Aug. 19, 1958 C. W. HANKS ET AL 2,848,523

VACUUM CRUCIBLE FURNACE

Filed July 27, 1956 3 Sheets-Sheet 1

FIG-1

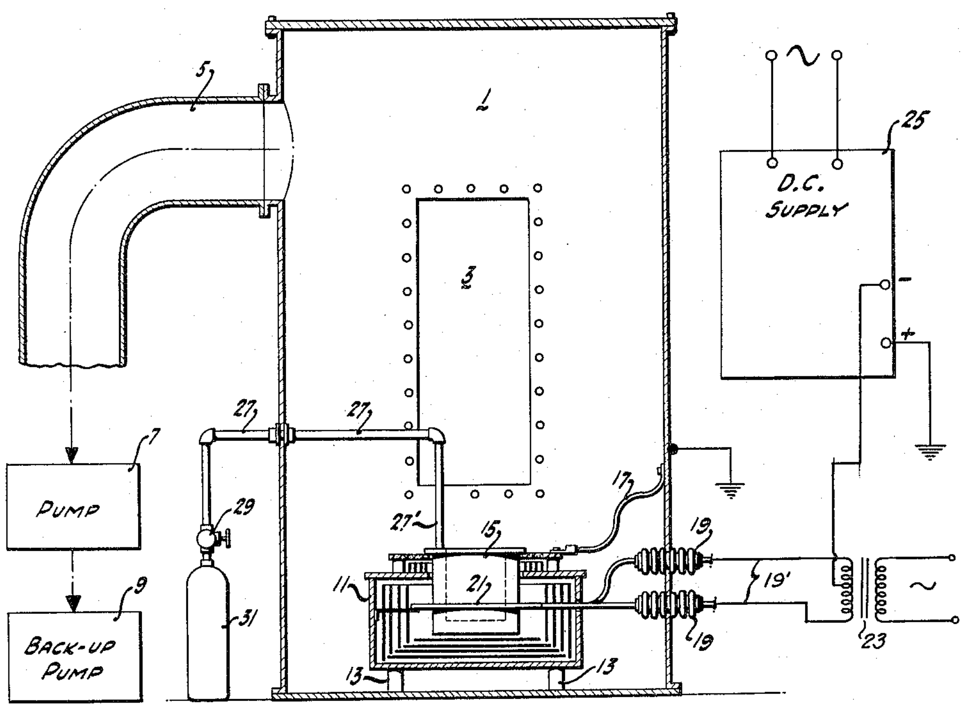


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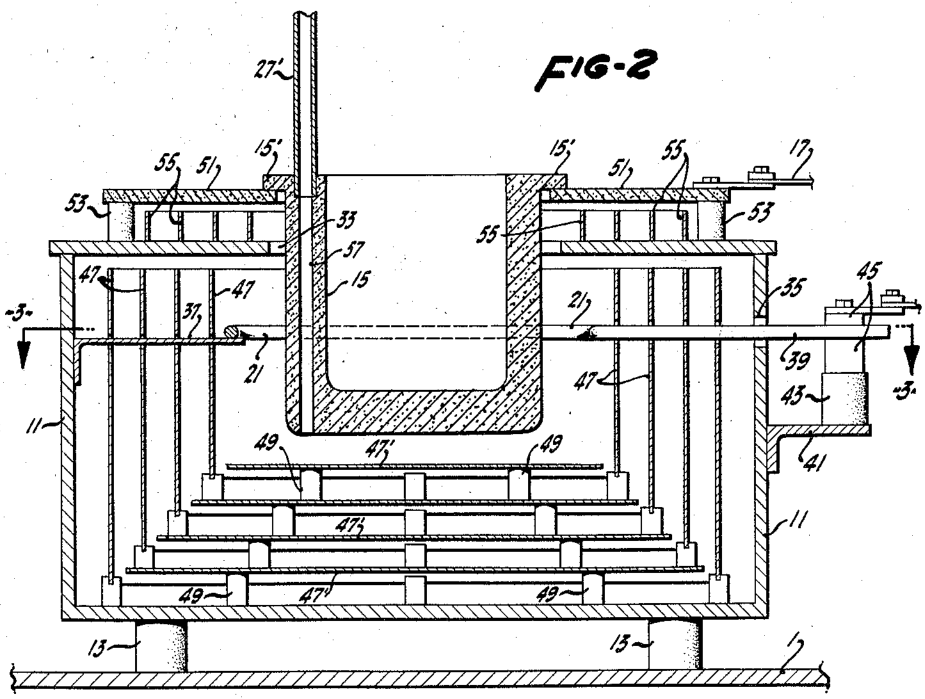
FIG-2



