May 13, 1941. M. J. CUTTLER 2,241,505

MANUFACTURE OF METAL TO PORCELAIN SEALS

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Fig. 1.

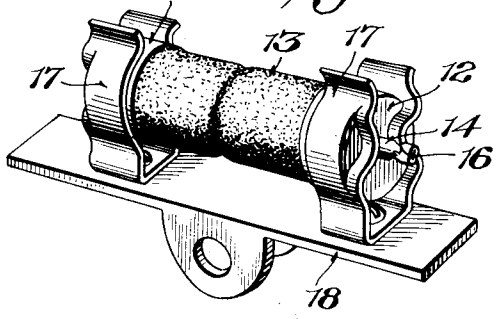


Fig. 2.

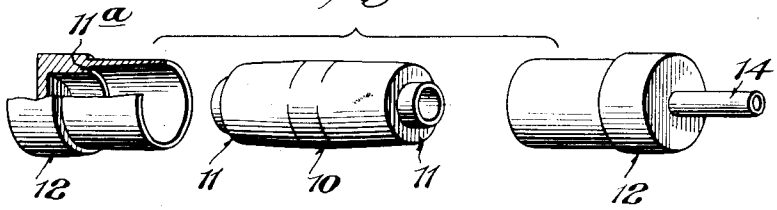


Fig. 3.

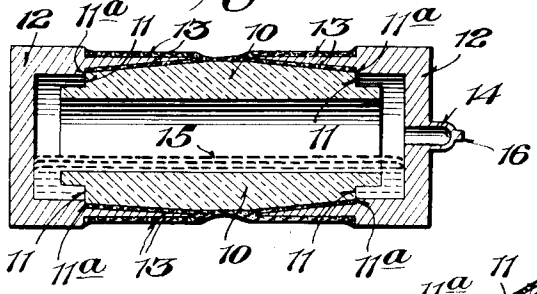
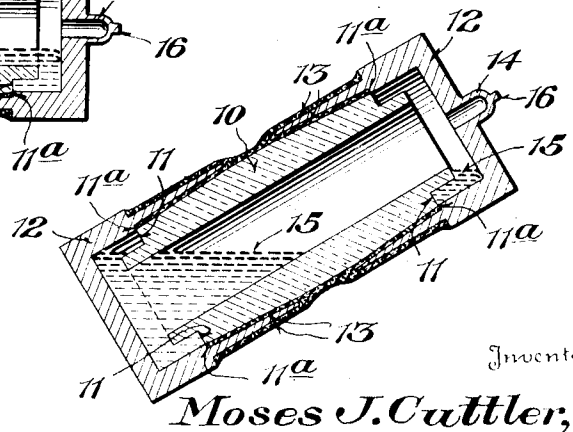


Fig. 4.



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Fig. 5.

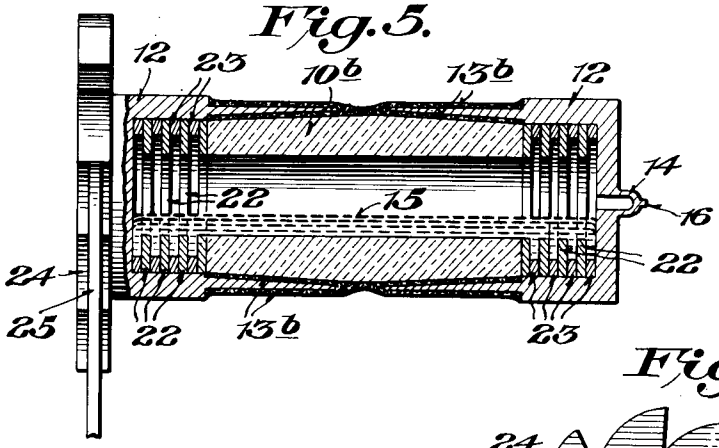


Fig. 6.

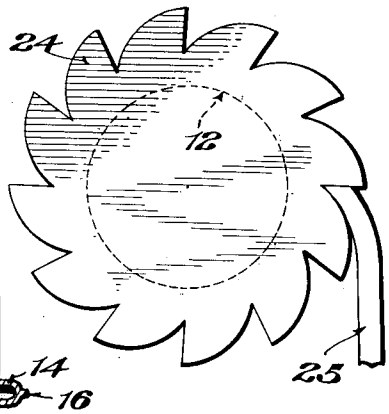


Fig. 7.

