Sept. 24, 1940. J. W. MARDEN ET AL 2,215,648

TELLURIUM LAMP AND METHOD OF OPERATION

Filed June 12, 1937 2 Sheets-Sheet 1

Fig. 1.

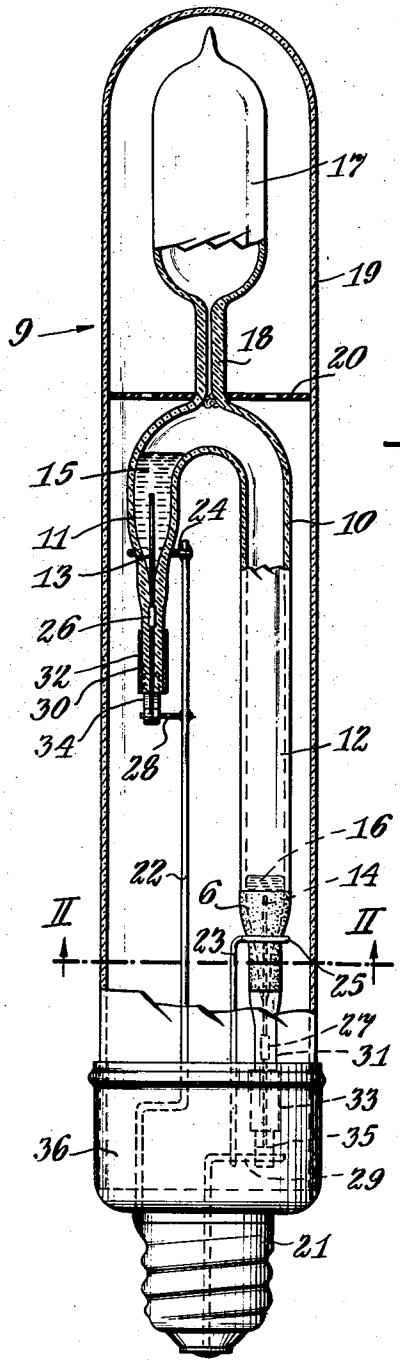


Fig. 2.

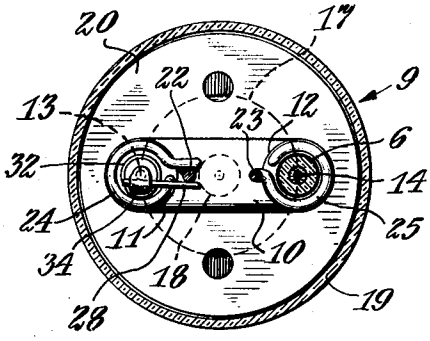
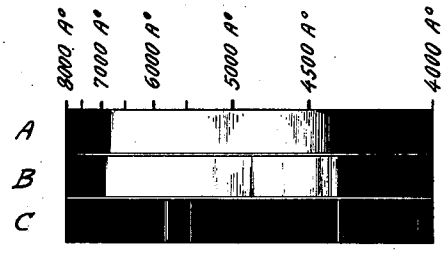
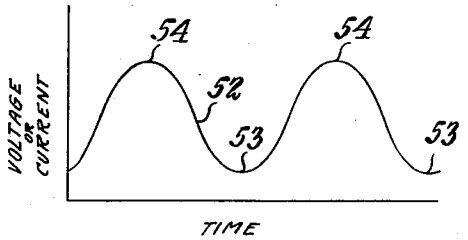


Fig. 3.



A : TELLURIUM VAPOR ARC SPECTRUM
B : SOLAR SPECTRUM
C : MERCURY ARC SPECTRUM

Fig. 4.



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Filed June 12, 1937 2 Sheets-Sheet 2

Fig. 5.

