Oct. 21, 1941. W. H. BENNETT 2,259,451

METHOD AND APPARATUS FOR ELECTRIC DISCHARGE

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FIG. 1

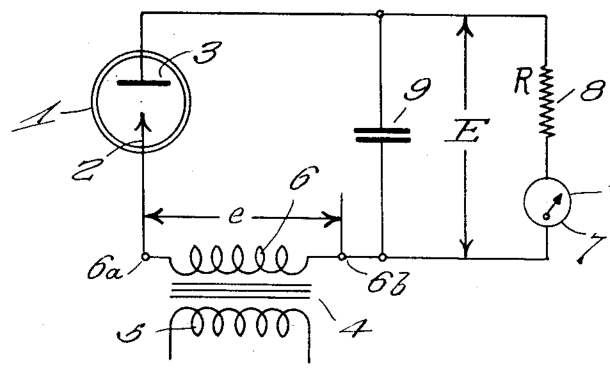


FIG. 2

FIG. 3

FIG. 4

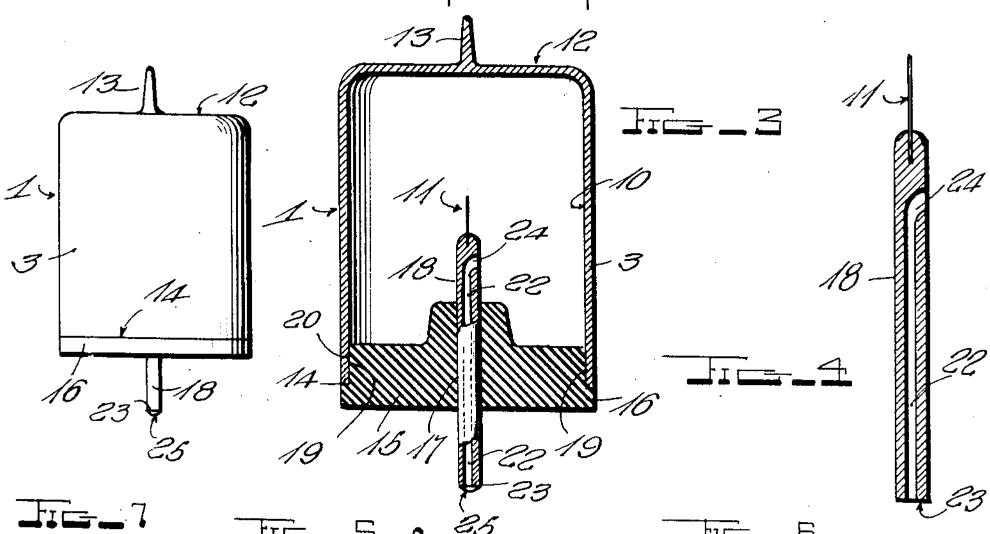


FIG. 7

FIG. 5

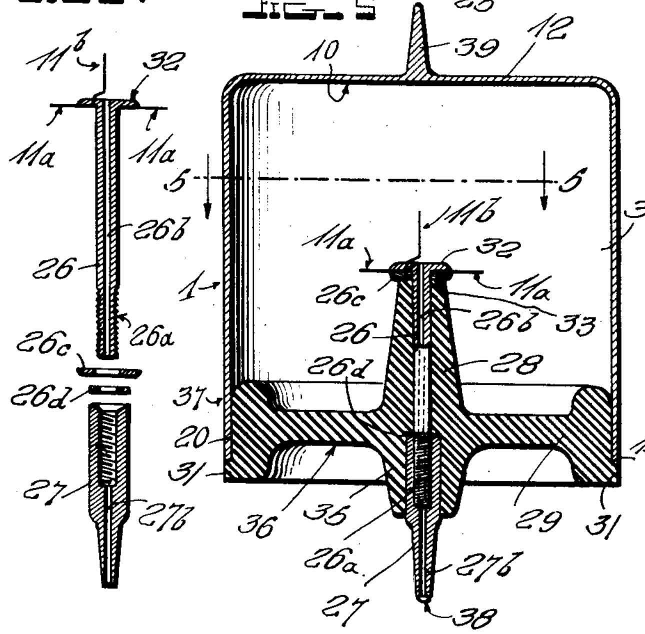
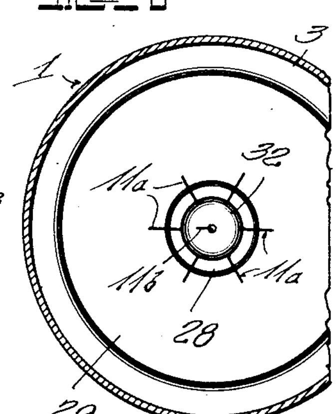


