United States Patent [19]

Akutsu et al.

[11] **3,898,504**

[45] **Aug. 5, 1975**

[54] **HIGH PRESSURE METAL VAPOR DISCHARGE LAMP**

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[73] Assignee: **Matsushita Electronics Corporation**, Osaka, Japan

[22] Filed: **Nov. 15, 1973**

[21] Appl. No.: **416,015**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 204,866, Dec. 6, 1971, abandoned.

[30] **Foreign Application Priority Data**

Dec. 9, 1970 Japan 45-109842

[52] **U.S. Cl.** **313/220**; 313/184; 313/214; 313/225

[51] **Int. Cl.** **H01j 61/30**; H01j 61/18

[58] **Field of Search** 313/183, 184, 214, 220, 313/221, 225, 229

[56] **References Cited**

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2,240,353	4/1941	Schnetzler	313/214 X
2,924,733	2/1960	Schirmer et al.	313/214 X
3,248,590	4/1966	Schmidt	313/184
3,586,898	6/1971	Speros et al.	313/229

FOREIGN PATENTS OR APPLICATIONS

485,274	5/1938	United Kingdom	313/184
106,842	3/1939	Australia	313/214

Primary Examiner—James W. Lawrence
Assistant Examiner—E. R. LaRoche
Attorney, Agent, or Firm—Stevens, Davis, Miller & Mosher

[57] **ABSTRACT**

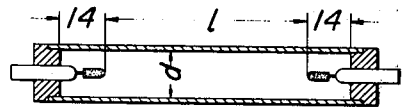
An electric discharge lamp having an excellent color rendition with a color acceptability higher than 1.0, a relatively high luminous efficacy and a good life performance, is provided, in a high pressure metal vapor lamp using a polycrystalline alumina ceramic tubing as the arc tube envelope within which sodium as a metal for producing radiant emission, mercury or cadmium as a buffer gas and xenon as a starting inert gas are contained, by controlling such quantities which are variable in the design of the high pressure metal vapor discharge lamp as the lamp wattage W in watts, an increased internal diameter of the arc tube envelope of the lamp d in millimeters, the interelectrode gap length L in millimeters and a lowered average potential gradient of the arc tube E in volts per centimeter in such a manner that they may satisfy the relations:

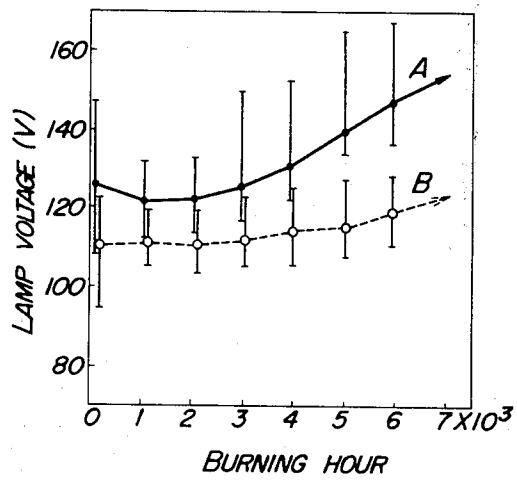
$$25 \geq e \geq 37.7 - 2.05d \text{ (but, } d > 9\text{)}$$

