

May 7, 1935.

S. SLEPIAN ET AL
POROUS LIGHTNING ARRESTER

2,000,719

Filed July 22, 1929

3 Sheets-Sheet 1

Fig. 1.

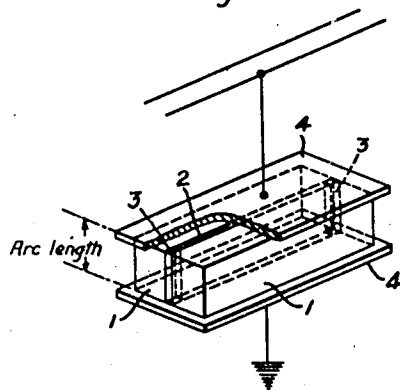


Fig. 2.

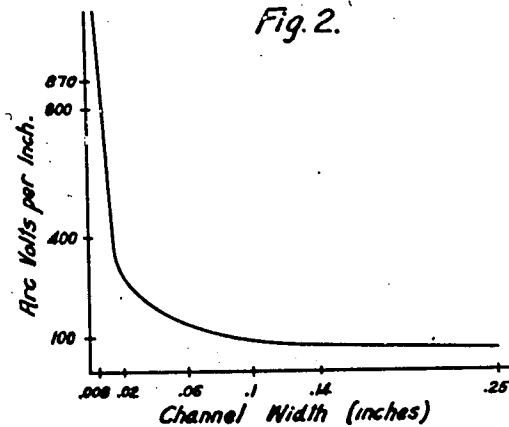


Fig. 3.

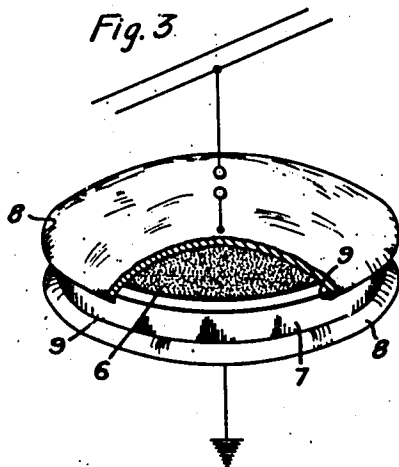


Fig. 4.

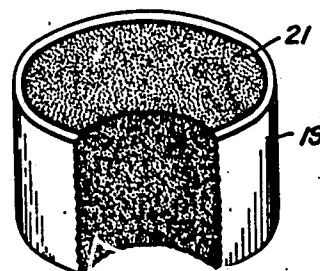
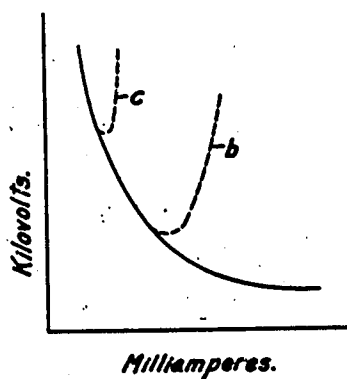


Fig. 5.



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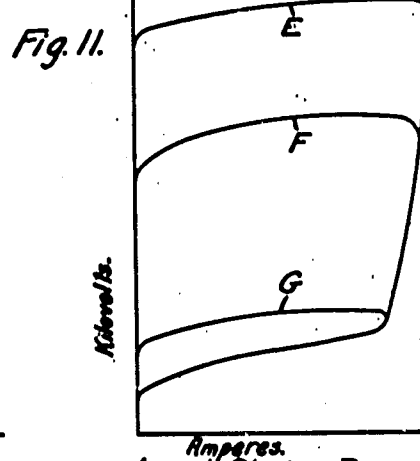
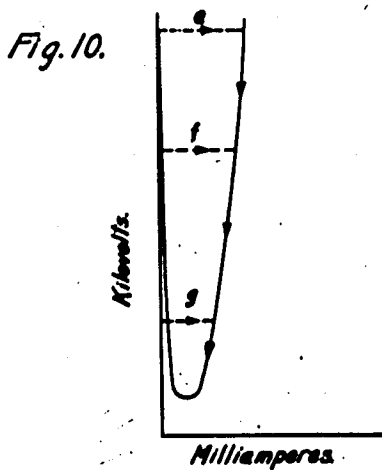
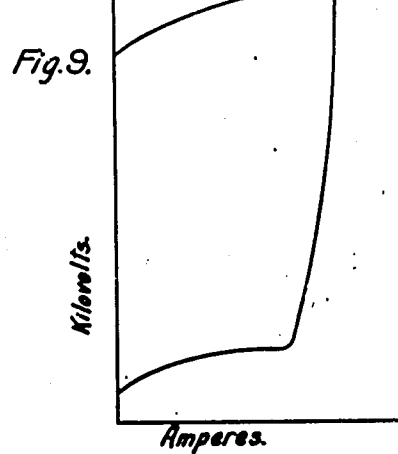
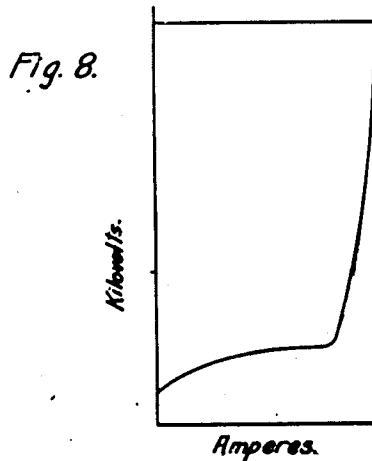
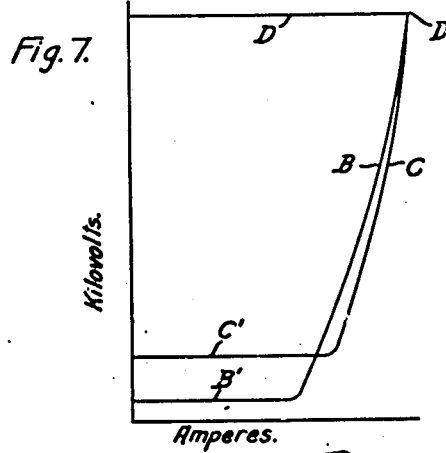
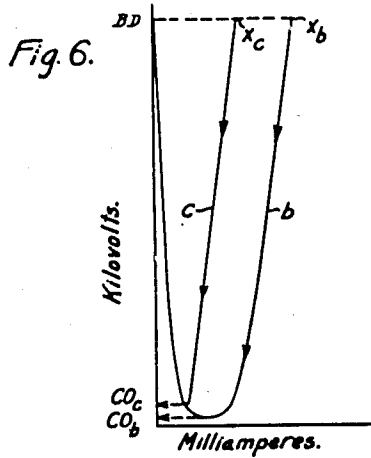
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POROUS LIGHTNING ARRESTER