FIG. 6



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METHOD AND APPARATUS FOR ELECTRIC DISCHARGE

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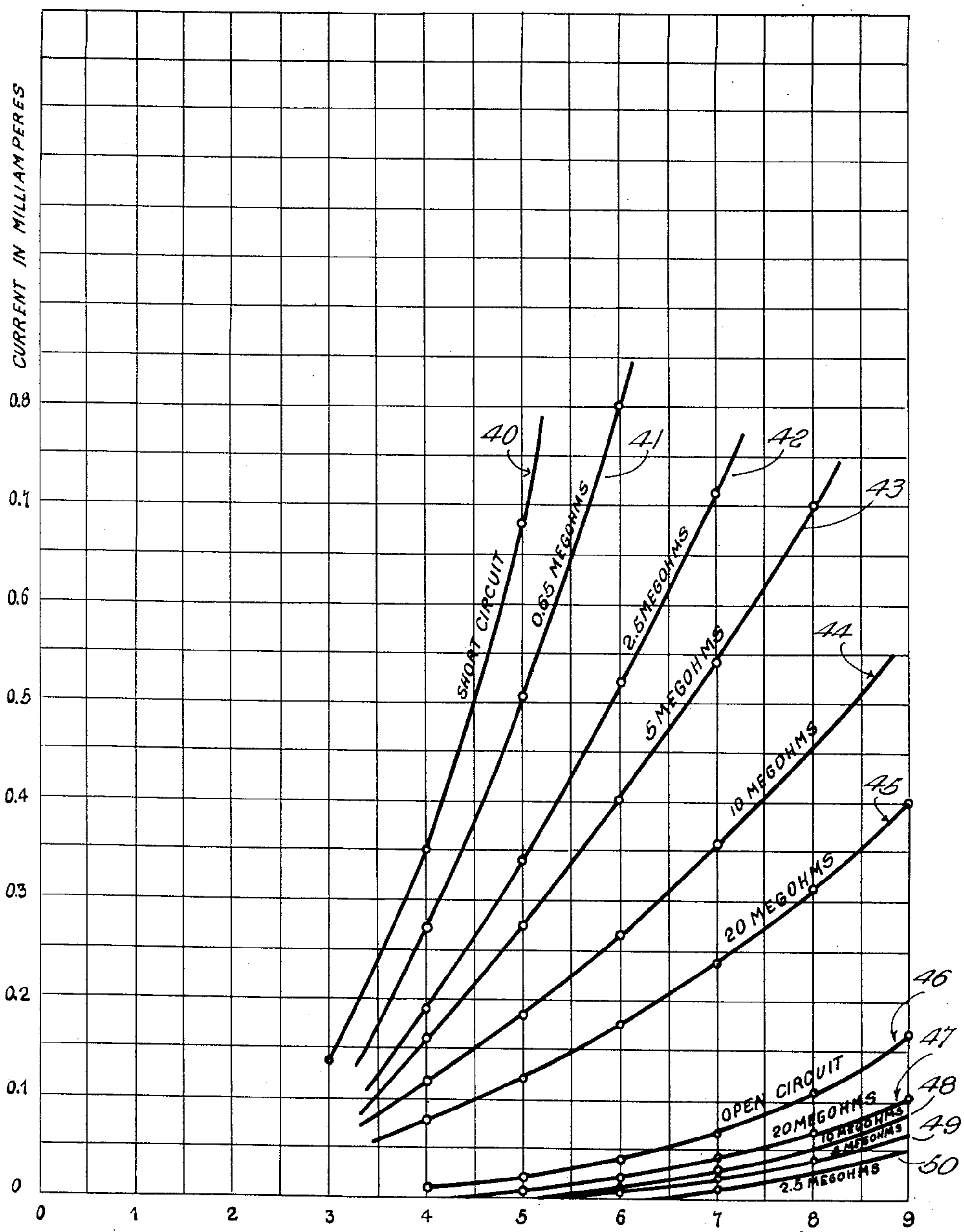
FIG. 8



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METHOD AND APPARATUS FOR ELECTRIC DISCHARGE

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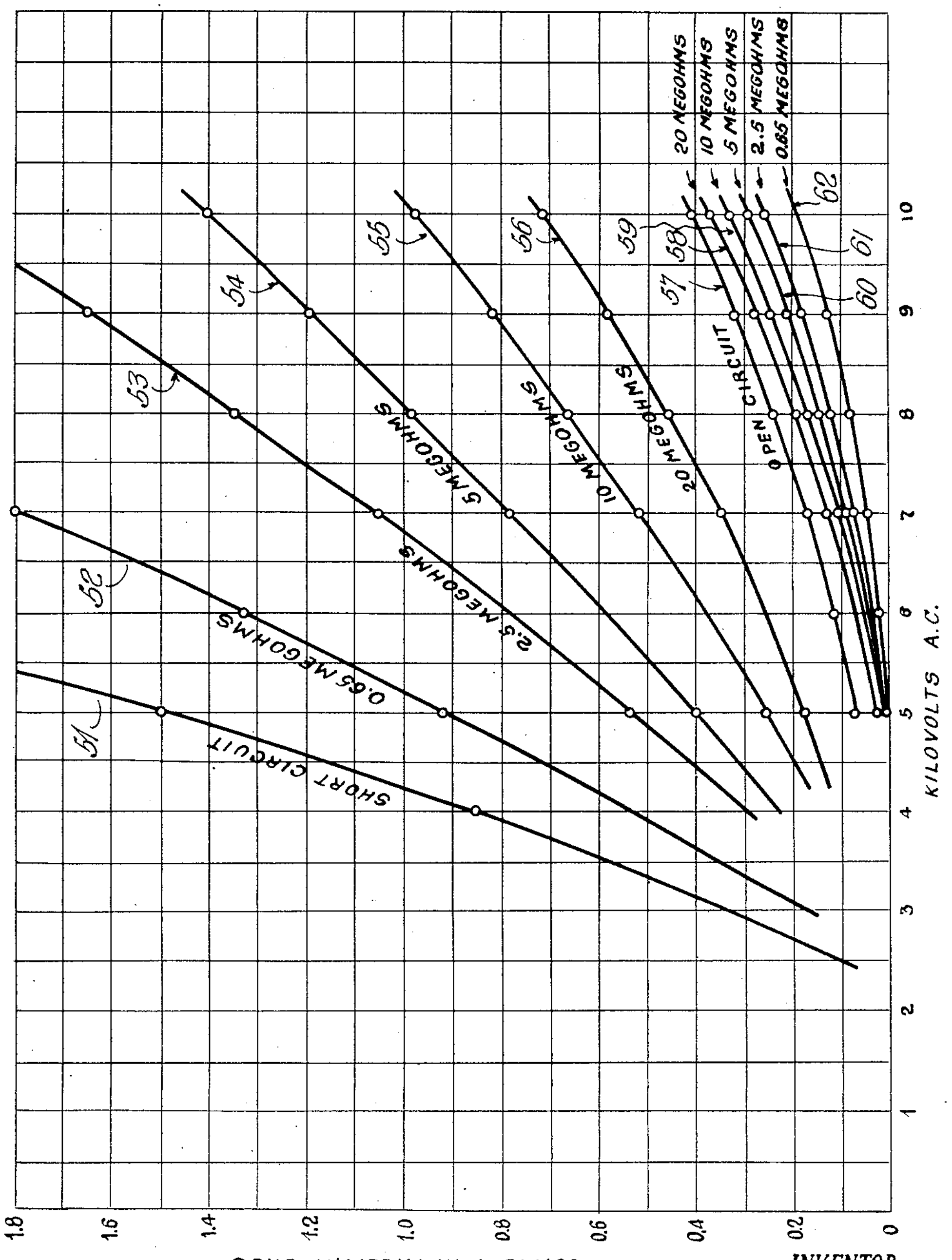