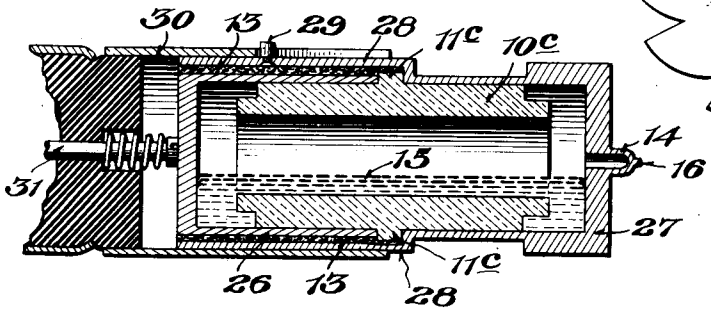
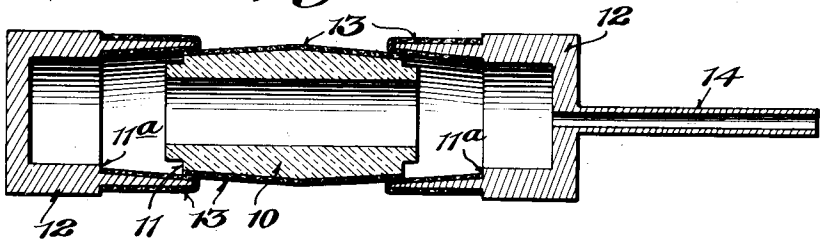


Fig. 8.



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MANUFACTURE OF METAL TO PORCELAIN SEALS

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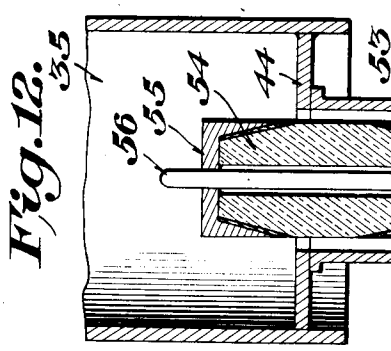


Fig. 12.

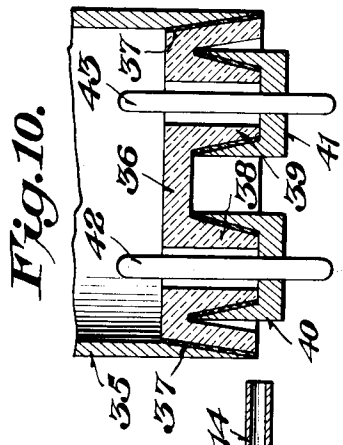


Fig. 10.

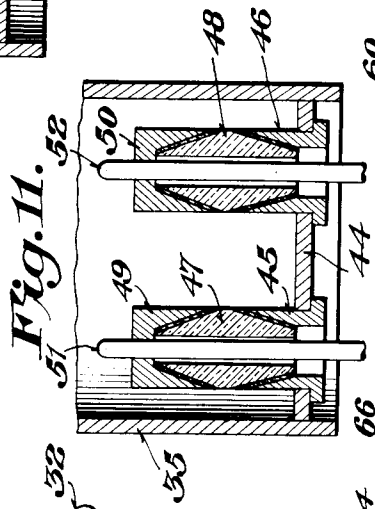


Fig. 11.

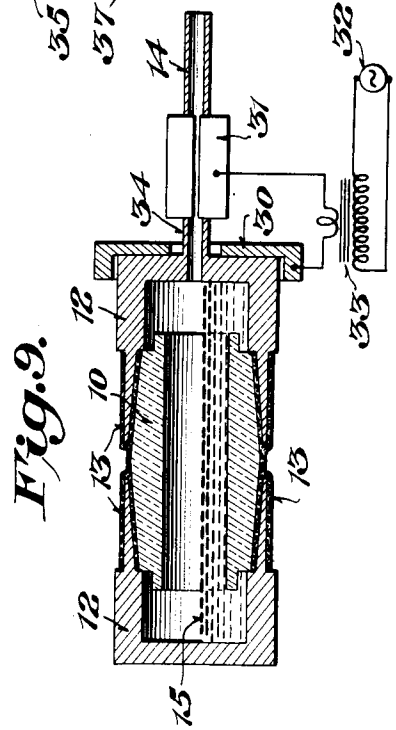


Fig. 9.

