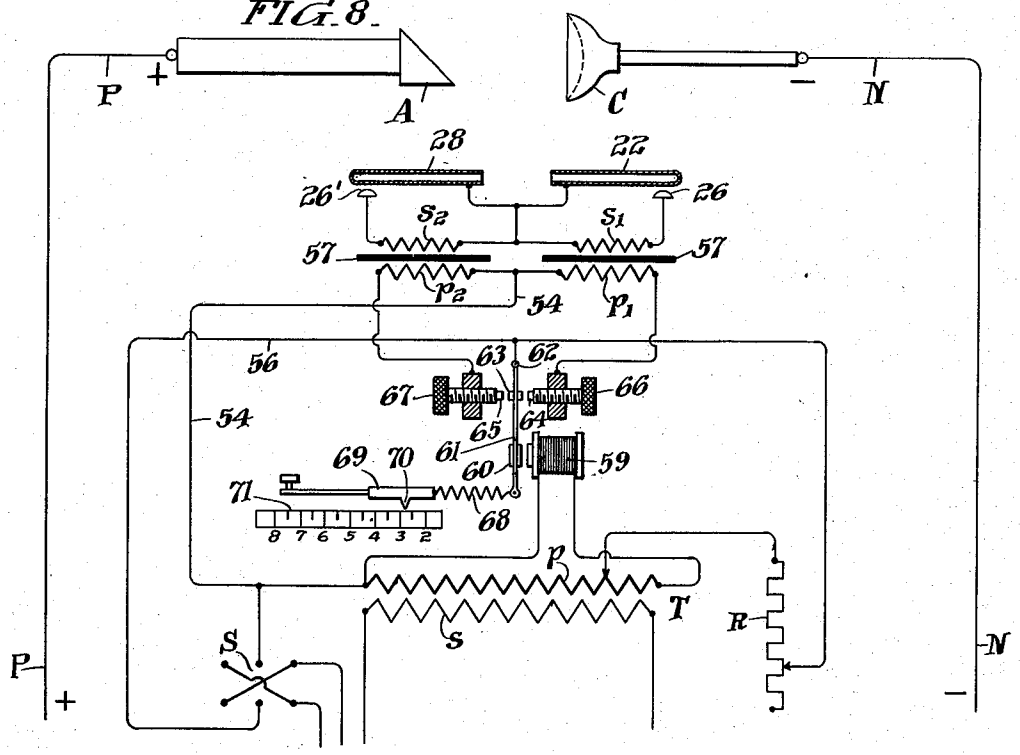
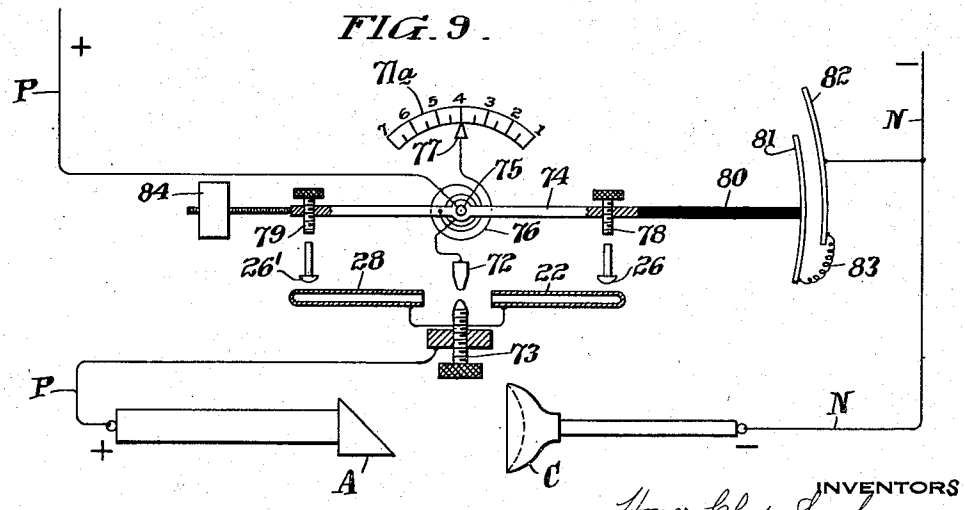


FIG. 9.



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5 SHEETS—SHEET 5.

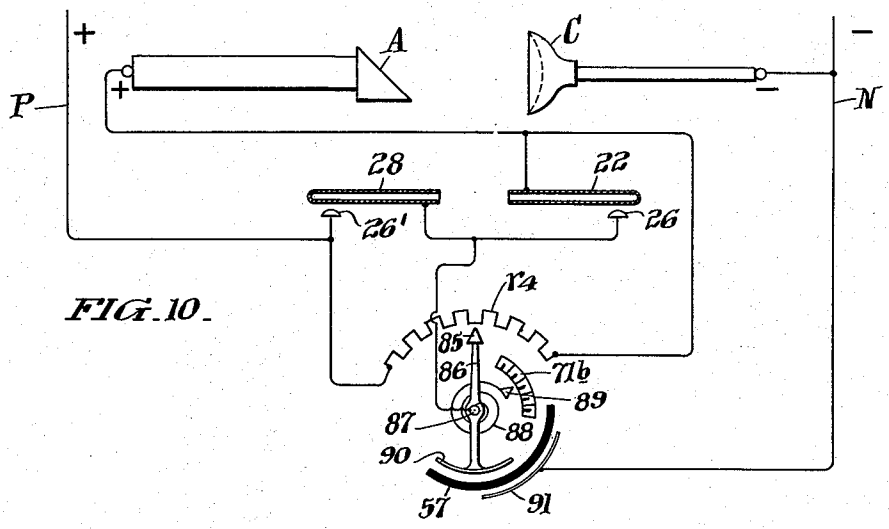
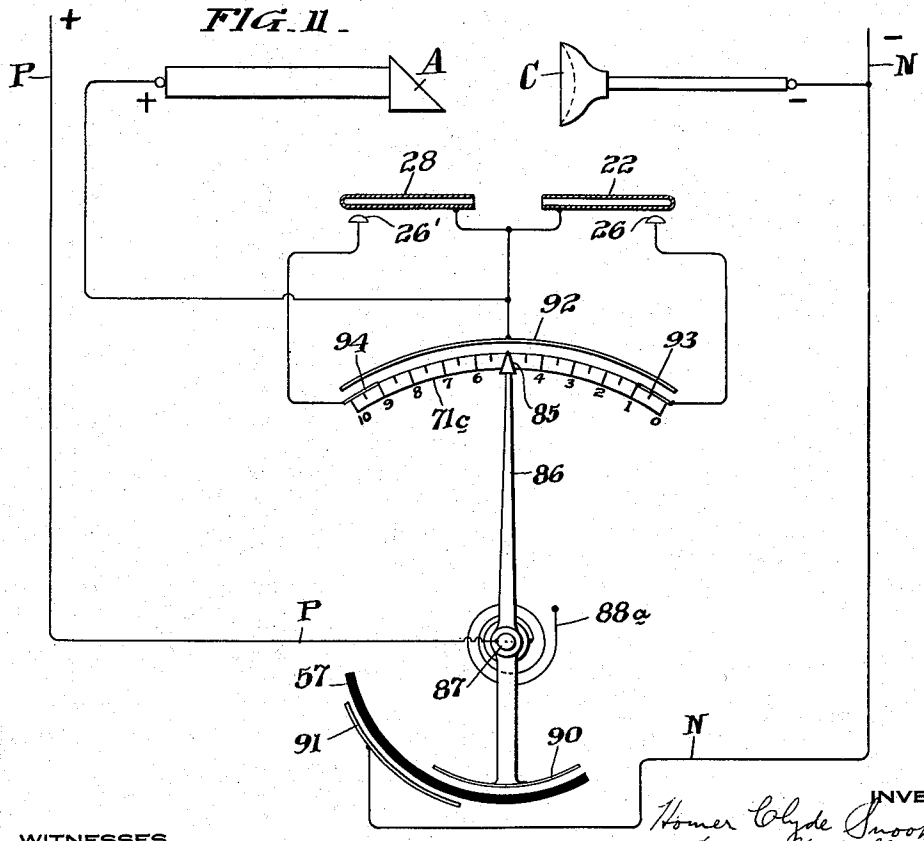


