

Jan. 18, 1938.

H. G. CORDES

2,105,463

VACUUM TUBE

Filed Oct. 24, 1927

5 Sheets-Sheet 1

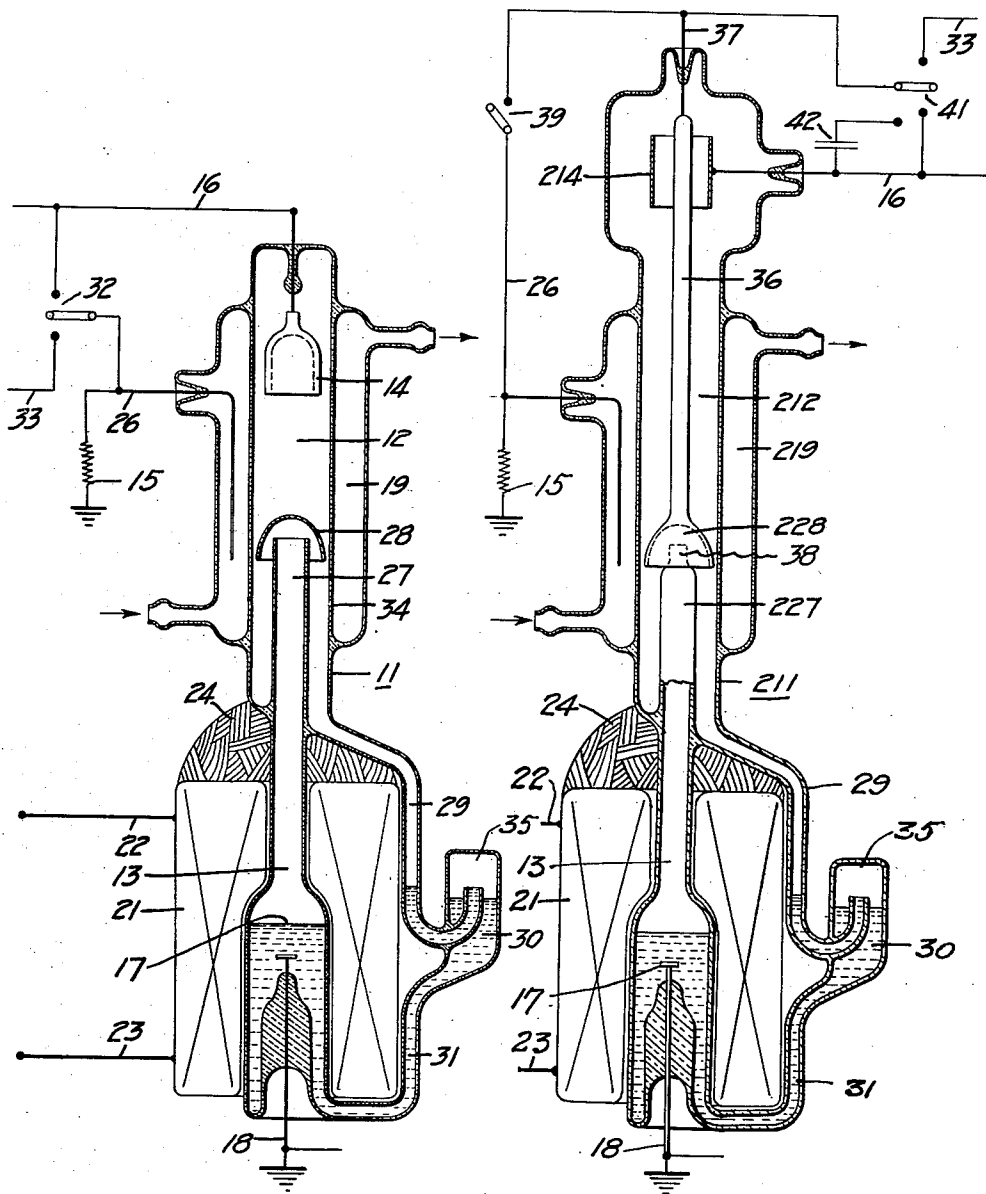


FIG. 1 FIG. 2

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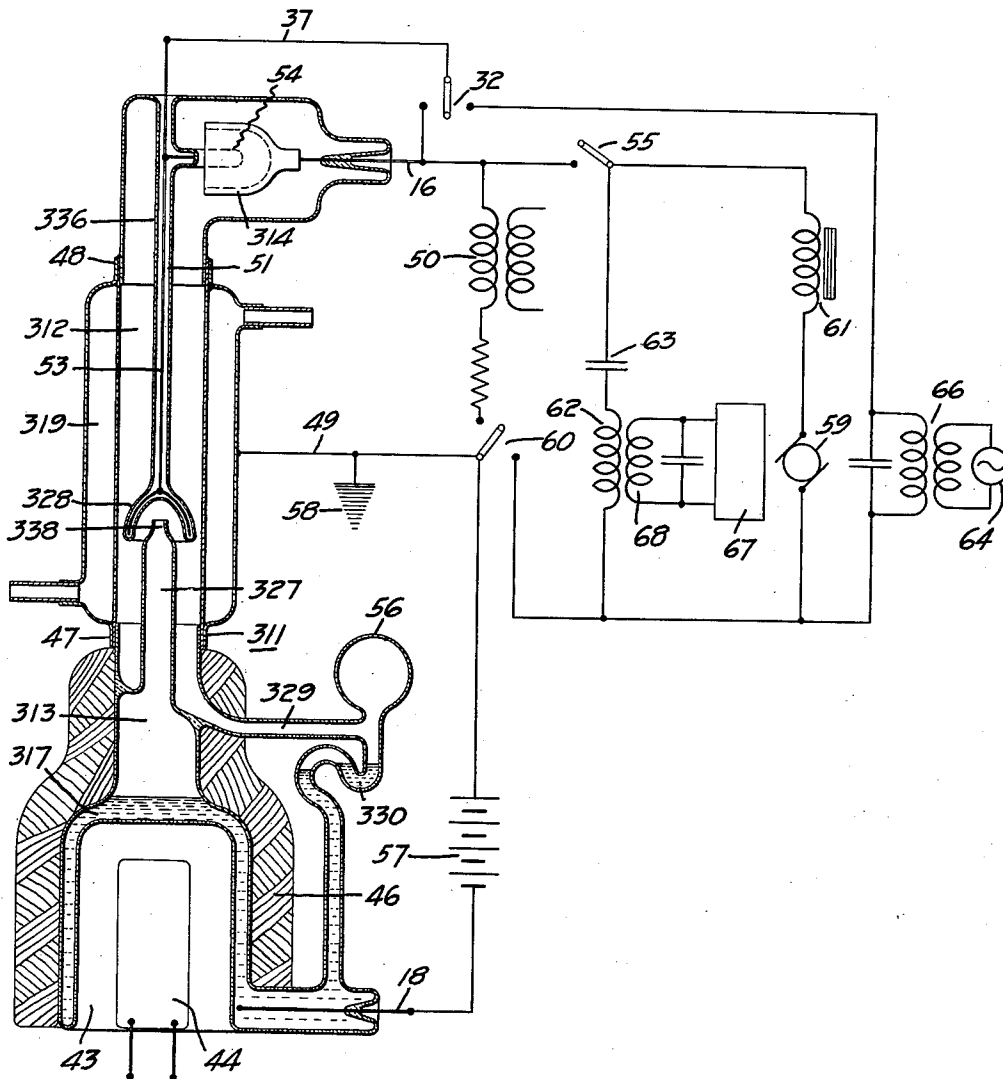
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FIG. 3.