Fig. 3

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METHOD AND APPARATUS FOR ELECTRIC DISCHARGE

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FIG. 10

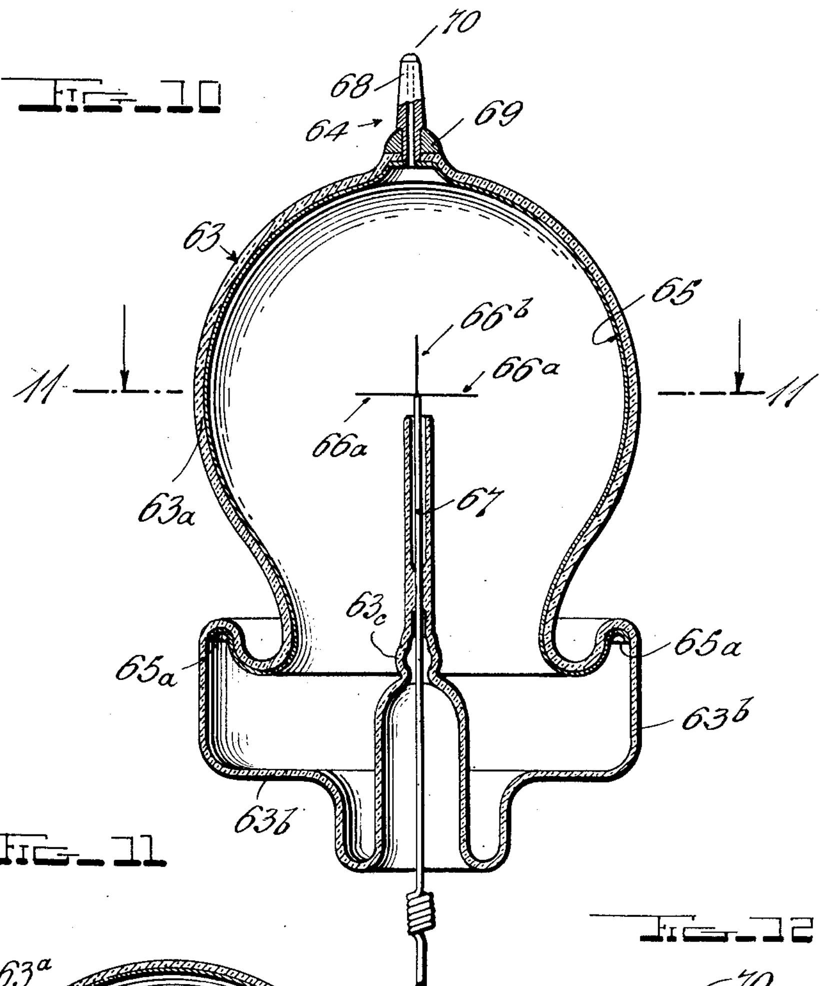


FIG. 11

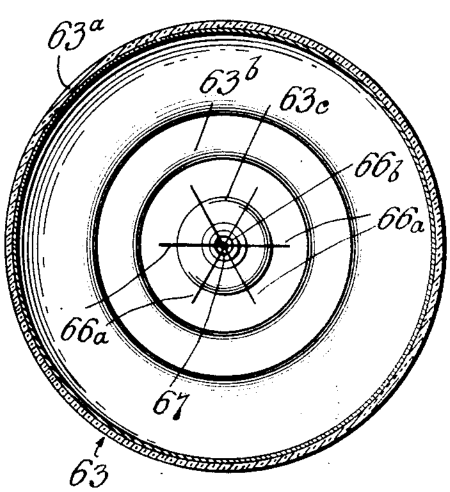
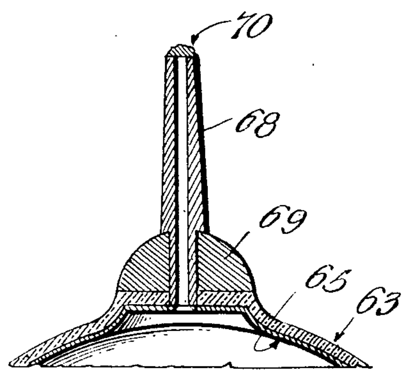


FIG. 12



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Patented Oct. 21, 1941

2,259,451

UNITED STATES PATENT OFFICE

2,259,451

METHOD AND APPARATUS FOR ELECTRIC DISCHARGE

Willard H. Bennett, Newark, Ohio, assignor to Slayter Electronic Corporation, a corporation of Ohio

Application September 6, 1940, Serial No. 355,696

10 Claims. (Cl. 250—27.5)

My invention relates broadly to electrical discharge systems, and more particularly to electrical discharge systems in which discharge and collecting electrodes are used in a gaseous atmosphere.

This application is a continuation-in-part of my application Serial Number 285,634, for Electric discharge systems filed July 20, 1939.

One of the objects of my invention is to provide a discharge apparatus which is smoothly and continuously conducting at a voltage in excess of approximately 500 volts.

Another object of my invention is to provide an electric discharge system including electric discharge and collecting electrodes operative in a gaseous medium so as to convey current principally in one direction by the drift of free electrons.

Still another object of my invention is to provide a novel arrangement of electric discharge system including discharge and collecting electrodes in a gaseous medium of a type which allows a drift of free electrons through that gas at pressures such that the mean free paths of the electrons and other charged particles are of a lower order of magnitude than the interelectrode distances.

