No. 682,691. Patented Sept. 17, 1901.

P. C. HEWITT.

METHOD OF OPERATING ELECTRIC LAMPS.

(Application filed Apr. 5, 1900.)

(No Model.) 3 Sheets—Sheet 1.

Fig. 1

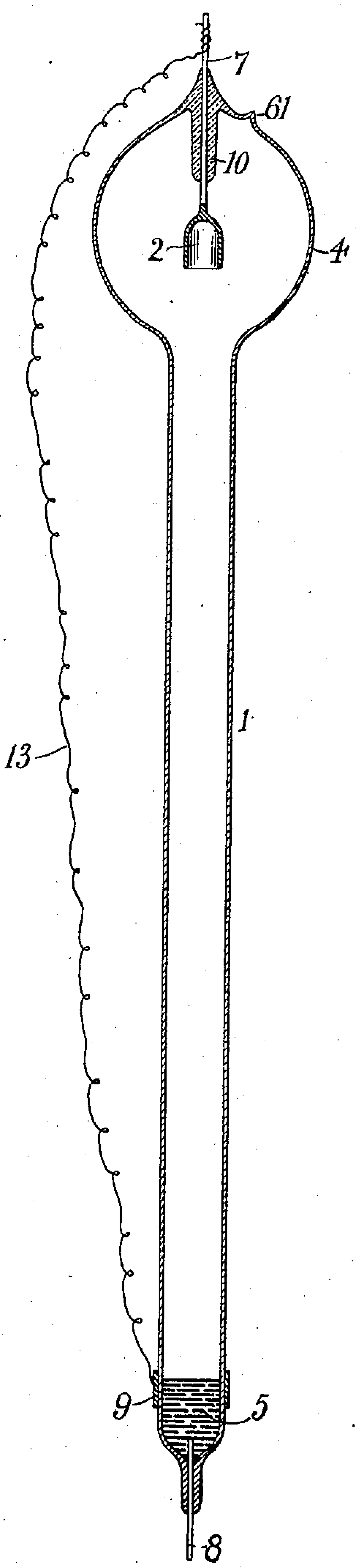
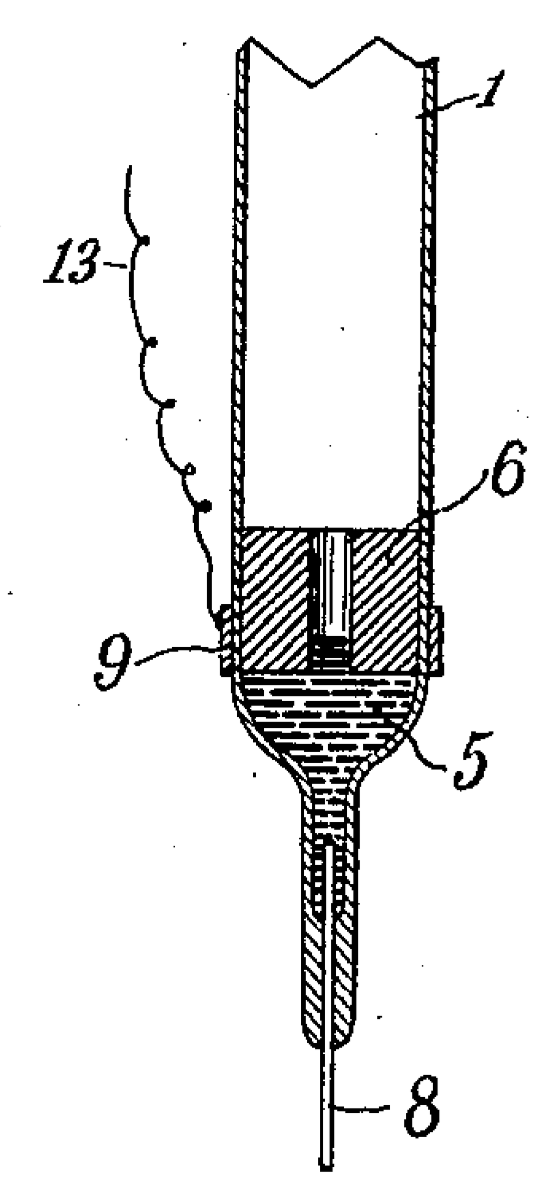


Fig. 2



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THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

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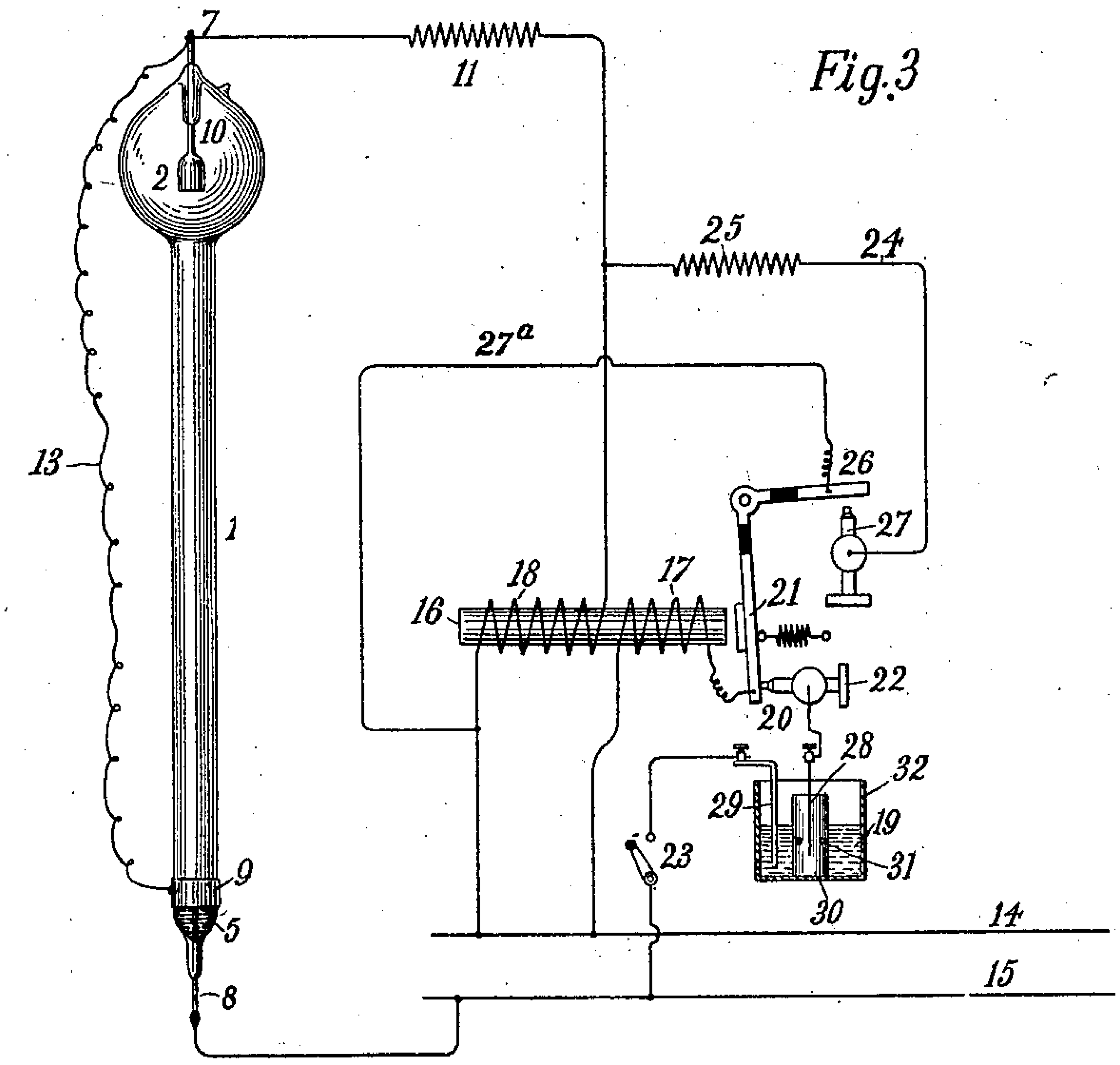