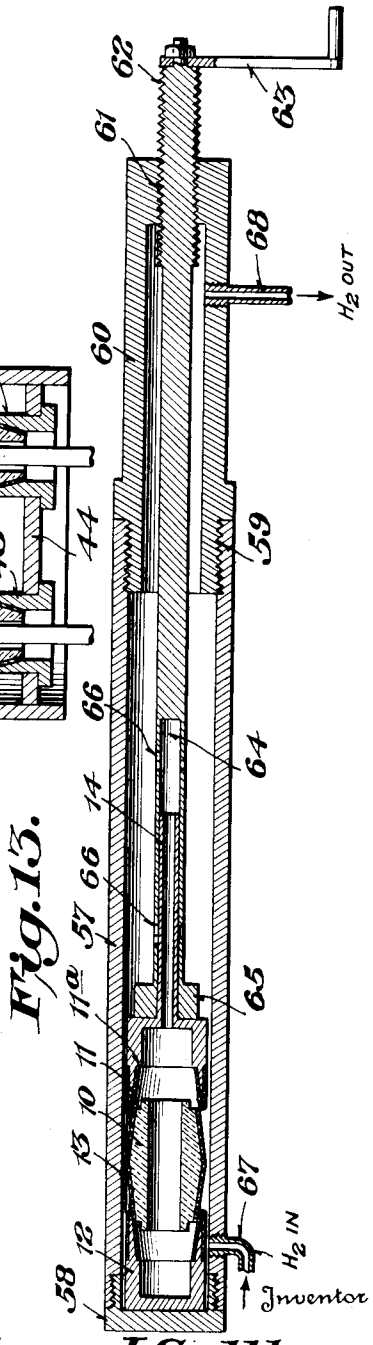


Fig. 13.

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Patented May 13, 1941 2,241,505

UNITED STATES PATENT OFFICE

2,241,505

MANUFACTURE OF METAL TO PORCELAIN SEALS

Moses J. Cuttler, New York, N. Y.

Application August 21, 1936, Serial No. 97,289

8 Claims. (Cl. 49—81)

This invention relates to manufacture of metal to porcelain seals; and it comprises a process of making such seals wherein a portion of a tube of a ceramic material of porcelain or steatite type is slightly tapered, a ferrous metal sleeve is correspondingly tapered to loosely fit the taper of said ceramic material, the tapered parts of said ceramic material and of said ferrous metal sleeve are coated with a ground coat vitreous enamel of boro-silicate type, these coated parts are fired to vitrify said enamel in an oxidizing or neutral atmosphere, the uncoated metal is cleaned, if necessary, and the coated parts are pressed together while being heated to a temperature sufficient to soften said enamel, usually in a neutral or reducing atmosphere. My invention also includes the hermetic seal resulting from the described process, this seal comprising a tube of ceramic material of porcelain type having at least one portion tapered and covered at said portion with a correspondingly tapered sleeve of a ferrous metal, the said parts being united by a fused film of a vitreous enamel of boro-silicate type; all as more fully set forth and as claimed.

This application is a continuation-in-part of my copending application, Serial No. 639,564, filed October 26, 1932.

There has long been an important demand for hermetic seals between electrically conducting and insulating materials, metal-to-glass seals for example have been known probably for nearly a century. During the past few years the demand for such seals has greatly increased owing to the many uses to which they have been put. Such seals are now used in all types of radio receiving and industrial power tubes, in mercury vapor lamps, X-ray tubes, mercury switches, mercury vapor rectifiers, photo-electric tubes, cathode ray oscillographs, electric lamps, neon signs, violet ray tubes, spark plugs and in many other applications, for example in sound pictures and television. Of course a large number of different seals for use in these various applications have been suggested in the art and are used commercially. But the best of such seals which have been so far developed leave much to be desired. This is seen clearly from the fact that the radio industry is now adopting the new so-called "all metal" vacuum tubes in which a new type of seal is employed.

The primary disadvantage of all metal-to-glass seals which have been suggested in the art is their lack of sturdiness. All such seals are fragile to a high degree and this seriously limits their range of usefulness. Another factor which has limited prior art seals is the prevalent belief that the two materials from which the seal is made should have matched coefficients of expansion or that the coefficients must be carefully graded from one part to another. Substantially all of the operative seals proposed in the art have been of the matched coefficient or of the graded coefficient type.

Porcelain is known to be considerably less fragile than glass but the great difference in expansion coefficients between porcelain and various metals has apparently been considered to present an insuperable obstacle to the development of porcelain-to-metal seals. While there have been a few suggestions in the art of uniting porcelain to metal no one has hitherto clearly described how a vacuum-tight, fused, vitreous seal between porcelain and metal can be produced.