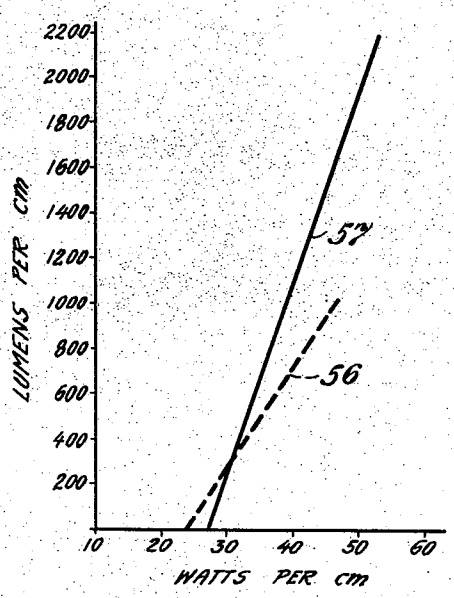


Fig. 6.

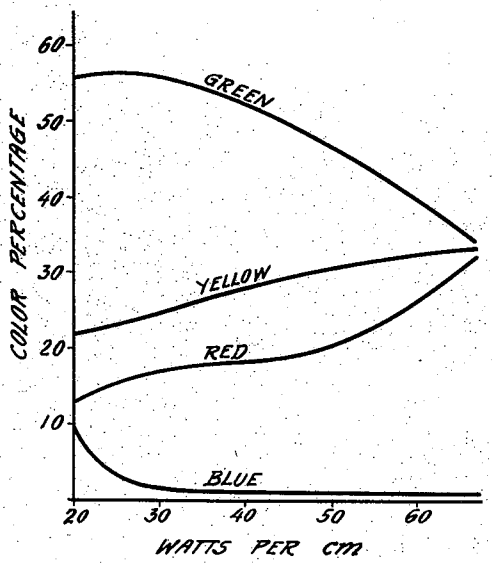
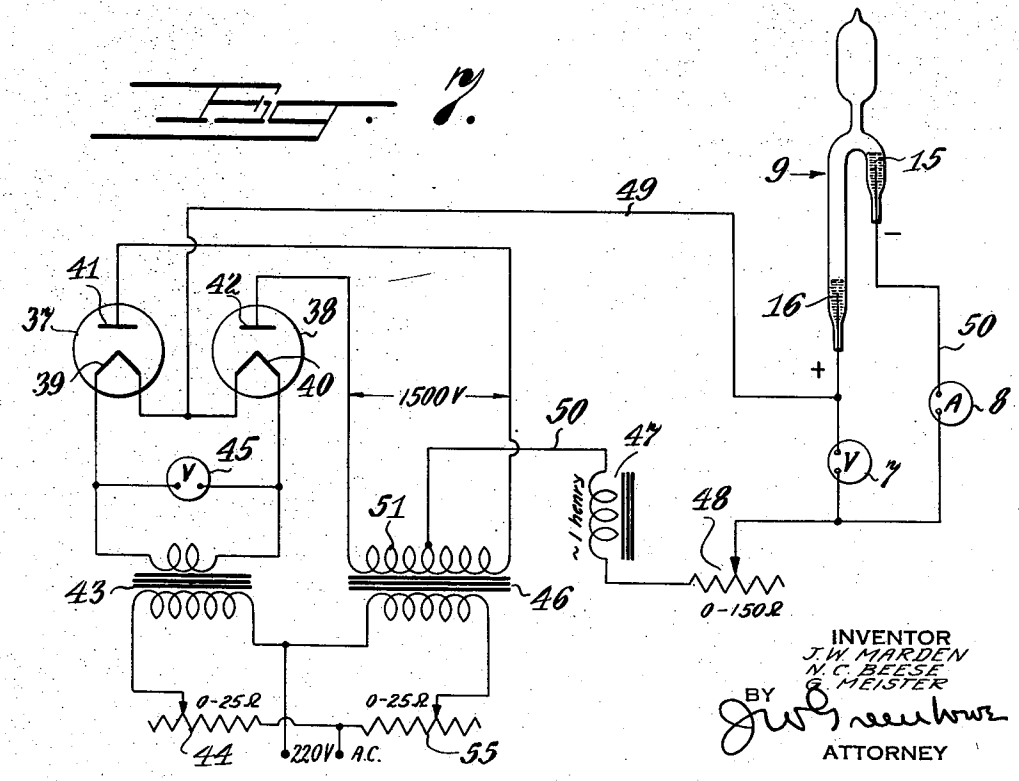


Fig. 7.



