A New Metal Halide Arc Lamp

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THE PRODUCTION of light using medium-pressure electric discharge devices (one to two atmospheres) is one of the older lighting techniques. Work was done in this field as early as 1906 by Kuch and Retchinsky[1] and even before. The commercial development of the medium-pressure device in which mercury was the active ingredient commenced in the period between 1920 and 1940. This source has been widely accepted. Unfortunately, however, the color rendition was poor, due mainly to the lack of red light being emitted by the elemental mercury. This serious drawback has been partially corrected through the use of fluorescent phosphors coated upon the inner wall of the lamp's outer jacket.

Spectroscopists[2] have used electrodeless electric discharge devices containing metals to study their emission lines. Most of the metals that have been studied have low vapor pressures at temperatures which are compatible with envelope materials having high transmission to visible radiation. To circumvent this difficulty, metal iodides were used. The vapor pressures of these iodides are significantly higher than for the corresponding metals. Quite unexpectedly it was discovered that certain of the basic concepts of the electrodeless devices could be utilized for practical lighting devices. Some work in this direction has been reported to this Society by Larson *et al.*[3] and Martt *et al.*[3a] who discussed the use of additives in conventional mercury lamps. This presentation will describe a completely novel source in which mercury has taken on a different role.

The use of metals other than mercury for medium-pressure arc discharges must take into consideration their relatively low vapor pressures when used in the elemental form. In general, their vapor pressures are of the order of tenths of torrs or less, at temperatures compatible with presently used envelope materials. These pressures are just too low to produce visible radiation efficiently. These low metal vapor pressures can be increased by orders of magnitude with the use of a metal iodide in lieu of the metal. Most iodides have vapor pressures of the order of torrs and higher at bulb wall temperatures of the order of 700 to 800 C. As the metal iodide diffuses from the wall into the gas of the discharge, it becomes dissociated, yielding free metal atoms and free iodine atoms. Thus, the discharge has produced for itself a high metal vapor pressure. These metal atoms will participate in the operation of the discharge. This participation will consist of: (1) excitation of atoms to energy levels from which they may radiate energy as they return to lower levels of excitation; (2) ionization and participation in the passage of current through the tube. For the efficient production of light by this device, a significant number of the radiative transitions need to be in the visible energy range. Of course, the metal atoms and iodine atoms do not stay in the higher temperature zones of the device exclusively. They will diffuse outward toward the bulb walls. As they diffuse outward, the temperature decreases so that at the bulb wall the temperature is down to a value of 700 to 800 C. During the passage of the various species through this temperature transitional region, a temperature will be reached at which volume recombination with iodine can occur. Thus metal iodides will again be formed and the metals cannot condense out on the low-temperature bulb wall. The iodides used can be chosen from the various metals of the periodic table. The basic requirements have been discovered to be as follows:

1. The metal atom must form an iodide which is stable at the operating temperature of the bulb wall.
2. The vapor pressure of the metal iodide molecule needs to be high.
3. The metal atom must have excitation levels lower than for mercury.
4. The metal atom's energy levels need to be such that a significant percentage of its emitted radiation is in the visible spectral region.

Three classes of metals have been studied. Representatives of each are presented in Fig. 1. They are metals having a simple spectrum of a few narrow lines, such as mercury. Mercury has lines in the region of 5780 Å, 5461 Å, 4359 Å, 4060 Å.

Secondly, there are metals having broadened emis-

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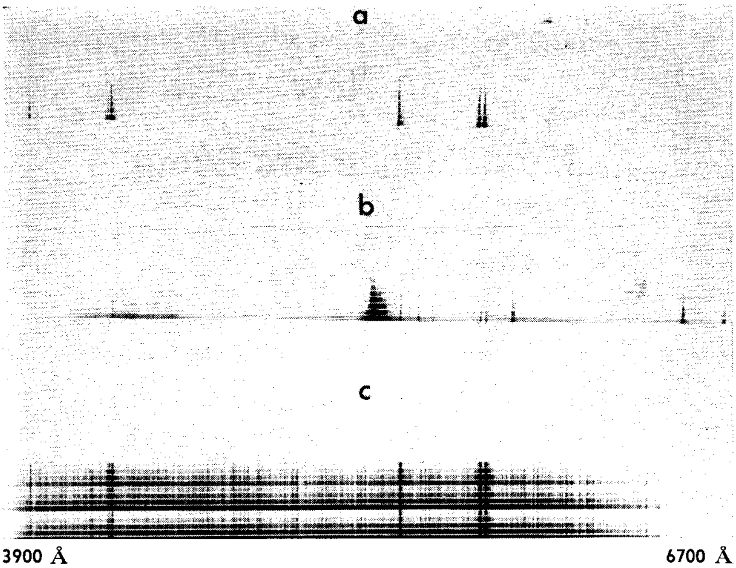