Fig. 3

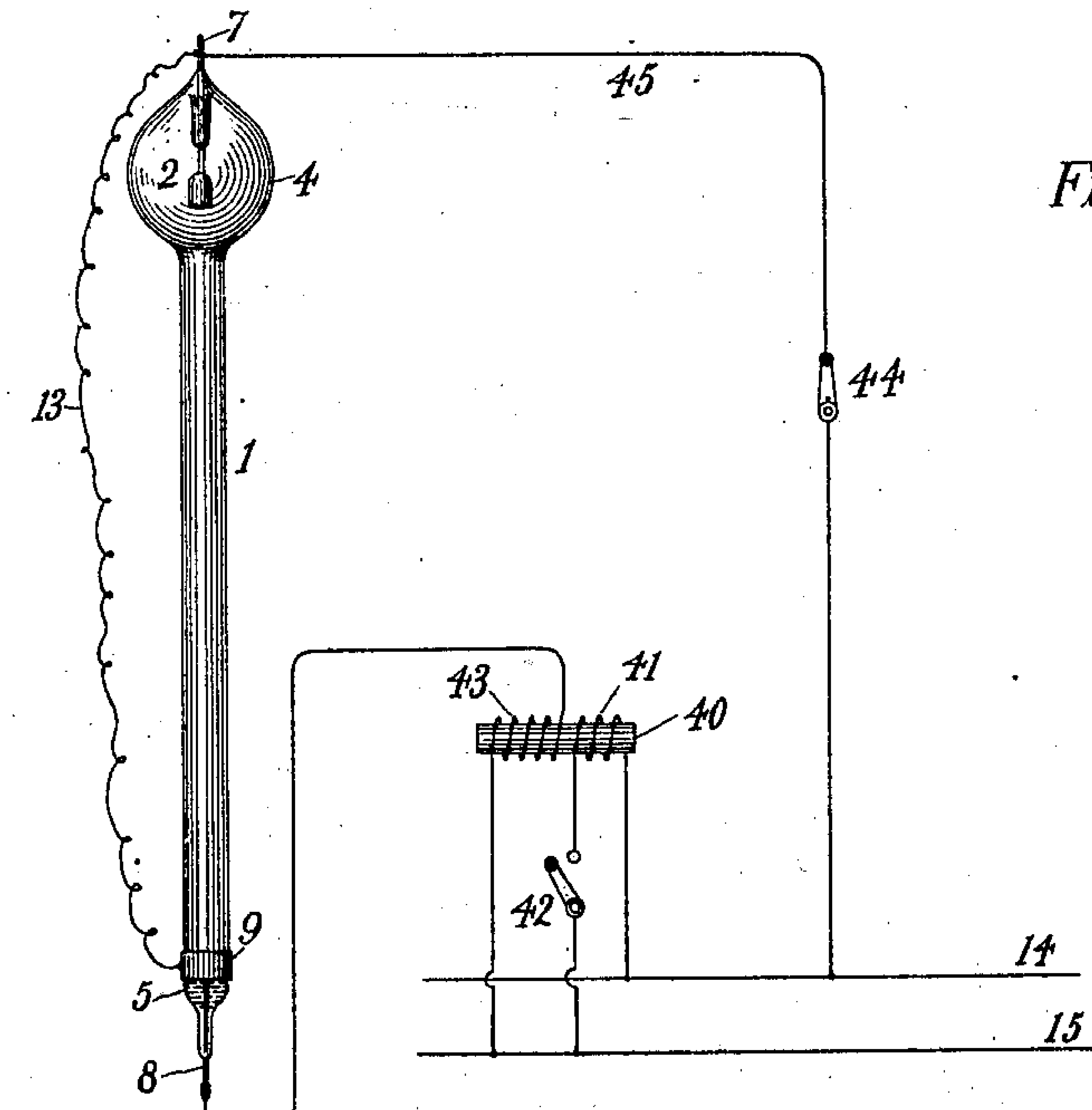

Fig. 4

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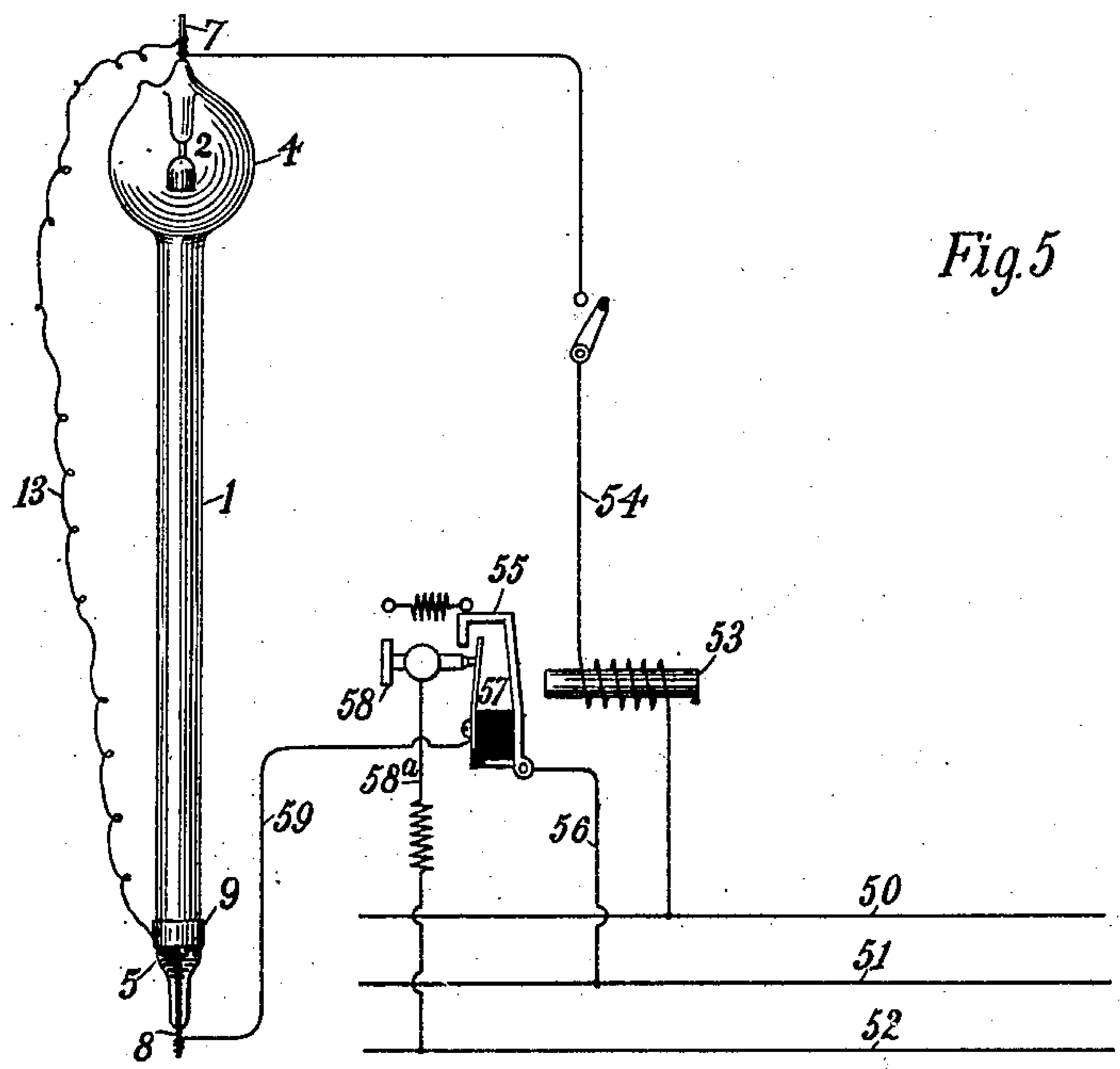