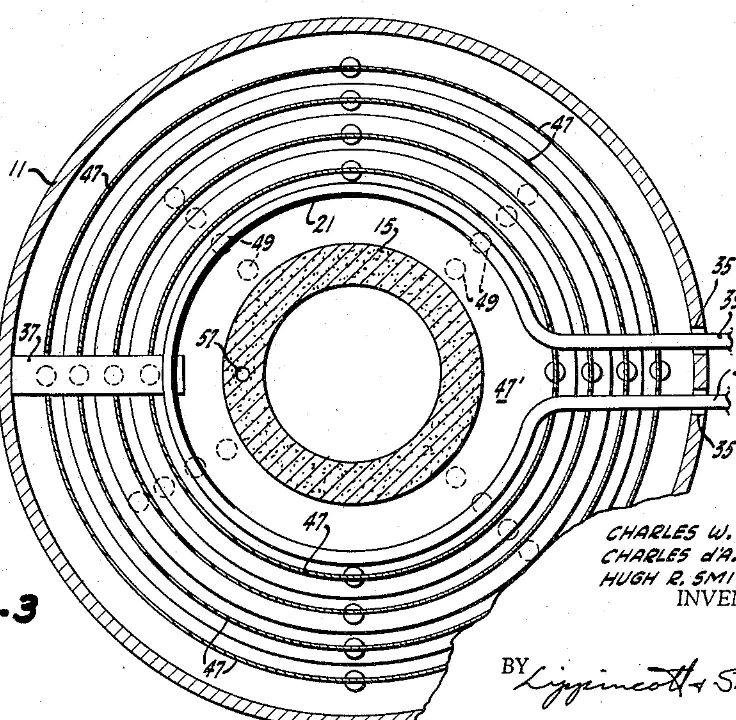


FIG-3

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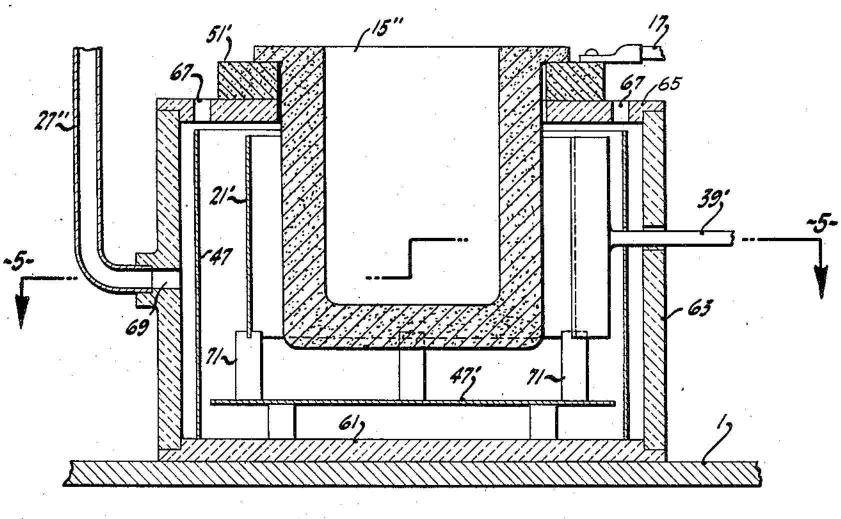
Filed July 27, 1956 3 Sheets-Sheet 3

FIG-4



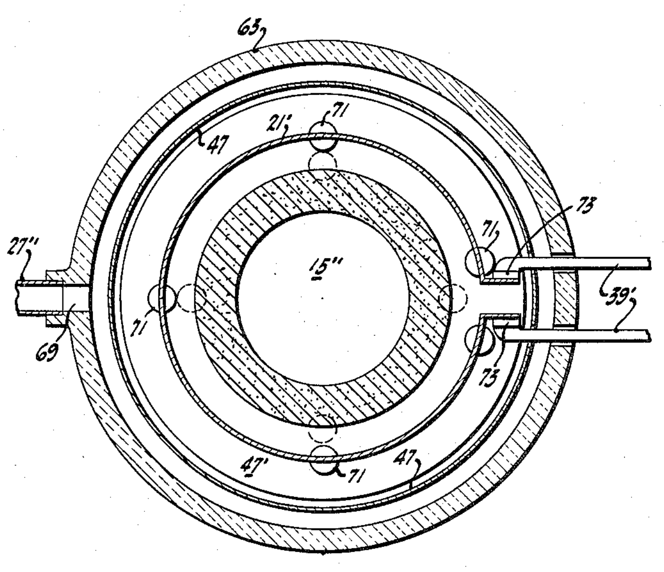




FIG-5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# United States Patent Office

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## VACUUM CRUCIBLE FURNACE

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**Application July 27, 1956, Serial No. 600,527**

**7 Claims. (Cl. 13—31)**

This invention relates to apparatus for melting and out-gassing refractory materials under high vacuum, and particularly to apparatus for heating the more refractory and highly chemically active metals, such, for example, as titanium and zirconium, which in their crude form contain large quantities of gas, in a receptacle such as a crucible or a muffle.

Conventional methods of vacuum melting for out-gassing purposes use either induction heating or arc heating of the melt. Induction heating has certain disadvantages for the purpose of melting materials in sponge or finely powdered form; the resistance of the unmelted material is high and the power cost is also high. The degree to which the material is out-gassed depends to a large degree upon the vapor pressure at the surface of the melt. In an arc discharge the vapor pressure is relatively high, since in such a discharge the current carriers are primarily ions, supplied largely by vaporization of the material of the melt by the arc at its point of impact, and by the released gas. By careful adjustment of the vacuum it is possible gradually to convert the conventional arc, having a clearly defined core, into a glow discharge that spreads more or less completely over the bombarded surface. This condition is difficult to maintain with crude metals, which are liable to evolve suddenly relatively large quantities of gas, destroying the nicely balanced conditions in the diffuse arc. Heating by discharge of this type to the receptacle itself as an electrode also presents considerable difficulty and is seldom attempted, since the ions in the arc must be supplied by the receptacle material and it consequently erodes.

