Dec. 2, 1947. F. M. PENNING 2,431,887

ELECTRIC DEVICE AND METHOD FOR HEATING MATERIALS

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Fig. 1.

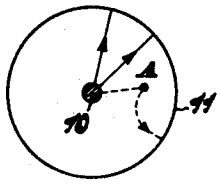
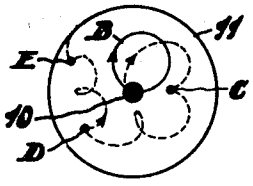



Fig. 2.



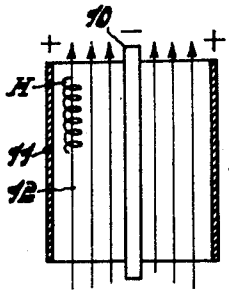




Fig. 3.

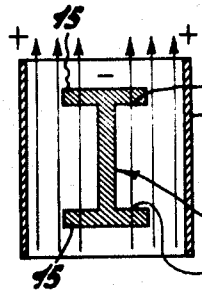



Fig. 4.

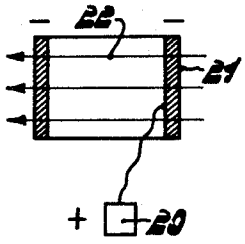



Fig. 5.

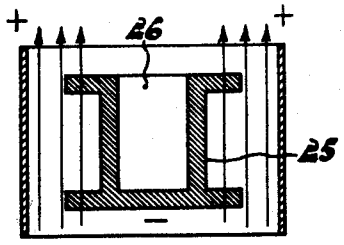



Fig. 6.

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ELECTRIC DEVICE AND METHOD FOR HEATING MATERIALS

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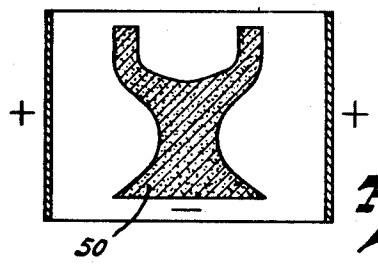



Fig. 8

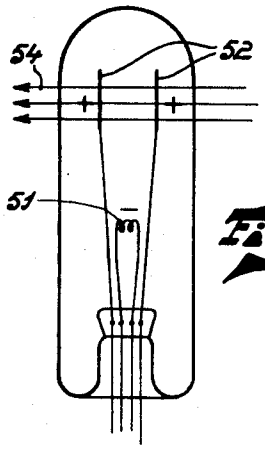



Fig. 9

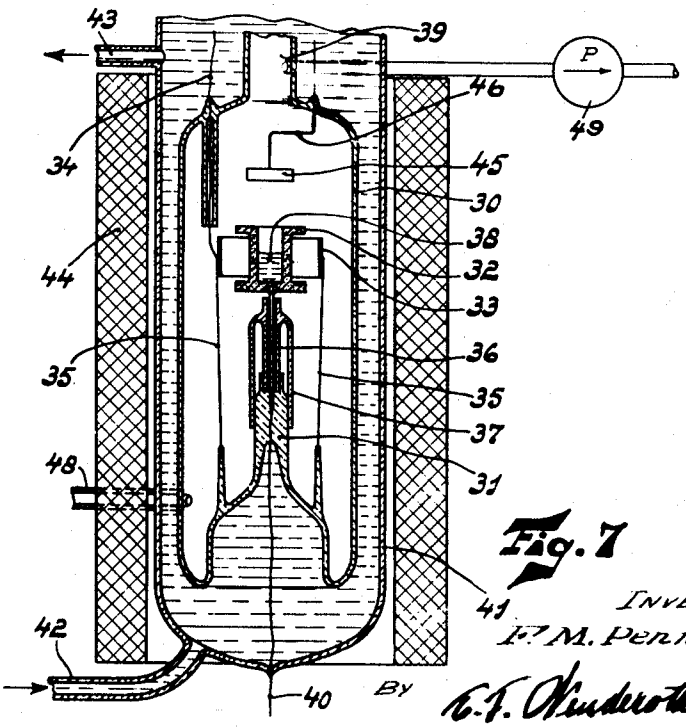



Fig. 7

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# UNITED STATES PATENT OFFICE

2,431,887

## ELECTRIC DEVICE AND METHOD FOR HEATING MATERIALS

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Application February 26, 1941, Serial No. 380,728
In the Netherlands January 16, 1940

10 Claims. (Cl. 219—35)

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Electric furnaces in which materials are heated to high temperatures in a low pressure gaseous atmosphere by high frequency currents are known. However, such furnaces are rather expensive and as a consequence thereof there exists the need of a less expensive electric furnace with which such heating operations can be effected.