and

$$\frac{10\,W}{13.3d - 76.4} \geq L \geq \frac{10\,W}{16d - 58}$$

9 Claims, 6 Drawing Figures





CURVE A : d = 9.0mm l = 65mm

CURVE B : d = 9.5mm l = 60mm

FIG. 1

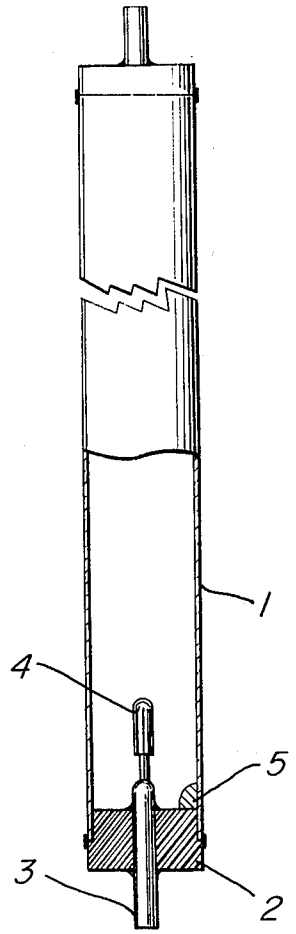


FIG. 2

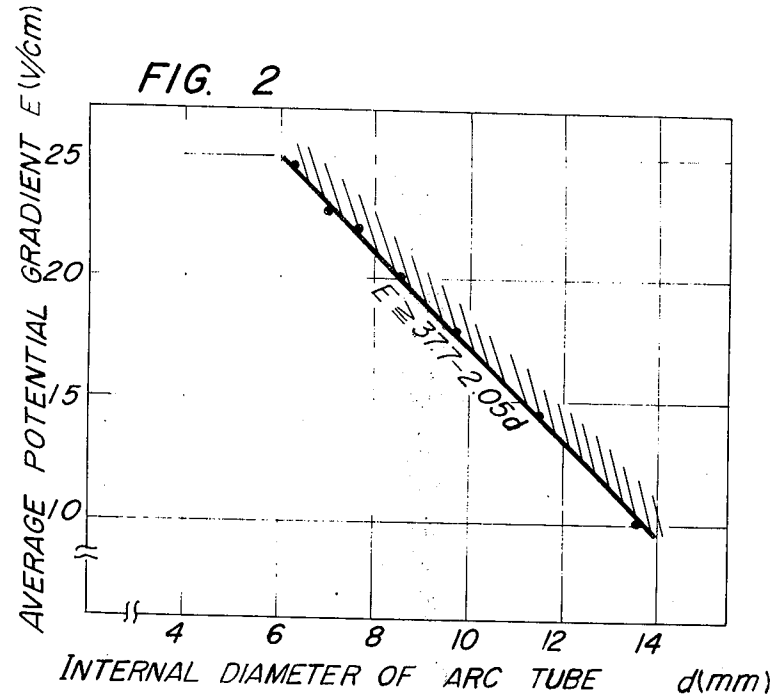

AVERAGE POTENTIAL GRADIENT E (V/cm)
25
20
15
10
E = 37.7 - 2.05d
4
6
8
10
12
14
INTERNAL DIAMETER OF ARC TUBE d(mm)

FIG. 3

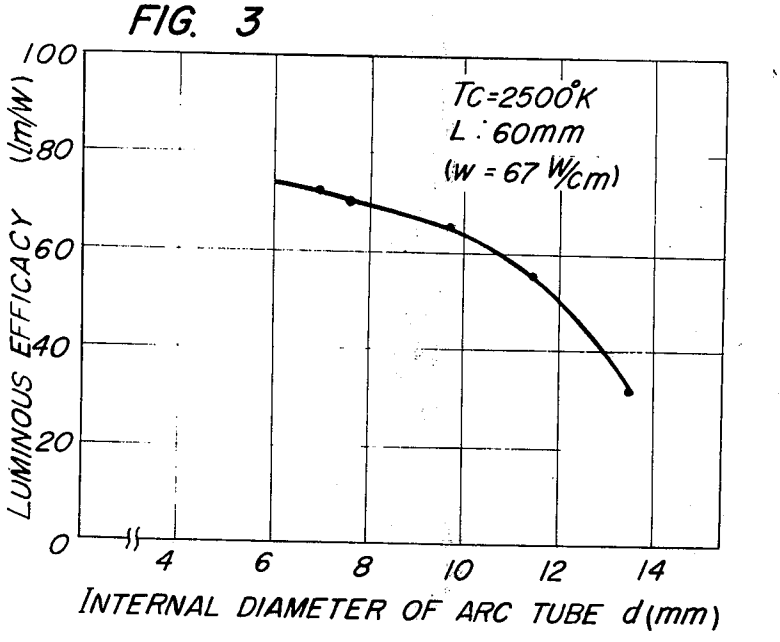

LUMINOUS EFFICACY (lm/W)
100
80
60
40
20
0
Tc=2500°K
L : 60mm
(w = 67 W/cm)
4
6
8
10
12
14
INTERNAL DIAMETER OF ARC TUBE d(mm)