FIG. 10.

FIG. 11.



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VACUUM REGULATION.

1,143,327. Specification of Letters Patent. Patented June 15, 1915.

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To all whom it may concern:

Be it known that we, HOMER CLYDE SNOOK and EDWIN W. KELLY, citizens of the United States, of Cynwyd and Philadelphia, State of Pennsylvania, have invented new and useful Improvements in Vacuum Regulation, of which the following is a specification.

Our invention relates to a method of and apparatus for regulating the degree of vacuum of an X-ray tube or other electrical discharge vacuum tube or device.

By our invention we make use of the principle of osmosis for the introduction of gas into or removal of gas from the vacuum, though as to some features of our invention vacuum regulators operating on other principles may be employed.

In accordance with our invention gas may be introduced into the vacuum to lower the vacuum, or removed from the vacuum to raise the vacuum, at will; or a current of gas, of either constant or varying quantity, may be continuously or intermittently passed through the vacuum tube. And in accordance with our invention the vacuum lowering regulator and the vacuum raising regulator may be operated differentially, by either manual or automatic control, and in response to electrical conditions, reflecting vacuum conditions, of either the low tension or high tension sides of the source of current supply.

Our invention resides in the features hereinafter described.

For an illustration of some of the many forms our invention may take reference is to be had to the accompanying drawings, in which:

Figure 1 is a longitudinal sectional view through an X-ray tube and its regulators. Fig. 2 is a horizontal sectional view taken through the regulators of Fig. 1. Fig. 3 is a diagrammatic view illustrating a mode of manually controlling the vacuum regulation. Fig. 4 is a diagrammatic view illustrating a modified form of manual control for the regulation. Fig. 5 is a diagrammatic view of regulation by manual control in the low tension side of the circuit. Fig. 6 is a diagrammatic view of a modification of part of Fig. 5. Fig. 7 is a diagrammatic view of a further modification of a part of Fig. 5. Fig. 8 is a diagrammatic view of automatic regulation by use of low tension current. Fig. 9 is a diagrammatic view of automatic regulation in response to high potentials. Fig. 10 illustrates a mode of automatic differential regulation in response to high potentials. Fig. 11 illustrates a mode of regulation responsive to high potentials. Fig. 12 is a sectional view of a form our regulator may take. Fig. 13 is a sectional view of another form our regulator may take.

In Fig. 1 is illustrated an X-ray tube fitted with regulators and with means for cooling the X-ray tube and its cathode and anti-cathode. A tube so cooled by air or other suitable medium coöperates advantageously with our system of regulation, though it is to be understood that our invention is equally applicable to vacuum tubes or X-ray tubes which are not cooled or which may be of any other type.

Referring to the drawing, B is the usual glass bulb of an X-ray tube having the usual glass anode stem D and the usual glass cathode stem E. Within the tube are the usual anode or target A and cathode C. In the example illustrated the head 1, of copper or other suitable material is secured to metallic tube 2, as of steel, which fits over the tubular glass stem 3 joined to the stem D at 4. A tube 5, of copper or other suitable material, is set into the head 1 and preferably welded thereto forming a vacuum tight joint. The tube 5 extends through the stem D and at its end is welded or soldered at a vacuum tight joint to the platinum or other tube 6 which is sealed into the end of the glass stem D forming a vacuum tight joint. A corrugation 6^a in the tube 6 yields, under expansion and contraction of the tube 5 due to temperature changes, and thereby prevents breakage of seal between tube 6 and glass stem D. Within the tube 5 is disposed a metallic tube 7 which at its inner end has any suitable metallic projection 8 forming electrical contact with the tube 5 or head 1. Near its outer end the tube 7 is connected, as by soldering or brazing, to the metal ferrule 9 embracing the end of the glass stem D. Electrical connection is made from the positive terminal of a suitable high tension source of current with the ferrule 9 or the tube 7. The extreme end of the tube 7 is connected by rubber hose or otherwise with a supply of any suitable cooling medium, for example, a supply of air under pressure. Accordingly the air will pass into and

through the tube 7, strike the head 1, from which the tube 7 is suitably spaced, extracting heat from the head 1 which conducts the heat away from the target proper, the air then passing outwardly as indicated by the arrow through the annular space between the tubes 5 and 7 to the outer air through perforations 10 in the cap or ferrule 9.

The cathode C is counterbored to receive the tube 11 of copper or other suitable material, there being a vacuum tight joint between the cathode C and the tube 11 as by welding, brazing, soldering, etc. At its other end the tube 11 is welded, soldered or brazed to the platinum tube 12 sealed in the outer end of the glass cathode stem E making vacuum tight joints. Within the tube 11 is a metallic tube 13, spaced at its inner end from the cathode C and having the projection 14 making electrical connection with the cathode C or the tube 11. The other end of the tube 13 is soldered or otherwise connected to the metallic ferrule 14, making an air tight joint therewith, the ferrule 14 being secured upon the end of the outer tube or sleeve 15 of glass or any other suitable material. Electrical connection is made from the negative terminal of the aforementioned source of current with the ferrule 14 or the tube 13 which communicates electrically with the cathode C. The sleeve or tube 15 is supported upon the glass cathode stem E by the member 16, of cork or other suitable material, which has a plurality of longitudinally extending grooves 17 forming air passages. The tube or sleeve 15 preferably terminates in the bell 18 which extends around the bulb B to any suitable distance.

Air or other cooling medium is introduced into the tube 13, passes therethrough and strikes the cathode C, cooling the same, and then passes outwardly in the annular space between tubes 11 and 13 into the sleeve or tube 15 thence through the passages 17 over the outside of the cathode stem E into the bell 18 from which it issues over the outer surface of the bulb B, all as indicated by the arrows. And we have found that the air or other medium issuing from the bell 18 clings or remains close to the bulb B even beyond its middle or equator.

