APPENDIX

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Iodide discharge lamps

In Section [1.12] and [4.1.2] it was stated that the colour rendering properties of high pressure mercury lamps can be improved by the addition of cadmium and zinc or both. Since the energy levels of these elements are lower than those of mercury, small quantities only are required in order to produce their spectral lines with sufficient intensity. Colour rendition is improved by the blue and red spectral lines thus generated. The cadmium content should not be too high since otherwise the intensity of the green cadmium line will become excessive. There are two objections to this method of improving colour rendition:

1. Since the eye sensitivity to the red and the blue lines added is low, the extra energy needed to emit these "inefficient" lines causes the luminous efficiency of the lamp to decrease considerably.
2. The quartz of the discharge tube is attacked by cadmium and zinc. This is accentuated since in order to obtain sufficient cadmium or zinc vapour pressure, the tube wall must be at a higher temperature than in a lamp without these metals. This can be achieved either by increasing the loading per cm^2 of the tube wall, or by improving the thermal insulation of the tube, for instance by operating the tube in a high vacuum outer-bulb.

As a result of the above, mercury lamps with these metal additives have not become popular in practice.

There exists, however, another method of improving the colour rendering properties of high pressure mercury vapour lamps*, which avoids the first disadvantage completely (the efficiency is even considerably higher than with high pressure mercury vapour lamps) and has the second disadvantage only to a small degree. Here, the element from which emission is required is added to the mercury as an iodide. This iodide can only exist as such at

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* H. H. Reiling, *Journ. Opt. Soc.* Amer., **54**, p. 532, 1964; B. Kühl & H. Krense, D.P. 1184008.

or near the wall, and is dissociated in the hot discharge path, so that in this region the metal and iodine both appear in atomic form. Since the energy levels of iodine are higher than those of the metal, it is mainly the spectrum of the metal which appears and in this the resonance lines dominate.

Consequently the choice of metals is no longer limited to those having a sufficiently high vapour pressure at the temperature of the tube wall, but is extended to those having an iodide which at this temperature has a sufficiently high vapour pressure.

In choosing iodides of metals for which the resonance lines lie in various parts of the visible spectrum, we obtain the following advantages:

1. The intensity in the ultra-violet becomes much lower than with the mercury discharge, since the resonance lines of the metals chosen lie in the visible part and these metals will consequently not radiate in the U.V. or hardly so. Furthermore, the mercury atoms hardly radiate since their energy levels are higher than those of the chosen materials. Consequently the mercury serves only to initiate and maintain the constricted discharge. After evaporation the mercury vapour serves as the impact gas and as a thermal insulator around the constricted discharge. Because of the low intensity in the U.V. a larger part of the total radiation is produced in the visible region and thus a higher luminous efficiency is achieved.
2. The position of the lines in the visible region and their intensity is determined by the choice of iodides and their concentrations and these can be chosen so that the colour properties of the discharge are good.

In this way therefore, a high pressure discharge is possible where the mercury serves only as the impact gas, where metal-iodides diffuse into the discharge, there dissociate and diffuse back again to recombine either at or near the wall of the tube. The iodine and mercury atoms, because of their high energy levels do not produce much radiation. The emission is mainly by the added metal atoms. In Fig. A.1 the spectral energy distribution of an iodide discharge, in which thallium iodide, indium iodide and sodium iodide are added to the mercury (HPI), is compared with that of a pure mercury discharge (HP). To obtain a clearer picture, the energy is combined in spectral regions. The area between the wavelength axis and the graph is proportional to the energy radiated. It is clear that the U.V. radiation of the iodide discharge is much smaller than that of the mercury discharge. In the far U.V. this is also true. The total radiation of the high pressure mercury discharge is equal to 0.72 $(P-A)$ (see Section [1.5]); with the iodide discharge this appears to be equal to $(P-\acute{A})$. The 28% radiation, missing in the mercury discharge, is consequently present with the iodide discharge. This is an indi-

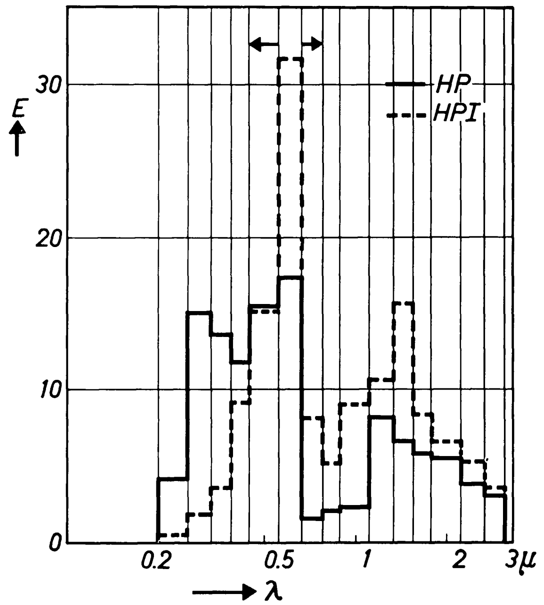

Fig. A.1 The energy distribution of the radiation of a high pressure mercury lamp (HP 400 W) compared with that of a high pressure mercury vapour lamp with added sodium –, thallium- and indium iodide (HPI 400 W). The radiant energy is combined over wavelength regions, which are denoted by vertical lines. The energy scale is arbitrary and linear, the wavelength scale is in μ and logarithmic.