I have discovered a new type of seal between metal and ceramic material of porcelain type. My seal may be of the graded type, this result being produced by my method incidentally without any specific attempt being made to produce this result. But my seal represents the first hermetic seal having ceramic and metal parts directly united by a fused film of vitreous enamel.

I have found that the so-called ground coat enamel which is employed commercially in the enameling of iron ware can be employed as a vitreous binder for producing a hermetically tight seal between porcelain and ferrous metals, provided the porcelain is surrounded by the metal and provided the seal is made in a particular manner. For best results I find it advantageous to slightly taper the metal and porcelain parts in such manner that there is a rather loose fit between them, say a play of about 0.002 to 0.008 inch. The taper employed may vary greatly, the best range being from about $\frac{5}{16}$ to $\frac{5}{8}$ inch per foot. It is also desirable to have the metal part which is in contact with the porcelain rather light in construction, having a thickness of say $\frac{1}{64}$ to $\frac{3}{32}$ inch. Of course the thinner the metal part is made the less strain there is on the seal.

In making my seal I employ a slip of the boro-silicate type used in making the so-called ground coat in the enameling of iron ware. This comprises a boro-silicate glass containing nickel and/or cobalt oxides made up with clay in a suspension in the usual manner. A typical composition of the boro-silicate glass employed is as follows:

SiO_2—59.52%; Al_2O_3—10.71%; NiO—6.46%; K_2O—7.73%; B_2O_3—14.49%; CoO—1.09%

The ceramic material which is employed as one element of my seal is of the non-absorbent or vitreous type. The grades comercially known as china or high grade electrical porcelain are satisfactory. The ingredients and the approximate proportions thereof which are commonly employed in the manufacture of this grade of porcelain are china clay or kaolin, 50 per cent; quartz or sand 25 per cent, and feldspar 25 per cent. The resulting porcelain is thus a complex aluminum silicate. It is also possible to employ a porcelain wherein the Al_2O_3 is replaced by MgO, commercially known as "steatite." For example, porcelains made from steatite are suitable as are also the so-called isolantite products.

In making my seal the pieces to be united are first tapered slightly. For example, if it is desired to unite a porcelain tube with an iron cap, the end of the tube is tapered on the outside and the inside surface of the iron cap is machined until the two tapered parts fit rather loosely say with a play of .002 to .008 inch. These tapered sections are then coated with the boro-silicate slip, described previously, either by spraying or by dipping, for example. These coated parts are dried and then fired at a temperature of from about 800° to 850° C. In this firing, which requires only 2 to 5 minutes, a neutral or oxidizing atmosphere may be employed. The porcelain slip is completely vitrified. The iron becomes oxidized to some extent during this firing and, if the enamel is chipped off, it is seen that some iron oxide has entered the coating. The enamel is very firmly adherent to the iron and is chipped off only with difficulty. In the usual process of enameling iron ware the ground coat is covered with a so-called cover coat which is not required in my invention.

After the tapered parts which are to be united are coated and fired they no longer fit. It is advantageous, however, to employ sufficient taper on the parts so that, even after coating they can be at least partly inter-engaged, which is of assistance during the following heating step. If the ferrous element is to be employed as a conductor of electricity, for example if it is to be employed as one end of a mercury switch, this part is carefully cleaned and highly polished in order that a good contact may be obtained. The two tapered sections are then inter-engaged and heated, while being pressed together, this time at a temperature of from about 600° to 700° C. It is advantageous to conduct this heating operation in a neutral or reducing (i. e. non-oxidizing) atmosphere in order to prevent oxidation of the iron and consequent impairment of the electrical contact. As soon as the enamel becomes softened the tapered pieces are pressed tightly together leaving a vitrified film of the vitreous ground coat enamel between the iron and the porcelain. The assembly is then cooled slowly and may be annealed if desired, although this is not usually required.

The seal resulting from the described process is vacuum tight and highly sturdy. It is much less fragile than metal-to-glass seals which have been proposed in the art, for example.

I have found that ferrous metals in general will operate satisfactorily in my process, that is, metals which are substantially iron and which have substantially the expansion coefficient of iron, including cast iron, Armco iron (commercially pure iron) and various steels such as cold rolled steel, cold drawn steel, nickel-chromium stainless steel, etc. In this connection I have found copper to be the equivalent of iron.