Sealed to the bulb B is a tube 19 whose interior space 20 is in communication with the interior of the bulb B. Supported by the tube 19 is the glass bulb or vessel 21 into which projects the tube 22 of platinum, palladium or any other suitable metal or material which is capable of operation as an osmotic member or membrane. The free end of the tube 22 is closed and its other end is sealed in the glass and its open end communicates with the space 20. An electrical connection is made by conductor 23 from the tube 22 to the platinum or other wire 24 sealed through the wall of the bulb 21. A second platinum or other suitable wire 25 is sealed through the wall of the bulb 21 and is preferably provided at its inner end with a button or head 26 of copper or other suitable material, preferably tipped with platinum, the head or button 26 being spaced from the tube 22 to form a spark gap, that part of the tube 22 directly opposite the button 26 being preferably thickened or provided with a layer of metal, such as a coil of wire 27, preferably of platinum, to prevent burning the tube 22. In the vessel 21 is confined a mass of gas or gases which are to be introduced into the bulb B for lowering the vacuum. The gas in the bulb 21 at the time of manufacture may be at atmospheris pressure, or above or below atmospheric pressure, but in any case preferably at a pressure high compared with the vacuum within the bulb B. This amount of gas or gases is sufficient for a great number of regulations of the vacuum in the bulb B, because of the very great amount of gas in bulb 21 as compared with the amount in the bulb B at any time. The gas in the bulb 21 is preferably hydrogen, though it is to be understood that any other suitable gas or mixture of gases may be employed. For example the monatomic gases such as argon, helium, neon, zenon, etc., may be employed either singly, or in combination with hydrogen or other gas.

A second tube 28, provided with a coil 27′, is sealed in the glass and has its open end in communication with the space 20 while its outer closed end is within the tube or bulb 29, in this case shown open to the atmosphere at 30. An electrical connection from the tube 28 is made by conductor 31 to the platinum or other wire 32 sealed in through the wall of the bulb 29. And disposed opposite the tube 28 is the button or head 26′ in electrical communication with the platinum or other wire 33 sealed through the wall of the bulb 29.

While the bulb 29 is shown open to the atmosphere, it is to be understood that the same may be closed to the atmosphere, like bulb 21, and may be more or less evacuated, or may contain gas other than any of the gases admitted to the bulb B through tube 22. And when the bulb 29 is open to the atmosphere as shown, the gas or gases admitted to the bulb B through tube 22 should be other than the nitrogen or oxygen of air or any other gas present in the air in substantial concentration. When it is desired to lower the vacuum within the bulb B a current of sufficiently high tension is passed across the gap between the head or button 26 and the tube 22 to heat the same to sufficiently high temperature, as, for example, above red heat.

We have found that by making the tube 22 the cathode and the button 26 the anode of the spark gap the heating is most

advantageously accomplished, particularly when the pressure of the gas in the spark gap is very much higher than that within the bulb B. The wall of the tube 22 being now heated, hydrogen, for example, will pass by osmosis from the bulb 21 through the membrane wall of the tube 22 to the interior of the tube 22 thence to the space 20 and thence to the bulb B, lowering the vacuum, the pressure of the hydrogen or other gas within the bulb B being slight indeed as compared with the pressure within the bulb 21. If on the other hand it is desired to raise the vacuum, that is, take hydrogen or other gas out of the bulb B, current is passed across the gap between the button or head 26′ and the tube 28, the latter again being the cathode by preference, and when the tube 28 is heated, and there being substantially no hydrogen in the air or within the tube 29, hydrogen will come out of the bulb B by osmotic action through the tube 28 and through its wall into the bulb 29, notwithstanding the fact that the gas pressure in the bulb 29 is very many times higher than the gas pressure within the bulb B. By preference, particularly when hydrogen is in the bulb 21, we make the tube 22 of platinum and the tube 28 of palladium. That is, in the lowering regulator we prefer to use a material for the tube 22 through which the gas does not so readily pass by osmotic action, while the tube 28 is preferably made of a material through which the gas will very readily pass by osmotic action. Temperatures, thicknesses of walls or osmotic membranes and differences in concentration of gas within and without the osmotic membranes being the same, the tube 22 may be said to have a lower osmotic co-efficient than the tube 28. Palladium has so high an osmotic co-efficient that we prefer not to use it in the lowering regulator, though it is to be understood that it may be there used. And this property makes it particularly desirable for the raising regulator as described. In electrical communication with the wires 25 and 33 may be provided the conductors 34 and 35 spaced from each other to form a spark gap.

In Fig. 3 is illustrated a mode of connection of the X-ray tube and the regulators. Here the positive conductor P from the source of high tension current for operating the X-ray tube is connected to the switch arm 36 normally engaging with the contact 37 connected by conductor 38 with the anode of the X-ray tube B. N is the negative conductor of the high tension source, and is connected to the switch arm 39 normally in engagement with the contact 40 connected by conductor 41 with the cathode of the X-ray tube. Either of the switch arms 36 or 39 may be swung over into engagement with contact 42 by pulling upon the cords 43 or 44 wrapped around pulleys 45 and 46 attached respectively to the switch arms 39 or 36. However switch arm 36 for the present purposes may remain in contact with contact 37. In communication with contact 42 is the conductor 47 which may be connected to either the wire 24 of the lowering regulator or the wire 32 of the raising regulator. With the parts in the position shown in Fig. 3 the X-ray tube is energized to produce X-rays. If it is desired to lower the vacuum, the conductor 47 is hooked on to wire 24 and then the cord 43 is pulled, transferring the switch arm 39 to contact 42, whereupon current will pass from the positive conductor P through switch arm 36, conductor 38 and conductor 48 connected with wire 35, then leaping the gap between wires 35 and 34 will pass through wire 34 and button 26 across the gap to tube 22, thence through conductor 23 and wire 24 and conductor 47 and switch blade 39 to the negative conductor N. The osmotic tube 22 will accordingly be heated and gas will pass into the bulb B to lower the vacuum. If on the other hand it is desired to raise the vacuum, instead of connecting the wire 47 to wire 24 it will be connected to wire 32. Since it may be more often required to lower the vacuum, the wire 47 may be left normally in connection with wire 24. And if the wire 47 is of considerable length it has substantial electrostatic capacity, and for this reason the gap between the conductors 35 and 34 is provided to prevent charging the wire 47 while the X-ray tube is in operation, the displacement current otherwise resulting would cause the lowering regulator to operate slightly and so undesirably lower the vacuum.

In Fig. 4 the arrangement is similar to that in Fig. 3 except that to the contact 42 is pivoted a switch arm 49 normally retracted by spring 50 into engagement with contact 51 connected by conductor 47^a to wire 24. With the parts in this position, to lower the vacuum, it is simply necessary to swing the switch arm 39 over on to contact 42. If it is desired to raise the vacuum, the cord 52 is pulled, moving the switch arm 49 in opposition to spring 50 into engagement with contact 53 connected by conductor 47^b with wire 32, the switch arm 39 being in this case also in communication with contact 42.