According to the invention, for heating materials above 750° C. the source of heat is furnished by a glow-discharge which takes place in a magnetic field which greatly lengthens the electron paths. This method of treating permits temperatures of the order of 2000° C. to be obtained with equipment which is relatively inexpensive. The magnetic field may be provided either by an electromagnet or by a permanent magnet while the heating operation may take place in a closed glass space. The gas in this space may have a low pressure.

It is already known to effect heating operations by means of a glow discharge. For example, it has previously been proposed to de-gas electrodes by means of a glow-discharge. However when heating to high temperatures is attempted the glow discharge too readily passes into an arc discharge and the heating becomes concentrated at a single point on the surface of the body to be heated. Furthermore, the heating energy greatly decreases since the arc discharge has a much lower operating voltage than a glow-discharge.

If now the paths along which the electrons travel from the cathode to the anode are greatly lengthened by a magnetic field, this will be found to have a stabilizing effect on the glow-discharge and heating of the cathode for longer periods and to higher temperatures is possible. A further advantage is that with the same supply of energy as otherwise would be required for the glow-discharge lower gas-pressures and lower voltages may be utilized. It is obvious that the strength of the magnetic field must be efficiently chosen in connection with the voltage existing between the electrodes and with the pressure of the gas. It is a further requirement that the radius of the arc according to which the electrons are deflected under the influence of the magnetic field should be of the same order of magnitude as or smaller than the length of the free path between the gas molecules.

The above-mentioned method may be carried out in different ways. Thus, the heating device may be constructed as a furnace and the body to be heated may be given the shape of a vessel in the hollow interior of which are provided the materials to be heated, melted or vaporised. It

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is also possible to utilize the body to be heated as a radiator of light and to use the device as a lamp. Finally the method may also be utilised for heating electrodes for a long time to a high temperature in order to remove occluded gases to a satisfactory extent.

In the above-mentioned cases the body to be heated or the furnace may be arranged, if desired, in a space of reduced gas-pressure. The arrangement should preferably be such that the gas-pressure in this space may be varied and may be adjusted during the glow-discharge to the most favourable value. This affords the further advantage that the glow-discharge can be more easily ignited at a higher pressure whilst, once ignited, it may be continued at a low pressure. Furthermore, with such an arrangement, the glow discharge may be conveniently extinguished by pumping off the gas and the heated object kept at a high temperature by the vacuum. For the purpose of regulating the pressure it is often efficacious to cause the gas continually to flow-in on the one side of the tube and to pump on the other side. In this way a continual renewal of gas takes place, which may be desired in those cases wherein during the heating many contaminating gases are set free.

According to one form of realisation of the method according to the invention the glow-discharge is caused to take place in helium of low pressure for as compared with most other gases the cathode volatilisation in helium is very slight.

The invention will be explained more fully with reference to the accompanying drawings in which

Fig. 1 represents diagrammatically a concentrically arranged cathode and anode and the course of the electron paths between them.

Fig. 2 diagrammatically represents the cathode and anode according to Fig. 1 and illustrates the electron paths produced under the influence of a magnetic field perpendicular to the plane of the drawing.

Fig. 3 is a lateral elevation of Fig. 2.

Fig. 4 shows the arrangement of a modified form of cathode with a cylindrical anode, part of the operative surface of the cathode being cut by the lines of force of the magnetic field.

Fig. 5 represents a cylindrical cathode, an anode arranged outside thereof and a magnetic field which is perpendicular to the axis of the cathode.

Fig. 6 shows a cathode formed as a vessel and surrounded by a cylindrical anode.

Fig. 7 represents a furnace according to the invention.