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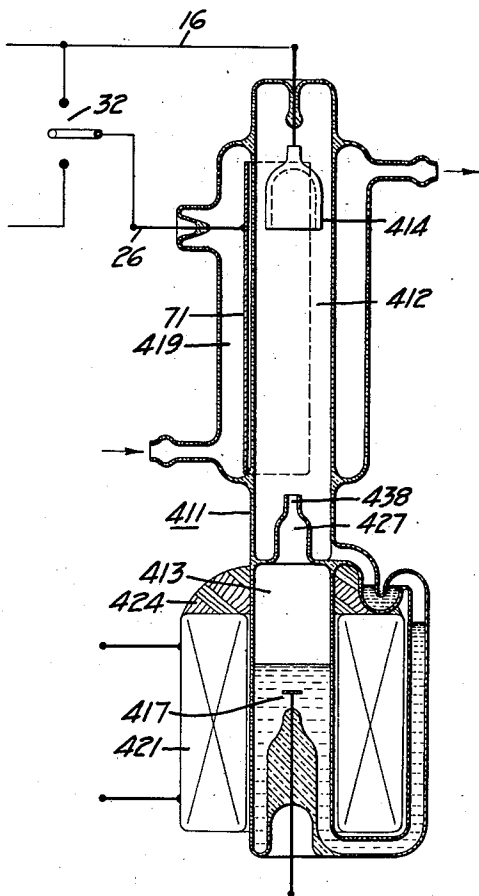


FIG. 4.

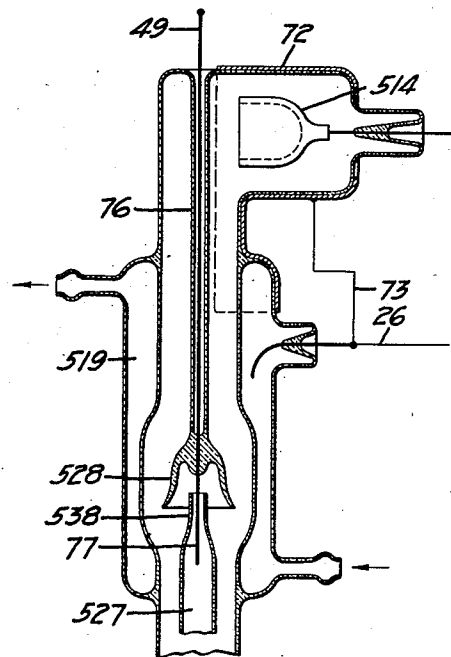


FIG. 5.

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FIG. 6

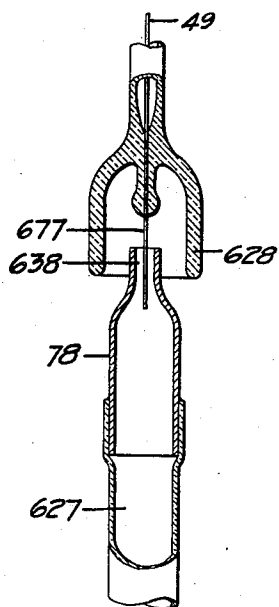


FIG. 7

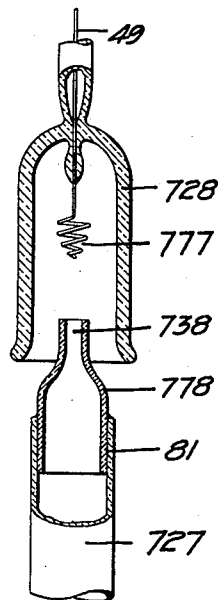
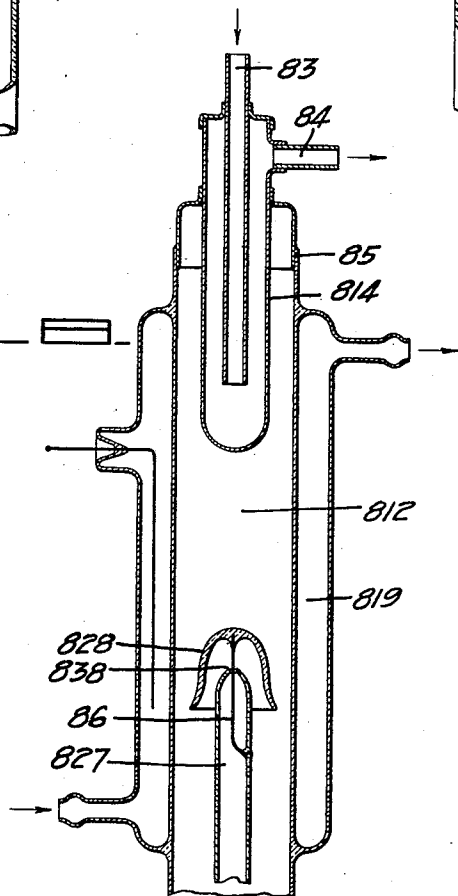


FIG. 8



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FIG. 9.

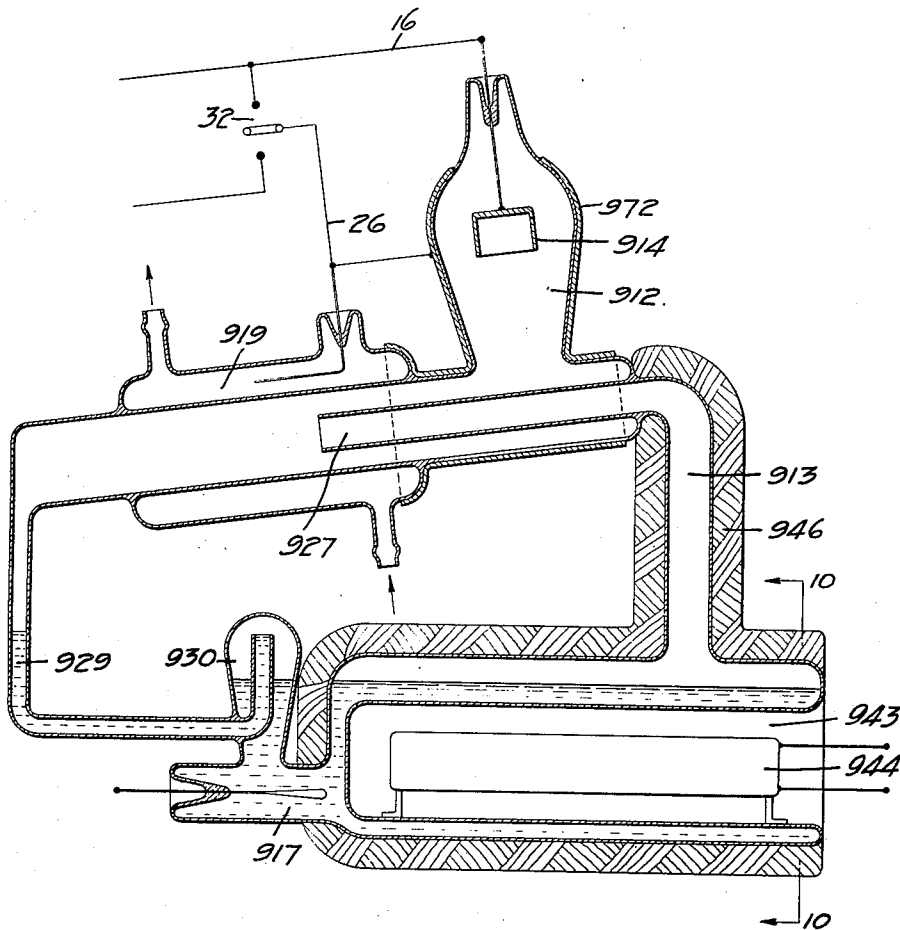
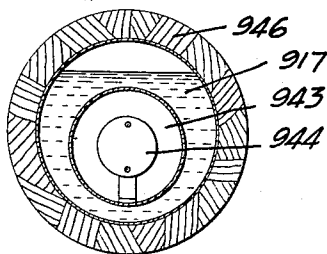