Arc melting, as the term is customarily used, also implies relatively low voltage, high-current operation. Long arcs are notoriously unstable. The heat evolved is proportional to the product of the current in the arc times the voltage across it. High voltage, low current operation has the advantage of requiring smaller conductors than does high current operation, and such conductors are not only less expensive than larger ones but they also carry away less heat from the melt.

The present invention uses a combined electronic and ionic discharge to supply the necessary heat. This differs from the conventional arc discharge in any number of ways. First, the discharge is initiated from a thermionic, electron-emitting cathode. Second, the ions, instead of being supplied from the bombarded surface, are supplied by a controlled flow of gas into the discharge region. Here the gas is ionized by collision with the electrons, and by controlling the pressure within the discharge area the number of ions so released can be accurately controlled. The positive ions so liberated tend to neutralize the space charge between the cathode and the bombarded surface. They also act as current carriers, as do also the released electrons, increasing the current, but the carriers added are relatively few; by far the greater proportion of the current is carried by the initial themionic discharge. The discharge is diffuse and



tends to spread over the entire surface of the bombarded anode, and since it is diffuse there is no concentration of current to a single spot which would form an arc crater wherein the anode is vaporized to form a true arc. By accurately controlling the pressure within the discharge, current and voltage can be regulated independently; the voltage can be made many times that across a true arc of like dimensions, while the current can be made many times as great as that which would be available by pure electronic discharge from a cathode of equal emitting area operating at the same voltage. Heating of the cathode is preferably initiated by passing current through it directly, although it may be indirectly heated. Heating of the cathode also occurs due to positive-ion bombardment and by radiation from the anode, and hence after the discharge has been maintained for a long enough period for equilibrium conditions to establish themselves, the cathode temperature is maintained partly by heat from these sources and the power supplied to it directly can be reduced.

The prime object of the present invention is to provide means for utilizing the advantages of such a controlled glow discharge in the heating of crucibles or muffles, that contain highly gassy materials, without the evolution of gas affecting the stability of the discharge and causing violent fluctuations of current flow and power consumption in the discharge. Ancillary to this object, other objects of the invention are to provide means for de-gassing refractory metals and the like under high vacua, i. e., vacua of the order of magnitude of 0.1 micron of mercury base pressure; to provide means for simultaneously maintaining a pressure of several microns of mercury within the discharge area without materially increasing the pressure at the surface of the melt; to provide a construction which strictly limits the area wherein discharge takes place to that between the electron emitting cathode and the bombarded crucible, so that the input power will not be absorbed by a generalized glow discharge that tends to fill the entire evacuated region due to cold cathode emission and the like, to provide means for developing the necessary heat by means of power applied at the most economical and practical ratio of voltage to current, using neither voltages so high as to require extraordinary insulation and invoking the danger of cold cathode emission from parts of the electrical system where discharge is not desired, nor current so high as to require leads so massive as to be both unduly expensive and to carry away a large part of the heat supplied by conduction.

Other objects and advantages of the invention will become apparent hereinafter.

In accordance with the present invention a main vacuum tank is provided having a large exhaust port connecting with a vacuum system including a pump of sufficient capacity to maintain the pressure in the tank within the desired range, in spite of the evolution of gas from the molten material. Connecting with this tank through an opening adapted to admit a suitable receptacle is an auxiliary chamber. The chamber is also provided with an exhaust port connecting to the vacuum system in such manner that the pressure within the chamber can be maintained materially higher than that in the enclosing tank. The connection can be made through an entirely separate duct; preferably, however, the exhaust port can be simply a restricted gap between the receptacle and the opening that receives it, and thus connect directly into the main enclosing tank, but through an aperture so small that, even with the difference in pressure between the chamber and outer container, the gas flow is not sufficient to raise the pressure in the main tank above the desired range.

The receptacle which contains the material to be treated is either made wholly of conducting materials, such as graphite or cerium sulfide or, if of a non-conductor, is provided with a conductive surface as by painting with aquadag. Within the chamber and positioned to face the receptacle when in place is a thermionic cathode with its emitting surface spaced substantially uniformly from the conducting surface of the receptacle. Means are provided for insulating the cathode from the receptacle, and cathode and receptacle are provided with terminals for establishing the necessary electrical potential between them to sustain a discharge at the desired values of voltage and current. Finally, means are provided for injecting into the chamber a controlled flow or "bleed" of gas, preferably one of the inert gases, such as argon.

The construction described, taken in connection with the necessary separation of the parts to withstand the applied electrical voltage, dictates an inner chamber, the volume whereof is large in comparison with the volume of gas that can escape from the chamber into the main tank, with required pressure difference between the two. The outer chamber also has a considerable volume capacity. The pumping system has sufficient capacity to keep the pressure within the main tank within the required range, in spite of the small bleed of inert gas into and out of the chamber; perhaps at a pressure of 0.4 micron of mercury, at a base pressure (i. e., pressure without the inert gas injection) of about 0.1 micron Hg.