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TELLURIUM LAMP AND METHOD OF OPERATION

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17 Claims. (Cl. 176—42)

This invention relates to vapor lamps, and more particularly to such utilizing tellurium as the vapor-forming material, with or without mercury.

The principal object of the invention, generally considered, is the provision of a tellurium vapor lamp of high efficiency and long life.

Another object of the invention is to provide a tellurium lamp having an inverted J-shaped envelope and pool type electrodes connecting with tungsten lead-in conductors, the cathode being formed in the short leg of the envelope and normally operated full to the bend, sufficient tellurium being present so that both lead-in conductors are submerged in tellurium.

A further object of the invention is a tellurium lamp which also contains an inert gas, the envelope of said lamp being provided with an auxiliary reservoir connected thereto by a capillary tube in order to guard against an undue amount of clean-up of the available gas.

A still further object of the invention is the provision for operating a tellurium lamp in such a manner that the voltage impressed thereon does not drop at any time to less than 20% of the normal operating voltage, in order to avoid extinguishment of the lamp.

Another object of the invention is the provision of a tellurium lamp associated with filter means such as neodymium, to remove some of the yellow from the light formed by said lamp in order to provide an illumination approaching that of daylight.

Other objects and advantages of the invention, relating to the particular arrangement and construction of the various parts, will become apparent as the description proceeds.

Referring to the drawings:

Figure 1 is a longitudinal sectional view, with parts in elevation, of one embodiment of the tellurium lamp.

Figure 2 is a transverse sectional view, on the line II—II of Fig. 1, in the direction of the arrows.

Figure 3 is a diagram showing a comparison between the spectra from a tellurium vapor lamp, the sun, and a mercury arc.

Figure 4 is a diagram illustrating the maximum permissible fluctuation in rectified current supplied to a lamp embodying the invention.

Figure 5 is a chart illustrating the efficiency of operation of lamps embodying the invention, for the purpose of comparing the operation of lamps on a motor generator set with such on a full wave rectifier circuit.

Figure 6 is a chart illustrating the change in the spectrum from the tellurium lamp as the power input varies.

Figure 7 is a diagrammatic representation of a preferred full wave rectifier circuit for use in operating the lamp.

Referring to the drawings in detail, there is shown in Figs. 1 and 2, one embodiment of the invention comprising a lamp 9 having a quartz envelope 10 bent to inverted J-shape in outline, forming a depending short leg 11 and a depending long leg 12. The short leg has sealed thereinto a substantially straight normally submerged tungsten lead-in wire 13, and the long leg has a substantially straight normally submerged tungsten lead-in wire 14, forming, respectively, connections with the surrounding tellurium pool forming the cathode 15 and the surrounding tellurium pool forming the anode 16.

In addition to the pools of tellurium, the envelope 10 contains some inert or rare gas, in order to assist in starting. The gases which may be employed are neon, argon, helium, or mixtures thereof, at a pressure of about 1 to 5 centimeters of mercury. In order to prevent clean-up of the gas filling to an undesired extent during operation, an auxiliary reservoir 17 is provided and connected to the main envelope 10 as by means of a capillary tube 18.