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3 Sheets-Sheet 2



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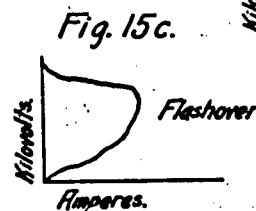
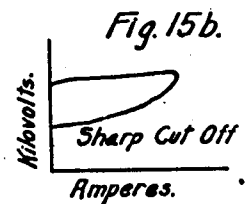
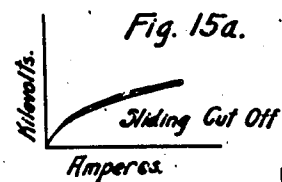
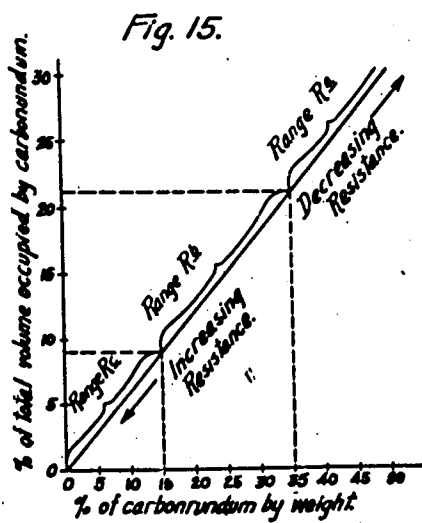
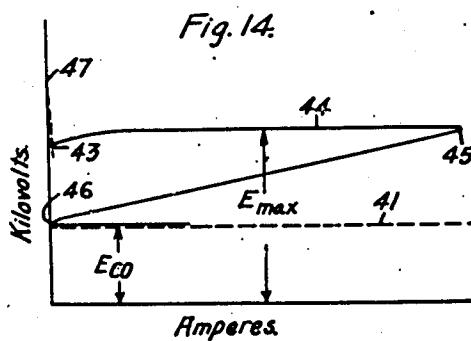
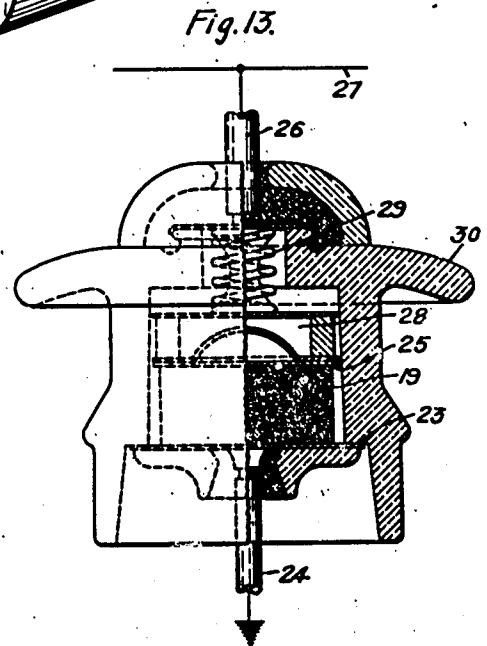
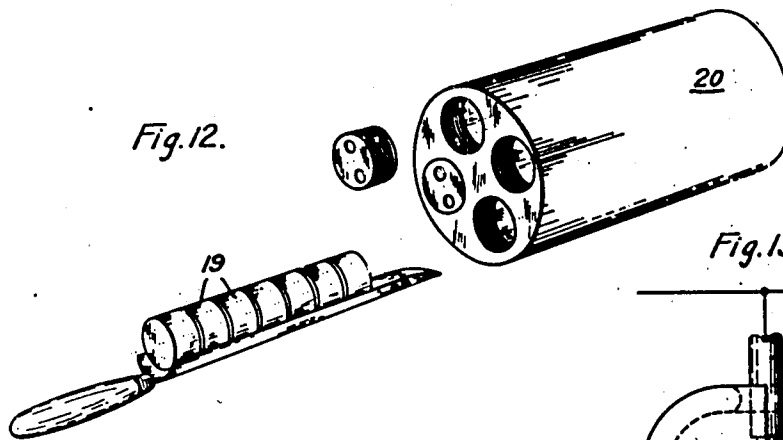
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POROUS LIGHTNING ARRESTER

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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,000,719

POROUS LIGHTNING ARRESTER

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Application July 22, 1929, Serial No. 379,899

44 Claims. (Cl. 175—30)

Our invention relates to a new type of light-
ning arrester utilizing a new principle never be-
fore applied to such devices, namely, the princi-
ple of restricted discharges in confined spaces
of such small dimensions that the walls of the
spaces exercise a strong delonizing effect upon
an arc passing therethrough, with the result that
the voltage gradient necessary to maintain the
arc is of the order of thousands of volts per inch
of arc length.

The principal object of our invention is to pro-
duce a lightning arrester having a better voltage-
current characteristic than any previous arrester
on the market, and at the same time having a
smaller size, being about one-half of the size of
the so-called autovalve arrester which was, in
turn, about one-half of the size of the best com-
petitive arrester on the market. The autovalve
arrester just referred to is an arrester operating
on the principle of glow discharges between high-
resistance plates, as described in the patent to
J. Sleplan No. 1,509,493, granted September 23,
1924.

In particular, our invention relates to the use
of a porous insulating block as a lightning ar-
rester, preferably with the addition of a small
quantity of powdered conducting material dis-
tributed throughout its mass, the arrester being
so used that it operates on the principle of a large
number of arcs which entirely fill some of the
pores of the arrester.

Referring to the accompanying drawings,

Figure 1 is a perspective view of our earliest
form of restricted-discharge path arrester,

Fig. 2 is a curve diagram showing the relation
between the voltage gradient and the channel
width of such an arrester,

Fig. 3 is a perspective view of an early form
of our invention utilizing fine insulating particles
without a binder,

Fig. 4 is a perspective view of a preferred form
of porous block element constructed according to
our invention,

Fig. 5 is a curve chart showing the volt-ampere
characteristic of a free arc in air, as compared
to the characteristics of two arcs in restricted
paths of different degrees of restriction,

Figs. 6 to 11 are other volt-ampere charac-
teristic curves explanatory of our invention,

Fig. 12 is a perspective view of a graphite sag-
ger which is used in the process of manufacture
of our preferred form of porous-block arrester,

Fig. 13 is a longitudinal sectional view of a
complete arrester including the porous-block ele-
ment shown in Fig. 4,

Fig. 14 is a reproduction of a cathode-ray oscil-
logram showing the volt-ampere characteristics
of our preferred form of arrester,

Fig. 15 is a curve diagram showing the rela-
tion between the percent of the total disc volume
occupied by the carborundum and the percent of
carborundum by weight contained in a disc made
of grog and carborundum, and

Figs. 15a to 15c are typical volt-ampere curves
showing the characteristics of the three ranges
of the proportions of the ingredients which are
shown in Fig. 15.

The fundamental principles of our invention
are best illustrated with reference to the first
form of apparatus which we tried out, as indi-
cated diagrammatically in Fig. 1. In this device,
the discharge takes place in a narrow channel
which is formed between two insulating plates
of such materials as glass, slate, soapstone, as-
bestos, wood, or any other material having a high
dielectric strength. The insulating plates are
so disposed as to provide a very narrow channel
between them, and they should be clamped into
position by some means (not shown) to prevent
them from spreading apart by reason of the gas-
eous pressure which is developed by the discharge.

The walls of the channels exercise a strong
delonizing effect upon the arc or discharge with-
in said channel, thereby increasing the voltage
necessary to maintain the arc or discharge in
the channel. The relation between the minimum
voltage gradient which will sustain an arc and
the channel width, for channels having insulating
walls, is shown in Fig. 2, for a certain range of
channel widths which could be readily measured.
It will be noted that, for widths decreasing from
 $\frac{1}{4}$ of an inch, this minimum voltage increases
very rapidly. When widths less than 1 mil are
reached, the minimum voltage for maintaining
a discharge begins to approach the breakdown
voltage of the entire arc path, thus approaching
the desired condition for efficient arrester opera-
tion.

We have found that a film of finely divided
conducting material on the walls of the channel
serves to lower the breakdown voltage of the
discharge path, thereby improving the charac-
teristic of the device for use as a lightning ar-
rester. In Fig. 1, this thin film of finely divided
conducting material is indicated at 2. In the
same figure mica spacers 3 are indicated, for de-
termining the width of the channel, and con-
ducting terminal electrodes 4 are shown on the
top and bottom of the plates 1.

In any slot or channel of constant width, the

discharge spreads laterally across the channel as the current increases and it tends to maintain itself at a substantially constant current-density, namely, the current-density at which the arc voltage is a minimum. For discharges in channels of practical widths, such as a few mils, the current-density is between 2000 and 4000 amperes per square centimeter. Reliable figures cannot be obtained for channels much narrower than a mil, because of the bowing out of the walls of the channels under the action of the gas pressures developed during the discharge. It was this impossibility of obtaining extremely narrow channels that lead us to turn to pores or extremely fine holes, wherein the more or less cylindrical walls of the pores would have a greater resistance to enlargement, under the gaseous pressure of the discharge, than the long walls of a channel member.

As illustrated in Fig. 3, one way of providing, in effect, a large number of narrow channels is by the utilization of a pile of small insulating particles or pellets, such as sand or powdered quartz. For example, pellets of $\frac{1}{16}$ of an inch diameter give an effective channel approximately $\frac{1}{2}$ of an inch in width and having a minimum discharge voltage of the order of 200 volts per inch. By reducing the size of the particles, the voltage necessary to maintain the discharge is raised.

For a lightning arrester designed for the higher voltages, the particles may be reduced to such size as to form a powder, in which case it is necessary to thoroughly dry out the material and to hermetically seal it in a container, and, if necessary, to include a drying agent, such as anhydrous calcium chloride, or anhydrous phosphoric acid. The particles must also be tightly and rigidly packed so that no channel of large width will form.