Fig. 5

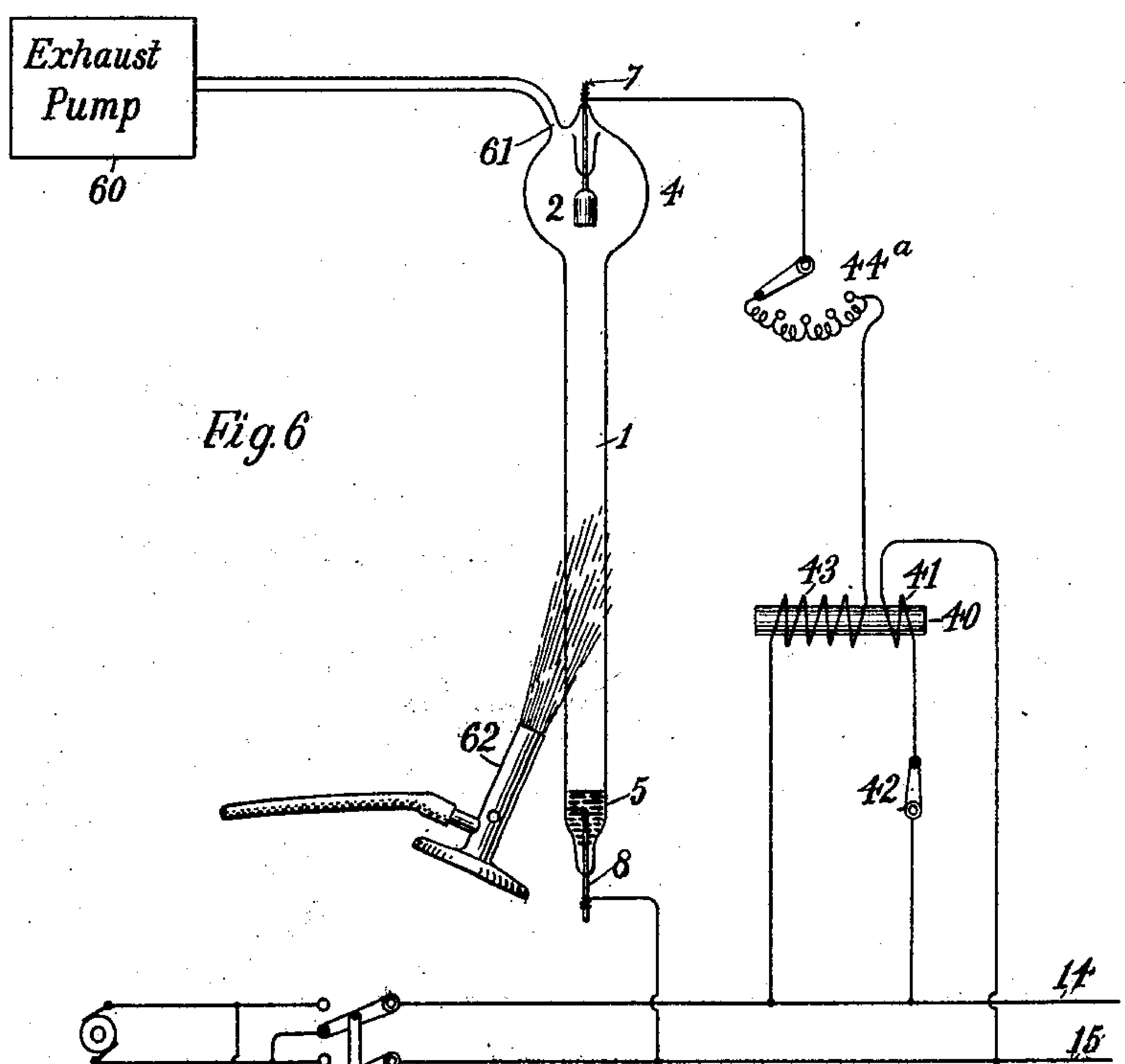

Fig. 6

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UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR TO PETER COOPER HEWITT, TRUSTEE, OF SAME PLACE.

METHOD OF OPERATING ELECTRIC LAMPS.

SPECIFICATION forming part of Letters Patent No. 682,691, dated September 17, 1901.

Application filed April 5, 1900. Serial No. 11,606. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Operating Electric Lamps, of which the following is a specification.

My invention relates to methods of and apparatus for electric lighting.

The general purpose of the invention is to produce light by converting electric energy into light through the agency of vapors or gases as efficiently as possible and with simple and durable apparatus.

In the ordinary conversion of electric energy into light a large amount of the energy is wasted in heat, and while the development of heat is usually, if not always, attendant upon the development of commercial light, yet from theoretical considerations it may be assumed that the efficiency of a light-producing device, other things being equal, would be increased in approximate proportion as the development of heat is suppressed.

My invention aims, among other things, to produce light by the conversion of electrical energy with the coincident production of as moderate an amount of heat as practicable, and I have found that gases or vapors possess this property in a greater degree than matter in any other state, and therefore they offer a field of operation in which the highest efficiencies can be obtained if proper means are devised for rendering the gases or vapors light-emitting under the influence of electricity.

It has been proposed to obtain light by the passage of alternating or intermitted electric currents of very high frequency through a more or less rarefied gas contained within hermetically-closed tubes, such gas being so acted upon by the currents as to become luminous. This class of apparatus, commonly known as "Geissler tubes," has been found for various causes to have no commercial utility as a means of illumination. It has also been proposed in some instances to pass electric currents through two electrodes consisting of bodies of mercury contained in hermetically-closed tubes and to obtain light from the electric arc between the two mercury electrodes; but prior to my invention no such devices, so far as I am aware, have been produced which are suitable for commercial use. They have usually been started by bringing the two bodies of mercury constituting the electrodes into actual contact with each other and then separating them, the electric current then being caused to arc across from one electrode to the other. Such method of starting has been found impracticable for any extended use and requires the presence of a considerable outside resistance to prevent an excessive current-flow when the bodies of mercury are in contact, and even when started they have been incapable of commercial operation with efficiency or for any considerable period of time. These and other difficulties have rendered such devices impracticable for use upon circuits in which the electromotive force is liable to vary, as in the ordinary