FIG. 10.



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UNITED STATES PATENT OFFICE

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VACUUM TUBE

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Application October 24, 1927, Serial No. 228,233

30 Claims. (Cl. 175—354)

This invention relates generally to devices utilizing electrical discharges thru gases, and is particularly applicable to mercury vapor vacuum tubes. The devices herein described are capable of being used for the rectification of high voltage alternating current or for the production of high frequency uni-directional current discharges from a source of continuous uni-directional current.

It is an object of this invention to devise means for more effectively controlling current discharges thru gases, particularly current discharges thru ionized mercury vapor.

It is a further object of this invention to devise a mercury arc rectifier capable of rectifying higher voltages than has heretofore been possible.

It is a further object of this invention to devise a mercury vapor tube capable of interrupting flow of relatively large currents of high potential.

It is a further object of this invention to devise improved means whereby relatively small currents may be utilized for piloting or controlling relatively large current discharges.

It is a further object of this invention to devise a mercury arc vacuum tube which will not permit an inverse flow of current when used together with reactive circuits.

Further objects of the invention will appear from the following description in which I have set forth the preferred embodiments of my invention. It is to be understood that the appended claims are to be accorded a range of equivalents consistent with the state of the prior art.

Referring to the drawings:

Figure 1 is a side elevational view in cross section illustrating a mercury vapor vacuum tube incorporating the principles of this invention.

Fig. 2 is a view similar to Fig. 1 but showing a modified form of the anode chamber and its associated electrodes.

Fig. 3 is a view similar to Fig. 1 showing a further modification of the invention, and also showing the manner in which the device may be utilized for the generation of high frequency oscillations.

Fig. 4 is a view similar to Fig. 1 showing a further modification of the invention, this modification differing in construction of the mercury pump and the details of the control electrodes.

Fig. 5 is a cross sectional detail illustrating another modified form of anode chamber and its associated electrodes, capable of being utilized with a mercury vapor tube such as shown in Fig. 3.

Figs. 6 and 7 are details in cross section showing modified forms of ionizing anodes.

Fig. 8 is a detail shown in cross section of an-

other modified form of anode chamber and associated electrodes, capable of being utilized with a vacuum tube such as shown in Fig. 1.

Fig. 9 is a cross sectional elevational view showing a further modified form of tube.

Fig. 10 is a cross sectional detail taken along the line 10—10 of Fig. 9.

The value of alternating current voltage which can be rectified by intermittent discharges thru mercury vapor in a vacuum tube is limited by arc-back when the inverse voltage exceeds a certain maximum value or by excessive inverse Geissler discharge current when the discharge frequency is high. For this reason it has been impossible in the past to utilize mercury vapor vacuum tubes to reliably rectify alternating current voltages exceeding about 10,000 volts or to reduce high frequency inverse current to a negligible value when producing high frequency uni-directional discharges.

It is well known that a low pressure of gas, either in the form of non-condensable (fixed gas) or condensable gas (vapor), is essential in a mercury vapor tube when it is desired to avoid excessive inverse current. Consequently, in mercury vapor tubes for rectifying high voltages, it has been the practice to keep the gas pressure as low as possible. However, when the gas pressure is decreased below a certain point a phenomenon known as "fading" occurs in rectifiers. Fading consists in an anode failing to pass current during part or all of a positive half-cycle due to the establishment of a high initial resistance in the discharge path space, that is, the space acts as an insulator until breakdown is produced by a relatively high positive potential impressed on the anode. In addition to low gas pressure, fading is known to be increased by lengthening the discharge path, by reducing its cross-sectional area, or by placing bends in it. The cause of fading is generally attributed to the formation of a static charge on the glass wall of a low pressure part of the discharge path. Increasing positively the charge on a conductor placed near the low pressure part of the path has been known as a means for neutralizing the static charge. My invention comprises means for reducing the gas pressure to a lower value than has heretofore been used and providing more effective means to neutralize the static charge.

The effects of charging conductors which are insulated from, and placed adjacent to, the discharge path has been published. The phenomena caused by the effects consists in either decreasing or increasing the breakdown value of the discharge path space. In terms of the well known concepts of charged elements and of space charge of the electron theory, the breakdown value is decreased by increasing the number of positive ions in the discharge path space and it is in-

creased by decreasing the number of positive ions. In other words, the breakdown value varies with the negativity of the space charge. I have found that the breakdown value can be thus varied more effectively as the rarefaction of the space is increased. Fading is attributed to the collection of positive ions from the space by the wall of the discharge path, especially when the rarefaction is high. I reduce undesired negativity by making the space more positive.

The starting band, or the filamentary extension of the anode, in a mercury vapor lamp to start the discharge constitutes a well known means for decreasing the breakdown value of the path space. On the other hand, metallic rectifier tubes are often constructed so that the anode is surrounded by the metal of the tube which is at the potential of the cathode and therefore tends to attract positive ions from the space around the anode; this tends to increase the breakdown value of the discharge path space. It is customary practice to place a shield around the anode to reduce the tendency of the metal to make the space charge too negative.

One feature of my improvement consists in establishing a desired breakdown value of the discharge path space and then cyclically varying this value to attain the result desired.

The breakdown-value-control surface may be either a metallic conductor placed in the discharge path space or a conducting sheath placed adjacent to the glass opposite to the space. In the first case the discharge current may concentrate at one point on the metallic conductor which may thereby become a source of secondary electron emission. In the second case a charge is distributed over the entire glass surface thus avoiding concentration and secondary electron emission. The sheath acts in a manner equivalent to a number of condensers (capacitive impedances) each in series with a metallic control conductor. Undesirable concentration of the discharge current may also be avoided by utilizing a high resistance conductor in a manner hereinafter described. The terms control surface and control conductor, as here used, control space charge including wall charge effects as distinguished from control of the state of ion emission from the cathode whether produced by heating the mercury, by passing a keep-alive current to the cathode, or by passing a pilot spark to the cathode.

