

May 2, 1933.

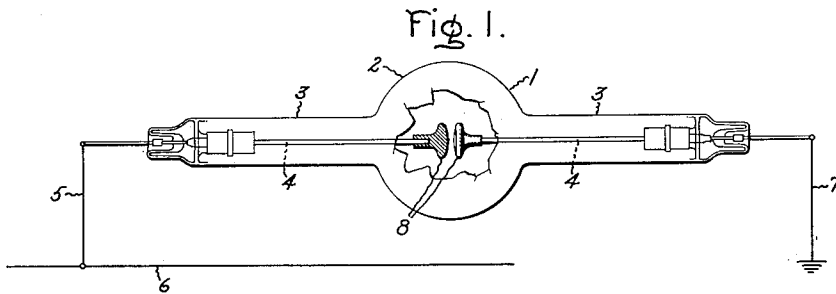
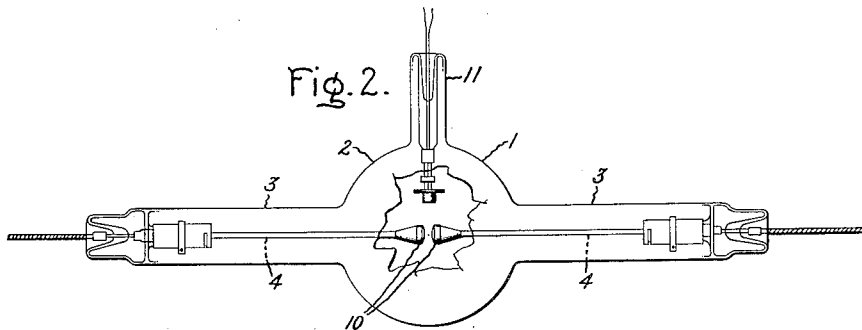
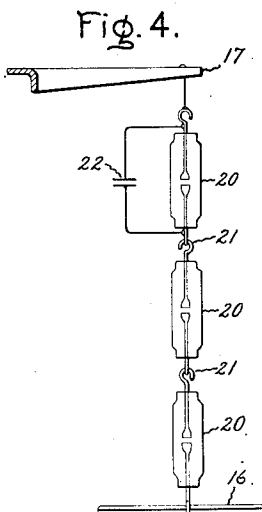
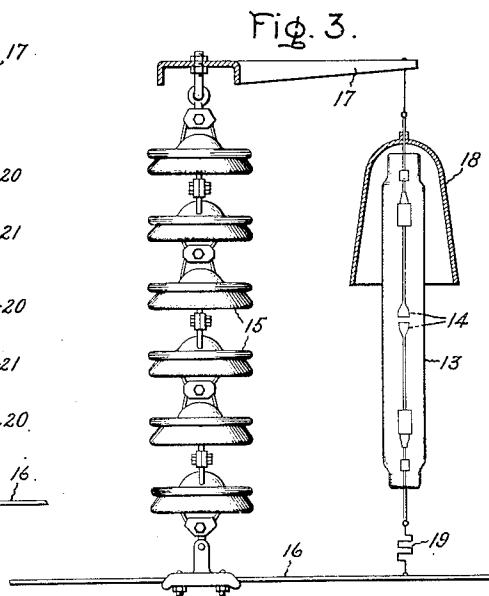
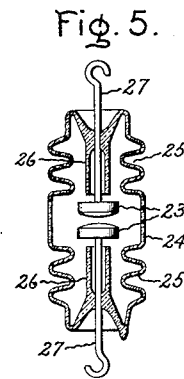
A. W. HULL