In Fig. 5 G is a source of alternating current, for example, a motor generator or inverted rotary, supplying current through the reversing switch S and adjustable resistance R to the primary *p* of the transformer T having the high potential secondary *s* delivering current through the synchronous high potential rectifying switch F to the positive and negative high tension conductors P and N connected respectively to the

anode A and cathode C of the X-ray tube. One terminal of the low tension alternating current circuit is connected by conductor 54 with one terminal of each of the transformer primaries p_1 and p_2 whose other terminals connect respectively with one terminal of the resistance r_1 and r_2 adapted to be swept over or engaged by the manually or otherwise operated switch arm 55 connected to the other conductor 56 of the low tension alternating current circuit. Associated with the primaries p_1 and p_2 are the secondaries s_1 and s_2, in whose respective circuits are included the lowering and raising osmotic tubes 22 and 28. Since these tubes 22 and 28 communicate with the interior of the X-ray tube, during operation of the X-ray tube these regulator tubes assume high potentials, and consequently between the primaries p_1 and p_2 and their secondaries s_1 and s_2 is provided high potential insulation 57. By this arrangement the X-ray tube may be kept in operation by energy delivered by the high tension conductors P and N and while in operation the vacuum may be lowered by bringing the switch arm 55 into engagement with resistance r_1, whereupon the secondary s_1 will pass current through the tube 22, the resistance of the tube 22 and the current strength being such that the tube 22 is raised in temperature, the temperature increasing as the amount of resistance r_1 in the circuit is decreased. And similarly if it is desired to raise the vacuum the switch arm 55 is brought into engagement with resistance r_2 whereupon the tube 28 is similarly heated by current derived from the secondary s_2.

Instead of connecting the tubes 22 and 28 in the manner shown in Fig. 5, they may be connected in the manner shown in Fig. 6 with relation to the secondaries s_1 and s_2. In this case these secondaries deliver current at potential high enough to leap the gaps of the characters described in connection with Fig. 1. Or as illustrated in Fig. 7, s_3 is a secondary of a transformer whose primary is in the low tension alternating current circuit of Fig. 5. Here one terminal of the secondary s_3 is connected to the interconnected tubes 22 and 28, a variable connection 58 being made with the resistance r_3 both of whose terminals are connected to the other terminal of the secondary s_3. By this arrangement heating current is passed through both tubes 22 and 28 so that both are continuously respectively admitting and extracting gas from the bulb B. By shifting the connection 58 along the resistance r_3 one tube or the other may be heated at will to higher temperature than the other and thus secure a differential regulation in that gas may be admitted more rapidly than it is extracted or extracted more rapidly than it is admitted. And whatever the position of the variable connection 58 there will be in effect a continuous stream of gas flowing into and out of the X-ray tube, unless, indeed, the temperatures of the tubes 22 and 28 are too low. A similar differential action may be secured by the arrangements shown in Figs. 5 and 6 by simply connecting the free ends of the resistances r_1 and r_2. And Fig. 7 may be modified in accordance with Fig. 6 so that differential regulation is available when the spark gaps are used for passing current to the tubes 22 and 28.

In Fig. 8 the source of alternating current and high potential rectifying switch of Fig. 5 are omitted, it being understood that the secondary s delivers high potential alternating current through the rectifying switch through the high potential conductors P and N. Here there is connected in parallel with the primary p of the high tension transformer T the winding of an electro-magnet 59 whose armature 60 is carried by the lever 61 pivoted at 62. Connection from conductor 56 of the low tension alternating current circuit is made with the lever 61 carrying the contact 63 adapted to engage either of the stationary contacts 64 or 65 adjustable laterally by the adjusting screws 66 and 67 respectively. The contacts 64 and 65 are connected respectively with one terminal of each of the primaries p_1 and p_2 whose other terminals connect with the conductor 54 of the low tension alternating current circuit. Attached to the lever 61 through spring 68 is the member 69 carrying pointer 70 coöperating with the scale 71. The pointer 70 may be moved to any point on the scale 71 and then clamped in the adjusted position. When the transformer T has sufficiently low magnetic leakage, the potential difference between the terminals of the primary p will rise and fall with the vacuum in the X-ray tube, since with higher vacuum the potential across the anode and cathode of the X-ray tube is high, and with lower vacuum the potential across the anode and cathode is lower while the tube is in operation. In consequence when the vacuum in the tube becomes higher the potential across the terminals of the primary p will become higher with resultant greater current through the winding of electro-magnet 59 which accordingly more powerfully attracts its armature 60, thereby bringing contact 63 into engagement with contact 64 energizing primary p_1 and causing its secondary s_1 to deliver current either conductively through the tube 22 as shown in Fig. 5 or across a spark gap as shown in Fig. 8 and Fig. 6. In any event when the primary p_1 is energized the osmotic tube 22 of the lowering regulator is heated and the vacuum is in consequence automatically lowered. If on the other hand the vacuum should become lower, the potential

across the primary p will fall, and the electro-magnet 59 will be weakened and the spring 68 will then gain control of the lever 61 bringing contact 63 into engagement with contact 65 thereby energizing primary p_2, causing current from the secondary s_2 to heat the raising regulator tube 28, to cause an automatic raising of the vacuum. By setting the pointer 70 to any desired point in scale 71, which may be calibrated in degrees of hardness of the X-ray tube, or in lengths of parallel spark gap corresponding with X-ray tube resistances, automatic regulation may be obtained for the desired degree of vacuum in the tube. And the apparatus will then operate automatically to keep the vacuum of the X-ray tube substantially that corresponding with the scale indication. The margin of fluctuation to either side of this value will be made smaller by adjusting the screws 66 and 67 inwardly so as to bring contacts 64 and 65 nearer the contact 63. Or by adjusting these screws outwardly, and separating the contacts 64 and 65 from contact 63, the margin of fluctuation of vacuum to either side of that indicated by the scale will be increased.

In Fig. 9 the automatic regulation is procured in response to fluctuations in potential of the high tension circuit across the anode and cathode of the X-ray tube. This method of regulation is therefore available whether or not the high tension transformer T has small magnetic leakage. The high tension positive and negative conductors P and N connect with the anode and cathode respectively as described. However, in one of these conductors, as P, there is a spark gap between the stationary terminal 72 and the adjustable terminal 73, the energy passed through the X-ray tube passing over the gap between these terminals. In this case the current for heating the regulator tubes 22 and 28 passes over the spark gaps similar to those described in connection with Fig. 1. Connection for this purpose is made from positive conductor P to the conducting member 74 pivoted at 75 and controlled by the torsion spring 76 whose free end carries a pointer 77 which may be clamped in any desired position with respect to the scale 71^a similar to the scale 71 in Fig. 8. The member 74 carries the adjustable contacts 78 and 79 coöperating respectively with the spark gap terminals 26 and 26′ and normally separated therefrom by spark gaps. To the insulating member 80, attached to the beam or member 74, is attached the metallic arc 81 disposed oppositely to the stationary metallic arc 82 which latter is connected with the negative conductor N. The arcs 81 and 82 may be electrically connected to each other by the small easily flexible wire 83. On the opposite end of the beam 74 is an adjustable counterweight 84 for balancing the beam so that its normal position shall be that indicated.