commercial systems of electric lighting, or even in connection with other circuits, such as those supplied by storage batteries, and they have little or no value, except, perhaps, for special scientific or laboratory experiments. These devices, so far as I am aware, have been essentially arc-lamps as distinguished from those in which the current passing from one electrode to the other does not form an arc. The exact distinctions between an arc and conduction not involving an arc are somewhat difficult to define, although not difficult to detect in practical operation. It is noticeable, however, that in the case of an arc there is intense heating of both the positive and negative electrodes, but particularly of the positive electrode, and the current passes from the electrodes into the conducting-vapor at definite points or positions, whereas in the other form of conduction the effect is to produce a halo around the electrode, as if the current passed evenly from the electrode, except that a dark space appears at or around the electrode. This space and its appearance seem to differ with different vapors used; but there is always a marked and well-defined difference between it and an arc, and when in the process of manufacture the last trace of arc disappears it is plainly noticeable. In the other form of conduction little or no heat is developed at the points where the current passes from the electrode into the vapor. Moreover, in the case of the arc there appears to be a narrowing at or near an electrode, whereas in the other form of conduction the body of light is of practically the same dimensions throughout the space between the electrodes or between points in close proximity to the electrodes. An arc, moreover, is striated, a condition which does not appear to be present in the other form of conduction. Again, the temperature established by the arc in any one place with a given flow of electric energy appears to be far in excess of that produced by a flow of the same amount of energy in the other form of conduction.

The lamps which I have produced do not operate upon the arc principle, but possess the characteristics of this special form of conduction. It is, moreover, essential that the proper adjustment of the resistance of the vapor path should be obtained, and I have found that this result can be secured in the case of vapors conducting in this manner, so that the electromotive force with which the lamp is adapted to be operated can be predetermined with as great a degree of accuracy as is usual in the manufacture of the ordinary incandescent lamps having carbon filaments, and the manner in which the resistance shall vary can be controlled in vapor-lamps with a much wider range of controllable resistance than is the case with a carbon filament, as the resistance of the carbon is a fixed factor, while the vapor resistance may be selected to vary at will within wide limits. It does not appear to have been appreciated prior to my invention that such a control of resistance on the part of a vapor was possible or practicable, and, as a matter of fact, in the forms of lamp hereinbefore referred to, wherein an arc is established between bodies of mercury, such control has not been obtained.

