TUNGSTEN RIBBON LAMPS FOR OPTICAL MEASUREMENTS

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The conditions are discussed which must be considered in the design of tungsten ribbon lamps for use as light sources in various optical measurements. Several different types are described.

For various types of optical measurements a uniformly radiating surface is needed whose intensity must be high and reproducible. Moreover in many cases the relative spectral distribution of the radiation of this surface must also be known. This is the case for instance in subjective and objective photometry, in pyrometry, in spectral photometry and in colorimetry. A few examples will serve to illustrate this statement.

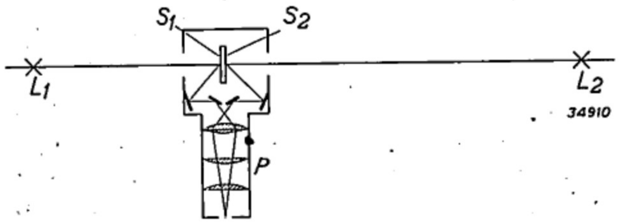


Fig. 1. Arrangement of apparatus for subjective photometry. L_1 and L_2 are the light sources to be compared. S_1 and S_2 are the comparison screens of the photometer P.

In subjective photometry one photometer screen S_1 is often illuminated by the light source L_1 to be measured, and the other photometer screen S_2 by a comparison lamp L_2 (*fig. 1*). The distance between L_2 and S_2 is so adjusted that upon looking through the photometer P the two screens appear to have the same intensity. In order to calculate the ratio of light intensity between L_1 and L_2 the law of the variation of brightness with the inverse square of the distance must be applied. This method involves the following requirements with respect to the comparison lamp L_2:

1) The light intensity must be reproducible.

2) The light intensity must be so high that the required illumination intensity of S_2 is obtained to L_1, L_2 in L_2. When the effective surface of S_2 is a circle with a radius of 10 mm, with a distance of 30 cm from L_2 to S_2 the luminous plane of L_2 must also fall within a circle of radius 10 mm.

The second example is taken from pyrometry. In the case of the much-used optical pyrometer of Holborn and Kurlbaum an image of the radiating body whose temperature is to be determined is projected on the plane of the pyrometer filament. This image and the filament are observed through a red filter by means of a simple microscope or with a magnifying glass. The current through the filament is so regulated that the filament appears just as bright as the image of the radiating body. In calibrating such a pyrometer the relation between the current through the filament and the "black body temperature" [1]) of the radiating body must be determined for the "effective wave length" used.

To do this the pyrometer is first set by means of a black body which has been raised to the melting temperature of gold. A small surface having a very great brilliancy is then observed through the pyrometer, and its brightness is then successively dimmed by known amounts. One observes how great the dimming must be in order that the brightness of the surface may be equal to that of the black body at the temperature of melting gold. Making use of Planck's radiation formula the black body temperature of the luminous surface can be calculated at the different degrees of dimming.

Means of carrying out such a calibration will not ordinarily be at hand, while it will nevertheless be considered necessary to be able to check a

Not only in primary but also in secondary pyrometer calibration, therefore, is a uniform radiating surface of reproducible high brilliancy needed.

A third example is encountered in spectral photometry. In this type of work it is often necessary, by means of a spectrograph for small wave length regions, to compare the brightness of an unknown light source with that of a comparison lamp of known spectral energy distribution. According to the method of measurement used the slit of the spectrograph must be entirely or partially illuminated by the comparison lamp. In practical cases this is usually accomplished by focussing the image of the luminous surface of this lamp on the slit. Thus here again is there need of a comparison lamp with a sufficiently large, uniformly radiating surface of reproducible high brilliance, whose spectral energy distribution must moreover in this case be known at least relatively.

It has been found that the need for such a lamp with a radiating surface can be met with the tungsten ribbon lamp, and such lamps are in common use for such optical measurements. The incandescent body of these lamps is formed by a tungsten ribbon about 20 μ thick, and for instance 2 mm wide and 20 mm long. This ribbon is heated to incandescence by means of an electric current.

Such a thin ribbon is particularly suitable for the purpose in view. Due to the small area of the cross section the heat conduction is small, so that the cooler sections at the ends are relatively short. Due to the favourable relation between radiating surface and electrical resistance per cm length, high temperatures can be obtained with relatively small currents. It is also important that the whole surface of the ribbon appears equally bright, in contrast to the case of a incandescent wire, where deviations from Lambert's law become appreciable along the edges.