A further object of my invention is to provide a new method of rectifying alternating current by employing discharge and collecting electrodes in a gaseous atmosphere in a manner to convey current principally in one direction by the drift of free electrons across the gap without depending on ionizing the gas in the principal portion of the gap for obtaining the conductivity.

Another object of my invention is to provide a rectifier for alternating current, comprising discharge and collecting electrodes, said rectifier being operative at conditions at which a further increase of applied voltage would increase the inverse current to the same order of magnitude as the normal current without injurious effects on the apparatus.

A still further object of my invention is to provide a rectifier for alternating current which utilizes the discharge from sharp pointed electrodes by the cumulative ionization mechanisms essential for the silent discharge.

A still further object of my invention is to provide a rectifier for alternating current which can be constructed in a form which is mechanically rugged and resistant to abuse, due to its inherent physical structure.

Further and other objects of my invention will be more apparent as this description proceeds.

With reference to the invention more in detail: Figure 1 is a diagrammatic view of the rectifier system embodying the discharge device of my invention; Fig. 2 is a side-elevational view of the rectifier employed in the circuit of Fig. 1; Fig. 3 is a side-elevational view similar to Fig. 2, partially broken away to show an internal structure of the rectifier; Fig. 4 is an enlarged view of the support for the emitting wire employed in the structure of Fig. 3; Fig. 5 is a longitudinal sectional view through a modified form of rectifier, embodying my invention; Fig. 6 is a transverse sectional view through the rectifier of Fig. 4 taken on line 5—5 thereof; Fig. 7 is an enlarged view of the support for the multiple emitting wires employed in the structure of Fig. 6; Fig. 8 shows characteristic curves of the performance of the single emitter tube of Figs. 1–4; Fig. 9 shows characteristic curves for the performance of the multiple emitter tubes of Figs. 5–7; Fig. 10 is a longitudinal sectional view of a further modified form of tube embodying my invention; Fig. 11 is a transverse sectional view taken on line 11—11 in Fig. 10; and Fig. 12 is an enlarged sectional view of a detail portion of Fig. 10.

In the prior art for discharge devices using conduction through gases, it has been customary to maintain current used in rectification by means of ionization produced by impact throughout the gap and this has necessitated using gas pressures much below atmospheric. Some of the disadvantages of this type of tube are the tendency to arc over and to arc back. Another way of stating this is that an increase of current is accompanied by a decrease in tube drop so that means separate from the tube must be provided for limiting the current to keep the tube from arcing over and burning up. In one type of rectifier operable at atmospheric pressure, the current is carried primarily by molecular ions. This type of device is free from the objections stated above with respect to erratic arc over, but is inefficient because the ions must travel a long distance through a fairly dense gas and much energy is consumed in keeping them moving. The methods which constitute this invention provide the advantages of both types without the disadvantages of either. The principal (forward) part of the current is carried the greater part of the distance in the gap by a drift of free electrons, which is a process which consumes very little energy. This current is carried a very small fraction of the total distance between electrodes by producing ions—a process which, because of the short distance, consumes very little energy. The inverse current which is small, is carried by ions and the combination of these two methods of conduction which is to be disclosed herein, provides a means for preventing arc back.

Referring to the drawings in detail, reference character 1 indicates the assembled unit of the electric discharge device of my invention consisting of the point emitter 2 and the target electrode 3. For purposes of explaining one application of my invention, I have shown the device connected as a rectifier in which alternating current is supplied through an input transformer 4 having primary winding 5 and secondary winding 6, the secondary winding being connected at terminal 6a to the emitting point 2 and the terminal 6b to one side of the output circuit through milliammeter 7. The output circuit is represented by a load resistor 8 having resistance R. The other side of the output circuit is connected to collecting electrode 3 as shown. A filter condenser 9 is connected across the output circuit of the rectifying system. The voltage across the secondary winding 6 which is the input voltage to the rectifier is designated *e*. The output voltage from the rectifier is designated E.

With reference to Fig. 2, there will be seen a side-elevational view of the rectifier diagrammatically shown in Fig. 1. In the present instance, there is shown a tubular metallic envelope 3, the inner surface 10 of which acts as a collecting electrode with respect to the emitting point 11. In the present instance, the tube is approximately 2″ in diameter and 2½″ from the enclosed end 12 to the free edges 14 thereof. Secured to the base 15 in a manner to shield the free edges 14 from the discharge is a dielectric lip 16. This base is apertured at 17 to properly seat mounting post 18 in a manner to maintain the wire 11 on the top thereof in a manner to space the point 11 approximately 1″ from all inner-surfaces of the target 3. The wire 11 is secured to the post 18, by welding or the like, and, in the present instance, is approximately .003 of an inch in diameter and approximately ¾ of an inch long. Since the tube is filled with a free electron gas, it is important that the dielectric material used is free from electron attaching vapors. I have found that a base of linen impregnated phenol condensation product which has been after-baked to remove a major portion of the impurities is a good substance for this base. The emitting wire 11 is formed from stainless steel. I have found, also, that such materials as tantalum and tungsten work well, however, some types of materials have more tendency to etch away under use than the ones mentioned above, and, for that reason, I prefer a wire from the group listed. These materials have been found particularly immune from the effects of etching under continued use in such gases as hydrogen. The envelope 1 may be of steel, copper, or brass. In the present instance, I have shown an envelope consisting of steel tubing.

It will be obvious from the drawings that a very close fit is necessary between the edges 19 of the dielectric base 15 and the lower portion 20 of the inner surface 10 of the envelopes. I have found that by making the base a few thousandths of an inch over-size and applying a good baking varnish to the edges 19 thereof and by forcing the base into the target member and allowing the varnish to properly dry, a leak-proof seal results therefrom.