Under proper conditions certain vapors and also certain materials which normally exist in the form of gases may be caused to remain in such condition as to convey electric currents under the influence of moderate electromotive forces after a current-flow has once been established. By properly correlating the resistances between the respective electrodes and the vapor or gas and the resistance of the vapor or path itself and providing a proper heat-radiating capacity a lamp may be produced which will take considerable currents at moderate electromotive forces and be self-regulating to such a degree as to permit of its use upon commercial circuits even though their electromotive forces may fluctuate through wide limits. To render the lamp as stable and self-regulating as possible upon the circuit, it should have the resistance between the respective electrodes and the gas or vapor path reduced as much as possible, so that these resistances relative to the resistance of the gas path shall be small. The gas or vapor path then constitutes the principal portion of the resistance of the lamp, and as the electromotive force at its terminals increases the total opposition to the passage of current may be made to increase also. This may be due in a measure at least to the fact that the greater amount of current flowing under the increasing pressure tends to develop a higher temperature, which in turn tends to increase the resistance of the lamp, so that a balance can be effected, rendering the lamp self-regulating. I do not, however, desire to be understood as advancing this theory of its regulation as the only one or as being necessary, but merely one which may be advanced from the results obtained.

Some materials when in a gaseous or vaporized state possess the capacity of emitting light under the influence of electric currents in a much higher degree than others. The vapor of mercury is efficient as a light-yielding material, and owing to its molecular weight and its low boiling or vaporizing point it is well suited to the purposes of my invention. Moreover, it readily serves under the influence of the current to transfer the heat generated in the lamp to convenient points for radiation. Some of the materials normally existing in the form of gases may, however, be used—such, for instance, as nitrogen. The amount of light, however, which may be obtained from nitrogen per unit of length appears to be less than that which can be obtained from mercury vapors, other things being equal. The spectrum is also a matter to be considered in determining the material to be used. Mercury gives a light which is clear and white, but wanting in red rays, so that while useful for many purposes it may be undesirable for others. Lithium and similar materials yield spectra with red and other colors. Nitrogen and other gases develop red rays in abundance, and when combined with the mercury rays a beautiful result is obtained. The selection of the material for the vapor or gas must be determined by the conditions and requirements. The invention will be more particularly described with reference to mercury vapor as a matter of convenience and clearness, being among the most convenient to practice the art.

The lamp should be constructed to utilize, as far as possible, all the resistance of the lamp in the conversion of the electrical energy into light; but as there may be more or less heat developed the structure should be such as will radiate the heat at a suitable rate. Usually it is advantageous to employ a cooling-chamber at some portion of the device outside the path of the current. In the case of mercury, for instance, an enlargement of the tube may project a distance beyond one of the electrodes, so that the excess of heat will be radiated. In some instances it is practicable to cause the radiation to take place through the walls of the tube surrounding the gas column at a sufficient rate to meet the requirements. If the temperature of the lamp is allowed to become too high, the lamp is liable to extinguish itself. When a fixed gas is used or vapors under such conditions that their densities cannot be unduly increased by heat in the tube, then the cooling-chamber may be dispensed with. The lamp may be made of such size as to render a special cooling-chamber unnecessary.

The ability to start the lamp readily is of the utmost importance, gases appearing to present a greater resistance to the passage of the current before the current is passing than after, and I have found that certain materials added to the lamp before or while in the process of manufacture produce a condition which makes it possible to start a current under a moderate increase of electric pressure, and thereupon the continuous or analternating current of low pressure readily traverses the lamp, producing an intense enduring light. I have obtained excellent results by the use of an independent substance for effecting the starting of the lamp which produces a preliminary condition favoring the passage of current. One of the substances which I have used is sulfur or its compounds—for example, a small quantity of the sulfid of mercury introduced at the same time as the mercury when mercury is employed for forming the vapor. The tube containing these materials is then heated by any suitable means, the air, moisture, and foreign gases being pumped out by a suitable air-pump. I have found it advantageous during the process of exhaustion to heat the tube by convenient means until a vacuum is formed and to then subject the contents of the tube to the action of an electric current of high voltage. I am able to thus produce more or less heat throughout the length of the tubes and produce such chemical reactions as may occur under the influence of the current and drive out foreign or deleterious gases and substances, leaving fairly pure mercury and a resultant sulfur compound the exact nature of which I am not prepared to state with definiteness, although from such tests as I have been able to apply it would seem probable that it is a compound of mercury and sulfur containing a less proportion of sulfur than exists in the form of sulfid of mercury. Its effects seem quite different from that produced by pure red or black sulfids of mercury such as I have been able to make or procure in the markets. With this material present in the tube it is possible at starting cool to transmit an alternating or intermittent current from one end of the tube to the other with a much lower electromotive force than is required if the sulfur compound or its equivalent were not present. It seems also desirable to free the tube as far as possible from certain foreign substances, and particularly from oxygen, and I sometimes treat the tube with a bath of heated hydrogen before placing on the pump and also when the lamp is being exhausted. I have found it sometimes advantageous to use interrupted currents of high voltage flowing in a given direction and to first constitute one of the electrodes the anode and the other the cathode and then to reverse the direction of the currents. I usually employ solid materials—such, for instance, as pure iron or other suitable substance—for one or both of the electrodes, and by thus constituting the respective electrodes alternately anodes and cathodes during the process of exhaustion I am enabled to heat each of them to a very high temperature, and thus drive out any occluded gases and foreign materials and produce any chemical reactions in them that might otherwise occur later on and ruin the efficiency of the tube. While the lamp is thus being treated and exhausted I connect the electrodes through a variable resistance with a suitable source of current of moderate electromotive force—such, for instance, as one hundred and ten or two hundred and twenty volts—the application of the high potential being also continued. In practice I find that the lamp should be run on the pump with a current at least equal to or, better, in excess of the current it is intended to afterward operate with. As the lamp approaches completion it suddenly becomes intensely luminous by reason of the passage of a considerable current of moderate potential from this source. The high-voltage current may then be temporarily withdrawn and the lamp further treated by current of low potential. Usually, however, it is desirable to use the currents of interrupted high potential at intervals, as they are useful for heating the electrodes and effecting the chemical changes as above referred to. When the lamp ceases to give off further foreign gases, it may be sealed off and it is then in condition for operation.