FIG. 4

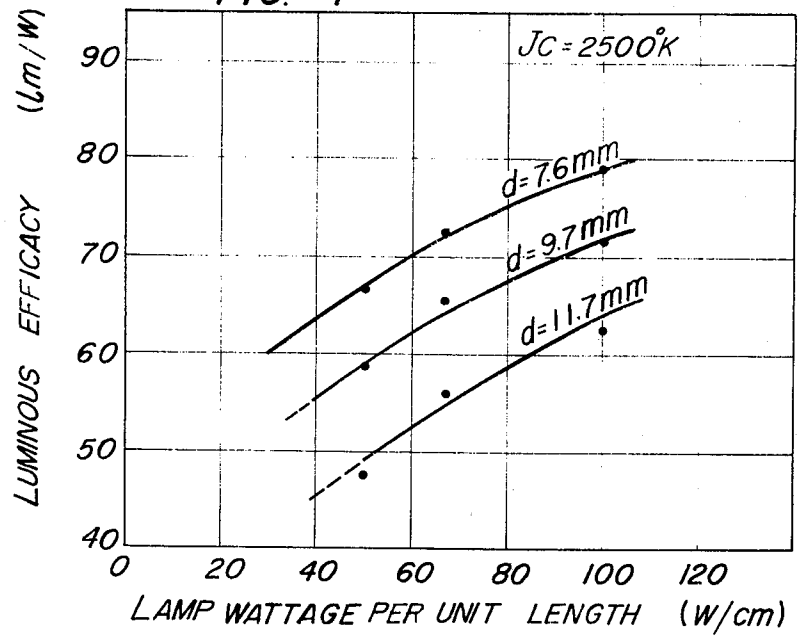

JC = 2500°K
d=7.6mm
d=9.7mm
d=11.7mm
LUMINOUS EFFICACY (Lm/W)
90
80
70
60
50
40
0
20
40
60
80
100
120
LAMP WATTAGE PER UNIT LENGTH (W/cm)

FIG. 5

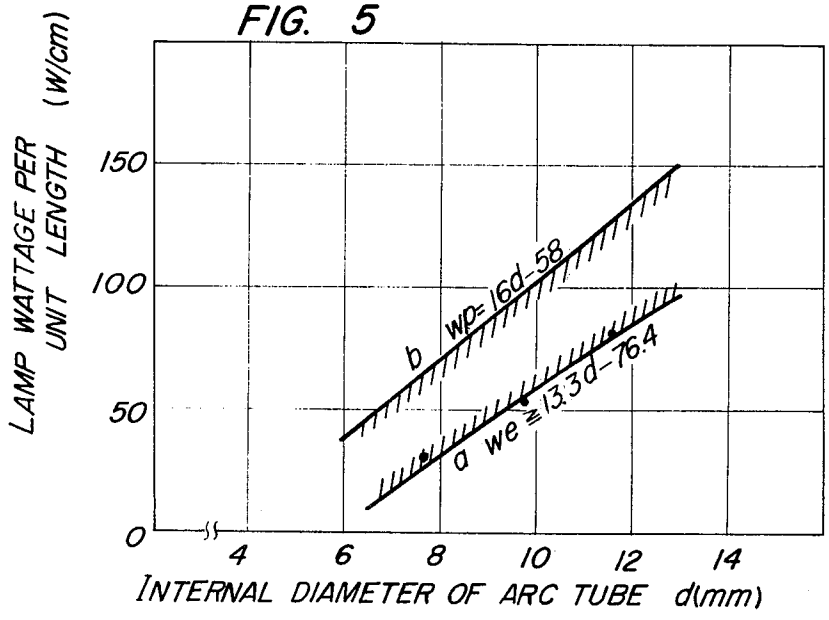
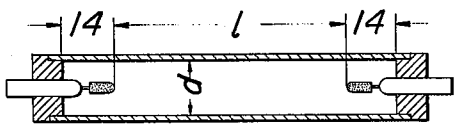
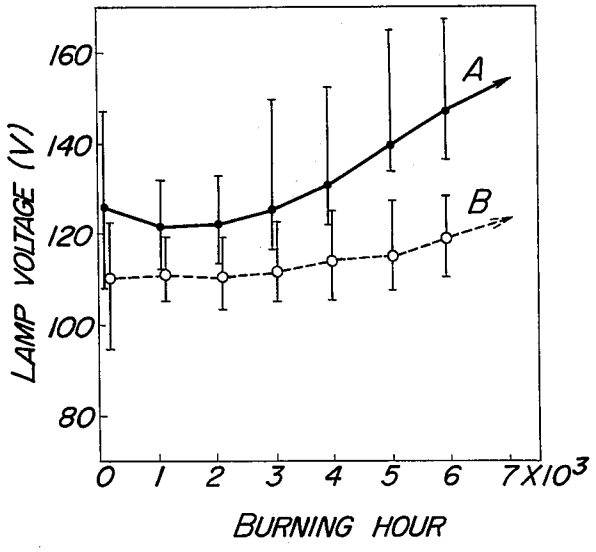