In normal operation the high potential energy will leap across the gap between terminals 72 and 73 and pass through the X-ray tube to energize the same. This spark gap length is less than the sum of the lengths of the spark gaps between 79 and 26′ and 26′ and 28, and less than the sum of the lengths of the spark gaps between 78 and 26 and 26 and 22, with the result that normally no current will pass over these regulator spark gaps. Under normal conditions the electrostatic charges on arcs 81 and 82, being of similar sign, cause these arcs to repel each other, and this repulsive force coöperating with the counterweight 84 and the spring 76 maintain the beam 74 balanced as shown. If however the vacuum of the X-ray tube should raise, the potential across the X-ray tube terminals will increase and the potential of the arcs 81 and 82 will be higher and they will repel each other with greater force, tilting the beam 74 in a clockwise direction about its pivot 75 bringing the terminal 78 closer and closer to the conductor 26 so that eventually the spark gap at these regulator terminals is shorter than the spark gap between the terminals 72 and 73 whereupon the current will pass through the regulator spark gaps at the right heating the lowering regulator tube 22 causing the vacuum to be automatically lowered. And if the vacuum has raised to a great extent the unbalancing of the beam 74 will be so great as to bring contact 78 into engagement with contact 26 which latter then acts as a stop for the beam. On the other hand if the vacuum of the tube is too low it will be automatically raised because of the decrease of potential of the arms 81 and 82 allowing the beam 74 to move in a counterclockwise direction on its pivot 75 to shorten the gap at the terminal 26′ thereby causing the current to pass across the spark gap between 79 and 26′ to heat the raising regulator tube 28, causing the automatic raising of the vacuum. By adjusting the screw contacts 73, 78 and 79 the amount of variation of vacuum to either side of that indicated by the scale 71^a may be adjusted. If the connection 83 between the arcs 81 and 82 is omitted and when in such case the arc 81 remains as indicated in the drawing or is connected to the positive conductor P, in such latter case substantial insulation intervening between arcs 81 and 82, the arcs 81 and 82 will carry charges of opposite signs and will therefore attract each other. And this attractive force will vary with the potential difference across the X-ray tube terminals and therefore with the degree of vacuum. With falling vacuum the attraction between the arcs 81 and 82 will become less and the beam 74

will then move in a clockwise direction about its pivot 75. Accordingly for this arrangement the arcs 81 and 82 and the counterweight 84 should be interchanged as to their positions with respect to the beam 74, or the spark gaps for the regulator tubes should be interchanged.

In Fig. 10 is illustrated a mode of automatic differential regulation responding to variations in potential conditions between the terminals of the X-ray tube, the same being operative while the X-ray tube is in operation. In this case an electrostatic instrument, which may be of the character illustrated or which may be of the quadrant electrometer type, responds to variations of potential to control the vacuum regulators. Here the two spark gaps of the regulators are in series with each other between the positive conductor P and the anode A of the X-ray tube. In shunt to these two spark gaps in series is the high resistance r_4 separated by a small spark gap from the terminal 85 on the conducting member 86 pivoted at 87 and controlled by the torsion spring 88 at whose end is carried the pointer 89 coöperating with the scale 71^b, similar to scales 71 and 71^a of Figs. 8 and 9, the pointer 89 being movable to any point along the scale and there clamped. The member 86 carries the arc shaped conducting plate 90 coöperating with the stationary arc shaped conducting plate 91 connected to the negative conductor N. Suitable high tension insulation 57 intervenes between members 90 and 91 to prevent sparking across them. The plates 90 and 91 become oppositely charged at high potential and their difference in potential fluctuates with the vacuum in the X-ray tube. As the vacuum in the X-ray tube raises, the potential difference between the plates 90 and 91 increases and the attractive force between them increases with the result that the member 86 rotates in a counterclockwise direction on its pivot 87 with the result that that part of resistance r_4 in shunt with the spark gap between tube 28 and the button 26′ of the raising regulator is decreased so that this regulator spark gap will be more or less completely robbed of its current and therefore the tube 28 will cool; simultaneously more current will pass from positive conductor P through resistance r_4 to the terminal 85 and thence to button 26 and across the gap to the lowering regulator tube 22, with the result that the tube 22 will increase in temperature and admit gas into the tube to reduce the vacuum. As the vacuum is reduced the potential across the X-ray tube terminals decreases and the member 86 moves in clockwise direction with relative decrease in temperature of tube 22 and increase of temperature of tube 28.

In Fig. 11 a mode of automatic regulation employing high tension potential differences is illustrated. Here the terminal 85 on the member 86 pivoted at 87 and having the control spring 88^a is separated by a substantial spark gap from the arc shaped contact 92 connected to both of the regulator tubes 22 and 28. With the terminal 85 which may serve also as a pointer is associated a scale 71^c similar to the scale 71^b of Fig. 10. The length of spark gap between members 85 and 92 is greater than that of each of the regulator spark gaps. And the length of each of the gaps between member 92 and members 93 and 94 is greater than each of the regulator spark gaps. The positive terminals 26 and 26′ of the regulator spark gaps are connected with the terminals 93 and 94 which contact 85 is adapted to very closely approach or engage. The member 86 carries an arc shaped conducting plate 90 coöperating with the stationary plate 91 and separated by insulating material 57 as in Fig. 10. The plate 91 is connected to the negative conductor N and the positive conductor P connects with the member 86. When the vacuum of the X-ray tube raises the potential difference between the plates 90 and 91 increases with the result that the member 86 partakes of clockwise movement about its pivot 87, current in the meantime passing from positive conductor P across the gap between members 85 and 92 and thence directly to the anode A, and thence through the X-ray tube to conductor N. When the potential rises sufficiently the contact 85 approaches or engages the contact 93 whereupon current will pass across the gap at the regulator tube 22 increasing the temperature of the regulator tube 22. Fall of vacuum of the X-ray tube is accompanied by movement of the member 86 in opposite direction, and when it closely approaches or engages the contact 94 the regulator tube 28 is similarly heated with resultant raising of the vacuum. The contacts 93 and 94 may be placed at any desired positions along the scale 71^c; and as the contacts 93 and 94 are placed nearer and nearer together the margin of regulation is progressively decreased.