When no starting material is present in the lamp, it is possible to start by heating it by any convenient means—such, for instance, as a Bunsen burner or an electric heating-coil of any convenient construction—and simultaneously applying to the terminals a difference of potential, substantially equivalent to that upon which the lamp is designed to operate and at the same time a boosted electromotive force to enable the regular current to pass; but in the case of gases owing to the electric phenomena, the exact nature of which I am not yet able to state, the lamp lights up, and when once lighted will continue in operation as long as required. When, however, the starting material is used, the lamp may be started without preliminary heating by means of electric currents of the proper electromotive force, usually higher than that upon which the lamp is normally intended to run. This may be conveniently done by placing in the circuit leading to the lamp the secondary coil of a transformer, the primary of which is connected with the supply-circuit through a suitable circuit-interrupter, or an alternating current from a suitable transformer may be used, the purpose being to first cause a current to pass through the space between the electrodes, which then appears to afford a path for the operating-currents of moderate potential. The readiness with which currents of lower electromotive force are caused to flow when a lamp provided with the starting material has been subjected for an extremely short period to a higher electromotive force would indicate that the starting is not in this case due to the heat development of the current, but to some other electrolytic or electrochemical action, the exact nature of which it is difficult to determine. For the purpose of constructing the lamp it is not essential that the theory of the action should be determined.

I have found that other materials than sulfur and mercury may be used to produce the startling material in the lamp. For instance, I have employed solenium and mercury with good results and also phosphorus and mercury and other materials. After the lamp is started it is probable that the starting material does not continue to act as a current-carrier, but that it is forced out of the path of the current or undergoes a change; but when the lamp is again cooled it resumes the proper relation and condition to be availed of for again starting. I have found it advantageous when the lamp is to be started without heating and by means of moderately-high voltage-currents to surround the glass or wall in the neighborhood of one of the electrodes, or in the case of an alternating-current lamp each of the electrodes, by a band of conducting or semiconducting material—such, for instance, as foil, which in turn is placed in electrical connection with the other electrode or grounded by means of a small conductor. This device appears to lessen or neutralize, to a certain extent at least, the surface tension or static charge which gathers about the electrode during the application of the starting-current, and it reduces the effective starting resistance of the lamp. A lamp which could be started only by extremely high potential currents, if at all, without this band may be started without difficulty when it is present. When the lamp is once in operation under the influence of alternating or continuous currents of low pressures, the presence of the conducting-band seems to no longer exercise its function to the same degree, although it may remain without interfering with the operation of the lamp, as it is insulated from the neighboring terminals of the lamp.

In the accompanying drawings, illustrating my invention, Figure 1 represents one form of a complete lamp. Fig. 2 illustrates a modified form of electrode. Figs. 3, 4, and 5 illustrate systems of circuits for operating the lamp. Fig. 6 illustrates, partly in diagram, an organization of apparatus for exhausting and treating the lamp during exhaustion.

Referring to the figures, 1 represents a glass tube of such dimensions as may be required—say, for example, a tube of three-quarters of an inch in diameter and two or three feet in length and having a wall of such thickness as not to be fragile. The particular dimensions of the tube to be chosen are determined by the electromotive force and the current with which it is to be operated and other considerations which will be hereinafter pointed out. This tube is provided with two electrodes, (indicated at 2 and 5, respectively.) If the lamp is to be run by continuous current, the electrode 2 is usually the anode and the electrode 5 the cathode. In the drawings I have shown the electrode 2 as being of an inverted-cup shape; but other forms may be employed—such, for instance, as a closed spherical, oval, cylindrical, and other shapes. I have obtained excellent results by using a pure iron for this electrode; but other metals may be substituted. It is suspended within or near the neck of an enlargement or chamber 4, which I usually employ, this chamber serving to increase the heat-radiating capacity of the lamp and to retain impurities. The electrode 2 is suspended by leading-in conductor 7, of platinum or other suitable material, extending through the glass wall, and I usually provide a long seal 10 for protecting more or less of the leading-in conductor within the lamp. The electrode 5 is shown in this instance as being a small quantity of mercury. A leading-in conductor 8 connects with this electrode. Surrounding the lower end of the tube adjacent to and usually projecting a slight distance—say one-eighth of an inch above the level of the lower electrode—there is placed a thin band 9, of conducting material—such, for instance, as foil—and this is electrically connected by a conductor 13 with the leading-in wire 7. When the lamp is to be operated by alternating electric currents, it may be useful to place a circular band in similar relation to the other. electrode and connect it with the leading-in conductor 8.

The lamp is started by means either of first heating it—as, for instance, with the flame of a Bunsen burner or other convenient means—or by applying to the terminals an electromotive force of higher potential—such, for instance, as may be obtained by a rapidly alternating or intermittent current. In Fig. 3 I have represented a system of circuits and apparatus for securing an intermittent current of higher potential from the same main circuit 14 15 upon which the lamp is to be run. The apparatus consists in this instance of a converter having a core 16, provided with two coils 17 and 18. One terminal of the coil 17 is connected with the conductor 14. The remaining terminal is connected with an insulated contact 20 on an armature 21, which is operated by the core 16. A contact-point 22, against which the point 20 normally rests, is connected with one terminal of a circuit-interrupting device 19. The remaining terminal of this circuit-interrupting device is connected through a suitable key or switch 23 with the conductor 15. One terminal of the coil 18 is connected with the conductor 14, and the remaining terminal is connected with the leading-in wire 7. The leading-in wire 8 is connected with the main line 15. When the current is turned on—as, for instance, by the switch 23—the interrupter 19 causes rapidly-intermitted currents to pass through the coil 17. This induces a current of any desired potential in the coil 18. The effect of this high potential is to produce within a lamp such an electrical or electrochemical condition as will result in effecting a passage of the currents of normal potential which are simultaneously applied by the main circuit 14 15. When currents commence to flow through the lamp from the conductors 14 15 under the influence of the normal electromotive force upon the main circuit, the core 16 attracts the armature 21, separating the contacts 20 22. The same movement of this armature may operate to close a shunt-circuit 24 around the coil 18 through a resistance 25 offering sufficient resistance to the flow of current to cause enough current to still flow through the coil 18 to hold the armature 21 in its forward position as long as the lamp continues to operate. In this figure I have shown this as accomplished by an insulated contact 26, carried by the armature 21 coming into contact with a point 27, this point being connected with the conductor 24, while the insulated point 26 is connected by the conductor 27^a with the opposite end of the coil 18.