One way of filling the tube is to provide the mounting member 18 with a central aperture 22 which extends from the lower end 23 thereof to a position in the tube at 24, which is below the emitting wire 11 as shown more particularly in Fig. 4. In this manner, the tube can be connected with a vacuum device not shown, exhausted and properly filled with the desired gas, and then the tip sealed with solder or the like indicated at 25. A projecting member 13 is provided on the upper end of plate 12 to serve as a connection means for the target in the circuit of the discharge system.

In Figs. 5 and 6, I have shown a device containing multiple discharge points similar in general arrangement to the device illustrated in Figs. 1–4, except that a plurality of emitting wires 11a and 11b are employed for coaction with the internal surface 10 of the target 3. In this arrangement, the mounting member for the emitting points is formed in two parts indicated at 26 and 27. The portion 26 is supported in the vertical extension 28 of base 29 as shown. The portion 26 supports the member 32 forming the mounting means for the emitting wires 11a as shown more particularly in Fig. 7. The emitting wires 11a extend radially with respect to the mounting means, and there is also a vertically projecting emitting wire 11b. The emitting wires 11a and 11b each terminate, in the instance disclosed, approximately 1″ from the internal surface 10 of target 3. In the arrangement illustrated, the points of the emitting wires are spaced approximately ¾″ apart.

In the multiple electrode discharge device illustrated, the internal diameter of the cylindrical target is approximately 3″ and the vertical dimension, between the top 12 and the lower edges 14, is also approximately 3″. The base 29 for the wire emitters 11a and 11b comprises a molded dielectric material free from poisoning effects in hydrogen or like free electron gases, and capable of withstanding heat of approximately 150° C. without shrinkage. The base 29 is molded in a manner to be slightly over-sized, and is wedged into the lower end of the target 3, and suitable baking varnish is applied in the same manner as that disclosed for the tube shown in Fig. 2. It will be noticed that the molded base 29 is provided with a neck portion 28 extending from the lower inner surface of the base 29 to a position just below the under surface 33 of a washer 26c engaged with the member 32. This is done to aid in shielding member 26 from the inner walls 10 of the tube 1. A stem portion 35 extends down from the outer surface 36 of the base 29 in a manner to aid in shielding that connection from the outer surface 37 of the target member 3. Base 29 has an annular skirt which forms a binding zone for the lower portion 20 of the cylindrical target 3. The annular periphery of the target 3 indicated at 14 is protected from the emitter by an annular lip 31 on base 29 as shown.

The lower end of member 26 is screw-threaded at 26a to receive the internally screw-threaded portion of member 27. Both member 27 and member 26 have axial bores, 26b and 27b, respectively, through which the tube may be exhausted and thereafter the proper operating gas introduced. Members 26 and 27 are interconnected by the screw-threaded joint as illustrated with gasket 26d serving to maintain a gas-tight joint between members 26 and 27 and base 29. When the desired gas is introduced into the interior of the envelope, the axial passage 27b is sealed by solder as represented at 38. The axial passage 26b passes through the member 32 as represented more particularly in Fig. 5. In order to provide a connection for the target 3, a projecting member 39 extends from the top 12 of the envelope as indicated and to which the connection may be made in accordance with the circuit arrangement illustrated in Fig. 1.

The operation of the devices shown in Figs. 1–4 are as follows: Having been assembled and filled with a free electron gas to a pressure of substantially atmospheric, the tube is placed in the circuit with the contact end 18 connected to terminal 6a of secondary winding 6 of the A. C. transformer 4 and the opposite end 13 of the tube connected through a capacitor 9 back to the terminal 6b of winding 6 of the transformer 4.

When the point emitter 11 is negative with respect to the target electrode 3, then the tube passes current. If, however, the point emitters are positive with respect to the target electrode, then only a very small amount of current is passed. Thus a substantially unidirectional current is pased when an alternating potential is applied.

To reverse the polarity of output the tube is merely inverted and the end 13 connected to terminal 6a of winding 6 of the transformer 4 and terminal 18 connected to terminal 6b of transformer 4.

The discharge current produced in a tube constructed as hereinbefore described is essentially electronic in character, in accordance with my invention, due to a number of factors the control of which constitutes the distinguishing feature of the method of my invention. Besides the provision of a pointed electrode and high potential energy to constitute means for establishing an electric discharge of the type desired, the factors of most importance are the nature and pressure of the medium of discharge and its efficacy in determining and maintaining the type of discharge which is produced. Various experiments have been recorded in the art of electrical discharges of the effects of voltage, current, pressure, and other variations on discharge through different gases, particularly in regard to the visible effects achieved in the field of glow discharges, the electrical circuit characteristics involved and even the chemical effects attributable to the discharge. Little or nothing has been done, however, in the evolution of new types of discharges more efficacious in application to particular problems, and it is from this field of research that the invention herein disclosed has been evolved.

Electronic discharges are known which are produced by emission from activated electrodes in vacua, the discharge being adversely affected by the presence of even small amounts of gas in the tubes. Glow discharges are known which result from complete or substantially complete ionization of gas at low pressures in enclosed tubes, which condition may be maintained at a lower voltage than that required to initiate it. Disruptive spark and arc discharges are also known and may be produced under various pressure conditions and in different media at different break-down voltages. The discharge produced in accordance with my invention is electronic in character and non-disruptive, yet takes place in a gaseous medium at substantially atmospheric pressure and differs widely, therefore, from discharges of the types described above.

Another type of discharge known in the art, and one from which that produced in accordance with my invention more immediately proceeds, is corona or brush discharge which takes place in air or gases at substantially atmospheric pressure and under conditions which prevent complete ionization and resulting glow discharges. Corona and brush discharges, and others under the term "silent" and "dark" discharges are known to be accompanied by a phenomenon called "electric wind" which is due to the movement in the field of the discharge of molecules of the medium, a movement which is cumulative and becomes evident as motion in the medium itself. Such discharges depend for their conductivity upon molecular ions principally, and are unsuited for efficient action in electrical apparatus such as rectifiers.