When in operation, it is desirable to maintain the lamp hot while, at the same time, keeping the auxiliary reservoir 17 fairly cool. For that purpose, the lamp, and for protection the auxiliary reservoir, are desirably confined in an outer envelope 19, which may be of ordinary glass if the device is used for the production of visible light only, or of ultra-violet transmitting glass or quartz, if used for the production of ultra-violet light. This outer envelope keeps the whole apparatus warm during operation, and in order to prevent an excess amount of heat from reaching the auxiliary reservoir 17, a partition 20 of mica, or the like, is applied at the point indicated about the capillary tube 18, so as to confine the greater part of the heat to the part of the tube 19, which surrounds the inverted J-shaped or light-emitting envelope portion 10. The anode 16 normally runs hotter than the cathode 15 and for this reason the anode heat is desirably conserved in any desired manner, as by the application of gold paint to the exterior of the envelope around the anode pool, as indicated at 6.

The lamp is desirably operated when positioned upright as indicated in Fig. 1, and in order to hold the envelope 10 in place, with respect to an associated base 21, relatively heavy lead-in or supporting wires 22 and 23 extend from said base and are provided with portions 24 and 25, respectively bent to encircle the depending legs 11 and 12 of the envelope, and hold said envelope in place.

The tungsten leads 13 and 14 are connected thereto, desirably through ribbon portions 26 and 27, respectively, in order to prevent leakage, and branch conductors 28 and 29 extending from the bracing conductors 22 and 23, respectively. The tips 30 and 31 of the envelope 10 are desirably surrounded by cylindrical metal bracing portions 32 and 33, also connected to the branch conductors 28 and 29 by the extensions 34 and 35, to provide additional rigidity in mounting the envelope 10 in the exterior envelope 19. The base portion 21 is desirably enlarged, as indicated at 36, and sealed around the adjacent portion of the exterior tube 19.

The foregoing lamp should be operated on direct or rectified current, having as little fluctuation in the voltage as possible. In order to accomplish this purpose, provided that direct current of the desired voltage is not available, a motor-generator is desirably employed. Next in preference, is a full-wave rectifier circuit of such a character that the impressed voltage at no time drops to below 20% of the normal operating voltage.

Such a full-wave rectifier circuit is illustrated diagrammatically in Fig. 7, in which 37 and 38 represent diodes, such as UV—872, having incandescent cathodes 39 and 40 and associated anodes 41, 42. Assuming a 220-volt A. C. supply circuit, a step-down transformer 43 connected thereto through a variable resistance 44 desirably serves to supply the cathodes 39 and 40 with current, said cathodes being shown connected in series, with a voltmeter 45 indicating the potential applied to said cathodes by the transformer 43. The resistance 44 may be varied from 0 to approximately 25 ohms.

A step-up transformer 46 may serve for supplying power to the connected lamp 9 through the diodes 37 and 38, a suitable inductance 47, and a variable resistance 48. In order to operate the arrangement for full-wave rectification, the anode 16 of the lamp 9, which may have a voltmeter 7 across its terminals, is connected through conductor 49 to the midpoint between the cathodes 39 and 40, and the cathode 15 is connected through conductor 50, the inductance 47, the variable resistance 48, and ammeter 8, to the midpoint of the secondary winding 51 of the transformer 46 so that, in operation, not only are both waves of the supply current rectified to the lamp 9, but the inductance 47 prevents the applied voltage from at any time dropping to less than 20% of the normal operating voltage across the lamp 10, as represented by the chart in Fig. 4. In said chart the wavy or sinusoidal line 52 represents the pulsating voltage applied to, or the pulsating current passing through, the lamp 9 during the extreme condition for successful operation, the minima points 53 thereof representing 20% of the values represented by the maxima points 54.

The value of the resistance 55 may be such that as much as 25 ohms may be placed in the circuit to the primary of the transformer 46, while the variable resistance 48 is such that up to 150 ohms may be inserted in the secondary circuit. The value of the inductance 47 is desirably about 1 henry, and the step-up transformer 51 may be so designed that 1500 volts is normally developed at the terminals of the secondary.