In Fig. 3, is illustrated a practical arrangement of such an embodiment of our invention, wherein the insulating particles 6 are held by a porcelain ring 7 and electrodes 8 so disposed at the ends of the ring, or soldered to a metal glaze on the porcelain, so as to provide a hermetical joint 9.

Small holes or pores

Our invention is preferably embodied in a porous block, composed of a composite material consisting of powdered particles suitably bound together, as indicated in Fig. 4. Before giving a detailed description of the composition and processes of manufacture of such an arrester, we wish first to give some general explanations concerning the nature of discharges in small holes or pores.

Referring to Fig. 5, it will be noted that the volt-ampere characteristic of an arc in the open air, as shown by the full-line curve, is a drooping characteristic, the voltage decreasing with increased currents. If the arc is confined to a small hole or pore, the volt-ampere characteristic curve is entirely changed. For very small currents, the voltage characteristic is drooping, following substantially the curve for the unrestricted arc, but when the current is increased enough to be restricted by the hole, there is an increase in voltage with further increases in the current, thus producing the upwardly curving dotted-line characteristics *b* and *c*, the latter curve being for the smaller pore.

A long hole of several inches length, in insulating material, has a breakdown voltage-gradient of the order of 50,000 volts, or more, per inch of

length, depending upon the size of the pore and the nature of the material. The breakdown voltage-gradient of holes or pores of short lengths is still higher. For holes, of say 1/100 inch in diameter and larger, the minimum arc voltage, which is the minimum voltage on the volt-ampere characteristic, is less than 1000 volts per inch. Consequently, if the curves corresponding to those shown in Fig. 5 are extended to the left, they meet the voltage axis at a point fifty or more times as high as the minimum voltage points, as indicated in Fig. 6.

Referring to Fig. 6, if the voltage applied to a hole is raised until the breakdown voltage is reached, and then held at that value, the current passing through the hole is the intersection of a horizontal line through the breakdown voltage *BD* and the curve *b* or *c* corresponding to the hole, as indicated at x_b or x_c in Fig. 6. When the voltage is lowered, the current reduces, following back on the curve *b* or *c*, as indicated by arrows in Fig. 6, until the minimum arc-sustaining voltage, or cutoff voltage CO_b or CO_c , is reached.

If the voltage is further reduced, the current drops substantially to zero, or to the leakage current passed by the porous material. The voltage at which this happens is the cutoff voltage.

It will be noted that the curve *c* for the smaller hole has the same breakdown voltage *BD* as the curve *b*, but that the cutoff voltage is higher for the smaller hole.

It is clearly desirable, in a lightning arrester, to have a cutoff voltage as near as possible to the breakdown voltage. This is accomplished by using exceedingly fine holes. When this is done, however, the current carried by a single hole reduces to a very small value, down to perhaps a few milliamperes. It is necessary, then, to use a very large number of these fine holes in parallel and this is more effectively accomplished by utilizing a material having very fine pores.

If all of the pores through the porous material have the same breakdown voltage, and if all of the pores are of uniform cross-section in size, so that they have the same cutoff voltage, a characteristic such as the curve *B* or *C*, shown in Fig. 7, is obtained. At the initiation of the discharge, as represented by the upper horizontal part *D* of the curves in Fig. 7, enough pores break down to carry the current necessary to carry off the lightning charge and commence reducing the voltage, as indicated at *D'*. When the voltage is lowered, the current reduces, in all the pores together, until the lower horizontal portion *B'* and *C'* of the curve is reached, and then the discharge ceases in all of the pores together. As before, the curve *C* for the finer pores has a higher cutoff voltage *C'*.

If the pores are not all of the same diameter, they will not all cease carrying current at the same time, as the voltage across the discharge is lowered. The lower branch of the volt-ampere characteristic will then depart from the horizontal and may look like the curve shown in Fig. 8.

Similarly, if all of the pores do not have the same breakdown voltage, the upper branch of the characteristic is no longer horizontal, but is inclined upwardly as indicated in Fig. 9. Variability in the breakdown voltage of the pores may arise from the fact that the pores are distorted in various degrees, and possibly other causes.

Trace of conducting material

By the utilization of porous material without the inclusion of conducting material, it is not convenient to bring the breakdown voltage sufficiently near to the cutoff voltage to be of the highest grade of service as a lightning arrester or protective device for discharging excessive voltage surges.

We have found, however, that, by adding very small traces of finely divided conducting material to the porous material, it is possible to lower the breakdown voltage without changing the other portions of the volt-ampere characteristic very much.

Fig. 10 indicates this effect on the discharge in a single hole. The breakdown voltage, without conducting material, is indicated at *e*; with a slight amount of conducting material at *f*; and with still more conducting material at *g*. For a single hole, the volt-ampere characteristic, which is obtained by raising the voltage to the breakdown value, and holding it at that point, and then lowering the voltage, is shown in Fig. 10 by the dotted lines and by the arrows.

The effect of adding conducting material, upon the characteristics of discharges in a multiplicity of holes or pores, is shown in Fig. 11. The cutoff portion or bottom branch of the curve in Fig. 11 is not altered by the addition of the conducting material, but the upper branch of the characteristic curve is brought down by changing from a slight or negligible amount of conducting material (curve E), to an insufficient amount of conducting material, as represented by curve F, and finally to a sufficient amount of conducting material, as indicated by the curve G. The conducting material lowers the breakdown voltage and thus makes the cutoff voltage and the breakdown voltage more nearly equal.

In addition to a general lowering of the breakdown characteristic, the incorporation of a small trace of conducting material in a porous-block arrester has been found to have two other very important effects, which may very probably be explainable as follows. The addition of the conducting material has the effect of (1) flattening out the voltage-current characteristic of the arrester, by making the breakdown voltages of the pores smaller so that they more closely approach the voltages necessary to maintain a discharge in the pores, the maintaining voltage being, of course, the cutoff voltage of the arrester, or the voltage at which the arrester ceases to carry a discharge. The addition of the conducting material also has the effect of (2) increasing the life of the arrester, presumably by causing breakdown to occur in more pores at once, thereby distributing the discharge over a larger number of pores.

The manner in which these two results are effected may very probably be explained somewhat as follows. For a given length of pore, in an insulating material, the breakdown voltage is affected but very slightly by the size or diameter of the pore, but the voltage gradient of the discharge in the pore, once breakdown has occurred, increases very rapidly as the diameter of the pore is decreased, or, conversely, the arcing voltage or maintaining voltage or cutoff voltage is very much lower for large pores than for small pores. In any natural or inherently porous material, there are some slight irregularities in the lengths of the various porous paths from one surface to another, so that the breakdown voltages of

all of the pores, in an insulating material, are not the same.

The effect of the slight traces of conductor material, which are incorporated into the porous-block arrester material, is to produce extremely attenuated chains or needles of conducting particles disposed in the walls of the pores, so that the potential gradient or electrostatic field, in the pores between the opposite terminals of the arrester, is rendered non-uniform. These needles are believed to produce needle discharges which initiate the ionization of the gaseous material in the pores, thereby lowering the breakdown voltage, and making the breakdown voltages of all of the porous paths more nearly equal. In other words, the effect of the needle discharge is more noticeable in the porous paths of high breakdown voltage than in those having the lower breakdown voltages. The cross-sections of these needles or chains of minute conducting particles, probably making loose contacts with each other, are so small that no material current can be carried by the needles, so that, when the discharge is once initiated, by breaking down the gaseous space by reason of the ionization produced by the needle discharges, the discharge current is distributed throughout the entire volume of the pores without being affected by the presence of the needles, because the current carried by the needles is probably negligible compared to the current carried by the pores.

This explanation, which seems to be the proper explanation of the phenomena involved, also explains the fact that a larger quantity of conducting material is required for porous arresters having large pores than for the more finely porous materials, because the voltage gradient necessary to maintain an arc in a large pore is much smaller than in a small pore, so that more conducting material must be utilized, in the case of the large pore, in order to bring down the breakdown voltage to the vicinity of the cutoff voltage. Too much conducting material will needlessly increase the leakage loss, which is measured in milliamperes, or fractions of an ampere, and as the quantity of conducting material is increased more and more until it becomes very excessive, it will begin to short-circuit the arcing paths through the pores because the voltage drop in the conducting paths will become smaller than the minimum voltage drop necessary to maintain the arcs in the small pores.