While the theory of operation of my seal is not important, it will be noted that it is made of two elements having quite different coefficients of expansion connected by a film of vitreous material having still a third coefficient. The coefficient of expansion of the metal is nearly twice that of the porcelain insulator. The ground coat of vitreous enamel, on the other hand, is considerably lower than that of the iron but not as low as that of the insulator. It is my theory that iron oxide dissolves in or diffuses to some extent into the enamel during the initial firing. This fact can be established by examination of pieces of enamel which have been chipped from the metal. The enamel close to the surface of the iron contains a considerable percentage of iron. The presence of this iron tends to raise the expansion coefficient of the enamel and thus a graded expansion coefficient may be automatically produced. A similar diffusion phenomenon appears to take place on the surface of the porcelain insulator when coated with the enamel. I prefer employing unglazed porcelain and it is evident from inspection that there is a slight penetration of the porcelain material into the enamel and vice versa. It therefore appears that my method may inherently and automatically produce a graded seal having a coefficient of expansion varying substantially from that of porcelain to that of iron.

It will be noted that, in the finished seal, there is probably a compressive strain on the porcelain. But the resistance of porcelain to compression is very high. On account of the graded nature of my seal this strain is more or less evenly distributed throughout the vitreous binder rather than being applied directly to its surface. The external concentric position of the metal insures than only compressive forces are present, that is, the film of vitreous enamel is always under pressure rather than under tension. It is possible, of course to reduce the strain on my seal by reducing the thickness of the iron but, as a matter of fact, I have never had any difficulty from failure of my seals so the assumed strain appears to be taken care of satisfactorily in my seal. Thus, the facts remain as stated whatever the theory may be to account for the properties of my seal.

The taper of the iron and porcelain in my invention is not essential although it is important for several reasons. Since the final heating, during assembly of the two elements of my seal, is usually conducted in a controlled atmosphere, the parts are not readily available during this heating and it is of convenience to partly inter-engage these parts in order to facilitate the assembly thereof. The taper on the elements to be assembled also insures that the enamel will not be removed by friction in parts during assembly. It is advisable to prevent as far as possible the sliding of the layers of enamel over each other since this tends to remove these layers. If the tapers of the two parts differ slightly this insures a concentric and uniform distribution of the enamel in the seal. The tapered combination prevents the formation of cavities and channels.

As indicated previously my new seal can be employed wherever a hermetic seal is desired between a ferrous element and a ceramic of porcelain type. The accompanying drawings illustrate several modifications of my invention show-

ing how my seal can be applied in making tiltable mercury switches, vacuum tubes, etc. In this showing

Fig. 1 is a perspective view of a mercury switch embodying the invention mounted in a holder;

Fig. 2 is an exploded view of one form of a mercury switch;

Fig. 3 is a vertical section through such embodiment in horizontal position;

Fig. 4 is a view similar to Fig. 3, but in tilted position;

Fig. 5 is a longitudinal section through a modified form of the invention;

Fig. 6 is an end view of Fig. 5;

Fig. 7 is a longitudinal section through a still further modified form of the invention;

Fig. 8 shows the various elements of my mercury switch coated with fused enamel and ready for the assembling operation;

Fig. 9 shows the switch elements assembled and the method of sealing off the tubulature;

Fig. 10 shows my porcelain-to-metal seal as applied to the making of a radio vacuum tube;

Fig. 11 shows a pedestal type seal modification;

Fig. 12 shows a shortened pedestal seal; while

Fig. 13 is a showing of an equipment which may be employed during the sealing operation.

In the figures like elements are indicated by like reference numerals. Referring now more especially to Figs. 1 to 4 inclusive, 10 is a tubular insulator composed of heat resisting refractory material such as porcelain or other types of natural or artificial ceramics, this tube tapering from its middle toward either end. Metal caps 12 overlie the ends of the insulator 10 and extend nearly into contact with each other but being spaced sufficiently to insulate each from the other, these caps being composed of iron or other metal which does not easily amalgamate with mercury. The interior surfaces of the caps are tapered reversely to the taper on the insulator so as to snugly receive the ends of the insulator. At each end of the insulator there is provided a shoulder 11 and the caps 12 are provided with interior shoulders 11*a* engaged by the shoulders 11 to establish proper relationship between the caps and the insulator. The caps are sealed to the insulator by a film 13 of a vitreous substance of the boro-silicate group such as vitreous enamel, the film also extending over a considerable portion of the exterior of the caps.