The use of an auxiliary reservoir 17 was adopted because when tellurium lamps were made up without such a reservoir, they became progressively harder to start, due in part at least to the clean-up of the inert gas filling. Some lamps, after a few startings, would not restart without first opening and introducing more inert gas. Then, lamps were made by running the arcs while the lamps were on the pumps, so as to absorb or adsorb quantities of gas and thus reduce the rate of gas disappearance in the sealed-off lamp. This helped to increase the life of such lamps, but a gas reservoir, such as indicated at 17, was adopted as a further assurance. The size of the reservoir is desirably such that the total volume of the lamp, including it, is several times the volume of the arc stream. The reservoir is desirably connected to the main envelope by the fine bore capillary tube 18, which is sealed off from the arc during operation by condensed or solidified tellurium. Such a sealed constriction is still porous to the gas, allowing it to diffuse from the reservoir through the porous plug and build up a sufficiently high pressure for easy starting.

When a tellurium vapor lamp was filled with hydrogen gas and operated on a pump, a black deposit formed immediately on the quartz envelope. The gas filling used was 10% hydrogen and 90% neon. It was found that merely torching or otherwise heating the quartz did not remove the discoloration, but an admixture of air at low pressure, while the quartz was heated to a high temperature, turned the black deposit yellowish-white, which could be vaporized by heat alone when the lamp was highly evacuated. It was thus found that by flushing the lamp with an inert gas having a small percentage of oxygen, or operating the lamp on the pump with such a flushing gas, would insure the removal of hydrogen gas and a much cleaner lamp.

A tellurium lamp operated on a circuit as diagrammatically illustrated in Fig. 7 has a light output expressed by the equation, $L=42.5\ (w-23)$, where L=lumens per centimeter of arc length; w=watts per centimeter of arc length. 42.5 is the maximum theoretical efficiency if the electrode losses can be neglected, while 23 is the number of watts per centimeter lost at the electrodes. This equation is represented by the dotted line 56 in Fig. 5.

Higher efficiencies are attained when such a lamp is operated on a D. C. motor-generator set with a ballast resistance in series with the lamp, the equation of such operation being represented by $L=81.5\ (w-27)$, 81.5 being equivalent to the maximum theoretical efficiency if the electrode losses can be neglected. This equation is represented by the full line 57 in Fig. 5, which indicates that, except for very low outputs, the efficiency is higher than when operated on the full-wave rectifier circuit.

The reason for the employment of pool type electrodes, as distinguished from solid tungsten electrodes, is that highly heated tellurium vapor is so chemically active that the former type of electrodes must be employed in order to keep down the effective temperatures. Free tellurium melts at a temperature of about 450° C. and by keeping the tungsten lead-in wires immersed in the material, they are less subject to attack than

if exposed to the highly heated vapor. The particular structure of envelope is chosen to maintain a constant and adequate supply of liquid tellurium at each electrode during operation. As the material tends to distill from the anode to the cathode, that is, from the lower to the upper pool, and inasmuch as the upper pool operates normally full, any excess runs back to replenish the anode pool.

The purity of the tellurium should be the highest possible because of the deleterious effect of many impurities on heated quartz. Small percentages of selenium are especially bad. Electrolytic tellurium of high purity may be employed.

An inverted U-shaped lamp, otherwise of the character described, was made and thermocouple junctions were attached to the lamp with asbestos ribbon about one centimeter above the electrode surfaces. During one observation the temperature over the cathode surface was 700° C. while that over the anode surface was 825° C. While such recorded temperatures are of course somewhat below actual values inside the lamp, the observed values show a difference in temperature due to polarity, and a tellurium vapor pressure of about 20 millimeters of mercury, as indicated by a temperature of 700° C.

In testing a tellurium lamp, one was made with a reservoir and a side tube of about 3 cc. combined volume, which were attached to the top of the lamp. In the side tube was mounted a section of a 10-watt, 110-volt tungsten lamp filament, so that it could be used as a pressure gauge. It was calibrated against a McLeod gauge. The initial neon gas filling of 11 millimeters was reduced to 7 millimeters after the lamp had burned several hours. A similar lamp was made with a 20 cc. reservoir, and a pressure gauge attached to the top of the lamp. This lamp was operated on the pumps for an hour with several different fillings of neon gas. Such treatment saturated the tellurium with neon, as well as flushed out volatile impurities. During the first 50 hours of burning, the gas pressure had not changed in an observable manner.