The conditions of operation are such that even in the initial stages of the treatment when gas is being evolved in relatively large volume, and usually in sudden bursts, the overall pressure within the tank changes by relatively small value, percentagewise. The changes that do occur do not, therefore, materially affect the rate of flow from the inner to the outer chamber, and this rate of flow is relatively so small that even much greater changes, persisting but for a short time, have negligible effect upon the pressure within the inner chamber. Each chamber, considered in relation to the flow into or out of it has a relatively long time constant, the combination being a pneumatic analogy of a resistance-capacity, two-stage, low-pass filter. With an exhaust gap from the inner chamber to the outer container of given size, the rate of flow outward is, to at least a first approximation, a linear function of the pressure differential and hence the pressure in the inner chamber and the nature of the discharge between the cathode and the crucible can be accurately controlled by controlling the injection of gas into the inner chamber.

It should be apparent from what has been said concerning the use of the gap around the crucible as the exhaust port, that even if a separate duct is supplied for connection of this chamber into the exhaust system there is no necessity at any time for a vacuum seal where the crucible enters. If a separate duct is used, the crucible can simply be set in place with the result that the gap is very nearly sealed and the escape through it becomes of negligible importance in comparison with the flow through the separate duct. Ordinarily, however, exhaust into the main container is so much cheaper and simpler to construct than is the provision of a separate exhaust line that the latter will seldom be used and is only mentioned here for the purpose of completeness.

All of the above is more fully explained in the detailed description of a preferred form of the invention which follows, this description being illustrated by the accompanying drawings wherein:

Fig. 1 is a diagrammatic representation of a complete vacuum-furnace installation embodying the present invention, including, schematically illustrated, the associated electrical connections and vacuum system;

Fig. 2 is a vertical sectional view of the auxiliary chamber including a crucible in operating position;

Fig. 3 is a transverse or horizontal sectional view of the apparatus illustrated in Fig. 2, the plane of section being indicated by the lines 3—3 of the second figure;

Fig. 4 is a vertical sectional view, generally similar to Fig. 2, of a modified form of auxiliary chamber; and

Fig. 5 is a horizontal sectional view of the apparatus of Fig. 4, taken along the line 5—5.

Fig. 1 shows the overall installation involving the present invention in schematic section. The outer main vacuum tank **1** may be of any conventional type. It is provided, on the far side as viewed in the diagram, with an access door 3 which may be closed and sealed, vacuum tight. The tank is provided with a large exhaust port connecting, through an exhaust duct **5**, with a vacuum pump **7**. Usually this will be a diffusion pump, backed up with a mechanical pump **9**.

Within the main tank is an inner chamber **11** mounted on insulating supports **13**. The detailed construction of this inner chamber will be considered in detail hereinafter. For the initial discussion, in connection with Fig. 1, the elements that need be described are merely a conducting crucible **15**, supported from the top with its body suspended through an opening in the inner chamber, from which it is insulated. A lead **17** connects to the body of the tank which is grounded. Insulating bushings **19** pass through the body of the tank and around electrical leads **19′** that connect to the terminals of a thermo-emissive cathode **21**. Alternating current is preferably used for heating the cathode and may be supplied by any appropriate source, which is indicated schematically as a transformer **23** having a center tap of its output winding connected to the negative terminal of a conventional D. C. power pack or supply **25**, the positive terminal of the latter connecting to ground.

Also entering through the wall of the tank is a duct **27** that connects through a needle valve **29** to a supply of inert gas, such as, for example, a cylinder **31** of argon.

The installation is described only in most general terms because, with the exception of the inner chamber and the various parts ancillary thereto all of the equipment is entirely conventional and its description is necessary merely to establish its relationship with the inner chamber.

The inner chamber **11** is shown, still diagrammatically but in considerably more detail, in Figs. 2 and 3. The material of which it is formed is relatively unimportant as long as the various portions will withstand the temperatures to which they are exposed and its walls are relatively impervious so that it will not absorb large quantities of gas and thus unduly protract its evacuation. It can be of either conducting or insulating material including, in the latter, ceramics. If conducting, construction is simplified by operating it at cathode potential, several thousand volts above ground, in which case it must be mounted on insulators **13** as is also indicated in Fig. 1. In the particular installation here described the material of this inner chamber **11** is still, the chamber taking the form of a fairly flat cylinder having a complete closure at the bottom and an annular closure at the top, the opening in the latter surrounding the cylindrical crucible **15** and being slightly larger than the latter to leave a small gap **33** around the periphery of the crucible and so to form the principal exhaust port for the gases escaping from the inner chamber.

Within the chamber **11**, and substantially surrounding the crucible suspended therein, is a thermionically electron-emitting cathode **21**. This is a rod of tungsten, bent into a substantially complete circle, with its two ends projecting out through apertures **35** in the chamber wall and forming a pair of electrical leads **39**. The clearance between the edges of the apertures **35** and the tungsten leads of the cathode can be quite small, since the voltage difference between the cathode leads and the chamber wall is small. This construction permits the side of the annular cathode **21** opposite to the leads to be supported on a metal bracket **37**, which can be welded to the cylinder wall. The cathode is positioned approximately midway, longitudinally, of that portion of the crucible **15** that actually hangs within the chamber **11**.

The leads **39** through which the cathode is supplied are supported, externally of the chamber **11**, by a bracket **41**. This bracket carries an insulator (or insulators) **43**, which in turn carries a pair of clamp blocks **45**. Leads **19'** connect from the blocks **45** and through the insulators **19** to the transformer **23** as already described.