In the practice of my invention, I employ as the medium of the discharge, gases of such a nature that electron attachment to molecules does not readily occur. Among the gases found to be non-electron attaching are purified hydrogen, nitrogen, helium, neon, argon, krypton, and xenon, and certain gaseous compounds such as carbon monoxide, carbon dioxide, and methane, as well as mixtures such as hydrogen and helium. As a group I term these and like gases "free electron gases"; opposed thereto are gases such as oxygen, ammonia, sulphur dioxide, which readily attach electrons to form stable negative molecular ions. All free electron gases do not produce identical performances in the system of my invention, but different gases and mixtures thereof vary in the results obtained as will be exemplified hereafter. There is, however, the common characteristic of the discharges produced therein that negative molecular ions do not occur to any substantial degree.

In devices in the prior art operating in gaseous atmospheres at low pressure and depending upon the ionization of the gas for conductivity, the ionization of the medium produces a visible glow through the medium and, in order to obtain that effect, the pressure of the medium must be substantially reduced, as is known. In the system of my invention where ionization beyond a limited sphere is not desired, the pressure is maintained relatively great, substantially atmospheric pressure having been found suitable in tubes of the forms disclosed. The pressure, however, is more directly related to the ion and electron mobilities in the particular medium and with a given electrode arrangement, and the pressure determined upon for coordinating all factors is at least that at which the mean free path of an electron is of a lower order of magnitude than any inter-electrode distance or any inter-wall distance in the discharge tube.

Between the emitter and the collecting electrodes, while an electric current passes, there is a relatively intense electric field and the resultant ionizing region adjacent the discharge tip and a much less intense electric field in the principal remaining portion of the gap. Extending across the principal portion of the gap from the small ionizing region to the collecting electrode is a region where ionization is substantially absent and through which electric current is carried on the useful (forward) half cycle by means of the drift of free electrons. At high enough voltages for a small inverse current to appear on the inverse half cycles, there is, on these inverse half cycles, a relatively intense ionizing region adjacent the discharge tip, and extending the rest of the distance from this small ionizing region to the collecting electrode, the field is less intense and the inverse current is carried by means of the drift of positive ions without the production of any substantial amount of ionization in this latter principal portion of the gap.

In Fig. 8, I have shown the characteristic performance curves for a single wire emitter type of discharge tube as represented by the structures of Figs. 1–4. The curves 40—46, inclusive, show the amount of forward current passing in the rectifier tube as a function of applied A. C. voltage for different load resistances. Curve 40 shows the forward current when the load resistance is a short circuit. Curve 41 for load resistance equal to 0.65 megohm; curve 42 for 2.5 megohms; curve 43 for 5 megohms; curve 44 for 10 megohms; curve 45 for 20 megohms and curve 46 for an infinite load resistance, that is to say, no load. Curves 46—50, inclusive, show the inverse current as a function of applied A. C. for various load resistances. Curve 46 shows the inverse current on open circuit; curve 47 for the load resistance equal to 20 megohms; curve 48 for 10 megohms; curve 49 for 5 megohms; and curve 50 for 2.5 megohms. The inverse current for 0.65 meghom and for short load resistance were too small to show on the diagram. Since there is no current being drawn off from the circuit when the load resistance is an open circuit, it is obvious that the same curve, namely, curve 46 should show both the forward and the inverse current being drawn.

In Fig. 9, I have shown the characteristic performance curve for a seven-wire emitter type of discharge tube as represented by the structures of Figs. 5–7, inclusive. Here again, curves 51–57, inclusive, show a forward current for various load resistances as a function of applied A. C. voltage, and curves 57–62, inclusive, show the inverse currents for various load resistances as a function of applied A. C. voltage. The load resistances were in the same order as before and the curves occupy corresponding positions.

Using the rectifier shown in Figs. 1–4, if the output circuit draws less than 30 microamperes, the application of 9,000 volts A. C. produces a D. C. output at 8,400 volts. Increasing the load by reducing the load resistance to 20 megohms, the output current is increased to 300 microamperes for an applied A. C. voltage at 9,000 volts, and a D. C. output voltage of 6,600 volts. Operating the rectifier shown in Figs. 5–7, inclusive, at a high load resistance, so that 30 microamperes or less current is withdrawn while the applied voltage is 9,000 volts A. C., and D. C. output voltage is 8,700 volts. Increasing the load by reducing the load resistance to 20 megohms, a current of 385 microamperes is delivered for an applied A. C. voltage of 9,000 volts, while the D. C. output voltage is 7,700 volts.

The construction of apparatus embodying my invention may take a variety of forms. A further modification—one embodying a plurality of emitter points disposed similarly as shown in Figs. 5–7—is illustrated in Figs. 10–12, the particular feature of which is the use of a glass envelope instead of a metal shell. Referring to Fig. 10 which shows the tube in longitudinal section, reference character 63 indicates an envelope of glass or like material which may be blown and shaped to the desired contour. As shown, the envelope 63 preferably includes a substantially spherical bulb portion 63a having an evacuating and filling connection indicated generally at 64, a lower base or closure portion 63b, and an inwardly directed supporting portion 63c. The substantially spherical portion 63a of the envelope is provided with a conductive coating of silver, aquadag, or the like at 65 which serves as the collecting or target electrode for the electric discharge; electrical connection is made to the metallic coating at the evacuating and filling connection 64 as shown more clearly in Fig. 12, to be described. The emitter wires shown at 66a extend radially with respect to a supporting member 67, and there is also a vertically extending emitter wire 66b. Connection is made to the emitter wires through the supporting member 67 which projects exteriorly of the envelope. The emitter wires 66a and 66b terminate equidistantly from the metallic surface 65 on the interior of the substantially spherical portion 63a of the envelope, at a spacing of approximately one inch in the embodiment shown. The metallic coating 65 terminates substantially at the junction of the spherical portion 63a with the base or closure portion 63b of the envelope, and may extend to the position 65a as indicated on Fig. 10. The supporting member 67 is fixed in a glass pinch in the inwardly directed supporting portion 63c of the envelope, which may be separately constructed and joined with the bulb and closure portions in a known manner.