To prepare a tube in the practice of this invention, I initially outgas the tube and electrodes to a very high degree and provide means, after sealing off, to maintain the required low gas pressure in the anode end of the discharge path which will hereinafter be termed the "anode chamber" by restricting the flow of mercury vapor into the anode chamber, by providing a cooling medium such as water or other refrigerant to cool the anode chamber, by providing diffusion and condensation pump action, and by providing Sprengel pump action.

The restriction of mercury vapor flow has been carried further than has been done heretofore to reduce the vapor pressure in the anode chamber, to reduce the ignition potential, and, in a high frequency discharge tube to increase the tendency to produce high frequency discharges. I use heat-insulation as one of the means to produce a large pressure difference. The extent of restriction of vapor flow is a distinguishing feature which is indicated by the difference in color of the luminosity in the high pressure and low pressure

side of the constricted part of the discharge path. The high pressure side when viewed thru water and pyrex glass has a yellowish-white glow while the low pressure side has a bluish glow which indicates much greater diffusion of the discharge. I have found that a great tendency for high frequency intermittent discharges to take place is produced by an abrupt change in the cross-sectional area of the discharge path at the low temperature produced by a cooling medium.

The practice of producing diffusion and condensation pump action in a mercury vapor tube is old. The novel feature of my invention comprises a higher vapor pressure in the cathode chamber than has heretofore been used to supply pumping vapor. I provide an external heater to heat thru a glass heat-conductor the cathode mercury both to produce a preliminary pumping action and to reduce the breakdown value of the discharge path space by increasing the vapor pressure in the cathode chamber. The heater also reduces the breakdown value when the rectified current is too small to maintain the cathode mercury at the proper temperature.

Another novel feature is a miniature Sprengel pump which removes permanently non-condensable gas from the operating part of the tube. The return-flow of condensed mercury passes thru a miniature fall tube and non-condensable gas is thereby compressed and liberated in a separate chamber which is sealed by mercury from the main part of the tube. Any mercury vapor tube may be made self-evacuating during operation by providing the tube with such a pump.

Referring now to that embodiment of the invention illustrated in Fig. 1, I have shown a vacuum tube 11 which is made of pyrex and which is evacuated to a high degree. The upper part of the tube is formed to provide an anode chamber 12 while the lower part is formed to provide a cathode chamber 13. Cooperatively associated with the anode chamber is an anode 14 to which is connected the lead-in terminal 16. The anode is cylindrical in form and is made of pressed graphite, altho it may be made of metal and may assume another form. The cathode chamber is formed to provide a receptacle for the cathode mercury 17 to which connection is made by the lead-in terminal 18 which is grounded. The anode chamber is cooled by means of a jacket 19 thru which cold water is circulated. The cathode chamber is heated by an electrical heater 21 supplied with current thru terminals 22 and 23. A heat insulating medium 24 is employed for minimizing transfer of heat from the cathode chamber or from the heater to the anode chamber. In addition to the usual anode and cathode, I provide a breakdown control surface by means of which I control discharges thru the anode chamber. In Fig. 1 the control surface is formed by the inner surface of the water-cooled glass which is charged by displacement current flowing to or from the conducting water in the cooling jacket 19.

Instead of having an unrestricted path for mercury vapor between the anode and cathode chambers, the mercury vapor from the cathode chamber is discharged into the lower part of the anode chamber thru a suitable tube 27, the discharge end of which is substantially smaller in diameter than that of the anode chamber 12. Positioned over the end of tube 27 is a vapor-deflecting cap 28 which is suitably supported (not shown) so that its periphery is spaced as shown from the anode chamber wall. This cap or deflector serves

as a means for restricting flow of mercury vapor from the cathode to the anode chamber, directs vapor flow away from anode 14, and separates the anode chamber which lies above the rim of the cap from the condensing chamber which is disposed below said rim. The deflected mercury vapor is condensed as it contacts with the cooled wall below the cap. The condensed mercury is returned to the cathode chamber by way of one or more fall tubes 29 which discharge into a suitable trap 30, the mercury from this trap being returned to the cathode chamber thru tube 31. Fall tube 29 is of relatively small diameter so that Sprengel pump action is produced by condensed mercury dropping down thru the same. This Sprengel pump action assists the condensation pump action in reducing the pressure in the anode chamber and transfers permanently non-condensable gas from the main part of the tube to the gas-chamber 35. I have found that the mercury in trap 30 in the lower end of fall tube 29 which seals the gas in chamber 35 from the main part of the evacuated space of the tube is outgassed to a greater degree than the mercury 17 of the cathode to which it is returned. The resistance 15 represents the resistance of the water (not shown) from the jacket 19 to the ground.

In order to explain the operation of the device, it will be assumed that terminals 16 and 18 are connected to a suitable source of current while by means of a double throw switch 32 terminal 26 may be connected either to terminal 16 or to terminal 33 upon which controlling potentials are applied. The cathode chamber is heated by supplying alternating current to the terminals 22 and 23 until the mercury vapor pressure in the cathode chamber attains a value of the order shown in the drawings which corresponds to a breakdown value of potential of the order of 1500 volts. Assuming now that switch 32 is open, that an alternating potential of about 15,000 volts is applied to terminals 16 and 18, that pumping action is taking place due to the mercury vapor flowing down past the rim of cap 28 and condensing, and that cold water is flowing from a grounded source thru supply tubing and jacket 19 to cool the anode chamber and charge the water negatively with respect to the anode 14 which increases the negativity of the discharge path space, then no breakdown will take place to initiate a current flow from the anode to the cathode. Now if conductors 16 and 26 are connected together by switch 32, flow of current will occur in one direction only and the device will operate efficiently as a rectifier. At a current density of about one half ampere per square inch, the discharge is bluish between anode 14 and the rim of the vapor deflector 28 while it is yellowish-white between the deflector and the cathode 17. The usual cathode spot is formed on the cathode provided the external resistance in the supply circuit permits sufficient current to flow. If switch 32 is opened again while alternating potential is being applied, the half-wave current discharges between the anode and cathode immediately stop.

In order to illustrate another mode of operation, it will be presumed that a direct current positive potential is impressed on terminal 16 with respect to terminal 18 and switch 32 is thrown to connect conductors 26 and 33. Due to the water being connected to 18 thru high resistance, a discharge does not take place as long as displacement current flows from the anode chamber to the water. However, if a positive potential is

placed on conductor 33 so that the flow of displacement current ceases then breakdown takes place between anode and cathode. I have found that because of the inherent properties of my device unidirectional discharges may take place at relatively high frequencies as controlled by potentials applied to conductor 26. The device may therefore be employed for the generation of radio frequency oscillating current.

I have found that it is practicable to supply fresh water to jacket 19 thru about ten feet of rubber tubing and discharging the water thru similar tubing. By operating the tube under such conditions, the external resistance (represented by 15) of the two rubber tubes in parallel between the control terminal 26 and the cathode terminal 18 is about one megohm which allows sufficient current to pass to operate the tube in the manner described above.