1,906,602

LIGHTNING ARRESTER

Filed Aug. 6, 1930

2 Sheets-Sheet 1



Inventor:
Albert W. Hull,
by *Charles E. Zeller*
His Attorney

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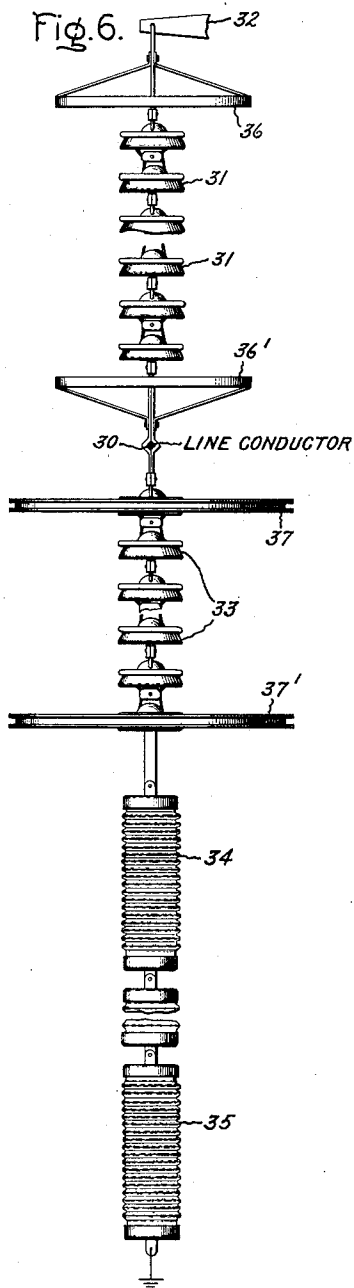
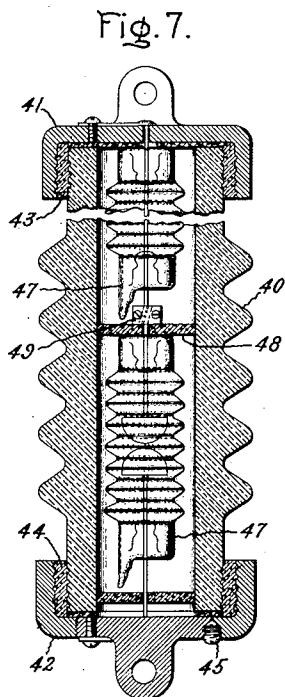
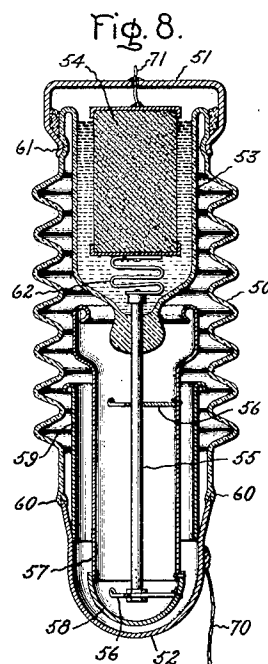
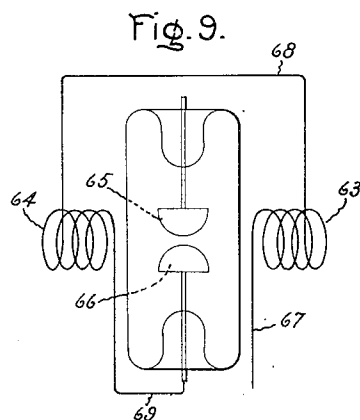
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2 Sheets-Sheet 2



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His Attorney.

UNITED STATES PATENT OFFICE

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK

LIGHTNING ARRESTER

Application filed August 6, 1930. Serial No. 473,386.