LAMP WATTAGE PER UNIT LENGTH (W/cm)
150
100
50
0
b wp=16d-58
a we=13.3d-76.4
4
6
8
10
12
14
INTERNAL DIAMETER OF ARC TUBE d(mm)

FIG. 6





CURVE A : d=9.0mm l=65mm

CURVE B : d=9.5mm l=60mm

HIGH PRESSURE METAL VAPOR DISCHARGE LAMP

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part application of the U.S. Ser. No. 204,866 filed Dec. 6, 1971 and now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a high pressure metal vapor discharge lamp using a polycrystalline alumina ceramic tube which is translucent and within which metal for producing radiant emission, buffer gas and inert starting gas are placed, and more particularly to the structure of such a lamp with which the vapor of the metal in the lamp can be maintained at a high pressure.

2. Description of the Prior Art

Since the polycrystalline alumina ceramic used for the arc tube envelope can withstand the attack of metal vapor at high temperatures and high pressures, as is disclosed for example in the U.S. Pat. No. 3,248,590, a high pressure metal vapor lamp discharge with a polycrystalline alumina ceramic envelope has been widely used in the practical field.

One typical example of such high pressure metal vapor discharge lamps is a high pressure sodium lamp which utilizes sodium as a metal for producing radiant emission. The high pressure sodium lamp produces yellowish-white radiant emission consisting of a continuous spectrum covering the whole visible region, while the conventional sodium lamp of low pressure type radiates mainly a yellow light corresponding to the sodium D lines. Therefore, from the standpoint of color rendition, the former may excel the latter but may still be surpassed by the conventional fluorescent lamp or the metal halide lamps.

The spectral distributions of radiant emission from a sodium vapor discharge lamp tend to broaden gradually over the entire visible region with rising sodium vapor pressure, so that the color rendition is also improved. A conventional high pressure sodium lamp operated at sodium vapor pressure of 100 to 200 Torr has a color temperature of about 2,100°K and a general color rendering index of about 30. Furthermore, a sodium vapor discharge lamp which is operated at a higher power input and sodium vapor pressure of higher than 300 Torr, will achieve color temperatures of 2,300° to 3,500°K and general color rendering indices of about 70 to 90. Moreover, it is also observed that the color acceptability of the discharge lamp with higher sodium vapor pressure is over 1.0. However, the increase in sodium vapor pressure might accelerate the reaction between sodium and the alumina envelope, which results in a bad life performance of the lamp. Moreover, the lamp voltage must be increased, so that an uneconomical ballast of a large size and with a very high open voltage is needed for operating the lamp. Thus, such a sodium vapor discharge lamp will be essentially disadvantageous from the life performance and the economic point of view, as compared with a conventional high pressure sodium lamp.

SUMMARY OF THE INVENTION

One object of the present invention is to propose a high pressure metal vapor discharge lamp capable of providing a good color rendition and a relatively high luminous efficacy, while holding a good life performance.

Another object of the invention is to provide a specific arc tube structure of the lamp having an increased lamp diameter, with which a good color rendition can be realized even by such a low lamp voltage that the lamp can be operated on an economical ballast.

For further objects and features and for a better understanding of the invention, attention is now directed to the following description of a preferred embodiment taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial sectional view of a metal vapor discharge lamp illustrating an exemplary lamp structure embodying the invention.

FIG. 2 is a graph illustrating the characteristic of the lamp in accordance with the invention in which the curve represents a function connecting the average potential gradient in the lamp envelope and the internal diameter of the arc tube.

FIG. 3 illustrates graphically the relation between internal diameter of the arc tube and luminous efficacy.

FIG. 4 illustrates graphically the relation between lamp per unit length of the interelectrode gap length and luminous efficacy of a metal vapor lamp discharge embodying the invention.