The facts and theory with which I explain the operation of the device is as follows: During a positive half-cycle on the anode, with switch 32 open, current cannot be started to flow from anode 14 to mercury cathode 17 due to the high negativity of the space charge produced by the water in the water-jacket 19 which is electrically connected to the cathode thru the resistance 15 mentioned above. Closing switch 32 upward connects the water in the jacket to the anode 14 which changes the charge of the water from negative to zero with respect to the anode; in other words, closing switch 32 neutralizes the high negativity and produces a lower breakdown value of the discharge path. During the half-cycle that the anode is negative with respect to the cathode and the water is similarly charged, the increase of breakdown value caused by the presence of the water acts to prevent inverse discharge which, in turn, determines the range of rectification. The water-cooled wall collects positive ions without producing an objectionable rise in temperature which is prevented by the presence of both the cooling medium and the distributed collection area; these positive ions would, in the absence of the charged wall, bombard the anode and thereby produce a condition favorable to inverse current.

The vacuum necessary for the tube will vary depending upon the potentials with which it is to be operated. During the process of evacuating my tube I have found that when the fixed gas pressure is still relatively high, a crest potential of say 14,000 volts will not be rectified, as an inverse discharge takes place whether the switch 32 is open or closed. When the gas pressure as shown by a McLeod gage connected to the high pressure part of the tube has attained a fairly low value, say of the order of one bar, then the discharge with switch 32 open is erratic and may be accompanied by inverse discharge to a certain extent. Under this condition of vacuum the inverse discharge ceases when switch 32 is closed to connect conductors 16 and 26. The tube will function fairly efficiently under this condition of vacuum altho slight fluctuations will occur in the rectified current. However, the factor of safety against inverse discharge is small. I prefer to carry the vacuum to a higher degree which produces a condition in which no discharge can pass between the anode and the cathode unless switch 32 is closed and in which the discharges can be arrested by opening switch 32. As my tube is particularly adapted for potentials exceeding 10,000 volts for which other mercury vapor rectifiers of the usual type are inoperable,

the vacuum is preferably carried to a degree at which no discharge will occur at such potential when switch 32 is open, the anode chamber being cooled, and the cathode being heated. Many obvious modifications of Fig. 1 may be made as, for example, passing a non-conducting cooling liquid thru jacket 19 in which a metallic film on glass is disposed to serve as a control conductor to influence breakdown value of the anode chamber.

In Fig. 2, I have illustrated a modified form of Fig. 1 in which an internal control electrode is employed to decrease the breakdown value of the discharge path by neutralizing the effects on its value produced by the charging of the water in jacket 19, and during the following half-cycle to aid by charging the water to produce an increase of breakdown value with respect to inverse current. The anode chamber 212 of the tube 211 is provided with an elongated internal control electrode 35; connection is made to 36 by means of lead-in terminal 37. The anode 214 is arranged adjacent the upper end of 36, is cylindrical in shape, and surrounds electrode 36. The lower end of 36 is expanded to form a deflector 228, similar in construction and function to the deflector 28 shown in Fig. 1. The electrode 36 is constructed so as to have relatively high resistance between its upper and lower ends, this resistance being greater for tubes adapted to be used upon the higher potentials. In practice I have obtained good results by making the electrode 36 of glass covered with a thin film of metal. However I may use instead a rod constructed of carborundum or silicon or any other suitable resistance material which will retain its resistance when high potentials are impressed on its terminals and which will not be attacked by mercury vapor. The upper end of tube 227 which discharges vapor from the cathode chamber has a restricted discharge orifice 38 which both increases the velocity of the vapor and establishes a greater difference of vapor pressure in the discharge path. I have found that the abrupt change in the cross-sectional area of the discharge path from that in the anode chamber to that in constriction 38 provides a condition which facilitates the production of high frequency discharges.

The anode chamber 212 is cooled by means of water-jacket 219. By means of switch 39 the liquid of this jacket may be connected in parallel with control electrode 36. A three-way switch 41 connects the control electrode directly to the anode terminal 16, or to this terminal in series with condenser 42, or, as in Fig. 1, to terminal 33. The mercury 17 is heated by heater 21 thru the glass wall of the tube which serves as a heat conductor.

The theory with which I explain the operation of the arrangement shown in Fig. 2 is substantially the same as that with respect to Fig. 1. When the potential of the anode 214 and of the control electrode 36 is increasing positively with respect to the cathode, a discharge takes place from the lower end of electrode 36 at the breakdown voltage of the high pressure vapor which may be in the neighborhood of 2000 volts. After such breakdown each element of area of the electrode 36 primes an adjacent element above it so that the discharge from electrode 36 climbs up until it initiates a main discharge from the anode 214 in a manner similar to the well known filamentary-extension-of-the-anode method of starting a mercury vapor lamp. In other words the initial discharge from electrode 36 neutralizes the neg-

ative space charge in a sheath adjacent to its surface and this sheath increases in thickness as the current increases. The high resistance in series with the control surface 36, or of the water between conductor 26 and the glass adjacent to space 212, tends to prevent the flow of a parasitic high frequency current in a circuit comprising anode 214; the presence of the resistance, I have found, increases the inverse breakdown value of the main discharge path, and tends to prevent puncture of the glass. In general, the flow of parasitic high frequency current thru the main anode must be prevented.

In accordance with the above mode of operation, an equivalent of the control electrode 36 may be formed by utilizing a number of separate conductors of progressively increasing length; the shortest conductor terminating near the anode 214 and the longest terminating near the deflector 228. The shortest of these conductors may be connected to the anode terminal 16 or to some external source of controlling potential, and the remainder may be interconnected in series by high resistances or small condensers. Each conductor would then initiate a discharge from the conductor immediately above it and therefore progress upwardly and initiate a discharge from the anode.

The resistance of the electrode 36 will vary with different conditions of operation. For example its resistance may be about one megohm when 10,000 volts effective are being rectified. One factor in the selection of the proper resistance for electrode 36 is that in order to pilot the discharge upwardly the resistance per unit length of electrode 36 should be greater than the resistance per unit length of sheath space. By sheath space I refer to the relatively low resistance sheath formed about electrode 36 in which the negative space charge is neutralized and which initiates a main discharge. Another factor which requires that the resistance of electrode 36 be high is that a feeble inverse discharge passes from the cathode to the lower end of 36 at about the same voltage as that which initiates a discharge in the preceding half-cycle. This feeble inverse current increases the negativity of the space charge thus protecting the anode from a large inverse current discharge.

It will be noted that switch 41 may be thrown so as to connect electrode 36 with terminal 16 in series with condenser 42. This arrangement is sometimes desirable as it reduces the effective current flowing thru electrode 36 and also permits a reduction in the resistance of this electrode. The electrode 36 may be used to the exclusion of the connection 26 to the water in jacket 219, or it may be used in conjunction with the same by closing switch 39.