- My invention relates to lightning arresters and particularly to arresters employed on electric transmission lines to protect the line and apparatus connected therewith from injury resulting from abnormal voltages produced on the line. This application is a continuation-in-part of my application Serial No. 328,759, filed December 27, 1928, and entitled "Lightning arresters".
- One of the most important requirements of a modern transmission line supplying electric power to a large number of industries is that it shall deliver a constant and uninterrupted supply of energy at all times regardless of weather or other conditions. While this is desirable in general for all industries using electric power, it is imperative in the case of certain ones where an interruption in the electric supply service means an expensive shut-down for an entire plant. On those transmission lines which are located in parts of the country which are subject to electrical storms, interruptions, in the summer time more commonly are due to lightning than to any other cause. A direct lightning stroke is comparatively rare, but induced charges on the line resulting from some distant stroke frequently are in excess of the insulation strength of the line. Excess voltages by either direct strokes or by induction may cause the line insulators, apparatus bushings, transformers, etc. to arc over, thereby producing a short circuit to ground on the line. Of itself, a discharge across an insulator generally does no particular damage, but this establishes across the insulator a path through which the power current of the system may flow. This current, being of high magnitude, is very destructive to the insulator and may cause a serious disturbance over the entire system. Hence, the line must be taken out of service and unless this is done promptly, the damage done to the line, as well as to apparatus connected therewith, may be of such a serious character as to require a considerable length of time to effect necessary repairs before the service can be resumed.
- Modern transmission lines are in reality insulated, not merely for the normal line voltage of the system, but to protect the system, as far as is economically feasible, from lightning disturbances. To make a system immune from lightning, it would be necessary to insulate the transmission line and all connected apparatus, such as oil circuit breakers, transformers, etc., for voltages higher than the maximum lightning voltage which would ever appear on the line. Lightning voltages greater than 2,000,000 volts have been measured on some systems. It is often economically better to discharge such voltages to ground rather than to insulate lines and equipment to withstand them.
- Since it is uneconomical to render the line immune from lightning by means of insulation, the more practical way is to withdraw the abnormal charge from the line and lead it to ground. It is well known that the wave front of a lightning discharge is very steep and this requires any apparatus, which is provided to withdraw the charge before the voltage reaches a dangerously high value, to operate with great speed. It is also known that the charge which must be withdrawn from the line to keep the voltage from rising to a dangerous value may amount to 10,000 amperes or more, hence the apparatus must also have the capacity for conveying currents of such magnitudes without injury to itself.
- It is an object of my invention, therefore, to provide an improved method of discharging high current, high potential surges and to provide a lightning arrester or electric transient discharge device, which shall operate at high speed, shall have ample capacity to carry off the discharge, shall be self-restoring to prevent any subsequent flow of power current and which shall be simple and economical to manufacture.
- The arrester forming my invention comprises essentially a pair of non-thermionic, well de-gassed electrodes of solid material, such as copper, for example, arranged relatively close to one another in a sealed envelope in which there exists such a high vacuum that ionization of residual gas will play

no essential part in the conduction of current through the device.

The nature of my invention will be better understood from the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

Referring to the drawings, Fig. 1 illustrates one form of arrester in accordance with my invention shown connected between a line and ground; Figs. 2 and 5 illustrate modifications of the same; Fig. 3 illustrates a further modification connected across an insulator string suspending a transmission line; Fig. 4 shows an arrangement comprising a plurality of arrester tubes connected in series, one of which has a delayed breakdown characteristic; Fig. 5 illustrates a modification having a corrugated envelope; Fig. 6 illustrates an arrangement in which a string of arresters and a discharge gap in series therewith is connected between a line and ground; Fig. 7 is a longitudinal section of a mounting for arresters in an insulating housing; Fig. 8 is a modified form of arrester embodying a series resistance; and Fig. 9 is a diagrammatic representation of an arrester provided with series-connected magnetic blow-out coils.

In the form of my invention shown in Fig. 1 the gas-tight envelope 1 which, for example, may be of glass, resembles in form an X-ray tube and comprises a spherical body portion 2 with two oppositely extending arms 3 in which are supported the leads 4, suitable seals being provided at the outer end of each arm to hold the high vacuum required. In Fig. 1 one lead is shown connected by wire 5 to a line 6 to be protected and the other lead is shown connected by wire 7 to ground. Supported by the respective leads 4 are the two blunt electrodes 8 which may assume various forms, and which during operation are not heated independently of the discharge and hence sometimes are referred to as "cold electrodes." They are here represented as protuberant buttons or discs and of relatively massive construction. The juxtaposed surfaces of the electrodes preferably are rounded, the radius of curvature being large in comparison to the distance between the electrodes as shown. The spacing of the two electrodes from each other may vary from a fraction of 1 mm. to 1 cm. depending upon the material of the electrodes and the voltage of the line which is to be protected. I have found that a spacing of 2 mm. gave excellent results for an operating crest voltage on the line to be protected of 22 kilovolts with aluminum electrodes. With copper electrodes a spacing of 0.75 mm. is suitable for a line of 11 kilovolts. Ordinarily the preferable spacing of the electrodes is in the neighborhood of a millimeter.