In Fig. 12 is shown a form of regulator which may be used both for raising and lowering the vacuum of the main bulb or X-ray tube and in which the gas to be introduced into the tube is liberated or produced as and when required. Here the osmotic tube 22^a consists of palladium, though other suitable material may be employed. In the bell or bulb 29^a open to the air at 29^b, is a cork or other member *a* through which extends the glass or other tube *b* in whose outer end is a cork or other stopper member *c* through which extends the wire or conductor *d* terminating in the space *e* between the part *c* and the wall *f* of porce-

lain or other porous material through which extends the platinum or other conductor g, the tube 22^a extending into the mouth of the bottle or tube b and separated by a gap from the conductor g. The tube 22^a is connected by conductor 23^a to the wire 24^a which may be sealed through the wall of the member 29^a. A wire 25^a may be sealed through the wall of the member 29^a and terminate in a button 26^a separated by a gap from the tube 22^a. In the space e within the bottle or tube b may be placed water, alcohol, oil, such as mineral oil, or any other suitable hydrocarbon or source of hydrogen or other gas required. When it is desired to lower the vacuum of the main bulb or X-ray tube current is passed from the positive conductor d through the water or electrolyte in the space e to the conductor g and thence across the gap to the tube 22^a which is again preferably a cathode. The passage of the electric energy through the material in the space e causes by electrolysis the evolution of hydrogen, which passes through the porous member f into the space surrounding the end of the tube 22^a, and since such tube is heated by passage of the current the gas will pass through the osmotic wall of the tube 22^a into the space 20 communicating with the interior of the main bulb or X-ray tube, to lower the vacuum. Or when oil or other hydrocarbon is in the space e, the wires d and g may be connected together, in which case some of the oil or other material will be carried through member f by electrostatic action, and then decomposed into hydrogen or other gas which then passes through the heated wall of the tube 22^a into the main bulb or X-ray tube to lower the vacuum. The same tube 22^a may be used for raising the vacuum, by connecting the wire 25^a with the positive conductor of the circuit and causing the current to leap the gap to the cathode 22^a heating the same, whereupon hydrogen or other gas will pass into the main bulb or X-ray tube through the wall of the tube 22^a which is surrounded by air, and operation being the same as hereinbefore described.

In Fig. 13 there extends through the cork or other stopper a a member h, of porcelain or other porous substantially non-conducting material. The member h may be hollowed out at its inner end as shown to receive the end of the tube 22^a. And the positive conductor d may be connected to the member h in any suitable way as by wrapping the same around the member h several times. The pores of the member h are charged with an oil or hydrocarbon or other suitable material as described in connection with Fig. 12. On passage of current from the conductor d to the tube 22^a which is connected to the negative side of the circuit by wire 24^a gas will be liberated and collect within the hollow end of the member h around the end of tube 22^a which is heated by the spark or arc with the result that the gas will pass through the walls of the tube 22^a into the space 20 in communication with the main bulb or X-ray tube, thus lowering the vacuum. And the vacuum may also be raised by passing current from the wire 25^a across the gap to the tube 22^a, which is surrounded by air, with resultant raising of the vacuum as hereinbefore described.

It will be understood that the structure of either Fig. 12 or Fig. 13 may be used in place of the two regulators in any of the arrangements hereinbefore described for both automatic and manual regulation.

While we have shown an osmotic regulator for lowering the vacuum of the main bulb or tube it is to be understood that other types of regulator may be employed for this purpose and coöperate in the differential and other regulations, both automatic and manual, hereinbefore described. For example, any other type of lowering regulator may be used, such as those involving material in communication with the interior of the main tube or bulb and which may be caused to liberate gas when heated or otherwise acted upon. In such case, however, it is preferred that the gas liberated from such regulator shall be of such character as may be removed from the main bulb or tube by a raising regulator of the character described. And the osmotic members hereinbefore described may take other than tubular forms, any form of osmotic membrane being comprehended within our invention, except where expressly otherwise stated.

Air cooling of the X-ray tube is of general advantage in connection with an X-ray or vacuum tube, but is of particular advantage in connection with a raising regulator of the character herein described because by the air cooling, particularly of the glass wall in the vicinity of a cathode, prevents heating which is otherwise likely to occur at this region with resultant devitrification of the glass with resultant liberation into the vacuum of gases of a character which may not pass through the raising regulator membrane.

What we claim is:

1. The method of regulating the vacuum of a vacuum tube, which consists in simultaneously introducing gas into and extracting gas from the vacuum.

2. The method of regulating the vacuum of a vacuum tube, which consists in simultaneously introducing gas into and extracting gas from the vacuum at different rates.

3. The method of lowering the vacuum of a vacuum tube, which consists in extracting gas from the vacuum, and simultaneously introducing gas into the vacuum at a

greater rate than gas is extracted therefrom.

4. The method of raising the vacuum of a vacuum tube, which consists in introducing gas into the vacuum, and simultaneously extracting gas from the vacuum at a greater rate than gas is introduced into the vacuum.

5. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during the impression of energy thereon introducing gas into and extracting gas from the vacuum.

6. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon introducing gas into and extracting gas from the vacuum at different rates.

7. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon introducing gas into the vacuum and extracting gas from the vacuum at a lower rate.

8. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon introducing gas into the vacuum and extracting gas from the vacuum at a higher rate.

9. The method of operating a vacuum tube, which consists in simultaneously introducing gas into and extracting gas from the vacuum, and automatically controlling the rates of introduction into and extraction of gas from the vacuum.

10. The method of operating a vacuum tube, which consists in simultaneously introducing gas into and extracting gas from the vacuum, and automatically controlling the rates of introduction into and extraction of gas from the vacuum in response to a change in the degree of the vacuum.

11. The method of operating a vacuum tube, which consists in simultaneously introducing gas into and extracting gas from the vacuum, and automatically controlling the rates of introduction into and extraction of gas from the vacuum, and simultaneously impressing energy on the vacuum tube.

12. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, simultaneously introducing gas into and extracting gas from the vacuum, and automatically controlling the rates of introduction and extraction of gas in response to variations in difference of potential between the vacuum tube terminals.

13. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, and a terminal external to the vacuum separated from said membrane by a spark gap.

14. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane and a terminal external to the vacuum separated from said membrane by a spark gap, said membrane constituting the cathode of said gap.

15. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, a bulb closed to the atmosphere and charged with gas, said membrane separating said gas from the interior of said tube, and a spark gap terminal separated in said gas from said membrane.

16. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, a bulb closed to the atmosphere and charged with an isolated mass of gas, said membrane separating said gas from the interior of said tube, and means within said gas for heating said membrane.

17. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, a bulb closed to the atmosphere and charged with an isolated mass of gas, said membrane separating said gas from the interior of said tube, and means within said gas for electrically heating said membrane.

18. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, a bulb closed to the atmosphere and charged with gas, one side of said membrane exposed to said gas, and a terminal separated from said membrane within said gas to form a spark gap.

19. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, a bulb open to the atmosphere inclosing said membrane, and a terminal within said bulb spaced from said membrane to form a spark gap, said membrane constituting the cathode of said spark gap.

20. The combination with a vacuum tube, of a bulb integral therewith and open to the atmosphere, an osmotic membrane forming a wall between the interior of said vacuum tube and the interior of said bulb and housed within said bulb, and means for electrically heating said membrane within said bulb.

21. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, a bulb open to the atmosphere inclosing said membrane, and a terminal within said bulb spaced from said membrane to form a spark gap.

22. An X-ray tube comprising a main bulb, a second bulb carried by said X-ray tube and sealing a charge of regulating gas, an osmotic membrane separating said main and second bulbs, and means within said second bulb for heating said membrane.

23. An X-ray tube comprising a main bulb, a second bulb sealed thereon, a charge of elemental gas sealed within said second bulb, an osmotic membrane forming a wall between said gas and the interior of said main bulb, and means for heating said membrane.

24. An X-ray tube comprising a main bulb, two bulbs integral therewith, one of said two bulbs closed to the atmosphere and containing a charge of regulating gas, the second of said two bulbs open to the atmosphere, and osmotic membranes intervening between said two bulbs and said main bulb.

25. The combination with an X-ray tube having a main bulb, of a second bulb integral therewith, an osmostic membrane separating said bulbs, and an electrical connection to said membrane, a terminal spaced from said membrane to form a spark gap, and an electrical connection through said second bulb to said terminal.

26. The combination with an X-ray tube having a main bulb, of a second bulb integral therewith, an osmostic membrane separating said bulbs, and an electrical connection to said membrane, a terminal spaced from said membrane to form a spark gap, an electrical connection through said second bulb to said terminal, and a spark gap between said terminal and a main terminal of said X-ray tube.

27. An X-ray tube comprising a main bulb, two bulbs integral therewith, one of said two bulbs closed to the atmosphere and containing a charge of regulating gas, the second of said two bulbs open to the atmosphere, osmotic membranes intervening between said two bulbs and said main bulb, spark gap terminals spaced from said membranes, and a spark gap between said spark gap terminals.

28. The combination with an X-ray tube having vacuum lowering and raising regulators, of electrical switching means for dissimultaneously electrically controlling said regulators.

29. The combination with an X-ray tube having vacuum lowering and raising regulators, of a source of energy for operating said X-ray tube, a switch for electrically controlling either of said regulators, and a switch for disconnecting a terminal of said X-ray tube from said source and connecting said first named switch to said source.

30. The combination with an X-ray tube having vacuum lowering and raising regulators, of a source of low potential energy, means for converting said low energy to energy of high potential for operating said X-ray tube, and means deriving low potential energy from said low potential source for controlling said regulators.

31. The combination with an X-ray tube having vacuum lowering and raising regulators, of a source of low potential energy, means for converting said low energy to energy of high potential for operating said X-ray tube, and means deriving low potential energy from said low potential source for controlling said regulators alternately.

32. The combination with an X-ray tube having vacuum lowering and raising regulators, of a source of low potential energy, means for converting said energy to energy of high potential for operating said X-ray tube, and means deriving low potential energy from said low potential source for controlling said regulators differentially.

33. The combination with an X-ray tube having vacuum lowering and raising regulators, of a source of low potential energy, means for converting said energy to energy of high potential for operating said X-ray tube, and means deriving low potential energy from said low potential source for controlling said regulators automatically.

34. The combination with an X-ray tube having vacuum lowering and raising regulators, of a source of low potential energy, means for converting said energy to energy of high potential for operating said X-ray tube, and means deriving low potential energy from said low potential source for controlling said regulators automatically in response to changes in difference of potential between the terminals of said X-ray tube.

35. The combination with an X-ray tube having vacuum lowering and raising regulators, of a high potential circuit for impressing energy upon said X-ray tube, and automatic means responsive to changes in difference in potential between the terminals of said X-ray tube for controlling said regulators.

36. The combination with an X-ray tube having vacuum lowering and raising regulators, of a high potential circuit for impressing energy upon said X-ray tube, and automatic means responsive to changes in difference in potential between the terminals of said X-ray tube for differentially controlling said regulators.

37. The combination with an X-ray tube, of means for cooling the same, and automatic means responsive to change in degree of vacuum of said tube for raising the vacuum thereof.

38. The combination with an X-ray tube, of means for cooling the same, and automatic means for raising and lowering the vacuum thereof in response to change in degree of vacuum.

39. The combination with an X-ray tube comprising a bulb, an anti-cathode and a cathode, of means for cooling the exterior of said bulb in the vicinity of said cathode, and automatic means responsive to change in degree of vacuum of said tube for raising the vacuum within said bulb.

40. The combination with an X-ray tube comprising a bulb, an anti-cathode and a cathode, of means for cooling the exterior of said bulb in the vicinity of said cathode, and automatic means responsive to change

in degree of vacuum of said tube for raising and lowering the vacuum within said bulb.

41. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, and a terminal external to said tube separated from said membrane by a spark gap, said membrane constituting the cathode of said spark gap.

42. A regulator for raising the vacuum of a vacuum tube comprising an osmotic membrane forming a wall between the interior of said tube and a region at higher pressure, and a terminal external to said tube separated from said membrane to form a spark gap.

43. Means for regulating the vacuum of a vacuum tube comprising a raising regulator and a lowering regulator, said lowering regulator comprising an osmotic membrane, and a terminal external to said tube separated from said membrane to form a spark gap.

44. Means for regulating the vacuum of a vacuum tube comprising a lowering regulator and a raising regulator, said raising regulator comprising an osmotic membrane, and a terminal separated from said membrane to form a spark gap.

45. An X-ray tube comprising a main bulb, a second bulb sealed thereon, a charge of hydrogen gas sealed within said second bulb, an osmotic membrane forming a wall between said gas and the interior of said main bulb, and means for heating said membrane.

46. Means for regulating the vacuum of a vacuum tube comprising a plurality of regulators, each of said regulators comprising an osmotic membrane, said membranes formed of different materials, and means for heating said membranes.

47. Means for regulating the vacuum of a vacuum tube comprising raising and lowering regulators, said regulators comprising osmotic membranes of different materials.

48. Means for regulating the vacuum of a vacuum tube comprising raising and lowering regulators, said regulators comprising osmotic membranes of different materials allowing passage of gas therethrough at different rates under like conditions.

49. Means for regulating the vacuum of a vacuum tube comprising lowering and raising regulators comprising osmotic membranes, means for supplying gas to the outer side of the lowering regulator membrane, said membranes allowing passage of gas therethrough with different degrees of freedom.

50. Means for regulating the vacuum of a vacuum tube comprising lowering and raising regulators comprising osmotic membranes, means for supplying gas to the outer side of the lowering regulator membrane, the membrane of said lowering regulator allowing passage of said gas therethrough with less freedom than the membrane of said raising regulator.

51. Means for regulating the vacuum of a vacuum tube comprising lowering and raising regulators comprising osmotic membranes, means for supplying gas to the outer side of the lowering regulator membrane, said membranes allowing passage of gas therethrough with different degrees of freedom, said membranes being of different materials.