Figure 1. Spectrum for (a) mercury discharge; (b) thallium-mercury discharge; and (c) thorium-mercury discharge.

sion lines; a member of this class is thallium (second spectrum in Fig. 1). This metal has its primary emission in the region of 5350 Å. Two weaker lines are to be found at longer wavelengths—in the red region.

Thirdly, there are others having a high density of lines throughout the visible region. Thorium, the third spectrum in Fig. 1, is representative of this class of metal. Thorium has such a high density of lines that its spectrum has been called a "forest of lines."

On the basis of the extremely high density and balance of lines in the visible spectrum of thorium, together with other considerations, it has been used as the major light producing metal for this lamp. It has an average excitation potential of approximately 3.0 electron volts. In addition, thallium and sodium are added to improve the color balance further. Sodium yields most of its radiation in the doublet 5890 Å and 5896 Å. It has another set of somewhat weaker lines at 5681 Å and 5688 Å. The average excitation potential of thallium is approximately 3.0 electron volts; that for sodium is approximately 2.0 electron volts.

To improve the efficiency of the discharge, a buffer gas is introduced. The main purpose of the buffer is to reduce the rate of diffusion of metal ions and atoms to the walls. With a decrease in the rate of diffusion, the probability of recombination of metal and iodide atoms in the gas increases. Any energy left over after recombination will be used to maintain the temperature of the gas. Mercury has proved to be an excellent buffer gas. Even though the average excitation potential for mercury is double that of any of the other species, a significant amount of energy is radiated by mercury in the visible region.

The spectrum for each of these is shown in Fig. 2, along with the total sum. The final spectrum shows the good balance which has been obtained between the various regions of the visible spectrum using these atomic species.

The pressure of this lamp during operation is of the order of several atmospheres. It has been shown[4] that in this pressure range thermodynamic equilibrium exists in the plasma. Thus, the ionization and excitation rates for the various atomic species will be a function of the plasma temperature. To obtain a significant amount of thorium radiation, not only is

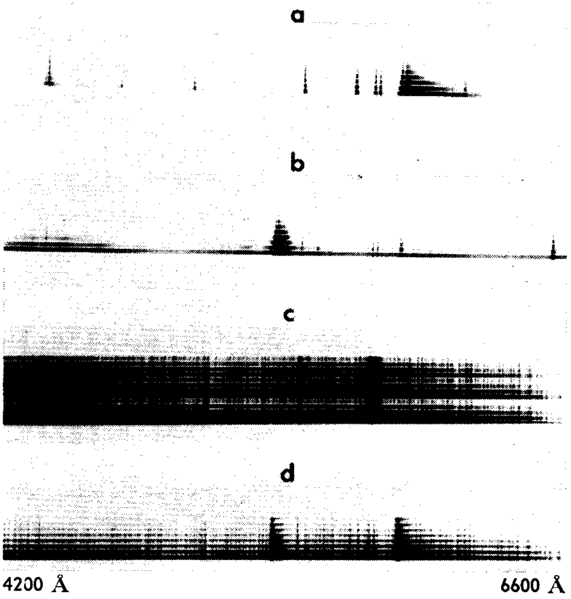

Figure 2. Spectrum for (a) sodium-mercury discharge; (b) thallium-mercury discharge; (c) thorium-mercury discharge; and (d) sodium-thallium-thorium-mercury discharge.

an optimum temperature needed, but also a high density of thorium atoms is required. Further, to obtain a good balance between the red and blue parts of the spectrum, it is necessary that the plasma temperature be relatively low. Studies have been made of the plasma temperature and how it is affected by the various components. Fig. 3 depicts the effect of iodine on temperature and Fig. 4 depicts the effect of sodium on temperature. As shown by these figures, the plasma temperature can be increased by an increase in the ratio of iodine to mercury and it can be decreased by an increase in sodium. Thus with these two handles, the average plasma temperature can be set, within reason, at almost any predetermined value.