FIG. 5 illustrates graphically the relation between internal diameter of the arc tube and lamp wattage per unit length of the interelectrode gap length of a metal vapor discharge lamp embodying the invention.

FIG. 6 illustrates graphically a comparison between the lamp voltage characteristics through the performances of the discharge lamps according to the invention and the prior art.

We, the inventors have performed a series of tests with discharge lamps using sodium as a light producing medium, that is, a high pressure sodium lamp, in which various lamp characteristics are investigated by varying the diameter and length of the arc tube envelope but with the quantities of sodium, mercury and inert gas in the arc tube being constant. As a result there have been revealed general tendencies as described in the following.

1. For a constant color temperature, luminous efficacy increases with decreasing lamp diameter, while luminous efficacy also increases with increasing lamp wattage per unit length of the arc tube.

2. Lamp wattage per unit length in excess of a certain limiting level adversely affects the life of lamp. Namely, the lamp voltage rises and the luminous flux shows a relatively large decrement during life, and in some extreme cases there is caused blackening of the arc tube envelope and a shift in the color of emitted light due to loss of sodium in the arc tube envelope.

3. For a constant color temperature, the average potential gradient of the arc of the lamp, which represents indirectly the vapor pressure in the arc tube, decreases with increasing lamp diameter. It is asserted from the inventors' experiments that the average potential gradient of arc must not be made higher than about 25 V/cm in order to obtain a good performance. This is, for the first time, made possible by using a lamp tube of a diameter larger than that of the usual high pressure sodium vapor lamps.

Considering the results obtained through the repeated experiments, the inventors have reached the conclusion that if the relation of the lamp wattage to the interelectrode gap length of the arc tube and the lamp diameter is appropriately controlled a preferred lamp structure can be obtained which is well balanced from the standpoint of the above mentioned tendencies. Namely, selecting the values for the average potential gradient E (Volts/cm), the interelectrode gap length of the arc tube L (mm), the internal diameter of the arc tube envelope d (mm) and the lamp wattage W (watt) such that

$25 \geq E \geq 37.7 - 2.05d$ (but, $d>9$) (I),

$$L \geq \frac{10\,W}{16d - 58} \quad \text{(II), and}$$

$$L \leq \frac{10\,W}{13.3d - 76.4} \quad \text{(III),}$$

one can attain the object of the present invention.

Reference should now be made to FIG. 1 which shows the structure of an arc tube of the lamp embodying the invention. In the figure, into the ends of a polycrystalline alumina ceramic tube 1 serving as an arc tube envelope are inserted ceramic end caps 2 for hermetic sealing, and niobium tubes 3, used as electrode lead-in-wires, pass through central perforations of the caps 2 at the ends of the lamp, and discharging electrodes 4 are soldered to the inner ends of the niobium tubes 3.

The inventors have made measurements of various lamp characteristics, assuming several combinations of the values for the internal diameter d of the arc tube, the interelectrode gap length of the arc tube L, and the quantities of sodium, and mercury or cadmium as buffer gas, taken from the following table. In all these cases Xenon is contained in the lamp to serve as an inert starting gas.

d (mm)	6.3,	7.0,	7.6,	9.7,	11.5,	13.5
L (mm)	40,		60,		82,	
quantity of sodium (mg)	15,					
quantity of mercury (mg)	3,	7.5,	30,	40,	50,	60,
quantity of cadmium (mg)	10,	20,	30,	40,	60,	80,

FIGS. 2 to 5 illustrate in graphical fashion the various lamp characteristics for lamps constructed for trial measurements on the basis of the possible combinations as mentioned above. The thorough and synthetic consideration of these characteristics will lead to the following results.

A. The average potential gradient E of the arc of the lamp, that is, the lamp voltage divided by the interelectrode gap length, decreases with increasing arc tube diameter d if the color acceptability is kept at the same level. In order to obtain a color acceptability of higher than 1.0, the relation between the average potential gradient E and arc tube lamp diameter d must be such that $E \geq 37.7 - 2.05d$, as apparent from FIG. 2.