In general, therefore, the desirable or permissible resistivity of the porous-block arrester material depends upon the fineness of the pores. Nevertheless, the resistivity of the porous-arrester material is always so high that it is of the order of the resistivity of a leaky insulator, being measurable in units of the order 10^3 to 10^6 ohms, or even much higher, per centimeter cube, as against something like 10^2 ohms for the autovolt arrester disc, 10^{-3} ohm for carbon, and 10^{-6} ohm for copper.

The resistivities here referred to are the resistivities to conductive currents or leakage currents, and not the equivalent resistivity $R=E/I$ when discharging.

A wide range of diameters of the pores seems to be available, ranging probably anywhere from a diameter of the order of 1 mil, or possibly more, to diameters of the order of 10^{-3} mils, or possibly less.

The foregoing values are not absolute and sharply fixed, as desirable results may be obtained with a ten-fold or even a hundred-fold

departure from any of the values stated. Our preferred construction will be described more particularly hereinafter.

The porous-block arrester is of such height, or length between the terminals of the high-resistance porous material, that the root-mean-square value of the maximum rated or operating line-to-ground voltage of the system to be protected may be of the order of 2000 or 3000 volts per inch of arrester-height, although the invention is undoubtedly of generic application susceptible of development into arresters of higher voltage-gradient.

Manufacture of porous-block arresters

The preferred embodiment of our invention utilizes a composite porous-arrester material in which the largest pores, which, within certain limits, seem to break down first and carry all of the current until the total current exceeds the capacity of said largest pores, are of uniform size and uniformly distributed through the material. This material is composed of a conducting substance and a non-conducting substance. We have found that the non-conducting substance should be one which will not laminate when molded, and which does not have any water of crystallization, like the clay previously utilized for molded resistance compositions. Moreover, we have found that it is necessary to use a non-conducting ingredient such that the pores will not be too fine, as hereinafter pointed out.

Our porous-block arrester requires two materials, to wit, grog and carborundum, which are subsequently carbon-treated as will be described. The grog is the equivalent of means for providing porosity between the conducting carborundum particles, as well as serving as an insulating binder. The carborundum, when coated with the carbon, is the equivalent of any conducting particles which are capable of being cemented into the body of the material without sacrifice of mechanical strength or life.

By the term grog, we mean calcined clay which we preferably obtain by heating kaolin clay to cone 8 or 9, or about 1300° C., in a kiln. This is merely a convenient temperature, which is not believed to be obligatory. This heating operation removes the water and this causes some of the inevitable shrinkage to occur in this early stage of the manufacture.

The calcined clay, which we designate as grog throughout this specification and in the appended claims, is a white porous substance having some vitrified lumps therein and having other particles ranging down in size, to impalpable dust. Practically all of the particles, however, are much coarser than the original clay particles. All palpable particles of the grog are highly porous, readily absorbing liquids.

Clays having a minimum amount of conducting impurities are preferable, as raw materials, since it is more satisfactory to add conducting material, in the proper proportions, than to trust to natural proportions, or to take out an excess conductive material. Also, the properties of the various materials, particularly the sizes of the constituent particles, play an important part in the successful operation of the arrester. By the utilization of grog, the proper size of the non-conducting particles may be obtained and controlled by a subsequent grinding operation.

To the same end, the grog material is kept covered up as much as possible, throughout the manufacture of our porous-block arrester, in

order to prevent its contamination with soot or other conducting impurities from the air.

While we prefer to use grog or calcined clay, it does not follow that this is the only material that will give a desirable performance. In general, it is believed that any granular insulating refractory material having the proper particle sizes may be used. Thus, it is possible that particles of zirconium silicate or other refractory insulating materials, may be used with a small percentage of ordinary clay, or other binder, and carborundum, or other conducting material.

The grog so obtained is then put into a grinding mill which is needed particularly on account of the large hard chunks in the grog. This reduces the material to a powder having particles of assorted sizes, which will pass through about a 50-mesh screen, or a screen having 50 holes per linear inch.

The material is then put through a ball mill which produces particles of much more uniform size than the grinding mill. Here, the grog is reduced to particles of smaller sizes, of which the following is an illustrative example:

Grog (calcined clay)	Percentage by weight
	Percent
Between 100 and 140 mesh.....	20
Between 140 and 200 mesh.....	40
Between 200 and 270 mesh.....	20
270 mesh and finer.....	20

The carborundum which we use is a commercial product which is sold in the trade as 100-mesh carborundum, but which actually tests out approximately as follows:

	Percentage by weight
	Percent
Between 100 and 120 mesh.....	9
Between 120 and 140 mesh.....	52
Between 140 and 200 mesh.....	38
Over 200 mesh.....	1

The grog, 75% by weight, and the carborundum, 25% by weight, are then very thoroughly dry-mixed.

Water is then added, using the minimum amount, or very little, if any, over the minimum amount of water which will dampen all of the particles and make it possible to stir the mixture. The resulting plastic material is then laid out to dry until it is sufficiently dry to be run through a granulator having a screen of from 12 to 20 mesh without adhering to the granulator. The semi-dry granulated material is then re-granulated through either the same or a finer screen, say 30-mesh, and is again spread out to dry. When it has dried until the percentage of water is about 6% by weight, the material is loaded in air-tight buckets to prevent further drying, and is then ready for molding, which should be done as soon as possible. The purpose of the granulation is to produce a material which will pour easily and will distribute itself into all of the corners of the mold, thus producing a more uniform molded product.

It will be noted that the pulverized grog and carborundum are first thoroughly dry-mixed and then wet-mixed. The effect of the dry-mixing is to cause the larger particles, either of carborundum or grog, to be coated by the smaller particles, of either the same or the other material,

forming resultant aggregates, or coated particles, which are larger than the particles before the mixing process. In this way, the smallest particles, or impalpable dusts, are, in effect, largely removed from the mixture by causing such particles of dust to become attached to the surfaces of the larger particles. When the material is subsequently molded, therefore, the voids between the larger particles are not completely filled by smaller particles.

It will thus be seen why the amount of water which is added just before the wet-mixing process must not be excessive, because an excessive amount of water would probably, according to our present theories, wash off these smaller particles from the larger particles, causing the smaller particles to fill up the larger spaces, with the result that the pores of the resulting porous material would be so fine that the volt-ampere characteristic would be unduly high and the life and the current-carrying capacity of the arrester would be impaired. However, a very slightly increased amount of water, over the bare minimum necessary to dampen the particles and render the mixture plastic, is desirable as it seems to impart more strength to the finished molded product.

The mixture of grog and carborundum may be pressed in the form of discs 19, in a suitable mold (not shown), under any suitable pressure. We are using a pressure of about 7 tons per square inch.

The discs are then taken out of the molds and allowed to dry at ordinary room temperature for a day, before being fired. If the discs are too wet when they are fired, the resulting lightning arrester will have a slightly lower voltage characteristic, with the cutoff less sharply defined, approaching that shown in Fig. 15a. On the other hand, if the discs are too dry when they are fired, they are weak mechanically and have a short life.

It is preferable to fire the discs 19 in a closed carbon or graphite sagger 20 (Fig. 12), in a substantially closed furnace, or in general terms, in an oven in the presence of carbon, the hottest portion of which has a temperature which, according to our present practice, is maintained as nearly as possible at 1360° C., although other temperatures, say between 800° and 1400° C., may be used. If a temperature much lower than 1360° C. is used, the fusion of the grog particles is in general not sufficiently complete to provide the necessary mechanical strength, whereas, if temperatures higher than 1360° C. are permitted, the shrinkage of the discs seems to increase, with consequent loss both in performance and life of the arrester. Of course, if more refractory mixes are used than our preferred grog mix above described, it may be possible, or even desirable, to use much higher temperatures such as 1800° C.

The saggars are moved slowly into and out of the hottest part of the furnace, the entire process requiring about 13 hours.

The effect of this firing of the discs in graphite saggars is to coat the particles of the material, and all of the surfaces of all of the pores, with condensed vapors of carbon, or, more generally stated, to coat the same with condensed vapors of any conducting material, the coated particles being small compared to the pore sizes. When the discs within the saggars are in the hottest portion of the furnace, a very small portion of the material of the sagger, or other carbonaceous material, is believed to be vaporized, and the discs are in the furnace long enough for the car-

bon or carbonaceous vapors to penetrate through all of the pores thereof. When the saggars containing the discs are moved to cooler portions of the furnace, at the end of the firing operation, the carbon vapors entrapped within the discs become solidified, thereby coating all of the pore surfaces as above described.