The spectrum obtained from a tellurium vapor lamp is very different from the conventional "line spectra" obtained with most metallic vapor arc lamps. It consists of a banded structure throughout the visible region, with a heavy continuous spectrum superimposed, giving an effect approximately that of an incandescent solid. In the ultra-violet region, a line spectrum predominates, with strong resonance lines at 2386, 2383 and 2142 Angstrom units. There is also a very weak continuous spectrum in the ultra-violet, the intensity of which decreases toward the shorter wave lengths. The combination of a continuous spectrum produced by the recombination of tellurium ions, and a banded molecular spectrum, produces a very excellent artificial white light.

At low temperatures, pressures and wattages, the light emitted by a tellurium lamp is bluish-white in color, while at higher operating conditions the light becomes a yellowish-white. At extremely high operating temperatures, the light is a golden yellow. This shifting of the color toward the red end of the spectrum, with increase in temperatures, is exactly opposite to that encountered with an incandescent solid, whose spectral shift is in accordance with Wien's displacement law. While the initial bluish-white light is obtained with a tellurium vapor pressure of only a few thousandths of a millimeter of mercury pressure, the golden yellow color is attained with vapor above atmospheric pressure.

Figure 3 shows at A the tellurium spectrum in the visible region. A solar comparison spectrum B is represented immediately below, and one C from a mercury arc lamp at the bottom. An analysis of the ultra-violet spectrum revealed the presence of several impurities, the more important being lead, copper, iron, silicon, and magnesium which, however, did not affect the light output or operating efficiency because they were present in only very minute quantities.

The efficiency of such a tellurium vapor arc lamp varies over wide ranges, depending quite largely upon the power supply to the lamp. At low energy input, an efficiency of 2 to 5 lumens per watt was observed, while at higher wattages about 15 lumens per watt is attained. At extreme operating conditions, lamps have been made to yield an efficiency of above 40 lumens per watt. The wattage loss at the electrodes is excessively high in this type of lamp, so its overall efficiency is lower than compared to mercury or sodium arc lamps. The combined anode and cathode falls of potential are between 50 and 150 volts for most of these lamps, the actual values depending upon the operating conditions and the structure of the lamps. A lamp of 6 millimeters inside diameter and 10 centimeters arc length, requires 1 to 2 amperes at 100 to 300 volts for steady operation, while lamps of 8 millimeters diameter and 10 centimeter arc length have been operated satisfactorily with 2 to 3 amperes at 150 to 200 volts.

Figure 6 illustrates the color variations accompanying changes in wattage supplied to such lamps. This data was obtained from two lamps of 6 millimeters and one of 8 millimeters inside diameter, each lamp having an arc length of about 10 centimeters. Various color filters were used, and the wattage was varied over enormous ranges. At low wattages, the color approximates that of a black body at 6000° K., but here the efficiency is very low. The accompanying table illustrates the light distribution percentages in the visible spectrum, as compared with other sources of illumination.

LIGHT DISTRIBUTION IN THE VISIBLE SPECTRUM

Color and wavelengths in Angstrom units

Source	Red, 7200 to 5950	Yellow, 5950 to 5650	Green, 5650 to 4950	Blue, 4950 to 4000
Tellurium, low wattage	14.5	22.5	56	7
Tellurium, high wattage	32	33	34	1
Black body at 6000° K.	15.1	22.5	55.8	6.6
200-watt tungsten lamp	23.5	27.5	41.5	2.5
High pressure mercury lamp	1	43	54	2

We have found that if a tellurium lamp, as just described, is surrounded by a thin layer of a filter, such as glass containing small quantities of material which would absorb some of the yellow in the light generated, color values are obtainable which very nearly duplicate daylight. A material which may be used in making such filter glass is neodymium.