FIG. 2 means that the lamp with the larger internal diameter of the arc tube can provide a good color rendition by a lower lamp voltage, that is, a lower sodium vapor pressure in the arc tube. Increasing the internal tube diameter, on the other hand, makes it possible to reduce the reignition voltage of the lamp and therefore the open voltage of the ballast with which the lamp is operated. Consequently, by utilizing an arc tube envelope with a large internal diameter, the life performance of the lamp might be improved and moreover the lamp can be operated on an economical ballast (of lower power loss, lighter weight and lower cost) as compared to conventional high pressure discharge lamps.

On the other hand, it is asserted from the inventors' experiments that the average potential gradient of the arc must not be made higher than about 25 V/cm in order to obtain a good performance characteristic in co-operation with such an economical ballast. Further it is asserted that the use of the lamp of a diameter not smaller than 9 mm is indispensable when consideration is made to the possible variations between the lamp electrodes or in the lamp characteristics through its performance. It is noted that the conventional high pressure sodium lamps have a diameter ranging from 6 to 8 mm. Therefore the lamp intended by the invention is, for the first time, achieved by using a lamp tube having a diameter exceeding the range. Accordingly, the average potential gradient E is given as $25 \geq E \geq 37.7 - 2.05d$ (but, $d>9$). This relation is given by the preceding condition (I).

The inventors' experiments, with respect to the range of the diameter d, have resulted in a comparative graph as indicated in FIG. 6. The characteristic curve A (thick line) of FIG. 6 shows a performance of a first group of test lamp tubes which has a 9 mm lamp diameter and 65 mm interelectrode gap. The characteristics curve B (dotted line) of FIG. 6 shows a performance of a second group of test lamp tubes which has a 9.5 mm lamp diameter and 60 mm interelectrode gap. Both lamp tubes were fabricated as a trial by the inventors and have an equal lamp wattage, i.e. 400 watts.

As clear from the comparative graph, the lamp voltage along the characteristic curve A quickly increases after the 3,000 burning hours. This quick increase of the lamp voltage also brought about a considerable reduction in the light emission of the lamp. Thus it was concluded that the design of the lamp tube having the characteristic A could not be practically employed. In contrast the curve B shows the lamp voltage which almost uniformly increases along an easy slope. This increase of the lamp voltage brought about little reduction in the light emission of the second test tube. About 85 percent of lumen-maintenance of this tube was confirmed after 6,000 burning hours. Thus it is concluded that the design of $d = 9.5$ mm ensures the desirable lamps for practical use having a service life of 6,000 hours. In order to obtain the measurements of the graph of FIG. 6, as mentioned above, the two groups of several sample lamps were respectively prepared for the case where d is equal to 9.0 mm and l equal to 65 mm and for the case where d is equal to 9.5 mm and l equal to 60 mm. Each point-mark on the curves A and B represents the arithmetic mean value of the lamp voltages which were measured on the respective group of sample lamps at the corresponding time of burning hour. The vertical line indicated through each point-mark represents a range of distribution of the lamp voltages of the respective group measured at the corre-

sponding time of burning hour. The upper and lower ends of each vertical line represent the upper and lower limits of the lamp voltages measured.

For better understanding brief explanation of the term "color acceptability" used herein should now be made. The chromaticness of rendered colors of 8 CIE test samples by the test lamp according to the invention, are connected with one another by line segments to form an octagon, on the chromaticness (U*, V*) plane, the area of which is represented by S*t*. In like manner, another similar octagon whose area is given by S*r*, is formed by the reference illuminant of the same color temperature to that of the test lamp. The color acceptability is defined as the ratio of S*t* to S*r*, i.e. S*t*/S*r*. The color acceptability of higher than 1.0 means that the test lamp in accordance with the invention produces light of more saturated chroma than the reference source of light.

B. For lamps giving a color temperature of 2,500°K and having a constant interelectrode gap length and a constant lamp input of 400 watts, the relation between the lamp diameter and the luminous efficacy is shown in FIG. **3**, that is, luminous efficacy increases with an decreasing arc tube diameter. Accordingly, it is preferable to adopt a diameter d not larger than 13 mm from the viewpoint of the lamp efficiency, because a considerable reduction of the efficiency is brought about with a diameter *d* above 13 mm. In combination with the condition (I), the diameter d must be given in the range $9<d \leqslant 13$.