Carbon impregnation may also be accomplished by firing these discs in an atmosphere of natural gas or hydrocarbons, such as those derived from oils, etc. The discs seem to break down the molecules of the gas, permitting the carbon to deposit upon the walls of the pores.

At any rate, the discs go into the furnace white and come out black, and they show black throughout every portion of their interior however finely they may be subsequently broken up, for examination. The amount of carbon absorbed by the discs in the saggars is only a trace.

After the firing operation, the parallel contact faces of the discs are preferably plated with a copper coating 21 (Fig. 4), by the Schoop-spray process, leaving about an eighth of an inch of uncoated surface around the periphery in order to avoid any risk of getting copper on the lateral surfaces. This copper coating is used in order to decrease the contact resistance and probably prolong the life of the discs.

In order to prevent flashover, the lateral surfaces of the discs are preferably coated with an insulating cement, such as a mixture of alcohol, shellac and pigment. A very satisfactory cement for this purpose is one invented by Byron V. McBride, and having the following composition:

Garnet shellac-----	3 pounds
Copal gum-----	¾ pound
Castor oil-----	¾ pound
Iron oxide (Venetian red)-----	5 pounds
Alcohol-----	¾ gallon

Our finished product comprises isolated conducting particles of carborundum, which serve as a means for uniformly starting the discharge through the short gaps or pores of the porous insulating material by the "trigger action of corona", as it has been called, discharging in fine brush-like streamers from sharp projections on the conducting particles.

It is only by the utilization of grog, or other granular material, that the best results have been obtained. A mixture of grog and carborundum gives a very desirable performance characteristic. The mixture, when molded and baked, has a long life when subjected to repeated discharges, and is capable of carrying a discharge of many hundred amperes without being broken or destroyed. As a result of the utilization of grog, the field of porous-block arrester application is not limited to low currents.

The calcining operation does not appreciably destroy the binding power of the kaolin if the resulting grog is used with the proper amounts of conducting material and water as above described.

While we prefer to use carborundum, supplemented by the trace of carbon, as our conducting material, other materials having similar properties may be substituted. Brass, lead, copper, nickel, graphite, iron, aluminum, and alloys such as ferro-silicon, ferro-manganese, ferro-chrome, and ferro-tungsten, give good results, and a description of the preparation and use of some of them will be included hereinafter as constituting one of the forms of our invention. Many of these metals necessitate the use of firing temperatures

much less than 1360° C. It is possible, also, that still other materials, such as conducting oxides and sulphides of metals, may be found suitable for use as the conducting particles.

In Fig. 13 we have shown an embodiment of our invention in a finished lightning arrester comprising a porous block or disc 19, which is similar to the one shown in Fig. 4 and which is manufactured according to the processes just described. This arrester element or disc 19 is assembled between a bottom plate 23 to which a ground lead 24 is connected, and a top plate 25 which is connected, by means of an upper lead 26, to a transmission line 27 which is to be protected from lightning.

Interposed between the upper lead 26 and the top plate 25 of the particular porous-block arrester shown in Fig. 13 is a series gap device 28, for the purpose of normally keeping the line voltage off of the arrester. If the leakage current is sufficiently small, the series gap may be omitted. On the other hand, when the arrester includes a properly designed series gap device 28, as shown, which is capable of interrupting the leakage currents which would otherwise flow, due to line voltage after the termination of any discharge, the magnitude of these leakage currents is more or less immaterial as long as the leakage does not greatly exceed 10 amperes.

As was common in autovalve lightning arresters of the type mentioned in the beginning of this specification, a spring 29 is also utilized, for yieldably pressing the gap device 28 against the top of the arrester and holding the parts in position. The whole is enclosed in a suitable porcelain casing 30.

Properties of our porous-material arrester

The volt-ampere discharge characteristic of our porous-block arrester, as determined by means of a cathode-ray oscillograph, is shown in Fig. 14. The crest value of the maximum alternating-current voltage at which the transmission or distribution line may operate is indicated by the dotted horizontal line 41. When a surge occurs on the line, the voltage rises above the maximum or crest value 41 of the line voltage, and at a point 43, the first pores of the arrester break down. Thereafter, additional pores break down in rapid succession, as the surge voltage increases from the value indicated by 43 to a maximum voltage E_{max} indicated at 44 which is only slightly higher than the breakdown voltage indicated at 43. This is the maximum voltage permitted by our arrester when dissipating the surge, and the current necessary to be handled by the arrester, during the few microseconds of the discharge, may be 500 or 1000 amperes, or even 5000 amperes in high-voltage arresters. After the maximum current value has been reached, the voltage begins to fall, and it will be noted that the curve shown in Fig. 14 begins almost immediately to bend back on the downwardly sloping portion of the curve, which extends from the point 45, near the maximum current point, to the point 46, near the Y-axis, thus establishing the cutoff voltage E_{co} , which is the normal crest-voltage rating of the arrester, or 1.4 times the root-mean-square rating of the arrester, and is only slightly larger than the crest line voltage 41. During some or all of the period 45 to 46, the pores of the arrester are successively ceasing to carry their discharges, as the minimum arc-sustaining voltages for the different pores are passed.

When a series gap is used, as indicated at 28 in Fig. 13, its effect is to cause the overall breakdown voltage to have a momentary value 47, as indicated in Fig. 14, which will be slightly higher than the breakdown voltage of the series gap. As soon as the series gap 28 breaks down, the voltage instantaneously falls until the discharge is taken over by the porous-block arrester, as indicated by the dotted lines in Fig. 14. This is because the series gap has no valve characteristic, since the voltage across the gap immediately falls from a matter of many kilovolts to some 20 or 30 volts, during the discharge, whereas the arrester block itself always has a discharge voltage which is higher than the line voltage, thus operating like a back electromotive force imparting, to the arrester, its valued valve characteristic.

Figs. 4 and 13 show a porous disc 19, which in actual size is about 2 inches in diameter, and about 1 inch thick, and is sufficient for protecting an alternating-current line having a root-mean-square voltage of 3000 volts from line to ground.

The breakdown voltage, indicated at 43 in Fig. 14 is, in general, about twice the cutoff voltage E_{co} . The maximum voltage E_{max} permitted by the arrester is, in general, not much more than the breakdown voltage 43, and somewhat less than two and one-half times the cutoff voltage E_{co} , and in no case should it be more than four times this value. Where the series gap is used, the maximum gap voltage should not be over four times the cutoff voltage E_{co} and it is usually about two or three times this value, in order to allow for variations in the performance of the series gaps.

The cutoff voltage E_{co} is not, in general, an absolutely clearly defined point. Without the series gap, the current through the arrester will not drop to zero at E_{co} but will drop to a value of, say 1 to 10 amperes, or even, in some designs, down to 1 milliamperes, which represents the leakage current flowing through the arrester at this voltage. In general, it may be said that the cutoff voltage is the voltage at which substantially all of the pores cease carrying discharges by means of arcs filling the entire pore volumes.

The line voltage has a crest value of 41 which is necessarily at least a fraction of one percent less than the cutoff voltage but is usually about 5% or 10% less than this voltage. In general, it may be said that the crest voltage of the line should be more than 70% of the cutoff voltage; that is to say, the root-mean-square line-to-ground voltage should be more than one-half of the cutoff voltage.

The specific resistivity of our porous arrester material is between 1000 and several hundred thousand ohms per centimeter cube, and preferably around 14,000 ohms per centimeter cube, when measured with direct-current voltages at a voltage gradient of 400 volts per centimeter. These values are slightly higher at a voltage gradient of 200 volts per centimeter, and are much higher at extremely low voltage gradients; the preferred value of resistivity being somewhere in the neighborhood of 20,000 ohms per centimeter cube, when measured at a voltage gradient of 200 volts per centimeter. For these tests, the length of the test sample, in the direction of current flow, is about an inch, or such that the total voltage exceeds 300 or 400 volts which corresponds to the minimum sparking potential in air.

The average diameter of the pores in our preferred porous material, as indicated by the velocity of a liquid of known viscosity flowing there-

through under a given pressure head, is between .5 mil and .01 mil, preferably between .5 mil and .05 mil, or in the neighborhood of .1 mil or 1/400 millimeter. The pore diameters, obtained in this way, must be regarded as giving only a general indication of the magnitudes involved, as they are figured from formulæ which presuppose that perfect pores or channels are formed in the porous material, whereas the material is rather a honeycomb structure which does not exactly fit in with the formulæ.