We have also found that if a small quantity of mercury is introduced into a lamp containing tellurium, that it is possible to get the mercury spectral lines simultaneously with the tellurium spectrum. Such a lamp combining mercury with tellurium is desirably constructed as illustrated in Figs. 1 and 2, except that the auxiliary reser-

voir 17 is omitted, to avoid the condensation and entrapment of mercury therein. In order to obviate clean-up of the rare gas during operation, the lamp may be operated while on the pump with the tellurium in contact with the gas, so as to saturate it with said gas prior to sealing off. After this has been accomplished, the mercury is introduced in any desired manner together with the desired pressure of inert rare gas, which pressure may correspond with that of the embodiment not utilizing mercury, as the mercury pressure at low temperatures is very small. Preferably, such a small quantity of mercury is introduced that it is substantially all vaporized under normal operating conditions.

We found that such a lamp containing mercury was highly efficient, the generated light was of a good color, and the lamp could be restarted after burning much more easily than a lamp containing tellurium alone.

The color of the light generated by our mercury-tellurium lamp was yellowish when the lamp was operated at 20 lumens per watt. We found that a specific lamp, with 47 millimeters arc length gave 4500 lumens with 200 watts. A similar lamp, but containing tellurium without the mercury, gave only 1000 lumens at the same wattage. It seems that not only are the starting conditions improved by the addition of mercury, but the temperature of operation is lowered, which is very desirable.

In the publication entitled "Zeitschrift für Physik", vol. 101, page 214, 1936, appears an article about discharges in tellurium vapor by R. Rompe. In this article, there is a description of a lamp having tellurium electrodes formed generally as we have described. However, we have secured some results different from that described by Rompe, and our invention involves a number of features which are improvements over the Rompe lamp. An example of the improvements are that we use an auxiliary gas reservoir to prevent an undue amount of clean-up of the rare gas during operation. We also use an outer envelope which conserves the heat of the lamp and renders its operation more efficient. We also suggest that this outer envelope may incorporate filter means, such as neodymium glass, or similar material, for absorbing some of the yellow in the generated light and give the transmitted light an appearance approximating that of natural daylight. We also suggest the use of mercury for improving, not only the quality of light emitted, but also the operation of the lamp, and in order to make it easier to start.

From the foregoing disclosure, it will be seen that tellurium lamps, constructed in accordance with the invention, give a continuous instead of a line spectrum, as ordinarily found in vapor lamps, and for this reason are more valuable for illumination than such line spectrum lamps. The color changes are very pronounced as the power supply to the lamps is varied. At low wattage the color is practically identical with that given off by a black body at 6000° K. The special color distribution makes the tellurium vapor lamp ideal for certain applications.

Although a preferred embodiment of the invention has been disclosed, it will be understood that modifications may be made within the spirit and scope of the appended claims.

We claim:

1. A lamp comprising a curved envelope, a plurality of electrodes, each comprising a substantially straight metal conductor surrounded by a pool of tellurium, and a reservoir connected to said envelope by means of a tube of relatively small bore.

2. A lamp comprising a quartz envelope generally inverted J-shape in outline, an electrode disposed adjacent each end and each comprising a straight tungsten wire submerged in a pool of tellurium, and a reservoir joined to said envelope by a passage so small, that tellurium is kept therefrom.

3. A tellurium lamp comprising a gas-containing tube of quartz having a bend providing depending legs of unequal length, the short leg having a straight tungsten lead-in conductor sealed thereinto with the inner end portion submerged in a pool of tellurium, the long leg having a tungsten lead-in conductor with its inner end portion submerged in a pool of tellurium, and a gas reservoir connected to said tube by a passage so small that tellurium is excluded during operation, while depletion of the gass is retarded.