A characteristic feature common to all the discharge path breakdown control surfaces is illustrated by the glass surface of the discharge path opposite the water in jacket 219, by the surface of electrode 36, and by the equivalent electrodes herein described. In each of the illustrations the control surface consists of a plurality of elemental control surfaces arranged so that the elements of surface are interdependent. For example assume that a decrease of breakdown value is to be produced by electrode 36 to initiate a discharge to anode 214 from cathode 17. The piloting discharge, that is, the electron flow, passes first from the cathode to the nearest-to-cathode end of electrode 36 where the vapor pressure is relatively high and spreads to other elements of surface

toward the anode as is the case in starting a mercury vapor lamp by means of a filamentary extension of the anode. The upper elements therefore depend on the lower for a relatively low breakdown value and the lower elements depend on the upper to pilot more effectively the discharge to the anode. It is thus seen that a discharge can be initiated at a relatively low potential thru a discharge path which has a relatively high breakdown value due to length, bends, and low pressure by means of a plurality of elemental control surfaces connected to the piloting potential source so that the impedance in the piloting circuit is decreased as the piloting discharge spreads towards the anode.

Fig. 3 shows a further modification of the invention, and illustrates the manner in which the tube may be used for the generation of high frequency oscillations. The lower end of the tube in this instance is provided with a pocket 43 within which is disposed the electrical heating element 44. This construction permits the mercury 317 to surround the heater, thus affording more efficient transfer of heat. The exterior of the lower tube portion is preferably provided with a jacket 46 of heat insulating material. The water jacket 319, is preferably constructed of some suitable metal such as nickel iron or chrome iron alloy, and is sealed as at 47 to the glass of the cathode chamber, and at 48 to the adjoining walls of the anode chamber. This arrangement makes possible a lower pressure in the anode chamber 312 than can be obtained by the use of a glass jacket, for the reason that the metal more effectively conducts the heat to the cooling liquid. Another advantage is that this metal jacket may serve as an electrode and for this purpose I have shown a terminal conductor 49 connected to the walls of the same.

The control electrode 336 in this instance consists of a hollow glass tube 51 having a hollow deflecting cap 328 formed upon its lower end. Positioned within this tube and within the hollow cap 328, there is a conductor 53, which is connected to an external terminal conductor 37. Arranged adjacent to and preferably surrounding a lateral extension 54 of the tube 51 there is the anode 314 to which is connected the terminal conductor 16.

In conjunction with the tube 329 for returning condensed mercury to the cathode chamber, I may utilize a cleanup bulb 56 which may contain in auxiliary electrode of tungsten, activated charcoal or other material for absorbing gases. After draining thru tube 329 the mercury is returned to the cathode chamber thru a suitable trap 330. The control electrode 336, or anode extension, functions in the same manner as the control electrode shown in Fig. 2. When the anode 314 is charged positively with respect to the cathode, no discharge will take place if switch 32 is opened due to the negativity of the space charge, but when this switch is closed to connect the anode and the control electrode, a discharge will take place between the anode and cathode due to the decrease of negativity of the space charge produced by current from conductor 53 acting thru the glass 328 and 336. The piloting action of the control electrode 336 is substantially the same as that previously described with respect to Figs. 1 and 2.

The use of the metallic water jacket 319 makes it possible to use a "keep-alive" current between this jacket and the cathode. For example I have shown a source of direct current potential as

represented by the battery 57, connected across the terminals 49 and 18. With this arrangement a current is continuously passed from the water jacket to the cathode, thus keeping the mercury vapor in the cathode chamber continuously ionized. The alternating current to be rectified may then be impressed across terminals 16 and 49 as indicated by transformer 50, i. e. across the anode and water jacket, and the water jacket or terminal 49 may be grounded as indicated by ground connection 58.

If the tube shown in Fig. 3 is to be used exclusively as a rectifier of high voltage alternating current, the conductor 53 may be connected directly to the anode 314 within the tube.

One circuit with which the device shown in Fig. 3 may be used for the generation of high frequency discharges has been shown. In this case a suitable source of direct current, such as a generator 59, has its positive lead connected to anode 314 by way of switch 55 and its negative lead connected to the "keep-alive" anode or jacket 319 by way of switch 60, a suitable high frequency choke 61 being inserted in series with the positive lead. An oscillatory circuit consisting of inductance 62 and capacitance 63 is likewise connected across the anode 314 and jacket 319. A suitable master oscillator 64 is coupled across the "keep alive" anode or jacket 319 and control electrode 336, as by means of stabilizing circuit 66. The output or work circuit, as indicated at 67, is suitably coupled to the oscillatory circuit as by means of inductance 68. The high frequency controlling impulses impressed upon the controlling electrode 336, initiate a series of current discharges from the anode to the cathode at a frequency dependent upon the frequency of the stabilizing circuit 66.

The cathode ionizing current flowing from the water jacket 319 to the cathode 317 will reduce the potential required to initiate a discharge between the anode and the water jacket. If this ionizing current is sufficiently large the current passed thru the heater 44 may be reduced to zero; in other words the heater may be used only for starting purposes.

In the modification shown in Fig. 4, no means has been provided for utilizing pump action of the mercury for reducing the pressure in the anode chamber. The reduction of pressure in the anode chamber in this instance is produced solely by cooling the anode chamber and by providing a greater restriction between the anode and cathode chamber. For example the tube 427 which leads mercury vapor from the cathode chamber is provided with a very small discharge orifice 438. Instead of utilizing the liquid in the cooling jacket 419 for forming a control electrode, I provide in this instance an external metal sleeve 71 which is connected to the terminal conductor 26. This construction permits the use of non-conductive cooling liquids, such as cold oils.

In the operation of the modification shown in Fig. 4, the orifice 438 between the cathode and anode chambers permits a very small amount of mercury vapor to pass from the cathode into the anode chamber and all of this mercury is condensed in the lower part of the anode chamber, thus causing a vapor pressure in the anode chamber which is substantially less than the pressure in the cathode chamber. For a current of 1 ampere the diameter of this orifice may be about $\frac{1}{2}$ millimeter when the crest potential to be rectified is of the order of 15,000 volts. It is

to be understood that the anode chamber must be made longer, or the diameter of the orifice smaller, as the voltage to be rectified is increased. Under best operating conditions an arc discharge will not pass from the anode to the cathode until switch 32 is closed to connect together control and anode electrodes, and intermittent discharges can be stopped by opening this switch. The initial potential, or the potential necessary upon the control electrode for causing a discharge between the anode and the cathode, may be decreased by increasing the current thru the electrical heater 421.

Fig. 5 shows a modification of the construction shown in Figs. 1 and 3, particularly with respect to the construction of the control electrode, and to the arrangement of maintaining a condition of ionization in the cathode chamber. As in the construction of Fig. 3 the electrode provided by the cooling jacket 519 does not extend close enough to the anode for dielectric current passing thru it to break down the initial resistance of the anode chamber caused by fading due to the low gas pressure produced by the cooling medium. The break down of this resistance is accomplished however by utilizing an external metal sheath or coating 72 which surrounds that part of the tube adjacent to the anode 514, and which also surrounds at least a portion of the jacket 519. By means of conductor 73, this coating 72 is connected together with terminal 26 from jacket 519. The tube 527 leading from the cathode chamber is provided with a restriction or orifice 538, similar to the orifice shown in Figs. 2 and 3. Positioned over the end of this orifice there is an inverted cap-shaped deflector 528 which is preferably made of insulating material such as glass, and is supported from the depending glass tube 76. Extending downwardly into tube 527 thru the orifice 538, there is a conductor 77, which for convenience, may be sealed into the deflecting cap 528 and connected to the terminal conductor 49.