The electrodes may be constructed of various materials, such for example as copper, tungsten, graphite or aluminum. Successful operation, however, is not limited to the use of these materials. I prefer to use copper, and in particular copper which has been thoroughly de-gassed in finely divided form, as by being sprayed, dripped or distilled in a high vacuum to give opportunity for the occluded gases to escape. It is necessary that both the envelope and the electrodes with their supporting leads be thoroughly freed after assembly from occluded surface gases. A high degree of vacuum within the envelope also is necessary, the exhaustion being carried to such an extent that ionization of residual gas plays no essential part in the operation of the arrester.

As a result of this construction, and removal of gas, when the arrester is subjected to a high voltage discharge having a steep wave front, the current between the electrodes starts as a pure electron discharge, but immediately changes to a discharge of arc-like characteristics conducted through the vaporized electrode material. I have found that the arc voltage is of the order of 1000 volts or less with discharge currents as high as 20,000 amperes. Repeated discharges, I have found, produce no material heating of the electrodes, the vaporization being due to electrical action on the surface. As soon as the transient electric discharge, such as a surge or lightning stroke ceases, the vapor condenses, the breakdown voltage returns to its original value, and the electrodes appear intact. The time lag in passing from a pure electron discharge to an arc is less than 10^{-7} of a second. The time lag in passing back again from arc to an insulation condition after the discharge ceases, depends upon the duration and intensity of the discharge. With heavy discharges it is usually of the order of 10 micro-seconds. Under operating conditions, the voltage gradient necessary for breakdown is about 500,000 volts per cm. for copper or tungsten electrodes, and about 100,000 volts per cm. for graphite electrodes. These values may be raised by carefully smoothing the opposing surfaces of the electrodes, as by polishing, or by burning off projecting points with small currents.

It will thus be seen that the arrester which I have devised fulfills in a very admirable manner the requirements for a successful arrester. Upon the arrival of a steep wave front of a predetermined value, break-down between the electrodes begins without delay, starting as a pure electron discharge and immediately changing to a vapor arc of high current-carrying capacity and moderate voltage drop. The discharge being thus carried to ground, the voltage wave accordingly is reduced to a safe value before

reaching apparatus which may be damaged. Discharges between the electrodes of 50,000 amperes have been observed. The electrodes were not visibly heated or injured by successive discharges of this value.

Three arrangements suitable for using the arrester in connection with a high voltage line are the following:

The first and simplest arrangement is to connect the arrester directly from line to ground with either no resistance at all or very low resistance in series with it. In this case the lightning surge is discharged very rapidly and the potential of the line in the vicinity of the arrester is reduced to essentially zero. On account of the shortness of the interval of discharge the heat penetrates the electrodes of the arrester such a small distance that the arrester is able to recover its insulating power before damage is done to the system or the arrester, the dynamic current from the line being very quickly interrupted without causing line disturbances. No continuous dynamic current flows through the arrester, the dynamic current generally being interrupted in less than one-half cycle.

The second arrangement preferably utilizes in series with the arrester a resistance which is approximately equal to the surge impedance of the line. This resistance slows up the rate of discharge of the lightning surge to such an extent that dynamic current may build up before the surge has disappeared. This is especially true in the case of high power systems. In this case dynamic current may flow through the arrester until the end of the half cycle in which the surge appears, but it is not built up in the succeeding half cycle.

In most cases, however, the arrester recovers its insulating power before the dynamic voltage appears. For a third and preferred type of connection I use a resistor having such characteristics that the current therethrough increases much more rapidly than the voltage between its terminals. An example of such a resistor is one manufactured and sold by the General Electric Company under the trade name Thyrite being manufactured from carborundum having a free carbon content of not over 10% and having a grain size of the order of that which will pass a 250 mesh screen. The carborundum grains may be held together with a binder of clay. In the manufacture of this material a small amount of water is used and after being subjected to a compressive force of the order of 18,000 pounds per square inch, and being allowed to dry, it is fired. The firing process is carried on in a neutral atmosphere at a temperature of from 1300° to 1600° C. Such a resistance material has been described and claimed in United States Patent 1,822,742 patented

September 8, 1931, discharge device and resistance material, and assigned to the same assignee as the present application.