As shown in Fig. 1, the switch may be supported by means of clips 17 which receive the caps 12, the clips being similar to the ordinary fuse clips and being mounted on a tiltable support 18. With the support in its horizontal position, the mercury 15 forms a conductive path between the two caps 12 as shown in Fig. 3. When the support 18 is tilted, the mercury is divided into two pools as shown in Fig. 4 and electrical contact between the two caps is broken. The breaking or closing of the circuit between the two caps is effected within the tubular insulator and with a mercury-to-mercury contact so that the arc incident to the opening or closing of the circuit is produced within the insulator. This arc never touches the iron and hence does not corrode the same.

In the modification disclosed in Fig. 5, the caps 12 are sealed to the tubular insulator 10*b* by a cement film 13*b* composed of a vitreous material of the boro-silicate group in the same manner as in the modification disclosed in Fig. 3. A plurality of washers 22 and spacers 23 are interposed between each end of the insulator 10*b* and the end of the corresponding cap 12 for the purpose of increasing the contact area between the mercury 15 and the caps 12. These washers and spacers also serve to establish the relative position of the caps and insulator. In this modification, one of the caps 12 is provided with a ratchet wheel 24 adapted to cooperate with a pawl 25 to effect partial rotation of the switch each time it is tilted, thus uniformly distributing the effect of the arc over the entire inner surface of the insulator. This ratchet wheel may be applied equally well to any of the previous modifications and also to the modifications subsequently to be described.

The modification disclosed in Fig. 7 is adapted for use with a single socket. In this modification, the insulator 10*c* is provided with a pair of caps 26 and 27. The cap 26 has its inner end in abutment with the central rib 11*c* of the insulator. The cap 27 extends the full length of the insulator and has an offset portion 28 overlying the cap 26 and forming a shoulder which abuts against the rib 11*c*. A cement film 13 seals the two caps together as well as insulating one from the other, this seal being composed of a vitreous substance of the boro-silicate group. The cap 27 carries a stud 29. The device just described is adapted to be inserted into a socket 30 having a spring pressed central contact 31 and is held in place by engagement of the stud 29 in a bayonet slot formed in the socket.

The method of making my seals has already been described. An equipment which can be employed in this operation is shown in Fig. 13. In this showing 57 is a metal tube of stainless steel or other heat resisting metal. This is closed by the cap 58 at one end while at the other end a threaded connection 59 is used for attaching another tube 60 which may be of ordinary steel since this part is not heated. The end of tube 60 is solid but is screw threaded at 61 to receive a plunger rod 62 which is provided with a handle 63. Rod 62 forms the operating element during the sealing operation. This rod is counterbored at 64 and at the end is provided with a shoulder 65. The counterbore 64 is designed to receive the tubulature 14 of cap 12 and is provided with two holes 66 to provide access for the hydrogen or other gas used during sealing. The tube 57 is provided with an inlet 67 for hydrogen or other gas and tube 60 is provided with an outlet 68 for this gas. Tube 57 is of a size sufficient to provide an easy sliding fit for the caps 12.

In operation the insulator 10 and caps 12 are coated with the vitreous enamel film 13 and these parts are then assembled as best shown in Fig. 8. It will be noted that the thickness of the enamel coatings is such that the tapered sections do not fit but the parts to be united can nevertheless be inter-engaged to some extent. This assembly is slipped into the tube 57 in the manner shown, tubes 57 and 60 having been previously disconnected at 59. The counterbore 64 is then slipped over the end of tubulature 14 and tube 60 is screwed tightly into tube 57. The handle 63 is turned until plunger rod 62 forces the assembly against the bottom of tube 57, the bottom of this tube and the shoulder 65 on plunger rod 62 tending to hold the caps 12 in alignment. The end of tube 57 is then introduced into a furnace and hydrogen is passed through the tube 67 to flush out all the air which is present. As soon as vitreous enamel 13 has softened the handle 63 is turned and the plunger rod forces the caps 12 over the insulator 10, thus

producing a tight seal under a pressure of hydrogen or inert gas which prevents oxidation of the caps 12. The hydrogen pressure is maintained during cooling of the assembly, after which tubes 57 and 60 may be disconnected and the sealed switch elements removed.

After the switch assembly is cooled the switch is filled with mercury 15 through the tubulature 14. It is first evacuated and then hydrogen or an inert gas, under reduced, or super-atmospheric pressures is introduced into the switch. If desired, of course, the switch may be sealed when evacuated. It is then ready to have the tubulature 14 sealed off. This is accomplished as shown in Fig. 9.