Before we begin to discuss the different designs of tungsten ribbon lamps manufactured by Philips, we shall first examine the radiation properties of the normal to the surface may be represented by

$$I_{\lambda T \Theta}\, \Delta\lambda\, \Delta S.$$

As has already been mentioned in a previous article [2]), the radiation properties of a black body are accurately known. The way in which $I_{\lambda T \Theta}$ depends upon wave length and temperature is given by Planck's radiation formula. Furthermore the radiation of a black body satisfies Lambert's law, according to which

$$I_{\lambda T \Theta} = I_{\lambda T} \cos \Theta \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For the radiation of other materials formula (1) is found to be approximately correct for not too large values of Θ. When however Θ approaches 90°, very great deviations may occur.

The radiation of a given substance at wave length λ, temperature T and sufficiently small values of Θ is often compared with that of a black body at the same length and temperature. The ratio of $I_{\lambda T}$ of the substance under consideration to $I_{\lambda T}$ of the black body is called the spectral emission coefficient $e_{\lambda T}$. Since no substance completely absorbs all incident radiation, as is the case with a black body, the emission coefficient is, according to Kirchhoff's law, always less than unity.

The value of $e_{\lambda T}$ for a given substance is found to be dependent on the purity and the degree of smoothness of the surface. Small depressions in the surface act more or less as black bodies, and therefore increase the emission. The smoother the surface the smaller the emission coefficient. In investigations of radiation properties of substances, therefore, one must always strive not only for great purity but also for very smooth surfaces.

In the case of tungsten the physical properties in general and the radiation properties in particular have been the subject of much research. On the basis of the results of these investigations we shall now discuss the questions which are of interest in connection with tungsten ribbon lamps, namely:

Reproducibility of the radiation of a tungsten ribbon in the course of time

It is also true of tungsten that the radiation depends upon the nature of the surface. It has been found that at a high temperature it makes little difference in the radiation emission of an ordinary drawn wire or rolled strip whether or not the surface has also been polished. The main point is that such a wire or strip should be "aged" for some time by heating it to a high temperature in a high vacuum or in an inactive atmosphere. During this process a bright shiny surface is formed whose radiation emission is found to be reproducible.

In order to prove this the current was determined of a gasfilled ribbon lamp, the ribbon of which had been heated in a high vacuum during evacuation when the lamp was being made. The true temperature at the middle of the ribbon was 2835 °K. This current was sent through the lamp for 100 hours, while the brightness of the middle of the ribbon was measured as a function of the time. This brightness was found to remain constant within the limits of error of the measurement (0.5 per cent).

Reproducibility of the radiation properties of different ribbons

The reproducibility for different ribbons is important in cases where the spectral emission coefficient must be used, for example, for the calculation of the temperature or of the spectral energy distribution from the black body temperature measured. The spectral emission coefficient $e_{\lambda T}$ must be known as a function of the temperature and wave length. This value is obtained from measurements of $e_{\lambda T}$ which are usually carried out in the investigations in question on several tungsten surfaces. For the wave length and temperature in question values of $e_{\lambda T}$ are found which exhibit slight differences from surface to surface. From these an average value of $e_{\lambda T}$ is found, which may be used in the calculation for any given ribbon lamp.

When the available material for observation is reviewed, it is found that the possible deviation of the emission coefficient of one ribbon with respect to the average for many ribbons must be placed at 1 per cent.

Furthermore the possible error in the assumed average value of the emission coefficient must be estimated.

Various investigators give different average values. This may be due partially to differences in methods of measurement. Moreover, the different degrees of purity and the different treatment of the surface of the tungsten investigated will play a part. In the case of the tungsten ribbons under discussion it would seen reasonable to give particular weight to the measurements by Hamaker[3]) which were performed on the very material in question. The possible error in the average values given by Hamaker may be considered 1 per cent. Therefore if we use his average value for a given tungsten ribbon, we must take into account a possible error of 2 per cent. This holds for the whole visible region of the spectrum. It is possible that the errors in the infra red and ultra violet regions are somewhat larger.

Calculation of the relative spectral energy distribution

For the calculation of the relative spectral energy distribution the temperature of the tungsten must be determined, the spectral energy distribution of the black body must be determined relatively for this temperature, and the value found must be multiplied by the corresponding spectral emission coefficient $e_{\lambda T}$ of tungsten for every wave length.

An example will show that this method leads to a fairly accurate knowledge of the relative spectral energy distribution.