During the starting of the lamp by the application of higher potential currents a high static charge appears to occur near the electrode 5 and upon the outer surface of the lamp, and this is removed or reduced by the presence of the band 9 connected through the conductor 13 to the leading-in wire 7. In practice I have found that with this band removed or the conductor 13 interrupted it is exceedingly difficult, if not impossible, to start the lamp with currents of reasonable electromotive force unless the lamp is heated by artificial means. The exact position at which the band 9 may be located appears to differ somewhat in different cases, probably owing to the good conductivity of the gas coming from or forming part of the electrode. The proper position is usually slightly beyond the effective joint between the electrode and the gas.

It should be noted that the potential of the main circuit 14 15 is applied to the lamp during the time that the higher potential starting-current is applied, and if an intermittent current, in distinction from an alternating current, is employed and a continuous current is to be used for operating the lamp it is usually desirable, though not necessary, to so connect the terminals that the electromotive forces shall be in the same direction—that is to say, the positive side of the main circuit being connected with the electrode 2 the positive side of the higher potential circuit is connected with the same electrode. The connections may, however, be in opposite directions. With alternating currents, the electrode 2 being alternately anode and cathode, the connections may be followed out on the same principle.

The circuit-interrupter 19 which I have shown is an adaptation of a device commonly known as a "Wehnelt" interrupter. It consists of two electrodes 28 and 29, of lead, separated by a jar 30, of non-conducting material, having small perforations 31 and immersed in sulfuric acid contained within a vessel 32. An electrode 28 is placed within the jar and an electrode 29 outside of it. The action of the electric current is to generate gases, which forming within the perforations temporarily interrupt the circuit and the gases disappearing the circuit is again completed with great rapidity. Other forms of circuit-interrupting devices, however, may be employed.

Unless special means are provided to prevent it a lamp of this character using mercury vapor is liable to have a more or less flickering effect, probably due to the shifting of the position at which the current enters the cathode. I have succeeded in obviating such flickering in various ways. The tendency of the current seems to be to remain in the gas or vapor until it reaches the portion of the cathode most distant from the anode, and if a small body of mercury surrounds the cathode it will, unless means are provided to prevent it, wander over the surface of the mercury, and thus produce the flickering. I find that by sufficiently obstructing the path beyond the portion of the cathode nearest the anode the current will be forced to enter the cathode at a more or less fixed point, and thus become steady and obviate the flickering. A cylinder of porcelain or other suitable substance 6, as shown in Fig. 2, may be placed in the mercury, leaving only a perforation through which the current must pass. Where the cathode is at the end of the tube, this difficulty may be overcome to a large extent by making it concave and arranging it so that the current will enter it on the concave surface.

I have used in some instances in place of the form of apparatus above described for producing the higher-potential starting-current a simple spark-coil, as shown in Fig. 4, comprising a core 40, with a primary coil 41, adapted to be connected by means of a switch 42 between the main conductors 14 and 15, and also provided with a secondary coil 43, one terminal of which is connected with the electrode 5 of the lamp and the remaining terminal with the main conductor 15. A switch 44 is included in the conductor 45, which leads from the electrode 2 to the main conductor 14. The coils 41 and 43 are so proportioned as to produce a higher difference of potential at the terminals of the coil 43 upon breaking the circuit of the coil 41, and the discharge from this coil suffices to produce in the vapor path of the lamp the proper conditions for permitting the current from the main circuit to flow through the lamp by way of the conductor 45 and the coil 43.

In Fig. 5 a modification in the circuit organization is shown, in which a three-wire system of distribution is represented by the conductors 50, 51, and 52, the difference of potential upon the outside conductors 50 and 52 being assumed to be twice that between the middle or neutral conductor 51 and the respective outside conductors. The purpose is to apply the higher difference of potential to the lamp upon starting and automatically shifting the lamp to the lower potential when current commences to flow. For this purpose any suitable form of circuit-changing switch may be employed. In the drawings I have shown a magnet 53, having its coil included in the conductor 54, leading to one terminal of the lamp. The armature 55 of this magnet is connected by a conductor 56 with the neutral conductor 51. It is normally held away from the magnet, so that an insulated contact 57 is pressed back by a contact-point 58, which in turn is connected by a conductor 58^a with the main conductor 52. The insulated contact 57 is connected by a conductor 59 with the remaining terminal of the lamp. When the lamp is started, its terminals are in connection with the two conductors 50 and 52; but current flowing through the conductor 54 in sufficient quantity to operate the lamp causes the magnet to draw the armature 55 forward, closing the contact between the spring-contact 57 and armature 55 and simultaneously breaking the contact between the point 58 and the spring-contact 57, thus shifting the lamp to the lower-voltage circuit. A resistance may be included in the conductor 58^a to prevent a short circuit upon the conductors 51 52 when the armature is being drawn forward.

As already stated in connection with Fig. 1, the condensing and impurity-containing chamber 4 or its equivalent performs an important function in the operation of the lamp. As the lamp commences to operate heat accumulates and the increasing temperature appears to soon result in increased resistance on the part of the vapor-bath. If the heat is not conducted away after the lamp has reached its proper working condition with the same rapidity that it is generated, the lamp may extinguish itself. The chamber 4 is therefore constructed with sufficient radiating-surface to get rid of the excess heat and keep the lamp in the proper condition. The chamber 4 need not, however, necessarily surround the electrode 2; but it may be located elsewhere and be of other form, provided it is out of the vapor-path.

It may sometimes be desirable to insert a small balancing or steadying resistance in series with the lamp. This resistance is of importance mainly on starting certain kinds of lamps, which when cold, owing to the starting material or other construction, would take too much current until they have acquired their working condition. When a given electromotive force is applied to the terminals of the lamp, such steadying resistance does not cause any material reduction of potential at the terminals of the lamp until current commences to flow, and thereafter the greater the amount of current flowing the greater will be the resistance opposed to the flow of current, and thus the difference of potential at the terminals of the lamp will be held down. The coils of the starting mechanism are therefore usually not objectionable when left in circuit, for their resistance in a large measure compensates for moderate changes of voltage upon the circuit in which the lamp may be placed and also prevents too great a rush of current when the lamp first starts, for when the lamp starts it is in a condition to take a large amount of current. This might in some cases melt the leading-in wires or crack the glass were it not prevented by some such means as the steadying resistance. I have shown such a steadying resistance at 11 in Fig. 3; but when the lamp is running the steadying resistance causes but slight loss, as the amount of current is less.