Fig. 8 is a different form of construction of the cathode in the furnace according to Fig. 7.

Fig. 9 represents a discharge tube having arranged in it an auxiliary electrode by which the removal of occluded gases from the anode is rendered possible.

Fig. 1 diagrammatically represents a cylindrical cathode 10 and a cylindrical anode 11 which are coaxially arranged in a gaseous atmosphere of low pressure. If a voltage is applied to these electrodes the electrons proceeding from the cathode travel in vacuo according to the radially extending lines. In the presence of gas they collide with the gas atoms; with a low-gas pressure the path of an electron may assume, for example, due to a collision at A, the shape indicated by a dotted line. If the anode voltage is high enough ionisation may occur upon these collisions; the positive ions formed are drawn to the cathode and may set free therefrom not only the electrons required for their neutralisation but also further electrons. Assuming that an electron starting from the cathode forms on an average $n$ ions on its way to the anode, an independent discharge will occur when these $n$ ions set free together one additional electron from the cathode. During this discharge there occurs in the cathode a luminous phenomenon from which this discharge derives the name of glow-discharge. This luminous phenomenon is due to the lighting-up of the atoms hit by electrons. Owing to the frequent collisions of ions against the cathode the latter is heated more and more. When the energy supplied to the discharge increases, the possibility of the discharge passing from a glow-discharge into an arc discharge steadily increases. During the arc discharge the heating will be concentrated rather at a single point whilst the energy greatly decreases since the arc discharge has a much lower operating voltage than the glow discharge. The cathode is therefore heated to a much lower temperature.

In Fig. 2 the course of the electron path in vacuo is indicated by a curve B with the same cathode 10 and anode 11 as are shown in Fig. 1. The difference is, however, that this cathode and this anode are arranged in a magnetic field whose lines of force are perpendicular to the plane of the drawing. Due to this magnetic field the electrons undergo a strong deflection from the rectilinear path which they would attempt to follow under ordinary conditions. They are deflected according to a curve B whose radius of curvature depends at any point on the voltage between the electrodes and on the strength of the magnetic field. If the space is filled with gas of a very low pressure, these factors may advantageously be so chosen that this radius of curvature becomes of the same order of magnitude or small with respect to the length of the free paths between the gas atoms. Owing to this, the electron, for example after having left the cathode, will take through the magnetic field a path towards the anode as is diagrammatically shown in Fig. 2 by a dotted line. It may be seen how the electron successively collides in its path with gas atoms C, D and E. Since in these collisions the electron loses energy it can no longer reach the cathode whilst, on the other hand, it is prevented by the magnetic field from attaining the anode. In this way it may take a very long period of time before the electron has lost sufficient energy to reach the anode. This path is considerably longer than that in Fig. 1 so that also considerably more collisions with the gas atoms take place and consequently with lower voltages and a lower gas-pressure the same heating of the cathode may be attained and, besides, it is achieved that the glow discharge is stable and has little tendency to pass into the arc discharge.



Fig. 3 shows in lateral elevation the arrangement of Fig. 2. Moreover, the magnetic lines of force are indicated by arrowed lines 12 which extend parallel to the cathode. When an electron acquires a speed component parallel to the magnetic field this component is not influenced by the magnetic field. So long as the electron makes no collisions it consequently moves in a spiral path around a magnetic line of force and thus it may leave the discharge space. In order to prevent this Fig. 4 shows a shape of cathode 14 which is provided with flanges 15 and is arranged coaxially with respect to an anode 16. The magnetic lines of force are parallel to the axis of the cathode and cut the operative surface at the point 17 where they enter into the discharge space and at the point 18 where they leave said space. Owing to the latter fact the electrons which should have the tendency indicated in Fig. 3 will, when approaching the cathode wall, travel again in the opposite direction while moving around the lines of the magnetic field and travel in a zig-zag line between the flanges of the cathode to the anode. It is clear that the paths of these electrons are considerably lengthened and that consequently the possibility of collisions with atoms is appreciably increased.