C. For lamps giving a color temperature of 2,500°K and having a constant arc tube diameter, the relation between the luminous efficacy and the lamp wattage per unit length of the interelectrode gap length (i.e. the lamp wattage W divided by the interelectrode gap length) is illustrated in FIG. **4**. In this case the lamp wattage W is so designed as to be kept constant. Therefore, as seen from FIG. **4**, luminous efficacy increases with decreasing gap length, that is, increasing the lamp wattage per unit length. On the basis of a series of curves in FIG. **4** for lamps having the same color temperature of 2,500°K but different arc tube diameters, lamp wattages per unit length W_e (watts/cm) with which luminous efficacy of more than 60 lumens/watt is attained, are approximately given by the expression

$$W_e \geqslant 13.3d - 76.4 \qquad \text{(IV)}$$

which corresponds to the region *a* in FIG. **5**.

D. On the other hand, the increase in the lamp wattage per unit length of the interelectrode gap length in excess of a certain limiting level is accompanied by a relatively large lumen decrement of the lamp and the increase in the lamp voltage during life, which are due to the accelerated reaction between the sodium and the alumina envelope. As a result of a series of life tests performed by the inventors, such a limiting value, here referred to as W_p, for lamps with different lamp diameters is approximated by the relation

$$W_p = 16d - 58 \qquad \text{(V)},$$

where W_p is in watts per centimeter unit, i.e. watts/cm, which corresponds to the curve *b* in FIG. **5**. The limiting value W_p corresponds to those lamp wattages per unit length which secure lumen maintenance of more than 70 percent and keep the increase in lamp voltage within 15 percent of initial value in around 6,000 hours.

By the harmonic combination of the results (A) through (D) as described above an electric discharge lamp can be provided which attains the object of the invention. The process of deriving the essential conditions for a lamp satisfying the object of the invention, is now described in the following.

In order to get a good color rendition and obtain good performance characteristics, from the formula (I) it should follow that

$$25 \geqslant \mathbf{E} \geqslant 37.7 - 2.05d \text{ (but, } d>9)$$

From the stand point of lamp wattage, the luminous efficacy and the life performance of the lamp should be taken into consideration so that the above relation (IV) and (V) must hold.

Namely, from the relation (V) it follows that

$$W = W_p \cdot \frac{L}{10} \leqslant (16d - 58) \cdot \frac{L}{10},$$

$$\text{or} \qquad L \geqslant \frac{10\,W}{16d - 58},$$

which is identical with the relation (II) as mentioned before. Moreover, it follows from the relation (IV) that

$$W = W_e \cdot \frac{L}{10} \geqslant (13.3d - 76.4) \cdot \frac{L}{10},$$

$$\text{or} \qquad L \leqslant \frac{10\,W}{13.3d - 76.4},$$

which is equivalent to the relation (III) mentioned before.

As has hitherto been described, in order to realize a high pressure metal vapor discharge lamp having a high luminous efficiency, a good life performance, and color acceptability of higher than 1.0, the lamp should be so designed that the above given relations (I), (II), and (III) may be simultaneously satisfied.

When the discharge lamp is operated together with a ballast, it is desired to use a ballast of lower power loss, lighter weight and lower cost. Accordingly a lower operating voltage of the discharge lamp is desired which can cooperate with such an economical ballast as described former. As one example, it is noted that the operating voltage of the discharge lamps needs to become not higher than 180 volts for use with usual ballasts whose secondary voltage must not exceed 300 volts according to the Regulations for Japanese Electrical Manufactured Articles. The condition which makes it possible to operate the lamp together with such an economical ballast at such a relatively low open voltage, can be obtained through the modification of the formula (I). Namely, it follows that

$$V_{LO} \geqslant E \cdot \frac{L}{10} \quad (37.7 - 2.05d) \cdot \frac{L}{10} \text{ (but, } d>9\text{), and } E \leqslant 25$$

$$\text{or} \quad L \leqslant \frac{10V_{LO}}{37.7 - 2.05d} \text{ (but, } d \geqslant 9\text{), and } E \leqslant 25 \qquad \text{(VI)},$$

where V_{LO} is the value in volts of a critical lamp voltage, below which the economical lamp ballast can be designed.

The most economical ballast is a single choke one, which is usually used for popular high pressure vapor discharge lamps.