If, as here shown, the material of chamber **11** is steel and the temperature within the crucible is to be high enough to melt titanium, for example, means must be provided for preventing the walls of the chamber **11** from becoming unduly heated. A preferred method of preventing radiation reaching the walls in material quantities is to provide a series of heat shields **47** within the chamber and surrounding both the cathode and crucible. Those shown comprise thin cylinders of polished, refractory sheet metal, molybdenum being that usually employed. The polished surfaces of the shield reflect a large proportion of the radiant heat falling upon them. Those shielding the walls are cylindrical in form, apertured at the opposite sides, as shown, to permit the passage of the bracket **37** and leads **39** of the cathode. At the bottom of the chamber these shields are completed by discs **47'**, of the same material, supported by spacers **49**. With these shields in place the walls of the chamber **11** remain relatively cool, in spite of the high temperature of the crucible and its high coefficient of radiation if it is coated with aquadag.

The means for suspending the crucible **15** within the chamber **11** comprise, preferably, a ring of graphite **51** mounted on the cover of the chamber **11** by ceramic stand-off insulators **53**. Lead **17** is electrically connected to the graphite ring **51** for grounding crucible **15**. The crucible **15** hangs from this ring by a flange **15'** on its upper rim. Heat shields **55**, similar to those already described as within the chamber, preferably surround the projecting portion of the crucible.

As has already been mentioned, various other materials are suitable for forming the inner chamber. One very satisfactory material is graphite, which is easily machined and highly refractory. If this material is used, multiple heat screens between the crucible and the chamber walls are not necessary although power will be conserved by providing at least one shield below the bottom and around the sides of the crucible.

It should be noted that the walls of the inner chamber, of conducting material, serve to form focusing electrodes that concentrate the electrical discharge upon the crucible. It is, perhaps, somewhat surprising that little or no discharge takes place at the gap **33** surrounding the crucible. This is because there is no thermionic emission that occurs at this point to initiate ionization; the ionic discharge is initiated almost entirely by the thermionic electrons from the cathode. The gas density is low enough and the mean free-path of electrons in passing through the gas is long enough so that very little secondary ionization by collision can take place at this point, the field between the chamber walls and the crucible being entirely directed toward the crucible, thus accomplishing the focusing action already referred to. Much the same effect takes place if an insulating chamber is used. A surface charge collects upon the container walls, increasing until the potential approaches that of the cathode, whereafter they act very much as though they were directly connected thereto.

It will also be recognized that there is a very steep pressure gradient through the gap **33**, amounting to as much as a ten-fold ratio between the two ends of the gap. Ions that do form in the gap tend to be swept out of it into a region where the mean free path is much longer and there is no tendency in normal operation to set up a glow discharge which would waste power.

As has already been indicated generally in the discussion of Fig. 1, the pressure differential between the outer vacuum tank and the inner chamber is maintained by bleeding gas into the latter through the duct **27**. The end of the main duct, which can be of iron or steel and welded through the container wall, is shown in Fig. 1 as terminating in a downwardly directed elbow. The elbow connects to a length of refractory tubing **27'** and continues downward to connect with a passage **57**, extending downwardly through the crucible wall and opening into the body of the inner chamber through the bottom of the crucible, as shown in Fig. 2. The extension **27'** can be of refractory metal (molybdenum or tungsten) or of ceramic, the connections to the main duct **27** and the passage **57** being, if desired, luted to prevent leakage of gas into the main body of the tank. This arrangement makes unnecessary any specific provision for insulating the input duct from the body of the inner chamber. As a matter of safety, the tank is operated at ground potential. The crucible also operates at ground potential. Since the duct **27** connects only with the crucible it need not be insulated where it passes through the tank wall and the needle valve also remains at ground potential and could be manipulated without danger, whereas a duct entering the inner chamber at any other point would have to be insulated and would, even then, offer an opportunity for breakdown and undesirable glow discharges.



Such insulation is, of course, possible, and ceramic ducts can be used. If an insulating chamber is used there are many ways in which the gas bleed into the chamber can be accomplished and the problem of insulation becomes of minor importance.

Although mention has been made of luting or otherwise sealing the connections between the main duct **27**, its extension **27'** and the passage **57** through the crucible, it should be apparent that the pressure within the duct will be only very slightly higher than that within the body of the chamber **11**, a few microns Hg at most. At pressures of this order of magnitude there is very little coherent, stream-like flow of gas, the flow being very largely by diffusion, and leaks of small magnitude are unimportant. This situation obtains also as regards escape of gas from the inner chamber into the main tank. The temperature within the chamber is high, the velocity of the gas is high, and diffusion occurs rapidly, so that the pressure within the chamber tends to equalize itself rapidly. Gas particles escape from the inner chamber through both the gap **33** surrounding the crucible and the gaps **35** surrounding the cathode leads. The number of particles escaping, for a given temperature within the chamber, is proportional to the density of the particles within the chamber. Particles also enter the chamber through these gaps, the number entering also being proportional to the density of the gas particles external to the chamber. Because of the injection of gas into the chamber, the density within it will be higher than that without, and therefore there will be a net flow outward which is proportional to the differential pressure between the two bodies of gas. It should be apparent that an equilibrium will establish itself at a pressure where the number of particles entering the chamber through the inlet duct is equal to the number escaping through the various gaps. Any desired pressure differential within fairly wide limits, can be accomplished by manipulating the needle valve to regulate the amount of gas admitted to the inner chamber. What is necessary to maintain the required pressure differential is that the total open area of the exhaust ports be small in comparison with the area of the wall of the chamber wherein they are located, it being understood that any open aperture from the chamber into the tank is an exhaust port. When this condition obtains the pressure differential will be a direct function of the rate-of-flow of gas into the chamber irrespective of the volume of the latter. The smaller the total open area of the ports the less will be the flow required to maintain a given differential, and the less will be the duty imposed on the pump to maintain the pressure in the main tank at a required value. On the other hand, the longer and smaller in area the ports are the longer it will require to establish equilibrium of the system. Therefore, particularly where used for intermittent or batch operation, it may be more economical to provide relatively large ports and design the pumps and vacuum system to handle an increased flow of injected gas than to restrict the flow to a minimum value.