While the tubulature 14 is still connected to the supply of hydrogen or inert gas it is pressed together at point 34 near the end of the iron cap. The electrodes 30 and 31 of an electric welding equipment are connected to the cap 12 and the tubulature 14, respectively, as shown in Fig. 9. The welding equipment comprises a source of alternating electric current 32 and transformer 33. A heavy current is passed through the tubulature 14 between the two electrodes 30 and 31 which closes the tubulature by melting the metal and at the same time cuts off the tubulature from the electrode. Pressure is applied at point 34 of the tubulature and the electrodes 31 are also pressed together during this sealing operation. This effectively seals the switch with the vacuum or hydrogen pressure unimpaired. The sealed end of the tubulature can then be trimmed off if necessary. This completes the making of the electric switch which is described and claimed in my acknowledged copending application.

The mercury switch embodying the invention is of rugged structure and may be roughly handled without fear of breakage. The metal caps act as the electrodes, thus obviating the disadvantages attendant upon leading-in wires. It is symmetrical with respect to its longitudinal axis so that it is unnecessary to set it in any particular position.

The caps provide large heat radiating surfaces and as the caps are good conductors of heat, large currents can be used with the device without danger of overheating. If desired, the caps may be provided with fins to increase their heat radiation capacity. The making and breaking of the circuit takes place within the refractory tube which is sufficiently strong inherently to withstand the pressure and arcing, advantages incident to the making or breaking of a high amperage circuit. If desired, several of the switches may be combined to produce a compound switch merely by mounting the same in a suitable support with the caps of the switches contacting with each other in the arrangement required to obtain the desired effect. Furthermore, the construction of the device is such that the parts are capable of machine manufacture and assembly, thus reducing production cost.

The seals shown in Figs. 10 and 12 are especially adapted for use in the so-called all metal vacuum tubes. In these figures the metal shell of such a tube is indicated at 33. In Fig. 10 a large ceramic insulator 36 is provided which closes the end of the metal shell. This insulator is sealed to the metal shell by the large seal shown at 37. The insulator is provided with at least two tapered studs 38 and 39 through the centers of which openings lead into the interior of the shell. Two ferrous metal caps 40 and 41 are sealed over the studs 38 and 39 by means of my boro-silicate enamel and these caps are provided with rods 42 and 43 which pass through the openings provided in the studs 38 and 39. These rods provide support for the electrodes, etc., of the vacuum tubes, as well as serving as the usual leading-in wires.

In Fig. 11 there is illustrated a pedestal or pillar-type seal. The shell 35 is closed at the bottom by means of a metal diaphragm 44, which may be welded to the shell wall. This diaphragm is provided with at least two openings having upright annular flanges 45 and 46 which serve as the metal parts for two of my seals. The lower ends of the hollow porcelain insulators 47 and 48 are sealed into the flanges 45 and 46 and these insulators are surmounted by sealed caps 49 and 50. Rods 51 and 52 pass through the caps and insulators and serve as leading-in wires for this type of construction.

Fig. 11 shows still another type of seal within my invention which is particularly adapted for the all-metal vacuum tube. This seal may be called the short pillar-type seal. In this case the metal diaphragm 44 is provided with an opening having a depending annular flange 53 which is reversely bent at its lower end. The hollow porcelain insulator 54 is sealed into flange 53 and is surmounted with a sealed cap 55 which supports rod 56 serving as a sealing-in wire.

The various embodiments shown in my drawings are merely illustrative and represent only several of the many uses to which my new seals may be put. It will be immediately obvious to those skilled in the art how my seal can be adapted to the manufacture of other tubes wherein metal-to-glass seals are now employed. My seals can be employed in all applications wherein insulator-to-metal seals are required and in which it is possible to employ porcelain insulators or porcelain tubes.

My seals can be used to connect porcelain to glass. For example a copper sleeve can be employed as the metallic element in my seal, the other end of the copper sleeve being tapered down to a feather edge and sealed to glass by means of the so-called Housekeeper seal. By means of this combination of seals transparent windows can be provided in porcelain X-ray tubes for example.

The use of porcelain in power tubes and the like usually enables the use of much smaller tubes, since porcelain can be heated to relatively high temperatures without danger of breaking. And I have found that it is possible to heat my new seals to temperatures just below the softening point of the enamel binder without damaging the same. I believe therefore that my new seals will withstand higher temperatures than any hermetic insulator-to-metal seals previously suggested in the art.