Poiseuille's formula for studying the viscosity of a pure liquid offers the best means of determining the pore radii. This formula as modified for an unknown radius and known viscosity is as follows:—

$$R = \frac{\pi l}{2} \sqrt{\frac{8nQ}{PVGT}}$$

where

R=average effective radius of the pore in centimeters

l=thickness of disc in cm.

η =viscosity of the liquid in C. G. S. units

Q=volume of liquid in cc.

P=pressure in gm./cm.²

V=total pore volume in cc.

G=gravitational constant in dynes/gram

T=time in seconds for passage of quantity Q.

The actual volume of the open pores (V) in cc. may be determined by first weighing the discs dry in air to ascertain their dry weight D, then thoroughly saturating the discs with kerosene (or other impregnating liquid) in a vacuum and weighing these impregnated discs in air to ascertain their saturated weight W. The pore volume V is obtained by subtracting the dry weight D from the saturated weight W and dividing by the density G of the kerosene. Thus,

$$V = \frac{W - D}{G}$$

The maximum diameter of our pores is even more difficult to estimate. As indicated by the pressure necessary to just bubble a gas through a liquid of known surface tension, which is placed above our material, the maximum apparent diameter of pores is less than 1 mil, and preferably less than 1/2 mil.

The radius of a true capillary tube may be determined from the pressure necessary to just bubble a gas with a liquid of known surface tension. This is Jurin's law and is for application only to true capillaries. It is possible that in these discs the bubbles from several adjacent tiny pores will combine to form one large bubble. In applying the formula unmodified to porous membranes it may be that only rough comparative results are obtained. They should be, however, at least of comparative value.

The formula is:

$$R = \frac{2T}{PG}$$

where

R=effective radius in cm.

T=surface tension in dynes/cm.

P=pressure in gm./cm.²

G=intensity of gravity in dynes.

The largest pores, aggregating a sufficient total cross-sectional area to carry the maximum rated discharge current, are believed to have an apparent diameter between about .1 mil and .5 mil in diameter. These figures are believed to indicate a rather extreme variation. The pore size of the large pores, which break down first and

hence carry all of the discharge, are very nearly of the same size, and in general, so nearly the same size that the maximum voltage 44 of Fig. 14 is not more than about four times the cutoff voltage 46 of the same figure.

In general, it may be said that the pores are of such small size that they materially restrict the discharge, thereby producing a sharp cutoff.

Stated in another way, it may be said that the pores are so small in diameter, that the cutoff voltage gradient, or the voltage gradient below which a discharge throughout the whole length of the pore cannot be maintained within the pore space, is greater than 1000 volts per inch, and is preferably between 2000 and 15,000 volts per inch, or around 4000 volts.

The number of pores of the larger sizes, which are believed to be the ones carrying the discharge, is such that the current density of the arrester is around 50 amperes per square centimeter of the arrester cross section, or between, say, 25 and 75 amperes per square centimeter. Thus, an arrester of about 2 inches diameter carries 1000-ampere discharges. The foregoing figures are based upon a discharge-rate which will assure an indefinitely long life. Of course, it will be understood that any of these arresters may be discharged at a rate many times higher, for a few discharges, but the arresters will not last long under such abuse.

Judging by the data obtained for arcs in restricted channels of somewhat larger thickness than the diameter of our pores, we would estimate that the current density of the arcs or discharges in the pores is of the order of 1000 amperes, or more, per square centimeter, perhaps something like 2000 or 4000 amperes per square centimeter. These figures are largely conjectural, however, and are given mainly for the purpose of showing that the discharges are much more concentrated than the glow discharges in air, as in Dr. Slepian's autovalve arrester previously mentioned, wherein the current density of the discharge was about 10 amperes per square centimeter. It has been found, in these discharges in restricted spaces, that no distinction can be drawn between a glow discharge and an arc discharge. There is only one kind of discharge and it partakes of the nature of both glows and arcs as they are ordinarily known. The restricted discharge is like an ordinary glow discharge in having a high discharge voltage of the order of thousands of volts; it is like an ordinary arc in having a high current density.

As to the proportions of the ingredients of our fired porous material, while we prefer to utilize a mixture composed of 75% grog and 25% carborundum, by weight, with a trace of carbon from the carbon sagger, the same general characteristic of arrester may be obtained with from about 15% to about 35% of the total weight in carborundum, the different proportions depending upon the purity of the grog and the shrinkage of the block upon firing.

We have found it convenient to refer to the relative volumes of clay and carborundum, or equivalent materials. Thus, Fig. 15 shows the relation existing between the volume percentages and the weight percentages of carborundum, with respect to the volume and weight of the whole disc, and this figure also indicates the ranges R^a, R^b and R^c within which the characteristics shown in Figs. 15a, 15b and 15c, respectively, are obtained. If the percentages, either by volume or weight, are kept within the limits

of the preferred range R^b , the desirable characteristic of the type shown in Fig. 15b may be expected. If there is too little conducting material, as indicated by the range R^c , the arrester would flash over, as indicated by the curve in Fig. 15c. On the other hand, too much conducting material produces the undesirable characteristic of a sliding cutoff, as indicated by the curve in Fig. 15a. If the amount of conducting material is only slightly more than the maximum value indicated for the preferred range R^b , it is possible to secure operation in range R^b by oxidizing out some of the conducting material, that is, by removing some of the carbon, in case carbon is used, as in our preferred construction.

Porous discs should contain a minimum of about 9% of carborundum by volume, supplemented, as previously noted, by the trace of carbon; as otherwise the spacing between the conducting particles, or between the "broken chains" of conducting particles, becomes excessive and a flashover or puncture results, due to the "streak conduction" or surface leakage in the larger pores. With more than 21% of the volume occupied by carborundum, the contact phenomenon between the carborundum crystals commences to appear in the discharge characteristic, so that, in general, less desirable results are obtained.

In the foregoing calculations of percentages, the specific gravity of the individual carborundum grains has been used rather than the bulk weight of a cubic centimeter of carborundum crystals, which, of course, would include considerable air spaces between the crystals.

Metal or graphite particles may be utilized in lieu of carborundum and carbon particles for providing the desired conductivity or "trigger action" for initiating the discharges through the pores by the corona discharges from the points of the conducting particles. For low-resistance materials, such as metals, the effective working range is greater, and the best working range is nearer the low limits indicated above. In general, it may be said that the volume percentages for metals are only about one-third as much as for carborundum, the percentages by weight depending upon the relative specific gravities. We should put the percentage ranges of volumes, for metallic particles, between a lower limit of $3\frac{1}{2}\%$ of the total volume of the disc, to an unknown upper limit. The tests on which the figures just stated are based have reference mainly to aluminum particles, although other materials have been tried. Thus, discs made of 20% brass filings and 80% grog, by weight, produce good results.

The life of the arrester is dependent somewhat on the sizes of the constituent particles. If the size of the particles is smaller than has been indicated for the preferred process of manufacture of our porous material, a more desirable electrical performance characteristic is obtained, but it is more difficult to obtain as great a life as with the preferred sizes of the materials. If the particles are much coarser than has been indicated hereinabove, for the preferred construction, particularly if the grog particles are too coarse, the sharp cutoff characteristic is destroyed.

The extremely long life of our preferred material has been demonstrated by tests indicating that, under normal operating conditions, with a series gap, the arrester utilizing a 2-inch diameter disc will stand about 1500 surge discharges of 1000 amperes each.

We are aware of a carborundum-block arrester composed of a mixture of a large percentage of

carborundum particles with fluor-spar and water-glass, which has been on the market for some twenty-six years, but this arrester was not operated according to our porous discharge principle. This arrester is shown in Fig. 2 of a patent to Percy H. Thomas, No. 882,218, granted March 17, 1908, and assigned to the assignee of the present application. The difference between our porous-block arrester and the Thomas carborundum-block arrester may be explained as follows.

The development of a complete breakdown through a semi-conducting porous body, such as our new lightning arrester, or the old one of Thomas, can probably be divided into 3 stages:—

(1) At very low voltages, current passes through the body by way of continuous series or chains of conducting particles which are in more or less good electrical contact. There are, present in the body, numerous chains which are not conducting current at the moment, because they have one or more small breaks in their continuity. The currents carried at this time are the conductive leakage currents previously discussed, and they can, of course, be increased very considerably in amount, by increasing the percentage of conducting material, as was the case in the Thomas arrester, wherein about 71%, by weight, was carborundum.