The nature and the intensity of the discharge from the cathode to the crucible is dependent upon the gas pressure (i. e., the density of population of the gas particles) within the chamber. The crucible can be heated by pure or substantially pure electronic discharge, such as would be obtained with pressures of the order of magnitude of 0.1 micron Hg. Without the injection of gas, at practicable voltages across the discharge path, this discharge is space-charge limited, therefore to get an adequate current flow and hence an adequate expenditure of power for heating the crucible the potential gradient must be high, and the cathode-crucible spacing short. This results in a high concentration of the electric field between the two electrodes and any roughness of the crucible results in points of high field concentration, where the discharge accordingly concentrates. The result is local heating which becomes cumulative, an arc crater forms and results in vaporization of the crucible material, resulting in a definite, cored arc, which, once formed, is uncontrollable except by cutting the power supply entirely. Any asymmetry of the assembly, whereby the crucible is closer to the cathode at one part of its circumference than at another, has the same effect. For a purely electronic discharge therefore, the adjustment becomes very critical and the operation unstable.

With the present arrangement the cathode is positioned at least twice the distance from the crucible that would be required to establish the same current flow in high vacuum, with the result that a given asymmetry of arrangement has very much less effect, percentagewise, on the path-length and field concentration. The amount of gas admitted into the inner chamber is small, and the mean free path of the particles, when ionized, is still relatively long in comparison with the spacing between cathode and crucible. The increased spacing also results in a wider distribution of the field with respect to the crucible. The flow of electrons from the cathode is still high enough, however, so that the probability of electron collision with a gas particle is high. The negative electrons from the ionized gas are promptly swept out of the field to bombard the crucible, but the much slower positive ions, attracted toward the cathode, acquire much lower velocity and therefore remain in the field for a much longer time. The net effect is very largely to neutralize the space charge between the cathode and crucible. The very great majority of the current carriers entering into the discharge are still electrons and the cathode emission therefore supplies by far the greater proportion of the flow of heating current but there is, nonetheless, an ionic discharge which has a very important function in the operation. It spreads the field, spreads the discharge, prevents the formation of localized hot spots which would establish arc craters and stabilizes the entire operation.

Fig. 4 shows a modification of the construction of the inner chamber wherein insulating material is employed for its construction. The chamber in this instance is formed of a dense, highly insulating ceramic, (similar for example, to that used for spark plug cores) such as aluminum oxide, steatite or sillimanite. Being a good insulator the chamber can, in this instance, rest directly on the bottom of the tank **1**, without the use of supporting insulators **13**. The bottom of the chamber is formed of a disc **61** of such ceramic, the edge whereof is rabbetted to receive a cylinder **63**, of ceramic tubing. The cover **65** of the chamber rests on top of the cylinder **63**, positioned by a rabbetted edge similar to that surrounding the bottom disc. The cover **65** is annular in form, with its central aperture just large enough to clear easily the body of the crucible **15''**. The latter is supported by an upper flange from a graphite contact ring **51'** which connects to the lead **17**. In this case, however, the graphite ring **51'** rests directly on the cover **65** of the chamber, and separate exhaust ports **67** are provided in the cover, for the escape of the gas injected from the duct **27''**, which serves the same purpose as duct **27'** of Fig. 2. The duct enters the chamber through an aperture **69** in the side wall of the chamber.

The cathode **21'** is in this case formed of a thin sheet of tungsten, formed into a cylinder that rests on a number of ceramic struts **71**. Preferably the struts **71** rest upon a discoid heat shield **47'**, which may be identical to the heat shields **47'** shown in Fig. 2 and may be similarly supported. However, as indicated in the drawings, a smaller number of heat shields **47'** may be adequate in the Fig. 4 structure than is required in the Fig. 2 structure. These struts are provided with slots in their upper ends in which the edges of the cathode cylinder rest and which position the cathode. This arrangement is preferred to the use of a complete annular support for the cathode since it involves less cooling of the cathode by conduction and maintains more uniform emission over the cathode surface. One or more cylindrical heat shields **47**, similar to heat shields **47** of Fig. 2, may advantageously be provided around the outer side of cathode **21'**, as shown.