While I have described what I consider to be the best embodiments of my invention, it is obvious that various modifications can be made without departing from the spirit thereof. My seals may be combined in various ways with seals of the prior art and many such combinations will immediately occur to those skilled in this art. Such modifications as fall within the scope of the following claims I consider to be part of my invention.

What I claim is:

1. An electric device suitable for use as a mercury switch, electric discharge vessel, radio tube, X-ray tube, mercury vapor rectifier or the like, comprising a closed vessel, having a wall

portion constructed of a ceramic material of porcelain type, the said wall portion being of tubular form with a slight external taper, at least one electric element mounted within said vessel, a conductor passing through said tubular wall portion for conducting electricity to said electric element, a ferrous metal cap having an internal taper corresponding to the taper of said tubular wall portion closely fitting over the end of said wall portion and forming a closure therefor, and a thin vitrified film of a vitreous ground-coat of boro-silicate type between said cap and said wall portion forming a hermetic seal therebetween, the said electric element and the said conductor being electrically connected.

2. In the sealing of a ceramic of porcelain type to a ferrous metal, the process which comprises coating the exterior of a piece of such a ceramic material with a slip of a ground-coat, iron-ware enamel of borosilicate type made up with clay in a suspension, coating the inside contacting surface of a closely fitting sleeve of ferrous metal with said slip, heating the coated parts to temperatures sufficient to vitrify said enamel, then pressing the parts together while heating at temperatures sufficient to cause said vitrified coatings to soften and to fuse together, thereby producing a hermetic vitrified seal.

3. In the sealing of a ceramic of porcelain type to a ferrous metal, the process which comprises coating the exterior of a tapered, tubular piece of such a ceramic material with a ground-coat, iron-ware enamel of borosilicate type made up with clay in a suspension, coating the inside contacting surface of a closely-fitting, correspondingly tapered, iron sleeve with said enamel, and pressing the parts together while heating at temperatures sufficient to cause said coatings to soften and to fuse together, thereby producing a hermetic vitrified seal.

4. In the sealing of a ceramic of porcelain type to a ferrous metal, the process which comprises coating the exterior of a piece of such a ceramic material with a ground-coat, iron-ware enamel of borosilicate type made up with clay in a suspension, coating the interior contacting surface of a closely fitting sleeve of iron with said enamel, heating said coatings to temperatures producing vitrification of said enamel, cleaning the uncoated parts of said iron sleeve, then pressing said coated parts together while heating in a non-oxidizing atmosphere to temperatures only sufficient to produce softening and fusion of said coatings, thereby producing a hermetic vitrified seal.

5. In the sealing of a ceramic of porcelain type to a ferrous metal, the process which comprises coating the exterior of a piece of such a ceramic material with a ground-coat, iron-ware enamel of borosilicate type made up with clay in a suspension, coating the interior contacting surface of a closely fitting sleeve of iron with said enamel, heating said coatings in an oxidizing atmosphere to temperatures producing vitrification of said enamel, cleaning the uncoated parts of said iron sleeve, then pressing the coated parts together while heating in a non-oxidizing atmosphere to temperatures only sufficient to produce softening and fusion of said coatings, thereby producing a hermetic vitrified seal.

6. In the manufacture of electric discharge vessels at least partly constructed of a ceramic material of porcelain type, the steps which comprise making a ferrous metal cap closely fitting over a tubular, ceramic portion of said vessel, said metal cap being provided with a metallic tubulature communicating with the interior, coating the outer surface of said tubular ceramic portion and the inner contacting surface of said ferrous metal cap with a slip of a ground-coat iron-ware enamel of borosilicate type made up with clay in a suspension, firing said coated portions to vitrify said enamel, and pressing said coated portions together while heating the same to the softening point of said enamel thereby producing a hermetic vitrified seal.

7. In the sealing off of an electric discharge vessel provided with a metal tubulature communicating with the interior of said vessel and integrally united with a metal sleeve forming part of said vessel, the process which comprises attaching a welding electrode to said metal sleeve and another welding electrode to said tubulature at a point slightly spaced from said sleeve, passing an electric current between said electrodes and through said tubulature of a strength sufficient to soften said tubulature, and pressing together the walls of said tubulature while in said softened state at a point adjacent said sleeve.

8. An article of manufacture comprising a tube of ceramic material of porcelain type having a slight external taper along at least one section, an iron tube having a corresponding internal taper closely fitting said tapered section; said iron tube being hermetically sealed to said ceramic by a thin vitrified film of a slip of a vitreous, ground-coat enamel of borosilicate type made up with clay in a suspension.

MOSES J. CUTTLER.