Fig. 5 represents a further form of construction wherein an anode 20 is arranged outside a cylindrical cathode 21. The lines of force 22 of the magnetic field are perpendicular to the axis of the cathode. If desired, the cathode may also be given the shape of two plates arranged opposite one another, the magnetic field being perpendicular to these plates.

Fig. 6 represents a cathode 25 which essentially is formed with flanges as is the cathode 14 of Fig. 4 but, in addition, it has a central cavity 26 in which may be introduced a material which is heated by heat delivered by the cathode. Fig. 7 represents a heating furnace equipped with a cathode which offers these possibilities. The discharge tube consists of a wall 30 of Pyrex having sealed into it a stem 31 on which is mounted a cathode 32 provided with a cavity. The cathode is surrounded by an annular anode 33 which is led out of the tube by a conductor 34 and is maintained in its position by supporting wires 35. The stem 31 and the conducting wire 36 of the cathode are further surrounded by a tube 37 of quartz which safeguards the stem against arcing. The material to be heated 38 is introduced through an aperture 39 into the cathode 32 whereupon the interior space of the tube 30 is filled with gas of low pressure. The tube 30 is placed in a cooling vessel 41 provided with a supply conduit 42 and a discharge conduit 43 and is further surrounded by a coil 4. In connection with the gas-pressure prevailing in the tube and with the voltage to be applied between leading-in wires 34 and 40 the magnetic field set up by the said coil may be so chosen that the paths of the electrons are considerably lengthened. Due to the glow-discharge produced the cathode is very strongly heated and temperatures above 1000° C., if desired even temperatures of about 2000° C., may be attained, this heat being delivered to the material 38 which liquefies or vaporises. In order to ensure that the cathode can sustain these tem-

peratures it is made, for example, of graphite. It is efficaceous to utilise in this heating a filling of helium, preferably at a pressure of 5 mms. at the most since in helium volatilisation of the operative cathode wall occurs to a less extent. The arrangement of Fig. 7 is utilised, for example, for applying the material vaporised in the cathode **32** by vaporisation to a body **45** which is also mounted in the tube by means of a supporting wire **46**. It is obvious that the tube must be of other construction if it is intended to effect fusions of metals within the cathode **32** for in such cases it is necessary that the molten material can be easily removed from the cathode **32** or that the whole of this cathode is detachably mounted on the supporting rod **36** and may be removed through the aperture **39** from the tube **30**. It is also possible to modify the pressure of the gas within the tube **30**. For example, at the outset a higher pressure may be taken in order to effectuate a more easy ignition of the glow-discharge. When this discharge has once been ignited the pressure may be reduced, for example, by a vacuum pump **49** connected to the tube **30** at the aperture portion **39**. It is also possible to provide the tube **30** in addition to the outlet aperture **39**, with an inlet aperture **48**, by which renewal of the gas may be realised by the continual supply and discharge of gas.

Fig. 8 represents a cathode **50** which constitutes a variant of the cathode **32**.

Fig. 9 represents a discharge tube comprising an incandescent cathode **51** and two plate-shaped anodes **52**. When it is desired to de-gas these anodes **52** in the manner indicated above, this may be effected by means of a magnetic field **54** which is directed perpendicularly to the plates **52**. By temporarily connecting the cathode **51** as an anode and the plates **52** as a cathode, the latter plates will be strongly heated, during which heating degassing may take place.

What I claim is:

1. An apparatus for electrically heating materials to temperatures exceeding 750° C., comprising a discharge tube having an envelope containing an anode electrode and a heat generating cathode electrode spaced from said anode to form a discharge space and a gaseous medium within said envelope, means to increase the length of the path of electrons between said anode and cathode electrodes and to thereby increase the heating of the cathode electrode comprising a source of a magnetic field having lines of force extending through said discharge space and intersecting the paths of the electrons of the discharge, and means to confine the electrons to paths within the discharge space, said latter means comprising a portion of said cathode extending towards the anode electrode into the discharge space and intercepting a portion of the magnetic lines of force.

2. An apparatus for electrically heating materials to temperatures exceeding 750° C., comprising a glow discharge tube having an envelope containing an anode electrode, a heat-generating cathode electrode spaced from the anode to form a discharge space and a gaseous medium within the envelope, said cathode having an operative surface exposed to the discharge, and means to increase the length of the path of electrons between the anode and cathode electrodes and to thereby increase the heating of the cathode electrode comprising a source of a magnetic field having lines of force extending through the discharge space with at least a portion of the lines



substantially parallel to the operative surface of said cathode.