In the operation of that modification of the invention shown in Fig. 5, a "keep alive" current may be applied across the cathode and conductor 49, so as to maintain the vapor in the cathode in ionized condition. The heat developed by this ionized current passing thru the mercury vapor, superheats the vapor which passes up thru the orifice 538. By means of this device I have been able to substantially reduce the reignition potential of the device.

Fig. 6 shows a modified form of the ionizing anode shown in Fig. 4. The anode 77 in Fig. 5 may cause overheating of the walls of the cathode chamber. To prevent deleterious results due to such overheating, I provide the upper end of the tube 627 with a tip or shield 78 which is made of some material capable of withstanding a high temperature, as for example graphite or tungsten. This tip 78 is provided with an orifice 638 thru which extends the ionizing anode 677, this anode being preferably constructed of metal capable of withstanding high temperature, such as tungsten. In this improved construction the nature of the tip 78 and the ionizing anode permits the vapor passing up thru the orifice 638 to be highly superheated.

Fig. 7 shows another modified form of the ionizing anode shown in Fig. 6. In this case the vapor deflecting cap 728 is elongated and the tip 778 terminates short of the electrode 777. The tip 778 is preferably constructed of quartz, which is fused to the tube 727 by a graded quartz to

pyrex joint 81. The high fusing temperature of quartz permits a high current density in the orifice 738, and the high temperature of this orifice superheats the vapor passing thru it.

In Fig. 8, I have shown a modification of the construction shown in Fig. 1 in that the anode may be directly cooled by circulating liquid. This anode 814 is constructed of hollow metal thru which water may be circulated thru the intake and discharge pipes 83 and 84. The lower end of the electrode is of course sealed, and a metal to glass sealed joint 85 is provided between a flange on the anode and the adjacent walls of the tube. The use of a water cooled anode is desirable in that it reduces the pressure within the anode chamber 812 and thereby increases potential required to produce an inverse discharge. The deflecting cap 828 in this instance is of slightly modified construction in that it is supported by a tungsten wire 86 extending down thru orifice 838 and secured to the wall of tube 827.

Fig. 9 shows a modification of the construction shown in Figure 1 in which the cathode chamber 913 is extended and is surrounded by part of the anode chamber 912, as is shown. In this case to form a complete control electrode, a shield 972 surrounds the walls of the anode chamber 912 and also surrounds at least a portion of the cooling jacket 919. The electrical heater 944 is disposed within a horizontal pocket 943 and is thus surrounded by the mercury 917. Mercury vapor from the cathode chamber is discharged thru tube 927 at a point in the space surrounded by the cooling jacket 919, and the tube at this point is tipped so that the condensed mercury may drain back into the cathode chamber thru a drain tube 929. As in the case of Figure 1, the walls of the cathode chamber are preferably provided with a heat insulating jacket 946.

I claim:

1. The method of operating a mercury vapor tube having anode and cathode chambers comprising: establishing a high resistance in the anode chamber by cooling the chamber to the extent that said resistance cannot be broken down by a potential of ten thousand volts in the presence of a heated cathode chamber, and breaking down said resistance by piloting a discharge thru said chambers.

2. A vacuum tube having: anode and cathode electrodes for the passage of current periodically and intermittently therebetween, a discharge path between said electrodes thru an ionizable vapor, a surface capable of assuming a varying electrical charge positioned adjacent said path, means for connecting said surface to the anode comprising impedance of high enough value to prevent the flow of objectionable parasitic variable current therethru when sixty cycle alternating voltage is impressed on said electrodes, and means for artificially reducing the vapor pressure in the vicinity of said surface.

3. A mercury arc vacuum tube arranged to pass current periodically, intermittently, and unidirectionally comprising a solid anode in an anode chamber, a liquid-cooled wall arranged to reduce the vapor pressure in said chamber, and a cathode of mercury arranged to be periodically reignited with the aid of a heat conductor adjacent said mercury, and a source of heat of sufficiently high temperature to heat said mercury thru said conductor to the extent that the potential required to be impressed between said electrodes to produce said reignitions is reduced.

4. A mercury vapor arc rectifier tube compris-

ing an anode in an anode chamber, a mercury cathode in a cathode chamber, means for liquid cooling to reduce the vapor pressure in said anode chamber, means for heating said cathode by causing emission of electrons therefrom intermittently and periodically, and means for heat insulating said cathode chamber to the extent required to keep said cathode hot enough to allow breakdown between said electrodes at the operating voltage of the rectifier.

5. An arc vacuum tube arranged to pass current unidirectionally and intermittently to a cathode during operation thereof comprising an anode chamber, a cathode chamber containing mercury, means for vaporizing the mercury, and means including a suitable vapor-flow path for restricting the flow of mercury vapor from said cathode chamber to the extent that the vapor pressure in said cathode chamber is high enough to be broken down by the operating voltage.

6. The method of operating a vacuum tube containing an anode, a cathode of mercury, and a discharge path therebetween, which comprises: heating said mercury to the extent that self-ignition takes place at the operating voltage of the tube and simultaneously cooling part of said path to the extent that said voltage cannot produce inverse current of excessively large value.

7. The method of operating a vacuum tube provided with a cathode, an anode, a discharge path containing vapor, and a plurality of piloting elements arranged longitudinally along said path, which comprises: establishing a relatively high pressure-gradient in said path, producing a discharge from the piloting element nearest the cathode to initiate a discharge from the next adjacent piloting element, and so on toward the anode until a main discharge from the anode to the cathode is initiated, and repeating said initiation of the main discharge periodically.

8. A vacuum tube comprising: an anode, a cathode, a discharge path therebetween containing vapor, a cooling medium adjacent to at least a part of said path, a discharge-path control electrode comprising a plurality of elemental control surfaces disposed along said part at points having a substantially different electrical breakdown value with respect to the cathode and at least one of said values being influenced by cooling, and impedances in series with each of said surfaces arranged so that when a positive potential with respect to the cathode is impressed on said electrode the discharge starts from one of said surfaces and progresses to another of said surfaces having a higher breakdown value.

9. A mercury vapor tube comprising an electrode of mercury, means for vaporizing said mercury, a mercury-vapor condensing surface, and means including a receiving gas chamber maintained at less than atmospheric pressure for producing Sprengel pump action with mercury from said condensing surface.

10. The method of operating a vacuum container containing a pool of mercury which comprises heating the mercury to vaporize it, reducing the temperature of the vapor to condense it, and compressing fixed gas and storing it at a pressure below atmospheric to produce Sprengel pump action while returning said condensed mercury to said pool.

11. A vacuum tube comprising an electrical discharge path, a flow of relatively high pressure vapor in part of said path, a main condensing surface, and a vapor deflector arranged to deflect said flow toward said surface and to divide said

path into high pressure and low pressure parts.