The ends of the sheet of which the cylinder **21'** is formed are bent outwardly, as shown in Fig. 5, and secured to heavy connecting lugs **73**, to which are attached the leads **39'** that extend outwardly through the wall **63**. Whether or not the leads make contact with the wall is no moment, since the wall is insulating. The fact that the outwardly projecting ends of the cathode are cooled by the lugs **73** is desirable rather than otherwise, since such cooling lowers their resistance and concentrates the application of power at the emitting surface where it is needed. The leak through the apertures in wall **63** provided for the leads **39'** can be smaller than in the case of the chamber of Fig. 2 and this reduces the flow of gas necessary to maintain the desired pressure differential between the inner chamber and the main tank, reducing somewhat the load on the pump and permitting high vacua in the tank. This may or may not be an advantage, as has already been explained.

Although the ceramic walls of the chamber will be permitted to operate at higher temperatures than metal walls, and themselves usually have better coefficients of reflection than metal, it is preferable to provide at least one heat shield **47** and **47'**, of the same character as has been described in the other form shown, to reduce the temperature of the chamber walls and thus conserve the heat within the chamber. Such conservation is aided by the fact that the insulating material of the chamber is a poor conductor of heat; there is a high thermal gradient across its walls and the temperature of its external surface is much lower than that of its internal surface. Therefore heat loss by radiation from the side walls and the top of the chamber, and by conduction through the bottom **61** to the tank, is not too serious, even though the heat shields are omitted.

If the material to be treated does not require melting, a muffle can be used instead of a crucible. Effectively, this merely involves turning the chamber on its side, with appropriate mechanical changes for supporting the various elements, which should be obvious to anyone skilled in the art.

Also obvious should be the fact that many modifications are possible, whether the receptacle in which the heating occurs is a crucible or a muffle. In either case a crucible material which would be desirable because of its electrical characteristics may be one which is attacked chemically by the material to be treated. In this case an inner crucible may be used and heated by inward radiation from an outer, conductive one. As used in the more specific claims in this specification, the term "crucible" is intended to cover such an outer receptacle. Because radiation inward results in substantially black-body conditions, the temperature rise of an inner container heated by radiation will eventually be substantially identical with the temperature that would be obtained if the molten metal were directly in contact with the outer crucible, although the time required to melt the metal may be increased somewhat.

There are numerous other modifications of the invention that are believed to be sufficiently obvious from the descriptions already given to make it unnecessary to do more than merely touch upon them. For example, instead of providing an entirely separate chamber entirely enclosed within the main tank, the auxiliary chamber may be a part of the same structure separated from it merely by a diaphragm or septum apertured to receive the receptacle and for exhaust. Another modification would be to make the auxiliary chamber as a compartment completely outside of the main tank, connecting with the latter through apertures in the side wall. Such a construction might have advantages for muffle heating. In either of these modifications the auxiliary chamber would still be an "inner chamber" as the term is used herein, since, in operation, its exhaust would be through the main tank.

The invention as shown and described herein has been reduced to its simplest terms. Many other features can, of course, be added in order to adapt it to specific processes. Continuous, top feeding of the crucible can be added, as well as means for tapping the crucible from the bottom in order to adapt the invention to continuous instead of batch processing. Such additions which are not directly related to the present invention, may involve changes in sizes, shapes, and materials used. The specific apparatus shown and described is therefore not to be considered as limiting the scope of the invention, intended limitations being specifically set forth in the claims.

What is claimed is:

1. A crucible-heating furnace for melting and outgassing materials under high-vacuum conditions comprising the combination of elements designated as elements (*a*) to (*f*) inclusive and defined as follows:

Element (*a*): an inner heating chamber having an opening in the top thereof adapted to admit the body of a crucible therethrough, the upper rim of said crucible remaining external to said chamber;

Element (*b*): insulating means for supporting such crucible within element (*a*) so as to leave an annular gap between the edges of said opening and the walls of said crucible that is small in area as compared with the area of the top of the crucible so supported;

Element (*c*): an electron-emitting cathode positioned to surround said crucible, when so supported, at substantially uniform spacing from the walls thereof;

Element (*d*): terminals for making electrical connections to said crucible and said cathode to establish an electrical discharge therebetween;

Element (*e*): means for injecting a controlled flow of inert gas within element (*a*) to add a controlled degree of ionic electrical discharge to electron discharge from said cathode; and

Element (*f*): a vacuum-tight tank enclosing elements (*a*) and (*b*) and provided with an exhaust connection adapted for attachment to a vacuum pump of such size as to maintain the pressure in said tank externally of said inner chamber at a value materially lower than that within it despite liberation of gas from material within said crucible.

2. A crucible-heating furnace for melting and outgassing materials under high-vacuum conditions comprising the combination of elements designated as elements (*a*) to (*g*) inclusive and defined as follows:



Element (*a*): an inner heating chamber having an opening in the top thereof adapted to admit the body of a crucible therethrough, the upper rim of said crucible remaining external to said chamber;

Element (*b*): a crucible of conducting material having a cross-sectional area adapting it for insertion in said opening of element (*a*), leaving a surrounding gap of relatively small dimension in comparison with said cross-sectional area and the periphery of said opening;

Element (*c*): means for supporting said crucible with the body thereof within element (*a*) and the rim external thereto so as to leave a passage for gas out of element (*a*) through said gap;

Element (*d*): an electron emitting cathode within element (*a*) and surrounding said crucible when so supported by element (*c*);

Element (*e*): means including electrical connections to elements (*b*) and (*d*) respectively for maintaining a potential difference therebetween for initiating an electronic discharge;

Element (*f*): means for injecting into element (*a*) a controlled flow of gas to add to said electronic discharge an ionic discharge of controlled intensity; and

Element (*g*): a vacuum tank surrounding elements (*a*), (*b*) and (*c*) and having an exhaust port adapted for connection to a vacuum pump.