Fig. 11, being a cross-sectional view taken on line 11—11 in Fig. 10, shows the radial disposition of the emitter wires 66a and the continuity of the metallic coating 65 on the envelope portion 63a for the production of a uniformly distributed electrical discharge of the character of my invention. The filling of gas maintained within the envelope 63 has the same features which characterize the gases employed in the other embodiments of my invention hereinbefore described, for operation in accordance with my invention.

The evacuating and filling connection, shown generally at 64 in Fig. 10, comprises a metallic member 68 having a longitudinal bore and positioned in an aperture in the envelope 63. The member 68 is secured to the glass of the envelope by sealing means at 69, and the metallic coating 65 on the interior of the envelope extends in contact with the metallic member 68 which thereby affords electrical connection with the coating. The envelope is evacuated through the bore in the member 68, and the filling of a free electron gas is introduced therethrough, after which the bore is sealed by solder or the like at 70.

While the above description applies particularly to a diode in which there is a distance of approximately one inch from the discharge tip to the collecting electrode surface operating in hydrogen at substantially atmospheric pressure, other inter-electrode distances may be used, other gases may be used for free-electron conductivity, and other field arrangements can be used. The following distinctions apply for these other arrangements of electrodes and compositions of the gas.

For diode arrangements of the type shown herein, it has been found that for hydrogen there seems to exist a sphere around the tip of each discharge wire in which ionization takes place. If the ionizing regions around the wire tips overlap each other, there seems to be an interference between the action of the ionizing regions in such a way as to produce a reduction in the arc back voltage which the tube will withstand. There is also a tendency to form transients on the forward half cycle of a diode in which these ionizing regions overlap. For this reason, I prefer that the distance between the wire tips be at least ¾″.

With respect to varying the distance from the tip of the wire to the collecting electrodes, the following considerations apply. For a single-wire diode increases of gap-length do not produce proportional increases in the inverse voltage that the diode will stand. On the other hand, with multiple wire arrangements, the inverse peak which the tube will withstand increases more nearly proportionally but never completely proportionally to the gap-length. The reason for this seems to be that the field intensity can nowhere exceed a predetermined value, which for hydrogen at atmospheric pressure is approximately ten thousand volts per centimeter.

Other gases have been used in diodes and quite different performance is obtained with respect to the tolerable current densities and the tolerable inverse field intensities. The same general characteristics apply for the various free electron gases with respect to changes in the variables, the magnitudes only seeming to be dependent on the composition of gas used. For example, if pure nitrogen is used, it appears that for any given current density and applied field intensity, the tip of the wire becomes much hotter than it does in hydrogen. The result of this is that the potential drop necessary to obtain the onset current is reduced, or the potential drop through the ionizing sheath is less when the wire tip is hot than when it is cold. The benefit of this hot wire end is more advantageous than the disadvantage of the power being used to keep that wire tip hot. Nitrogen gives a tolerable inverse field intensity of the same amount, roughly, as for hydrogen. Argon, on the other hand, will tolerate a much lower current density than hydrogen or nitrogen, and so from the standpoint of current capacity, argon is not as preferred a gas as hydrogen, helium, or nitrogen.

Helium gives a lower inverse field intensity than hydrogen, but it also gives a lower gap drop on the useful half cycle, so that in some field arrangements helium is more advantageous than hydrogen, but for other field arrangements, helium is less advantageous. A mixture of hydrogen and helium has been found to be particularly advantageous for short gap low voltage devices.

Other gases which behave somewhat similarly to nitrogen in that they give hot wire end operation, include carbon monoxide, carbon dioxide, and methane.

In general, it may be said of these diode rectifiers that as long as the current per discharge wire is quite small, the current is passed entirely unidirectionally. With increase in the applied voltage or increase in the load resistance or combinations of the two, current is drawn on the inverse half cycle. This inverse current, of course, consists of the production by ionizations of positive ions near the wire tip and the drift of these positive ions across the gap during the inverse half cycle. The most efficient operation of these diodes is usually obtained with a small inverse current, but this is an advantage, because if a transient or switching surge is thrown on the rectifier by the operating circuit or the output circuit, such a transient does not have to produce a capacitive storage of charge across the inter-electrode capacity of the diodes, but is dissipated by a slight increase of the inverse current itself. Since the energy of a traveling wave along a line is generally quite small and becomes dangerous only because of the large peak voltage which it can produce upon being stored across an inter-electrode capacity, the dissipation of such a surge produces a negligibly small amount of heat in the rectifier without in any way disturbing its operation. These diodes generally allow the inverse current to pass only up to some maximum inverse voltage across the diode, and if too much voltage is applied to them, the inverse peak voltage may exceed the maximum tolerable inverse current. As long as the diode is operated approximately two to five per cent below the applied A. C. which produces the maximum tolerable inverse current, any surge that can be sent along the line will be dissipated by the inverse current of the diode. The use of more discharge wires in a diode, resulting in a less divergent field from discharge electrodes to collecting electrode, reduces the maximum tolerable inverse current which the diode will allow to pass. This does not necessarily reduce the maximum tolerable inverse peak voltage, however, but rather there accompanies this increase in discharge wires an increase of the onset voltage for the inverse current. Thus it may be said that the reduction of divergence of the field from discharge electrode to collecting electrode produces both an increase of the onset voltage for the inverse current, and, also a reduction of the maximum inverse current which can pass.