The region indicated by ⟵⟶ is the visible part of the spectrum*.

cation that the radiation losses of 28 % with the mercury discharge do indeed take place in the far ultraviolet (radiation being absorbed by the mercury vapour, the quartz wall or the air between the lamp and the apparatus measuring the radiation). This greater total radiation together with the greater part of the radiation appearing in the visible region explains the higher luminous efficiency, in spite of the better colour rendering properties of the iodide discharge. This is clear from Table A.1, where the efficiency is calculated for three different light sources by multiplying the luminous equivalent (at the peak of the eye sensitivity curve = 680 lm/W) by the total radiation efficiency, by the percentage of this in the visible region and by the average eye sensitivity in the visible part of the spectrum.

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* Measurements by L. B. Beyer.

TABLE A.1

Light Source	Light equivalent in lm/W	Total radiation efficiency	Part in the visible	Average eye sensitivity	Luminous efficiency*
High pressure mercury discharge	680	$0.72(P\text{-}10)/P$	0.3	0.5	$74(P\text{-}10)/P$ lm/W = 55 lm/W (P = 40 W/cm)
Hg + Cd and Zn	680	$0.72(P\text{-}10)/P$	0.3	0.35	$52(P\text{-}10)/P$ lm/W = 42 lm/W (P = 50 W/cm)
Hg + iodides	680	$(P\text{-}20)/P$	0.4	0.5	$135(P\text{-}20)/P$ lm/W = 90 lm/W (P = 60 W/cm)

* These efficiencies apply to very long discharges, where the electrode losses may be neglected. In practice the lamp efficiencies are about 10% lower.

Table A.1 shows that for mercury and for mercury with the addition of a small quantity of cadmium and zinc the heat conduction loss per cm is equal to 10 W, whereas this loss for the iodide discharge amounts to 20 W. This results from the fact that energy is being lost not only by thermal conduction, but also by dissociation of the iodides in the discharge and their recombination near or at the wall. It is very doubtful whether this additional loss of 10 W/cm is independent of pressure, loading and tube diameter, as is approximately the case for the heat conduction loss.

In Table A.1 we have chosen for the mercury discharge the lowest value for the loading per cm P and the highest one for the iodide discharge, since higher wall temperatures are needed with the Hg/Cd/Zn discharge and the iodide discharge and moreover with the iodide discharge, having a loss of 20 W/cm, it is very advantageous to choose a high value of P. If, however, the loading per cm with the mercury discharge is also chosen at 60 W/cm, an efficiency of 62 lm/W is obtained which is still considerably below the 90 lm/W of the iodide discharge.

Since only a small amount of ultra-violet radiation is emitted by the iodide lamp, there is little point in applying fluorescent powders to the outer bulb. By a different choice of iodides, it is possible to obtain extra radiation in the U.V. For special applications this can be of importance. For public lighting, however, a lamp without fluorescent powder is very suitable since with the smaller light source (the outer bulb of a mercury lamp with fluorescent powder is large as the maximum permissible temperature of the powder is limited) a smaller fitting can be used. By correct choice of the iodides and the ratio of the quantities one can obtain so good a colour rendition that use of a fluorescent powder becomes unnecessary.

A phenomenon which occurs with the iodide discharge, but not with the pure mercury discharge is that of the separation of the added materials, which results in colour differences along the discharge. This mainly occurs in the vertical burning position, where separation of the elements occurs by thermo-diffusion, because of which the colour of the discharge at the upper and lower part of the discharge tube becomes different. In the horizontal burning position this phenomenon is almost absent. Here, however, other difficulties occur. As a result of the large loss of 20 W/cm the iodide lamp is highly loaded, because of which the average wall temperature is high. Moreover, in the horizontal burning position a temperature difference exists between upper and lower side of the tube, so that in order to keep the maximum temperature the same, the loading must be lower than in the vertical burning position. Since the efficiency is proportional to $(1-20/P)$ this results in a lower efficiency than is possible with the vertical burning position and higher loading. Furthermore in the horizontal burning position the mercury vapour pressure cannot be made too high, otherwise the discharge bows excessively upwards and the temperature at the upper side of the tube wall rises still higher.

It is expected that the high pressure mercury vapour discharge with the addition of iodides, will have a great future in very many applications.

INDEX

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*) with fluorescent bulb