(2) When the voltage is further increased, the voltages across the breaks in the continuity of the chains may reach values of the order of several hundred volts, which are sufficient to break down said breaks or gaps, so that more and more of the conducting chains will carry current, and as the voltage is still further increased, there will be some brush or arc discharge in some portions of the pores. Below the complete breakdown of one or more pores, extending all the way from one arrester-terminal to the other, however, there is this transition period, more or less marked in extent, wherein the properties of both kinds of current conduction or discharge are present. If, however, a very large number of pores break down practically simultaneously, the increased current carried as a result of such breakdown will substantially completely mask the relatively small leakage current of the first stage of the process, so that this transition stage will be practically eliminated.

(3) The final stage of a complete break-down through a porous block consists in the complete break-down of a large number of the pores. When this occurs, the air spaces within the pores become highly ionized and conduct arcs or concentrated discharges through the pores, carrying so much current that the leakage currents along the walls of the pores are negligibly small in comparison. It has already been pointed out that this is the type of discharge which occurs in our porous-block arrester, and we have already described this type of discharge and indicated our knowledge and theories relative to its operation.

The Thomas arrester has been used for the past twenty-six years, with a block of about 1 inch in thickness and about 4 inches diameter protecting a direct-current circuit of either 350 volts or 700 volts against lightning. In the 350-volt application, no series gap was used. When applied to 700-volt lines, the Thomas arrester was equipped with a series gap which broke down at about 2000 volts. When the series gap broke down, however, the arrester discharged only relatively small leakage currents. Since the discovery of our restricted discharge principle as

applied to lightning arresters, we have tested this old type of Thomas arrester to the point of a complete break-down, finding that the break-down does not occur until about 4000 volts are applied, after which the arrester is capable of discharging about 500 amperes at a maximum voltage of somewhat over 5000 volts, and having a sliding cutoff voltage, at the end of the discharge, of around 2000 volts or more, but having a poor life when subjected to repeated discharges of such severity as to result in complete break-down as just described. It is certain that this Thomas arrester has never been used in actual service under conditions producing complete break-down, as in our porous-block arrester. The sparks between disconnected conducting particles, referred to in the Thomas patent, are the tiny sparks that can pass electrical currents across minute air gaps and not the arcs which completely fill the pore-volumes, as in the case of a complete breakdown of one or more pores.

In the foregoing specification, while we have described several forms of our invention, and have particularly described the best mode in which we have contemplated applying the principle of our invention, we do not desire to be altogether limited, in our broadest claims, to one particular form, or to the exact preferred dimensions, or ranges of limits, which we have indicated in the foregoing specification, as these limits were given as a result of our present experience and some of them may be found to be unnecessarily restricted. In other words, while we have done our best to give complete instructions as to our manufacturing process, with quantitative limits, to the best of our present ability, we do not wish to be prejudiced by such information, as we consider that we are entitled to broad claims covering the application of a new principle of design to the lightning-arrester art.

While we have referred, in the appended claims, to an electrical line or apparatus to be protected, we intend, by such language, to cover any of the known or suitable applications of lightning arresters.

We claim as our invention:

1. A lightning arrester for an alternating-current transmission line, characterized by having a plurality of mechanically restricted discharge paths between or within walls of a material having at least partially discontinuous conducting particles in the boundaries of said discharge paths, the degree of restriction and the degree of conductivity of said discharge paths as indicated by the cut-off and breakdown voltages, being such that the breakdown voltage is not over four times the cut-off voltage of the arcs or discharges through the restricted discharge paths, and the arrester having a cut-off voltage less than twice the root-mean-square operating voltage of the line.

2. A lightning arrester for an electrical device to be protected, said arrester comprising a composite porous block having pores, the boundaries of said pores including conducting particles in such limited quantities as to carry, at the rated normal voltage of the arrester, a leakage current of not over about 10 amperes, the size and degree of conductivity of the pores which carry the discharge, as indicated by the cut-off and breakdown voltages, being such that the breakdown voltage is not over four times the cut-off voltage of the arcs or discharges through the pores, the cut-off voltage of the arrester being less than about

140 per cent of the rated operating voltage of the device to be protected.

3. A lightning arrester for an electrical device to be protected, said arrester comprising a composite porous block having pores, the boundaries of said pores including conducting particles in such limited quantities as to carry, at the rated normal voltage of the arrester, a leakage current of not over two amperes, the size and degree of conductivity of the pores which carry the discharge, as indicated by the cut-off and breakdown voltages, being such that the breakdown voltage is not over four times the cut-off voltage of the arcs or discharges through the pores, the cut-off voltage at which the discharge is reduced to about two amperes being less than about 110 per cent of the maximum value of the rated voltage of the device to be protected.

4. A lightning arrester for an electrical device to be protected, said arrester comprising a porous block of a material having a resistivity between 1,000 and 200,000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter, the cut-off voltage of discharges through the pores of said block being less than about 140 per cent of the rated maximum voltage of the device to be protected.

5. A lightning arrester comprising a block of porous substantially non-conducting body-material having conducting particles distributed throughout its mass, said arrester having such resistivity as to bring the maximum discharge voltage down to between 200% and 300% of the cut-off voltage of the arrester.

6. A lightning arrester comprising a block of porous substantially non-conducting body-material having conducting particles, of a size which is small compared to the size of the pores, distributed throughout its mass, said arrester having such resistivity as to bring the breakdown voltage down to less than 400% of the cut-off voltage of the arrester, and an insulating coating on the lateral surfaces of said block.

7. A lightning arrester comprising a block of porous body-material having a coating of condensed vapor of a conducting material throughout its pores and surfaces, said coated block having such resistivity as to bring the maximum discharge voltage down to less than 400% of the cut-off voltage of the arrester.

8. A lightning arrester comprising a block of porous body-material having a coating of condensed vapor of a conducting material throughout its pores and surfaces, said coated block having a resistivity greater than 1000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter.

9. A lightning arrester comprising a block of porous body-material having a coating of condensed vapor of a conducting material throughout its pores and surfaces, said coated block having a resistivity of something of the order of 1,000,000 ohms per centimeter cube or less, but more than 1000 ohms per centimeter cube, at a potential gradient of 400 volts per centimeter.

10. A lightning arrester comprising a block of porous body-material having a coating of condensed carbonaceous vapor deposits throughout its pores and surfaces, said coated block having such resistivity as to bring the breakdown voltage down to less than 400% of the cut-off voltage of the arrester.

11. A lightning arrester comprising a block of porous body-material having a coating of condensed carbonaceous vapor deposits throughout

its pores and surface, said coated block having a resistivity not materially greater than something of the order of 1,000,000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter.

12. A lightning-arrester comprising a porous block of a material having a resistivity of the order of 10^3 to 10^6 ohms per centimeter cube at a potential gradient of 400 volts per centimeter, characterized by the fact that the maximum diameter of pores, as indicated by the pressure necessary to just bubble a gas through a liquid of known surface tension, which is placed above the porous block, is less than $\frac{1}{2}$ mil.

13. A lightning-arrester comprising a porous block of a material having a resistivity greater than 10,000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter, characterized by the fact that the average diameter of pores, as indicated by the velocity of a liquid of known viscosity flowing therethrough under a given pressure, is between .5 mil and .01 mil.

14. The invention as defined in claim 4, characterized by the fact that the average diameter of pores, as indicated by the velocity of a liquid of known viscosity flowing therethrough under a given pressure, is in the neighborhood of .1 mil.

15. A lightning arrester comprising a block having pores of various sizes, of which only the largest sizes constitute the pores which are active during a discharge, the active pores, aggregating a sufficient cross-sectional area to carry the maximum necessary discharge current, being between about .1 mil and about .5 mil in diameter, and the block having a resistivity between about 1,000 and about 1,000,000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter.

16. A lightning arrester of such size and capacity as to be able to handle repeated discharges of hundreds of amperes, for use with an electric power line having a given crest voltage, comprising a block having pores of various sizes, the active pores, aggregating a sufficient cross-sectional area to carry the maximum necessary discharge current, being so nearly of the same size and the resistivity of the block being such that less than about 10 amperes is carried by the arrester when the voltage drops to a value which is above the crest line-voltage and between one-half and one-quarter of the normal maximum discharge voltage of the arrester.