It has further been observed in the operation of the discharge with steel wires or tantalum wires or tungsten wires in hydrogen, that by continuing the discharge to times up to an hour at currents of approximately 0.1 microampere per wire, there is obtained a conical sharpening of the wire end. Indefinitely long continued operation of the discharge device continues to maintain the end of the wire sharpened in this conical shape. Although a .003 inch diameter wire is being used, the radius of curvature at the tip is less than 0.0005 inch and is probably of the order of a 0.0001 inch. Wires which are larger in diameter than 0.003 inch have a tendency to arc back at lower voltages than wires 0.003 inch or under. This is because the wire end tends to become at least red hot on the forward half cycle at a current of 0.2 microamperes or greater per wire, and the wire tip does not have time to cool to below a visible red temperature before arriving at the inverse half cycle. A hot wire end has a much lower onset voltage for both the forward and inverse current than cold wire end. For this reason, the wire size is restricted to 0.003 inch or under, principally because of the heat capacity of the metal in the end of the wire. The larger wire sizes can be etched to a sufficiently sharp wire-coned end by the action of the discharge to produce the necessary low voltage forward characteristics.

While there is a limited etching of the discharge wires in the system of my invention, there is no substantial disintegration of the discharge electrode such as has been experienced in discharges under different conditions due to the intensity of atomic bombardment of the discharge electrode, which has been most notable in the prior art where discharge currents have been produced in vacua or at low gas pressures. With the gas pressures which are prescribed for the system of my invention, the intensity of the atomic bombardment of the discharge electrode is reduced to such an extent that erosion of the electrode is substantially prevented. This is believed due to a blanketing effect of the gas molecules with respect to the discharge electrode, insofar as the physical bombardment of the electrode by atomic bodies is concerned, the gas molecules interfering with the bombarding atoms to dissipate the kinetic energy thereof and prevent their attacking the discharge electrode.

A long lasting device, stable in operation for long periods of time, is produced, therefore, in accordance with my invention.

It has been found further that small traces of the electron-attaching gases or vapors act as impurities to prevent the discharge device from operating efficiently. If means are used, however, to restrict the electron-attaching impurities to a low concentration initially introduced into the tube, the operation of the discharge itself will remove the remaining impurities. The sustained operation of a discharge in hydrogen can overcome a relatively large leak of air into the apparatus, although by shutting off the discharge for a while and then trying to start it again, a large leak of air into the apparatus will have introduced so much oxygen that sufficient discharge can not pass to recondition the tube properly.

While I have described my invention in certain preferred embodiments, I desire it understood that no limitations upon my invention are intended thereby but only such as are imposed by the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. The method of producing an electric discharge electron current which comprises passing current through a discharge path comprising an electric discharge electron emitting point and a collecting electrode while maintaining the discharge path within an atmosphere of a free electron gas through which electrons pass independently of molecular attachment.

2. The method of producing an electric discharge electron current which consists in passing current through a path which includes an electric discharge electron emitting point and a collecting electrode, and confining the electric discharge emitting point in a gas at substantially atmospheric pressure for preventing disintegration of the discharge point throughout the period of discharge, said gas being one in which electron attachment to molecules does not readily occur.

3. Electric discharge apparatus comprising an electric discharge emitting point, a collecting electrode, a vessel enclosing said electric discharge emitting point and said collecting electrode, and a gas enclosed within said vessel at substantially atmospheric pressure, said gas being one in which electron attachment to molecules does not readily occur, said electric discharge emitting point being directed toward said collecting electrode for establishing an electric discharge between the electric discharge emitting point and the collecting electrode through said gas.

4. Electric discharge apparatus comprising a chamber containing at substantially atmospheric pressure a gaseous medium in which electron attachment to molecules does not readily occur, and electric discharge and target electrodes within said chamber operative for producing an electric discharge characterized by electrons moving from said electric discharge electrode to said target electrode through said gaseous medium with substantially no molecular attachment of electrons in said medium.

5. Electric discharge apparatus comprising a chamber containing a substantially pure gas at substantially atmospheric pressure, said gas being one in which electron attachment to molecules does not readily occur, and means including a pointed cathode electrode within said chamber operative for producing an electric discharge characterized by an ionizing region at said pointed electrode and the absence of molecular attachment of electrons in said gas, said ionizing region being effective to increase the effective radius of curvature at said pointed electrode whereby the potential gradient in the gas adjacent said point is maintained below sparking conditions under increased applied potential for producing increased current flow in the said electric discharge.

6. An electric discharge system comprising electric discharge electrodes operative in a gaseous medium in which electron attachment to molecules does not readily occur, said medium being at a pressure greater than that at which the mean free path of an electron or other charged particle in the medium is of a lower order of magnitude than any inter-electrode distance in said discharge system.

7. An electric discharge system comprising a gaseous medium composed of gas molecules which do not form negative molecular ions by attachment to electrons, a collecting electrode, and an electric discharge electrode operative in said medium to produce free electrons for establishing an electronic discharge current through said gaseous medium.

8. An electric discharge system including an electric discharge and a collector electrode, a gaseous medium in which electron attachment to molecules does not readily occur enveloping said electrodes and having an ionizing region adjacent the discharge electrode, the pressure of said gaseous medium being at least that at which the mean free path of any charged particle in and beyond the ionizing region is less than the inter-electrode distance through said gaseous medium, free electrons emanating from said ionizing region being caused to drift to said collector electrode and constituting a substantially wholly electronic current through said gaseous medium.

9. Electric discharge apparatus comprising an electric discharge emitting point, a glass envelope for enclosing said emitting point and having an inner conductive coating constituting a collecting electrode for coaction with said emitting point, and a gas within said envelope at substantially atmospheric pressure, said gas being one in which electron attachment to molecules does not readily occur, said apparatus being operative to produce a unidirectional electric current of free electrons passing through said gas between said emitting point and said conducting coating.

10. Electric discharge apparatus comprising an envelope having an inwardly directed supporting portion in said envelope, a conductive member extending through said supporting portion and terminating in a portion central of said envelope, a plurality of emitter wires connected in said conductive member and extending into said envelope and terminating equidistantly from the wall of said envelope, an inner conductive coating on said wire constituting a collecting electrode for coaction with said emitter wires, a gas within said envelope at a pressure at least at the mean free paths of the charged particles produced therein are less than the distance between said discharge and collecting electrodes, said apparatus being operative to produce a unidirectional electric current of free electrons passing through said gas between said emitter wire and said conductive coating.

WILLARD H. BENNETT.