In the modified form of my invention shown in Fig. 2, the electrodes 10 are shown as having a conical form with slightly convex adjacent faces. In this form I have shown the envelope provided with the additional arm 11 for supporting a filamentary electrode to be used as a temporary cathode in de-gassing the electrodes 10 in accordance with well known procedure, such, for example, as that followed in de-gassing Coolidge tubes and as described in Coolidge Patent No. 1,203,495, May 9, 1913.

In the modification illustrated by Fig. 3 I have shown my arrester having an envelope 13 in the form of a long narrow tube and as having massive electrodes 14 similar to those illustrated in Fig. 2. In this case the arrester is shown arranged in parallel with the suspension insulator string 15 and its terminals are connected respectively with the line conductor 16 and with the insulator string support 17 which normally is grounded. To protect the arrester from rain and snow, I have shown it provided with the umbrella or shield 18 which preferably is constructed of some refractory material and may be secured to the arrester in any suitable manner. In this form of my invention I have also shown a resistance 19, the function of which has already been explained above, arranged in series with the arrester. This resistance may have different values or may be omitted entirely according to the constants of the line and the apparatus to which it is connected. While I have not shown a resistance in series with the vacuum tube discharge path in Figs. 4 and 6 it is to be understood, of course, that it can be so used when desired.

Instead of the arrester comprising a single unit as in Fig. 3 it may be found preferable in most cases to employ one comprising a plurality of similar units arranged in series. Such arrangement has the advantage that the failure of one or more units does not prevent the functioning of the arrester. Such an arrangement has been illustrated in Figs. 4 and 6. In the former figure three similar units 20, each essentially like that shown in Fig. 3 are shown hung in a string by means of hook-shaped terminals 21 between the conductor 16 and the support 17. Obviously each may be provided with its own shield such as 18 in Fig. 3 or a single shield may be provided to protect all of the units of the string. In Fig. 6 presently to be described a number of discharge tubes are connected in series with an air gap. Where several units are employed in series, it may be found desirable in certain cases to have the times of breakdown variable among the several units. For this pur-

pose I have shown one of the units, namely the upper one in Fig. 4, shunted by the small capacitance 22 whereby the shunted unit has its time of breakdown somewhat delayed.

In the form of my invention illustrated by Fig. 5 I have shown the electrodes 23 in the evacuated glass tube 24 whose walls are transversely corrugated as at 25. It has been found that with highly evacuated tubes a discharge frequently occurs over the surface of the glass either inside or outside even though the glass be clean and dry, at a voltage which is much less than that which would cause a similar discharge through air. It is probable that such discharges are started from the vicinity of a terminal by corona effect from the exterior of the tube or by a glow discharge on the inside surface of the glass, the discharge apparently progressing along the smooth surface of the tube from some initial point. I am aware that solid insulators commonly are made with transverse corrugations or petticoats where the insulator is adapted for outdoor use, the corrugations or petticoats serving to protect at least a part of the surface of the insulator from rain and snow. Moreover, it is well known that with solid insulators whose surfaces are never wetted there is little advantage to be gained in preventing flash-over by increasing the surface distance between terminals by the use of corrugations or the like. I have found that a discharge tube provided with corrugations, such as shown at Fig. 5 and also in Fig. 7, will withstand a much higher voltage applied to its terminals without breakdown than is possible with a tube not so provided. The tube shown in Fig. 5 has its end wall extended to form "pant legs" 26 surrounding the terminals 27 to prevent long path discharges from the terminals adjacent the glass wall of the envelope. The protuberant electrodes 23 are made as large as may be conveniently slipped past the corrugated portion of the tube. For the protection of a 22-kv. line I have successfully used a tube such as shown in Fig. 5 in which the electrodes are aluminum discs 1 inch in diameter, (about 2.5 c. m.) spaced 2 mm. apart, the tube having a total length of approximately 6 inches and exhausted to such extent that the internal pressure is materially less than 1 micron.