Sodium performs another very important function. As a consequence of its low ionization potential, it can become ionized at greater radial distances than other species in the plasma. Sodium will be a donor of electrons in this region. With an increased supply of electrons, the energy dissipated as heat in this outer region will increase. With the total energy of the arc remaining constant, the energy dissipated in the central core must go down. This will change the temperature profile across the discharge. Externally, this change in temperature profile will manifest itself as a stabler arc.

The temperature data presented here were obtained spectroscopically by comparison of the intensity of the lines.[5]

As mentioned above, to have an efficient lamp it is necessary to have a high density of thorium atoms. It has been shown[6] that the thorium pressure in the plasma is a direct function of the electrode temperature. Briefly, the thorium deposits out as the metal on the electrode. The electrode tip is bombarded by iodine atoms. These then combine with thorium to form thorium iodide. This compound, being volatile at these temperatures, readily vaporizes from the surface of the electrode and dissociates in the plasma.

Thus, by regulating the electrode temperature a high thorium atom concentration can be realized. Effective excitation of these atoms can be obtained by optimization of the plasma temperature by variations of iodine-to-mercury ratio in conjunction with a variation of the sodium atom concentration.

Lamp Construction

A sketch of the new metal arc lamp is shown in Fig. 5. The arc tube envelope is made of fused silica having a diameter of 20 millimeters. Molybdenum foil/tungsten electrode assemblies are pressed sealed into both ends of the tube. The electrode is a tungsten coil wrapped on a tungsten rod with a rod extension past the coil of approximately ⅛ inch. This rod extension length is extremely important as it controls the electrode temperature.

The quartz tube and electrode assemblies are evacuated and degassed using standard vacuum techniques. Metal iodides are introduced into the tube in addition to mercury (the buffer gas) and a moderate pressure of a rare gas, such as argon. The rare gas is introduced to facilitate ignition of the device.

The outer jacket is similar to the present mercury lamp and it is filled to a pressure of approximately ½ atmosphere with dry nitrogen gas.

Operating Parameters and Ballasting Requirements

The sketch shown in Fig. 5 is of the 400-watt lamp variety. The electrical and optical data for this lamp are presented in Table I. As can be seen, the lamp has been designed so that the electrical parameters are compatible with the mercury lamp.

The radiation parameters are also given in the table. This lamp combines high lumens and efficacy with a good color temperature and a high color rendering index. This is an indication of the balance

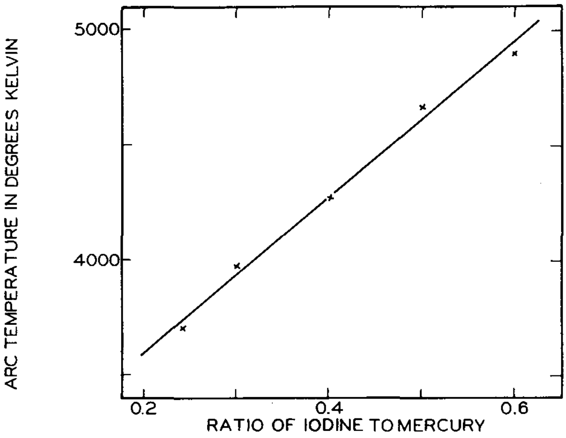

Figure 3. Effect of iodine-to-mercury ratio on arc temperature of metal halide arc lamp.