In order to utilize a choke ballast for the lamp made in accordance with the invention, V_{LO} should be taken to be about 60 percent of the supply voltage Vs. Namely, the formula (IV) might be again modifieid as follows:

$$L \leqslant \frac{6\ Vs}{37.7 - 2.05d} \text{(but, } d>9\text{), and } E \leqslant 25 \qquad \text{(VII)}$$

Here if the power supply line has a voltage of 230 V or 240 V, then

$$L \leqslant \frac{1400}{37.7 - 2.05d} \text{(but, } d>9\text{), and } E \leqslant 25 \qquad \text{(VII)'}$$

If the line voltage of the power supply is 220 V,

$$L \leqslant \frac{1300}{37.7 - 2.05d} \text{(but, } d>9\text{), and } E \leqslant 25 \qquad \text{(VII)''}$$

Further, if the line voltage of the power supply is either one of 220 V, 230 V and 240 V. Vs in the formula (VII) may be taken to be the minimum value of 220, then,

$$L \leqslant \frac{1300}{37.7 - 2.05d} \qquad \text{(VII)''}$$

As is apparent from the above description, a promising high pressure sodium lamp from the lamp characteristics and economic point of view cannot be provided without satisfying the relation (VI), especially (VII) except (II) and (III).

The features of the invention believed to be novel will be more particularly pointed out in the appended claims.

We claim:

1. A high pressure sodium vapor discharge lamp comprising a tube envelope containing therein sodium, inert starting gas, buffer gas comprising at least one of mercury and cadmium and discharge electrodes sealed in said envelope, said lamp satisfying the following relation between the tube diameter d in millimeters and an average potential gradient E in volts per centimeter

$$E \geqslant 37.7 - 2.05d,$$

wherein $E \leqslant 25$ and $d>9$.

2. A high pressure metal vapor discharge lamp using a translucent polycrystalline alumina ceramic tubing as the lamp envelope within which are contained sodium as metal for producing radiant emission, at least one of mercury and cadmium as a source of buffer gas, xenon as an inert starting gas and discharge electrodes sealed in said envelope, wherein the operating voltage E of the lamp is lower than such a critical value V_{LO} in volts of the lamp voltage that an economical ballast can be designed, and the lamp wattage W in watts, the lamp diameter d in millimeters and the interelectrode gap length L in millimeters simultaneously satisfy the following conditions:

$$L \leqslant \frac{10\ V_{LO}}{37.7 - 2.0d},$$

wherein $E \leqslant 25$ and $d>9$,

$$L \geqslant \frac{10\ W}{16d - 58}, \text{ and}$$

$$L \leqslant \frac{10\ W}{13.3d - 76.4}.$$

3. A high pressure metal vapor discharge lamp as claimed in claim **2,** wherein said critical value V_{LO} is 130 volts.

4. A high pressure metal vapor discharge lamp as claimed in claim **3,** wherein said critical value V_{LO} is 0.6 Vs, where Vs is a voltage value in volts of the power supply line.

5. A high pressure metal vapor discharge lamp as claimed in claim **3,** wherein said critical value V_{LO} is 140 volts.

6. A high pressure metal vapor discharge lamp using a polycrystalline alumina ceramic tubing as the arc tube envelop within which are contained sodium metal for producing radiant emission, a buffer gas comprising at least one of mercury and cadmium, inert starting gas and discharge electrodes sealed in said envelope, wherein the lamp wattage W in watts, the lamp diameter d in millimeters, the interelectrode gap length L in millimeters and the average potential gradient E in volts per centimeter simultaneously satisfy the following conditions:

$$E \geqslant 37.7 - 2.05d,$$

wherein $E \leqslant 25$ and $d>9$,

$$L \geqslant \frac{10\ W}{16d - 58}, \text{ and}$$

$$L \leqslant \frac{10\ W}{13.3d - 76.4}\ [\cdot],$$

whereby an excellent color rendition with a color acceptability higher than 1.0 is obtained with discharge of said lamp.

7. A high pressure metal vapor discharge lamp as claimed in claim **6,** wherein said buffer gas consists essentially of cadmium.

8. A high pressure metal vapor discharge lamp as claimed in claim **6,** wherein said buffer gas consists essentially of mercury.

9. A discharge lamp as claimed in claim **1,** wherein the diameter d is given in a range $9 \leqslant d \leqslant 13$.

* * * * *