Referring to Fig. 6, the method of manufacturing the lamp will be described more in detail. The tube, properly shaped and prepared, is first thoroughly cleansed with acids, alkalies, and water. I have found it convenient to first rinse the tube with dilute hydrofluoric acid and then wash with distilled water, and thereafter, if desired, it may be further washed by a bath of hot hydrogen. In case mercury is to be used for providing the conducting-vapor a small quantity of it is placed within the tube, and if the sulfid of mercury is to be used for forming the starting material a small quantity of that substance is added. Pure sulfur may be introduced instead of sulfid of mercury; but I have found that it usually is more difficult to secure the desired results with it than with the sulfid of mercury. The lamp is then sealed onto a suitable exhaust-pump 60, of any suitable character, through an exhausting-tube 61, and the process of exhaustion is commenced. Meanwhile artificial heat is applied to the tube—as, for instance, by a Bunsen burner 62 or an electric heater or in some other convenient manner. After the free gases and air have been exhausted an electric current of higher potential is applied to the terminals of the lamp—as, for instance, by a system of circuits and apparatus such as described in connection with Fig. 4—and the passage of this current through the lamp produces an effect somewhat similar to that noticeable in Geissler tubes. The operation of the exhaust-pump is continued and a difference of potential approximately equal to that under which the lamp is intended to be operated is applied to the terminals of the lamp. As the lamp approaches completion it suddenly becomes intensely luminous by reason of the passage of a current of considerable quantity. If the higher-potential current employed is an interrupted current, it is desirable to reverse the terminals of the lamp with reference to that current one or more times, for the cathode is thereby readily heated to a very high temperature, which aids in driving off any occluded gases and impurities. A circuit-reverser 63 may be employed for that purpose.

In the form of apparatus shown in Fig. 6 the connections of the spark-coil are somewhat different from those of the similar coil shown in Fig. 4; but the principle of operation is the same and the action of the apparatus can easily be determined by reference to the description of it in connection with Fig. 4. In place of the switch 44 shown in Fig. 4 I substitute a variable resistance 44[a], the object of which is to permit of varying the current passing through the tube 1 during the process of manufacture. The switch 42 may be replaced by an automatic circuit-interrupter—such as illustrated, for instance, in connection with Fig. 3.

The process of exhausting the lamp does not appear to remove the starting material, although apparently a different chemical compound is formed, and it is possible that some of the sulfur is thrown off or formed into some other combination and withdrawn from the tube. In any event sufficient of the starting material remains in the tube to permit the ready starting of the lamp when it is completed. The amount of sulfid of mercury to be introduced may be varied within wide limits. I have used in a lamp of approximately the dimensions hereinbefore referred to a quantity as small as may be taken upon the point of a pocket-knife and be plainly visible. Too much does not seem to exercise any very bad effect except retarding the process of exhaustion and possibly to blacken or coat the glass somewhat. When the pump ceases to withdraw any gases other than the mercury vapors, the lamp is completed and may be sealed off from the pump 60.

While I have described the lamp more particularly with reference to mercury vapors, I desire it to be distinctly understood that I do not limit myself to those vapors nor to materials which at ordinary temperatures exist in the forms of solids or liquids, for permanent gases may be employed. Usually with permanent gases the necessity of the chamber 4 is obviated, for the proper gas density and distance between electrodes are obtained when the lamp is constructed, and the lamp being made self-regulating the temperature controls and is controlled by the quantity of current flowing. I have also found that with mercury vapors the lamp operates successfully without the enlargement 4 if the diameter of the tube is an inch or more or even smaller.

In certain other applications filed by me April 5, 1900, Serial Nos. 11,605 and 11,607, and Serial Nos. 44,647, 44,648, and 44,649, filed January 25, 1901, claims are made to certain features which are disclosed herein.

I claim as my invention—

1. The method of starting a vapor-lamp comprising a vapor-containing chamber and a vapor or gas contained therein which consists in applying to the terminals thereof a higher difference of potential, thereby creating a conducting condition through the vapor or gas and thereafter operating by currents of lower potential.

2. The hereinbefore-described method of producing light by electric energy through the agency of an apparatus consisting of a closed chamber containing a vapor capable of emitting light under the influence of electric currents and also a material more readily subject to the action of electric currents than said vapor, which consists in first transmitting currents through the device by the instrumentality of one of the materials contained therein and thereafter transmitting currents through the instrumentality of the other contained material.

3. The method of producing light by electricity through the instrumentality of a closed vessel containing gas or vapor or vaporizable substance, which consists in first transmitting a current through the chamber by such current establishing a path for currents of a lower potential and thereafter traversing the lamp by such currents of lower potential and of approximately constant quantity.

4. The hereinbefore-described method of operating electric lamps in which light is produced by the conduction of electric energy through a light-emitting gas or vapor which consists in operating upon a starting material within the lamp by electric currents, thereby producing a condition on the part of the light-emitting vapor or gas which renders it capable of receiving currents under the influence of a moderate potential, thereafter operating the lamp by the conduction of currents through the light-emitting gas or vapor to the exclusion of the starting material.

5. The method of operating electric lamps in which electric energy is converted into light by its passage through a vapor or gas path which consists in producing a condition of the vapor or gas path under which it will convey currents of moderate differences of potential, by first passing through the vapor or gas path currents of higher electromotive force and then automatically discontinuing the application of the currents of higher electromotive force.

6. The method of starting electric lamps which convert electric energy into light by the passage of electric currents through a gas or vapor column, which consists in heating

the vapor or gas column, penetrating the same by currents of high difference of potential and thereafter operating the lamp by currents of considerable quantity and moderate difference of potential.

7. The hereinbefore-described process of operating electric lamps having a vapor-containing chamber, a vapor or gas within the same and a starting material, which consists in traversing the chamber by currents of a high difference of potential, simultaneously neutralizing the static charge upon the exterior of the chamber and thereafter traversing the chamber by currents of moderate potential.

8. The method of starting and operating a lamp containing a vapor or gas as the conducting medium, which consists in applying to the lamp a current of high potential while the lamp is connected up in a commercial circuit, and afterward cutting off the high-potential current.

Signed at New York, in the county of New York and State of New York, this 21st day of March, A. D. 1900.

PETER COOPER HEWITT.

Witnesses:
HENRY NOEL POTTER,
WM. H. CAPEL.