4. A tellurium lamp comprising an envelope of quartz having a bend forming legs depending therefrom, one leg being short and having a generally straight tungsten lead-in conductor sealed thereinto and normally submerged in a pool of tellurium, the other leg being longer and having a generally straight tungsten lead-in conductor sealed thereinto and normally submerged in a pool of tellurium, the amount of tellurium in the envelope being such that the first-mentioned pool, when used as a cathode, is maintained filled to the bend in the tube with tellurium.

5. A lamp comprising a refractory envelope containing tellurium, an inert gas, a pair of electrodes, and a reservoir connected to said envelope by means of a capillary tube.

6. A lamp comprising a curved envelope containing an inert gas, and a plurality of electrodes, each electrode comprising a pool of tellurium, said envelope including an auxiliary portion connected thereto by means allowing passage of the gas, but preventing passage of the tellurium.

7. A lamp comprising a quartz envelope, generally inverted J-shape in outline, containing an inert gas, a pair of electrodes each comprising a pool of tellurium, and a reservoir connected to said envelope by means of a capillary tube.

8. A lamp comprising a curved envelope, a plurality of electrodes each comprising a pool of tellurium in an end portion of said envelope, an outer envelope enclosing said curved envelope for maintaining the desired temperature during operation thereof, a base on said outer envelope, a reservoir connected to said curved envelope and extending therefrom and away from said base, and leads from said base to said electrodes, both of the leads extending into said pools through said envelope in approximately the same direction.

9. A lamp comprising an envelope generally inverted J-shape in outline, a reservoir connected thereto and extending upwardly from the bend therein, an outer envelope surrounding said J-shape envelope and reservoir, a base for said outer envelope, lead-in conductors from said base to electrodes in said J-shaped envelope, and a partition in said outer envelope at the point of union between said J-shaped envelope and reservoir.

10. A lamp comprising an envelope containing tellurium and enough mercury to facilitate starting.

11. A lamp comprising a rare-gas filled envelope

containing tellurium and enough mercury to improve starting conditions.

12. The method of producing artificial daylight comprising operating a tellurium lamp in combination with a neodymium glass filter.

13. A lamp comprising a refractory envelope containing tellurium, an inert gas, and a pair of electrodes, and a reservoir connected to said envelope by means of a tube so small that it will condense tellurium vapor as it attempts to pass therethrough and prevent further passage thereof, but will always allow the passage of gas.

14. A lamp comprising a quartz envelope inverted J-shape in outline and enclosing an inert gas, a pair of electrodes, each comprising a pool of tellurium disposed in an end of said envelope, and a reservoir connected to the normally upper portion of said envelope intermediate said electrodes by means of a capillary tube, the inside diameter of said tube being such that, upon operation, some tellurium is condensed therein preventing further passage thereof, while passage of the gas therethrough is still permitted.

15. A lamp comprising a rare gas filled envelope holding tellurium mixed with a quantity of mercury so small that it is substantially all vaporized under normal operating conditions, but enough so that the starting conditions are improved, the operating temperature lowered, and the lumen efficiency increased.

16. A lamp comprising an envelope with depending legs of unequal length making it generally inverted J-shape in outline, an outer envelope enclosing said J-shaped envelope, a base for said outer envelope, leading-in conductor-supports extending from said base, lead-in conductors extending through the depending legs of said envelope and connecting with electrodes therein, means extending from portions of said conductor-supports and forming rings receiving said legs for mounting said J-shaped envelope in the outer envelope, and conductors branching from said supports and connecting with said lead-in conductors for supplying energy to said lamp.

17. A lamp comprising a refractory envelope containing tellurium, an inert gas, and a pair of electrodes, a reservoir connected to said envelope by means of a tube so small that it will condense tellurium vapor as it attempts to pass therethrough and prevent further passage thereof, but will always allow the passage of gas, an outer envelope surrounding said refractory envelope and reservoir, and a partition in said outer envelope at approximately the point of union between said refractory envelope and reservoir for keeping heat from the latter.

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