3. A crucible-heating furnace for melting and outgassing materials under high-vacuum conditions comprising the combination of elements designated as elements (*a*) to (*e*) inclusive and defined as follows:

Element (*a*): a vacuum tight tank including an exhaust port adapted for connection to a vacuum pump;

Element (*b*): an inner chamber within said tank adapted to contain the body of a crucible therein, the rim of said crucible being external to said chamber and opening into element (*a*), said chamber also remaining provided with an exhaust port for connection to a vacuum system;

Element (*c*): an electron-emitting cathode positioned to surround said crucible;

Element (*d*): mutually insulated terminals for applying a difference of potential between said cathode and said crucible; and

Element (*e*): means for injecting a controlled flow of inert gas into element (*b*), whereby a combined electronic and ionic discharge may be maintained between said cathode and crucible unaffected by instantaneous changes in pressure in element (*a*) from sudden evolution of gas from material in said crucible.

4. A crucible-heating furnace for melting and outgassing materials under high-vacuum conditions comprising the combination of elements designated as elements (*a*) to (*f*) inclusive and defined as follows:

Element (*a*): a vacuum tank provided with a port adapted for connection to an exhaust system;

Element (*b*): an open receptacle for material to be heated, at least the surface of said receptacle being electrically conductive;

Element (*c*): an inner chamber so enclosing the body of elecent (*b*) that it opens into element (*a*), said chamber having an exhaust port opening into element (*a*), said port having an open area that is small in comparison with the wall of said chamber wherein it is located;

Element (*d*): a cathode having an electron-emitting surface facing and spaced from the conducting surface of element (*b*);

Element (*e*): insulating means interposed between elements (*b*) and (*d*); and

Element (*f*): means for injecting gas in controlled amounts into element (*c*).

5. A crucible-heating furnace for melting and outgassing materials under high-vacuum conditions comprising the combination of elements designated as elements (*a*) to (*g*) inclusive and defined as follows:

Element (*a*): a main vacuum tank;

Element (*b*): an auxiliary chamber communicating with element (*a*) through a wall apertured to admit the body of a receptacle for material to be treated and to provide a passage for escape of gas particles from said chamber into element (*a*), the open area of said passage being small in comparison with the area of the chamber walls;

Element (*c*): an open-ended receptacle for material to be treated, said receptacle having a body conformed to admit its insertion through an aperture in the wall of element (*b*) with its open end in element (*a*), at least the outer surface of said receptacle being electrically conducting;

Element (*d*): a thermionic cathode within element (*b*) and having an electron-emitting surface facing and substantially uniformly spaced from the conducting surface of element (*c*) when the latter is inserted in element (*b*);

Element (*e*): insulating means electrically separating elements (*c*) and (*d*);

Element (*f*): terminals for applying an electrical potential difference between elements (*c*) and (*d*) to initiate an electronic discharge therebetween; and

Element (*g*): means for injecting a gas in controlled amount into element (*b*).

6. Apparatus for melting and out-gassing refractory metals under high vacuum by means of electrical bombardment comprising the combination of elements designated as elements (*a*) to (*g*) inclusive and defined as follows:

Element (*a*): a vacuum-tight outer tank;

Element (*b*): an inner chamber mounted within element (*a*);

Element (*c*): a vacuum system connecting into elements (*a*) and (*b*) and adapted to maintain different gas pressure within said elements, the pressure in element (*b*) being the higher;

Element (*d*): an electrically conducting crucible supported within element (*b*), the cavity within said crucible opening into element (*a*);

Element (*e*): an electron-emitting cathode surrounding element (*d*);

Element (*f*): means for establishing a potential difference between elements (*d*) and (*e*) to cause an electronic discharge therebetween; and

Element (*g*): means for injecting a controlled flow of gas into element (*b*) to add a controlled amount of ionic discharge to said electronic discharge.

7. A vacuum furnace for out-gassing materials at high temperatures, comprising a pair of connecting vacuum chambers, a first one thereof having an exhaust port adapted for connection to a vacuum pump, a receptacle for material to be treated adapted to be positioned with the body thereof extending into the second of said chambers and with an open end projecting into said first chamber, said receptacle when so positioned leaving a restricted passage connecting said chambers to permit evacuation of said second chamber through said exhaust port, and at least a portion of the surface of said receptacle being electrically conducting, a thermionic cathode having an electron-emitting surface facing and substantially uniformly spaced from said electrically conducting surface, insulating means interposed between said receptacle and said cathode, terminals for applying an electrical potential difference between said receptacle and said cathode to initiate an electronic discharge therebetween, and means for injecting a controlled flow of gas into said second chamber.

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UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 2,848,523 August 19, 1958

Charles W. Hanks et al

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 55, for "still" read -- steel --; column 5, line 69, after "ten-fold" insert -- pressure --; column 10, line 40, for "being" read -- remaining --; line 41, for "remaining" read -- being --; line 66, for "elecent (b)" read -- element (b) --.

Signed and sealed this 11th day of November 1958.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

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