17. A lightning arrester of such size and capacity as to be able to handle repeated discharges of hundreds of amperes, for use with an electric power line having a given crest voltage, comprising a block having pores of various sizes, the active pores, aggregating a sufficient cross-sectional area to carry the maximum necessary discharge current, being so nearly of the same size that less than about 10 amperes is carried by the arrester when the voltage drops to a value which is above the crest line-voltage and between one-half and one-quarter of the normal maximum discharge voltage of the arrester, the block having a resistivity greater than 10,000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter.

18. A lightning arrester for a commercial-frequency alternating-current transmission line, comprising a block having pores of various sizes, the active pores, aggregating a sufficient cross-sectional area to carry the maximum necessary discharge current, being so nearly of the same size that a leakage current of less than one-half of one

percent of the maximum normal discharge current is carried by the arrester when the voltage drops to between 60 percent and 25 percent of the normal maximum discharge voltage of the arrester, the block having a resistivity between about 1,000 and about 1,000,000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter, the voltage necessary to maintain said leakage current through said block being less than about 140 percent of the crest value of the commercial frequency voltage of the transmission line.

19. A lightning arrester for an electrical apparatus to be protected, said arrester comprising a block having pores of such small size that they materially restrict the discharge, thereby producing a sharp cut-off, the cut-off voltage being slightly higher than the maximum voltage of said apparatus to be protected, said block having such resistivity as to bring the maximum discharge voltage down to less than four times the said cut-off voltage of the arrester.

20. A porous lightning arrester for an electrical apparatus to be protected, said arrester having pores so fine that the cut-off voltage is more than 2,000 volts per inch of thickness of the arrester, said cut-off voltage being only slightly more than the maximum voltage on the apparatus under non-discharge conditions of the arrester.

21. A porous lightning arrester for an electrical apparatus to be protected, said arrester having pores so fine that the cut-off voltage is more than 2,000 and less than 15,000 volts per inch of thickness of the arrester, said cut-off voltage being only slightly more than the maximum voltage on the apparatus under non-discharge conditions of the arrester.

22. A porous lightning arrester for an electrical apparatus to be protected, said arrester having pores so fine that the cut-off voltage is between approximately 3,000 and 9,000 volts per inch of thickness of the arrester, said cut-off voltage being only slightly more than the normal maximum voltage on the apparatus, said arrester having a conducting powder distributed therethrough, the pores being so fine and numerous, and the amount and disposition of said conducting powder being such that the maximum breakdown voltage, at a current density of more than 25 amperes per square centimeter of the total area of the arrester, is less than three times the cut-off voltage.

23. A lightning arrester made up of an insulating powder with enough finely divided conducting material added to make the breakdown voltage less than four times the voltage necessary to maintain a discharge in the interstices of the arrester.

24. A porous-material lightning arrester in which said pores have a cross-sectional dimension of less than one hundredth of a millimeter.

25. A porous-material lightning arrester with pores having such a degree of fineness as to require more than 1000 volts, per inch of material, to maintain the electrical discharge therethrough.

26. A porous-material lightning arrester containing conducting material, the amount of conducting material lying within such limits as to cause the breakdown voltage to be less than 20,000 volts per inch and the resistivity of the material to be more than 10^4 ohms per centimeter cube at a potential gradient of 200 volts per centimeter.

27. A porous material lightning arrester with conducting material, the amount of conducting material lying within such limits as to cause the

voltage per inch, at which discharge starts, to be less than four times the voltage per inch at which the discharge substantially ceases.

28. A substantially insulating porous block adapted for use as a discharge path for a lightning arrester and having pores, in the direction of the discharge, of the order of 10^{-3} mm. diameter, said block having a slight trace of conductivity sufficient to bring the breakdown voltage to somewhere near the discharge voltage.

29. A lightning arrester comprising material for so confining the discharge that the cut-off voltage does not differ from the breakdown voltage more than in the ratio of about one to four, the walls of the spaces confining the discharge having a sufficient degree of conductivity to bring down the breakdown voltage to the relative value stated, and the smallness of the confined spaces being sufficient to require such a small trace of conductivity as to prevent the flow of excessive leakage currents.

30. A lightning arrester comprising a molded composite material including finely divided carborundum and grog particles bound together in a solid mass, the proportion of carborundum, by weight, being about 25 percent.

31. A lightning arrester comprising a molded composite material including finely divided carborundum and grog particles bound together in a solid mass, the bulk of the carborundum particles being of a size something like 150 mesh.

32. A lightning arrester comprising a molded composite material including finely divided carborundum and grog particles bound together in a solid mass, the bulk of the grog particles being of a size something like 150 mesh.

33. A porous-block lightning arrester composed of powdered carborundum, a powdered clay-base binder and finely divided carbon all bound together in a solid mass, the amount of carbon being only a trace, and the amount of carborundum being less than 35 percent by weight.

34. A lightning arrester comprising a porous block having pores of less than 1 mil maximum effective diameter, said block being composed of a clay base, conducting particles larger than the maximum pore cross-sectional area, said last-mentioned conducting particles being less than 20 percent, by volume, of said block, and a trace of conducting particles which are substantially negligibly small compared to said maximum pore diameter.

35. A lightning arrester comprising a porous block having pores of a maximum diameter which is so small that a voltage gradient of more than 1000 volts per inch is necessary to maintain an arc therein, said block being composed of a substantially non-conducting binder material, conducting particles larger than the maximum pore cross-sectional area, said last-mentioned conducting particles being less than 20 percent, by volume, of said block and a trace of conducting particles which are substantially negligibly small compared to said maximum pore diameter.

36. A lightning arrester comprising a porous block having such fine pores as to require a voltage gradient of more than 1000 volts per centimeter in order to maintain a discharge resulting from complete pore breakdown, and having such small conductivity that its resistivity measures higher than 1,000 ohms per centimeter cube at a voltage gradient of 200 volts per centimeter,

practically all of its conductivity being due to a small trace of such finely divided conducting particles as to be coated upon substantially all of the walls of all of the pores of said block.

37. A lightning arrester comprising a porous block having such fine pores as to require a voltage gradient of more than 1000 volts per centimeter in order to maintain a discharge resulting from complete pore breakdown, and having such small conductivity that its resistivity measures higher than 1,000 ohms per centimeter cube at a voltage gradient of 200 volts per centimeter, practically all of its conductivity being due to a solid condensate of a vapor of a conducting substance, said condensate being coated upon substantially all of the walls of all of the pores of said block.

38. A lightning arrester comprising a block of porous body-material having a coating of a conducting material throughout its pores and surfaces, said coated block having such resistivity as to bring the maximum discharge voltage down to less than 400% of the cut-off voltage of the arrester.

39. A lightning arrester comprising a block of porous body-material having a coating of a conducting material throughout its pores and surfaces, said coated block having a resistivity greater than 1000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter.

40. A lightning arrester comprising a block of porous body-material having a coating of a conducting material throughout its pores and surfaces, said coated block having a resistivity of something of the order of 1,000,000 ohms per centimeter cube or less, but more than 1000 ohms per centimeter cube, at a potential gradient of 400 volts per centimeter.

41. A lightning arrester comprising a composite porous block having pores, the boundaries of said pores including conducting particles in such limited quantities that the block has a resistivity greater than 1000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter.

42. A lightning arrester comprising a composite porous block having pores, the boundaries of said pores including conducting particles in such limited quantities that the block has a resistivity greater than 1000 ohms per centimeter cube at a potential gradient of 400 volts per centimeter, the quantity of conducting particles being sufficient to bring the maximum discharge voltage down to less than 400% of the cut-off voltage of the arrester.

43. A lightning arrester for an electrical device to be protected, said arrester comprising a composite porous block having pores, the boundaries of said pores including conducting particles in such quantities that the block has a resistivity of something of the order of 1,000,000 ohms per centimeter cube or less, but more than 1,000 ohms per centimeter cube, at a potential gradient of 400 volts per centimeter.

44. A lightning arrester for an electrical device to be protected, said arrester comprising a composite porous block having pores, the boundaries of said pores including conducting particles in such quantities as to bring the maximum discharge voltage down to less than 400% of the cut-off voltage of the arrester.

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CERTIFICATE OF CORRECTION.

Patent No. 2,000,719.

May 7, 1935.

JOSEPH SLEPIAN, ET AL.

It is hereby certified that error appears in the above numbered patent requiring correction as follows: In the heading to the drawings, Sheets 1, 2 and 3, name of patentees, for " S. SLEPIAN ET AL" read J. SLEPIAN ET AL; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 6th day of August, A. D. 1935.

Leslie Frazer
Acting Commissioner of Patents.

(Seal)