3. An apparatus for electrically heating materials to temperatures exceeding 750° C., comprising a glow-discharge tube having an envelope provided with an opening and containing an anode, a heat generating cathode spaced from said anode to form a discharge space and a gaseous medium within the envelope, means to increase the length of the path of electrons between the anode and cathode and to thereby increase the heating of the cathode comprising a source of a magnetic field having lines of force extending through said discharge space and intersecting the paths of the electrons of the discharge, and means connected to said opening to regulate the pressure of the gaseous medium.

4. An apparatus for electrically heating materials to temperatures exceeding 750° C., comprising a glow-discharge tube having an envelope provided with inlet and outlet openings and containing an anode, a heat generating cathode spaced from said anode to form a discharge space and a gaseous medium within the envelope, means to increase the length of the path of electrons between the anode and cathode and to thereby increase the heating of the cathode comprising a source of a magnetic field having lines of force extending through said discharge space and intesecting the paths of the electrons of the discharge, and means connected with said inlet and outlet openings to circulate the gaseous medium through said envelope.

5. An apparatus for electrically heating materials to temperatures exceeding 750° C., comprising a glow discharge tube having an envelope containing an anode, a heat generating cathode spaced from the anode to form a discharge space and a gaseous medium within the envelope, and means to increase the length of the path of electrons between the anode and cathode and to thereby increase the heating of the cathode comprising a source of a magnetic field having lines of force extending through the discharge space and intersecting the paths of the electrons of the discharge, said gaseous medium consisting substantially of helium at a pressure less than 5 millimeters of mercury.

6. An apparatus for electrically heating materials, comprising a discharge tube having an envelope containing an anode and a heat generating cathode spaced from the anode to form a discharge space and a gaseous medium within the envelope, said cathode comprising an electron-emitting body provided with a cavity adapted to receive the material to be heated and with edge portions extending towards the anode into the discharge space, and means to increase the length of the path of electrons between the anode and cathode and to thereby increase the heating at the cathode comprising a source of a magnetic field having lines of force intersecting the paths of the electrons of the discharge and extending through the discharge space and said edge portions.

7. A device for heating a body to temperatures exceeding 750° C. by ionic bombardment, comprising a glow-discharge tube having an envelope, said body being arranged within said envelope and acting as a cathode during the operation of the device, an anode electrode spaced from the body to form a discharge space and a gaseous filling within the envelope, and means to increase the length of path of electrons between the anode and cathode and to thereby increase the

heating of the body comprising a source of a magnetic field having lines of force extending through said discharge space and intersecting the electron paths between the body and said anode.

8. An apparatus for heating an electrically-conducting body to temperatures exceeding 750° C., comprising a glow-discharge tube having an envelope containing the body, an anode electrode spaced from the body to form a discharge space and a gaseous filling, and means to increase the heating of the body comprising a source of magnetic field having lines of force extending through the discharge space and intersecting the electron paths between the body and said anode, the pressure of the gaseous filling and the intensity of the magnetic field having values at which the electron paths in the discharge are greatly lengthened.

9. In apparatus for heating a substance to a high temperature, the combination of, means to maintain a gaseous medium in a discharge zone, means to produce a glow discharge in said zone by causing a flow of electrons, means to support the substance to be heated in the vicinity of the glow discharge, and means to maintain a magnetic field with the lines of flux intersecting the paths of the electrons, whereby the substance is heated by the heat produced by the successive impacting between the electrons and the atoms of gas, and the gaseous medium provides effective heat insulation for the substance.



10. In the art of heating a substance to temperatures exceeding 750° C., the steps of, producing a glow discharge in the vicinity of the substance to be heated by causing electrons to flow through a gaseous medium, and producing a magnetic field with the lines of flux extending through the glow discharge substantially at right angles to the direction of the flow of electrons, whereby the magnetic flux causes the electrons to be deflected from their normal paths and along extended paths.

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