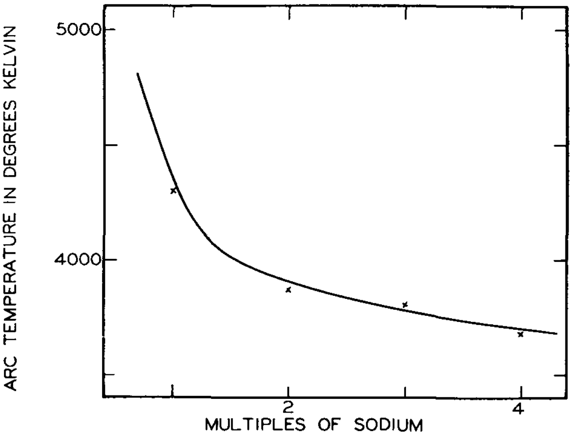

Figure 4. Effect of sodium on arc temperature of metal halide arc lamp.

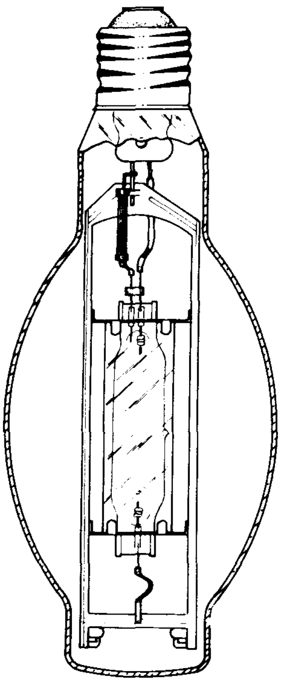

Figure 5. Metal halide arc lamp construction.

which has been accomplished between the various regions of the visible spectrum.

By a variation in the quantity and the types of atomic species, the color of light produced by a given lamp can be changed. In the laboratory color temperatures from as low as 2400 K to as high as 10000 K have been obtained with variations in lamp formulations. In all cases, the color rendering index ranged upward from a minimum of 60 with good efficiency.

Because of the role the electrodes play in maintaining the thorium pressure, and the presence of iodine in the tube, starting requirements are somewhat higher than for conventional mercury lamps with thoriated tungsten electrodes. The starting of this lamp is not based on a Penning gas mixture, thus the effect of temperature on starting is not as great as in other lamps. This effect is shown in Fig. 6. Due to the somewhat higher starting voltage requirements, it is recommended that a ballast having a high peak starting voltage be used as auxiliary equipment.

Applications of Lamp

This lamp has many applications as a light source. It can be used in all applications of the present JH-1 mercury lamp, such as street lighting and high-bay lighting and it markedly improves the level of illumination. Further, where an improved-color JH-1 lamp has been required, this new lamp will increase the level of illumination by nearly a third and increase the color rendering index of the installation.

Some of the more important applications will be indoor lighting, supermarkets, department stores, gymnasiums and similar applications where the combined requirements of light level and color rendition have previously required the use of fluorescent lamps.

Table I

ELECTRICAL PARAMETERS	
Power	**400 watts**
Current	**3.4 amperes**
Voltage	**135 volts**
RADIATION PARAMETERS	
Light Output	**32,000 lumens**
Efficacy	**80 lumens per watt**
Color Temperature	**5800 K**
Color Rendering Index	**85**
STARTING VOLTAGE	
Room Temperature	**275-volt RMS**
−20 F	**300-volt RMS**

Conclusion

Through the use of discharge lamps containing metal iodides, many different emission characteristics can be attained. This has opened a field of lighting just waiting for the ingenuity and subsequent exploitation by the lamp engineer.

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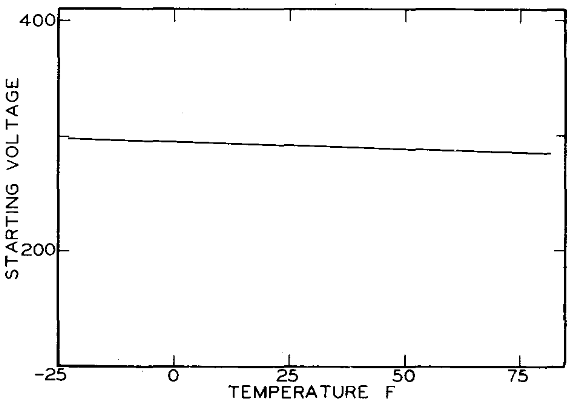

Figure 6. Metal halide arc lamp starting characteristics.