12. The method of decreasing the inverse current caused by the high value of the frequency of alternating potential impressed upon a discharge path between an anode disposed adjacent to low pressure vapor, and a cathode, which comprises: heating the cathode, establishing an initial dielectric strength of said path sufficiently high to prevent breakdown by the operating potential in the presence of the heated cathode, and impressing a potential of a positive average-value such as the operating potential on the anode with respect to the cathode while alternately producing at said frequency a decrease and an increase in the electrical breakdown value of said path to thereby decrease the inverse current flow.

13. The method of reducing the pressure of fixed gas adjacent to an anode before starting to operate a vacuum tube having a solid anode and a vaporizable cathode, which comprises the following two steps in a convenient order: heating the cathode to produce a suitable pressure of vapor, cooling a space between the anode and the cathode to reduce the gas pressure adjacent the anode then and thereby, producing diffusion pump action with said vapor to further reduce said gas pressure, and the final step of starting intermittent flow of current from said anode.

14. A vacuum tube arranged to pass current periodically, intermittently, and unidirectionally, comprising: an anode, a cathode, a discharge path therebetween containing gas, and a discharge-path control conductor extending in and along said path from a point having a relatively high electrical breakdown value to a point having a lower value with respect to the cathode and possessing sufficient impedance to render inverse current flow negligible, said lower value being influenced by the residual ionization produced by a preceding discharge thru said path.

15. A vacuum tube arranged to pass current periodically, intermittently, and unidirectionally, comprising: an anode, a cathode, a discharge path therebetween containing vapor, an electrical breakdown control surface adjacent to at least a part of said path, and cooling means capable of reducing vapor pressure in said part; said surface being charged to a potential having a negative average-value with respect to the anode and the anode being periodically charged positively with respect to the cathode.

16. A vacuum tube constructed with fused insulation-to-metal joints to prevent air-leakage, comprising: an anode, a cathode, a discharge path therebetween containing vapor, and a surface capable of being charged disposed adjacent to at least a part of said path in combination with a cooling medium arranged to cool said part; the anode and said surface being simultaneously charged negatively with respect to the cathode and the anode being charged to a negative average value with respect to the cathode.

17. The method of operating a vacuum tube containing mercury which comprises heating the mercury to produce vapor at a pressure corresponding to a relatively low electrical breakdown value, and cyclically impressing a potential of said value on the vapor to break it down periodically by simultaneously decreasing the negativity of the space charge of the vapor as described and increasing the ionization at the cathode at the beginning of each cycle.

18. A vacuum tube containing mercury vapor and comprising a condensing chamber having wall surface heated only by vapor, a cathode of

mercury, an anode, and a discharge path therebetween provided with a constricted part having the property of tending to interrupt periodically the flow of continuous current thru said part; a potential of positive average value being impressed on the anode with respect to the cathode and of high enough crest-value to break down said part after each interruption of current therethru.

10 19. A vacuum tube for passing current intermittently, periodically, and unidirectionally between electrodes, comprising: an anode in an anode space, a discharge path terminating at the anode and containing vapor, cooling means for
15 reducing the pressure in said space by cooling at least part of said path, a surface adjacent to, and between the terminals of, said path and arranged for increasing the electrical breakdown value thereof, and a surface adjacent to, and between the terminals of, said path and arranged
20 for neutralizing the effect of said increase.

20. The method of operating a vacuum tube containing mercury and provided with electrodes, which comprises: heating mercury in a vacuum to the extent that self-ignition would take place
25 between an anode and said mercury at the operating voltage which voltage is of such a value that self ignition would not occur without heating the mercury and impressing the operating
30 voltage between an anode and the heated mercury to pass current periodically, intermittently, and unidirectionally therebetween.

21. A vacuum tube for passing current periodically, intermittently, and unidirectionally thru
35 vapor, comprising: vapor, an anode, a cathode, a discharge path therethru and therebetween having a high pressure-gradient, a control surface adjacent to the high pressure end of said path capable of decreasing the electrical breakdown
40 value of the path, and a control surface adjacent to the low pressure end of said path capable of increasing the electrical breakdown value of the path to prevent inverse current.

22. The method of operating a mercury vapor
45 tube containing two electrodes and a discharge path therebetween divided into high and low pressure parts by a condensing chamber disposed adjacent to said path, which comprises the step
50 of decreasing the electrical breakdown value of the path at a point therein differing in pressure from that surrounding either of said electrodes to initiate a main discharge therethru.

23. In a vacuum tube: a condensing chamber, an anode, and a discharge path terminating at
55 said anode; said path containing vapor, and being divided into high and low pressure parts by passing adjacent to said chamber, and a composite surface comprising a plurality of elemental surfaces disposed in said parts, each capable of
60 decreasing the electrical breakdown value of the path to aid initiation of a main discharge therethru.

24. The method of reducing the voltage required to initiate electron flow thru a discharge
65 path between two electrodes, containing vapor, and divided into high and low pressure parts by a condensing chamber disposed adjacent said path which comprises the step of decreasing the breakdown value of the space charge at a plurality of points along said path between the two electrodes.

25. A vacuum tube arranged to pass current periodically, intermittently, and unidirectionally from an anode charged to a positive average potential with respect to a cathode comprising said
5 anode, said cathode, a discharge path therebetween containing vapor, a cooling medium arranged to reduce the pressure of vapor in the anode end of said path, and a surface capable of increasing the potential required to initiate current flow from the anode combined with a
10 conductor, having high impedance and capable of conducting continuous current, connected between said surface and a source of potential having a negative average value with respect to
15 said anode.

26. The method of outgassing mercury having all of its surfaces exposed to a pressure less than atmospheric in a vacuum container which comprises: maintaining a foreign gas pressure in
20 said container of the low value described, evaporating mercury from a pool of mercury in said container to produce mercury vapor, impressing a potential exceeding one thousand volts on said vapor with respect to a charged surface to aid
25 in dissociating said gas and vapor, condensing said vapor, and collecting said condensed mercury in a pool containing only mercury so treated while permanently removing foreign gas from
said vapor.

27. A mercury vapor container constructed with
30 fused insulation-to-metal joints to maintain the low pressure described comprising: a pool of mercury constituting a source of vapor, means including a charged surface for electrifying the vapor, means for condensing said vapor before
35 it reaches said surface, and means for forming a second pool of mercury consisting entirely of said condensed mercury and having all of its surfaces exposed to less than atmospheric pressure.

28. A vacuum tube comprising a mercury cathode, an anode, a condensing chamber, a discharge
40 path between the anode and the cathode, means including said chamber for dividing said path into high and low pressure parts, and means for reducing the value of a transient positive voltage
45 required to be impressed on the anode with respect to the cathode to initiate unidirectional discharge in said path combined with a source of transient voltage capable of producing breakdown of the path during each positive half-wave
50 impulse.

29. In a system for electron discharge a vacuum tube comprising an anode and a discharge
55 path terminating at said anode and containing a single, cooled, constricted passageway inclosing a surface capable of collecting positive ions proximate thereto, and electrical energy supply for charging said surface to an average negative potential with respect to said ions.

30. The method of reducing the voltage required to initiate continuous electron flow thru a
60 discharge path between two electrodes, containing vapor, and divided into high and low pressure parts by a condensing chamber disposed adjacent said path which comprises the step of decreasing the breakdown value of the space charge at a plurality of points along said path between the two electrodes.

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