52. Means for regulating the vacuum of a vacuum tube comprising lowering and raising regulators comprising osmotic membranes, means for supplying gas to the outer side of the lowering regulator membrane, the membrane of said lowering regulator allowing passage of said gas therethrough with less freedom than the membrane of said raising regulator, said membranes being of different materials.

53. Means for regulating the vacuum of a vacuum tube comprising lowering and raising regulators comprising osmotic membranes of platinum and palladium, respectively.

54. Means for regulating the vacuum of a vacuum tube comprising lowering and raising regulators comprising osmotic membranes of platinum and palladium, respectively, and hydrogen gas in contact with the outer face of said platinum membrane.

55. The method of operating a sealed vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon extracting gas therefrom automatically in response to change in degree of vacuum.

56. The method of operating a vaccum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon extracting gas from or introducing gas into said tube automatically in response to change in degree of vacuum.

57. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon extracting gas from or introducing gas into said tube automatically in response to change in difference of potential between the tube terminals.

58. The method of controlling the vacuum of a sealed vacuum tube, which consists in cooling said tube, and extracting gas therefrom automatically in response to change in degree of said vacuum.

59. The method of controlling the vacuum of a vacuum tube, which consists in cooling the tube, and extracting gas from or introducing gas into said tube automatically in response to change in degree of vacuum.

60. The method of operating a vacuum tube, which consists in impressing electrical

energy thereon, and during impression of energy thereon controlling the temperature of said tube, and extracting gas therefrom automatically in response to change in degree of vacuum.

61. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon controlling the temperature of said tube, and extracting gas therefrom and introducing gas into said tube automatically in response to change in degree of vacuum.

62. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon controlling the temperature of said tube, and extracting gas from and introducing gas into said tube automatically in response to change in degree of vacuum.

63. The method of operating a vacuum tube, which consists in impressing electrical energy thereon, and during impression of energy thereon controlling the temperature of said tube, and automatically introducing gas into and extracting gas from said tube simultaneously at different rates.

64. The combination with an X-ray tube having a vacuum raising regulator, of automatic means responsive to fall of vacuum for controlling said regulator.

65. The combination with an X-ray tube having a vacuum raising regulator, of automatic means responsive to change in difference of potential between the terminals of said X-ray tube for controlling said regulator.

66. The combination with an X-ray tube, of a vacuum regulator comprising spark gap terminals, and automatic means responsive to changes in vacuum for controlling the length of said spark gap.

67. The combination with an X-ray tube, of a vacuum regulator therefor comprising an osmotic membrane, a terminal external to said tube separated from said membrane to form a spark gap, a second terminal separated from said terminal to form a second spark gap, and automatic means responsive to changes in vacuum for changing the length of said second spark gap.

68. The combination with an X-ray tube, of a vacuum regulator comprising an osmotic membrane, a bulb on said tube inclosing said membrane, said membrane forming a wall between the interior of said X-ray tube and said bulb, a transformer external to said bulb, and connections from the secondary of said transformer into said bulb, said membrane included in the secondary circuit of said transformer, said secondary circuit being in its entirety external to the vacuum of said X-ray tube.

69. The combination with an X-ray tube, of a vacuum regulator comprising an osmotic membrane, means external to the vacuum of said tube for heating said membrane, and a transformer whose secondary delivers energy for heating said membrane, the current in the primary of said transformer automatically varying with changes of difference of potential between the terminals of said X-ray tube.

70. The combination with an X-ray tube, of a vacuum regulator therefor comprising an osmotic membrane, a terminal external to said tube separated from said membrane to form a spark gap, and a transformer including said spark gap in its secondary circuit.

71. The combination with an X-ray tube, of a step-up transformer for exciting the same, a vacuum regulator comprising an osmotic membrane, a transformer whose secondary delivers energy for heating said membrane, and means for connecting the primary of said second transformer in a circuit in shunt with the primary of said first named transformer, whereby the current in the secondary circuit of said second named transformer automatically varies with changes of difference of potential between the terminals of said X-ray tube.

72. The combination with an X-ray tube, of a step-up transformer for exciting the same, a vacuum regulator comprising an osmotic membrane, a terminal separated from said membrane to form a spark gap, a second transformer whose secondary circuit includes said spark gap, the primary of said second transformer connected in a circuit in shunt with the primary of said first named transformer.

73. The combination with a vacuum tube, of a scale having markings corresponding with degrees of vacuum, an index associated with said scale, a vacuum regulator, means for controlling said regulator, said means comprising means set by movement of said index.

74. The combination with a vacuum tube, of vacuum lowering and raising regulators, a scale having markings corresponding with degrees of vacuum, an index associated with said scale, means for controlling said regulators, and means determining the operation of said controlling means set with said index.

75. The combination with a vacuum tube, of vacuum lowering and raising regulators, a scale having markings corresponding with degrees of vacuum, an index associated with said scale, automatic means for controlling said regulators, and means determining the operation of said controlling means set with said index.

76. A regulator for the vacuum of a vacuum tube comprising an osmotic membrane, a member thereon forming the terminal of a spark gap, and another terminal external

to said tube forming the other terminal of said spark gap.

77. A regulator for the vacuum of a vacuum tube comprising a tube of osmotic material, a protecting member on said tube forming the terminal of a spark gap, and a second member forming the other terminal of said spark gap.

78. The combination with an X-ray tube, of means for cooling the same, and automatic means responsive to change in degree of vacuum of said tube for introducing into said tube an elemental gas.

79. The combination with an X-ray tube, of means for cooling the same, and automatic means responsive to change in degree of vacuum of said tube for introducing into said tube hydrogen gas.

80. The combination with an X-ray tube, of means for cooling the same, automatic means responsive to change in degree of vacuum of said tube for introducing into said tube an elemental gas, and automatic means responsive to change in degree of vacuum of said tube for extracting gas from said tube.

81. The combination with an X-ray tube, of means for cooling the same, automatic means responsive to change in degree of vacuum of said tube for introducing into said tube hydrogen gas, and automatic means responsive to change in degree of vacuum of said tube for extracting gas from said tube.

82. The combination with an X-ray tube, of means for cooling the same, and means automatically responding at different times to change in degree of vacuum of said tube for raising and lowering the vacuum of said tube.

In testimony whereof we have hereunto affixed our signatures in the presence of the two subscribing witnesses.

HOMER CLYDE SNOOK.
EDWIN W. KELLY.

Witnesses:
ALICE S. MARSH,
NELLIE FIELD.

Corrections in Letters Patent No. 1,143,327.

It is hereby certified that in Letters Patent No. 1,143,327, granted June 15, 1915, upon the application of Homer Clyde Snook, of Cynwyd, and Edwin W. Kelly, of Philadelphia, Pennsylvania, for an improvement in "Vacuum Regulation," errors appear in the printed specification requiring correction as follows: Page 2, line 95, after the comma, insert the words *or in combination;* page 5, line 107, for the word "arms" read *arcs;* and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 29th day of June, A. D., 1915.

[SEAL.]

J. T. NEWTON,
Acting Commissioner of Patents.