In Fig. 6 is shown a discharge system employing a plurality of vacuum discharge devices embodying my invention connected between line and ground in series with an air gap. The vacuum devices are enclosed within insulating housings whereby they are shielded from mechanical injury and from the weather.

Referring to Fig. 6 the line 30 is supported by a string of insulators 31 from a support 32. From the line to ground are

connected, in the order named, a plurality of ordinary insulators 33 and a plurality of externally corrugated shells 34, 35, each containing vacuum discharge devices as illustrated by Fig. 7. The end terminals of the string of insulators 31 are provided respectively with electrostatic shielding rings 36, 36' and the insulators 33 are provided with rings 37, 37', which function to distribute or grade the potential differences at these terminals with respect to the insulators and to the vacuum devices respectively. The arrester outfits generally indicated as 34, 35 and shown in detail in Fig. 7, comprise a corrugated tube 40 consisting of porcelain, or other suitable material and having end caps 41, 42 consisting of iron, or other suitable metal cemented to the tube 40, as indicated at 43, 44. The cap 42 is constructed to be dis-assembled by screw threads for insertion of discharge devices, a suitable locking screw 45 being provided. Within the shell 40 are housed corrugated glass-walled vacuum tubes 47 only two of which are shown. The tubes have mushroom-like electrodes closely juxtaposed to one another. Four or five vacuum tubes are used in a single shell in some cases. The individual tubes are separated by spacers 48 consisting of cork or the like. End terminals of the tubes adjacent the caps 41, 42 are connected to these caps by screws as indicated. An intermediate connection is indicated at 49. In the operation of this system a lightning discharge or surge first arcs through the air between the rings 36, 37 and then is discharged to ground through the series-connected vacuum gaps.

In Fig. 8, I have illustrated a modification of my invention, embodying a resistor and a vacuum gap in a single unit. The envelope of this unit consists of an intermediate member 50 of corrugated vitreous material, such as glass, to which are sealed terminal members 51, 52 of metal, for example, copper. Within the outer envelope is an inner re-entrant chamber 53 containing an insulating fluid, such as mineral oil, in which is located a resistor 54. Supported from the chamber 53 by a rod 55 and radial supports 56 is a tubular member 57 terminating in a rounded cap 58 of copper, or other suitable metal, which is spaced closely adjacent the similarly rounded outer terminal 52. A shield 59 is provided adjacent the lower seal 60 between the glass member 50 and the metal member 52. The upper seal 61 is protected with cement as indicated. The space within the sealed chamber in which is located the discharge gap between 58 and 52 is highly evacuated. The resistance 54, which contacts with the rod 55 by a spring 62, preferably consists of the material above described, which exhibits decreasing electrical resistance with increas-

ing voltage. Electrical terminals 70, 71 may be applied as indicated.

In Fig. 9 is illustrated diagrammatically another modification of my invention in which magnetic coils 63, 64 are provided connected in series with the electrodes 65, 66 by the conductors 67, 68, 69. The coils generate a magnetic field aligned with its lines of force at an angle to the discharge path (as shown at right angles) between the electrodes 65, 66. This field generated by the discharge current assists in interrupting the arc discharge.

While I have shown and described the arrester comprising my invention as connected between a line to be protected and ground, it is not limited to such use but may be employed, for example, to bridge the contacts of switches controlling circuits subject to dangerous line surges, or in fact in any circuit where it is desirable to by-pass high voltage waves or surges.

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

1. A discharge device for transient high potential electric currents comprising a sealed envelope, cooperating closely juxtaposed electrodes therein made of solid material and being so proportioned and arranged as to support without harmful effect a transient discharge of arc-like characteristic, the space in said envelope being evacuated and the electrodes being degassed to such extent that ionization of gas other than vaporized electrode material is negligible when a transient discharge sufficiently high to electrically vaporize electrode material is conducted therebetween.

2. A lightning arrester comprising a sealed envelope, electrodes therein spaced near enough to one another to permit transient electrical discharges to pass therebetween, the juxtaposed surfaces of said electrodes having a radius of curvature large in comparison to the distance between the same, the space in said envelope being evacuated and the electrodes being freed from gas to such extent that ionization of gas other than vaporized electrode material is negligible when a metal vapor arc is formed during the operation of said arrester.

3. A lightning arrester comprising a sealed envelope, electrodes of solid metal therein free from gas disengageable in a vacuum and having protuberant heads spaced apart a distance in the neighborhood of one millimeter, the space in said envelope being evacuated to such extent that ionization of gas other than vaporized electrode material is negligible during the operation of said arrester.

4. A device for discharging transient electric currents comprising a sealed envelope, cooperating closely juxtaposed electrodes therein made of solid metal previously de-

gassed in a finely divided state in a vacuum, said electrode being sufficiently massive to remain substantially intact when vaporization of surface material from said electrodes occurs by transient electric discharges occurring therebetween, the space in said envelope being evacuated to such low pressure that ionization of residual gas is negligible in the operation of said device.

5. In combination with an electric conductor subject to electrical surges, a discharge circuit therefor and a discharge device in said circuit comprising a gas-tight envelope and a pair of electrodes therein consisting of solid material which vaporizes under the action of the surge to conduct away the main body of the surge by an arc discharge, the space within the envelope and the electrodes themselves being free of gas to such an extent that ionization of any residual gas plays no essential part in the conduction of current between such electrodes.

6. In combination with an electric device subject to electrical surges, a discharge circuit and a lightning arrester in said circuit comprising a gas-tight envelope and a pair of solid electrodes mounted therein which vaporize under the action of the surge to conduct away the main body of the surge by an arc discharge, said electrodes having sufficiently large mass to support a high current, transient discharge while remaining substantially intact, and being spaced apart a distance not more than one centimeter, the envelope being evacuated and the electrodes being degassed to such an extent that ionization of any residual gas plays no essential part in the conduction of current between said electrodes.

7. The combination with an electric conductor subject to high voltage surges, a lightning arrester comprising a sealed envelope evacuated to such a degree that ionization of residual gas is substantially prevented and a pair of similar electrodes of solid material mounted therein in close juxtaposition, which vaporize under the action of the surge to conduct away the main body of the surge by an arc discharge said electrodes having an external rounded surface, the radius of curvature of which is large compared to the distance between said electrodes and being free of occluded gases, terminals extending through the walls of said envelope, and circuit connections whereby surges in said conductor may be carried away through said arrester.

8. The combination of an electric transmission line and a device connected in discharge relation thereto and comprising a sealed gas-tight envelope, a pair of similar, massive, copper electrodes therein which vaporize under the action of the surge to conduct away the main body of the surge by an arc discharge, and connections from said

electrodes extending therefrom through the walls of said envelope and connected respectively between said transmission line and ground, the space within said envelope and said electrodes and connections being free of gas to such an extent that ionization of any residual gas plays no essential part in the conduction of transient discharges between said electrodes.

- 10 9. A lightning arrester comprising a double-walled envelope providing a plurality of sealed chambers, one chamber containing closely juxtaposed gas-free electrodes having a large radius of curvature compared to the
15 distance between said electrodes and having the space between said electrodes evacuated to such low pressure that ionization of residual gas is inappreciable during operation and a second chamber containing a resistor
20 immersed in an insulating fluid.

10. A lightning arrester comprising a sealed envelope which is evacuated to a residual pressure of less than one micron of mercury, metal electrodes therein which are
25 freed from gas and have heads of about 2.5 centimeters in diameter, said electrodes being spaced apart about 2 millimeters, the juxtaposed surfaces of said electrodes having a large radius of curvature relative to
30 the distance between said electrodes.

11. A lightning arrester comprising a sealed envelope, blunt electrodes therein so proportioned and arranged as to support without harmful effect a transient discharge
35 of arc-like characteristics, the space in said envelope being evacuated and the electrodes consisting of material of such low vapor pressure that ionization of gas other than electrode material vaporized by a transient
40 discharge is negligible during the operation of said arrester.

In witness whereof, I have hereunto set my hand this 5th day of August, 1930.

ALBERT W. HULL.

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