Let us assume that the black body temperature for a definite, accurately known, effective wave length is 2500 °K, and that this is determined by pyrometry with a possible error of 10°. From this energy distribution. The only uncertainty which yet remains is the possible error of 2 per cent in the spectral emission coefficient, by which the relative spectral intensity of the black body must be multiplied in order to obtain that of tungsten. This possible error of 2 per cent is valid for the visible region of the spectrum; in the infra red and ultra violet it is probably slightly larger.

For the visible spectral region the calculation of the relative spectral energy distribution of the radiation of tungsten can be shortened with the help of the concept of colour temperature. It has been found experimentally that between 4 000 and 7 000 Å the relative spectral energy distribution of the radiation of tungsten at every temperature T is practically equal to that of a black body at a temperature T_c which is slightly different from T. T_c is called the colour temperature of tungsten corresponding to T. In *table I* T_c is given as a function of T. In order to calculate the relative spectral energy distribution of tungsten, the true temperature is determined and the corresponding colour temperature T_c is found from the table. It is then only necessary to find the relative spectral energy distribution of the radiation of a black body for the temperature T_c in a suitable table.

Table I

T	1200 °K	1600	2000	2400	2800
T_c	1210 °K	1616	2023	2432	2844

From the data here discussed on the radiation properties of tungsten it may be seen that the tungsten ribbon lamp in principle is capable of satisfying the requirements of various optical measurements.

Design and construction of ribbon lamps

In connection with the very divergent applications it has been found desirable to construct

This bulb is usually made of heat resistant glass. For the case in which the lamp must also be used in the ultra violet for wave lengths shorter than 3 500 Å or in the infra red for wave lengths longer than 25 000 Å a bulb of clear quartz may be chosen.

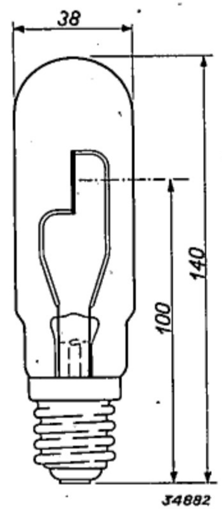
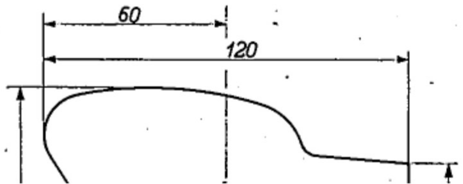


Fig. 2. Ribbon lamp with cylindrical bulb. The dimensions are indicated in mm.

If the optical focussing of the ribbon is important the horn-shaped bulb with the plane window fused on (*fig. 3*) is to be recommended. The radiation of the ribbon in this case passes through a ground plane parallel window which is fused to the bulb. The shape of the bulb is so chosen that the radiation from the back of the ribbon, which is reflected by the rear wall does not pass through the window. The combination of these two precautionary measures makes it possible to focus the image of the ribbon very well, and also makes it possible in the photometric application to apply



accurately the law of the variation of the intensity of illumination with the inverse square of the distance. The plane parallel window is made of heat resistant glass or quartz. In precise measurements it may be necessary to correct the spectral energy distribution of the radiation of the ribbon for the absorption by the window. To do this the spectral transmission curve of the window must be determined before it is fused into the bulb.

In spectral photometric investigations the bulb shown in *fig. 4* with two oblique plane windows may often be used. In such work it is often necessary to focus the image of the light source being investigated on the plane of the tungsten ribbon, and then to focus the image of this plane again on the plane of the slit of the photograph. With a vertical slit and a horizontal ribbon it is possible to illuminate part of the slit by the ribbon and the rest by the

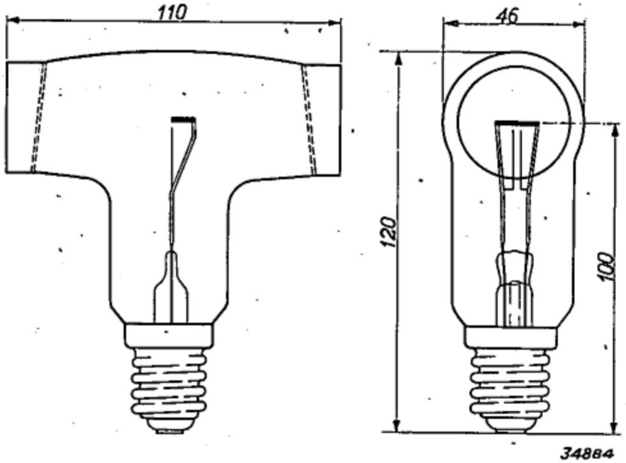


Fig. 4. Side and front views of a ribbon lamp with a bulb provided with two oblique plane windows. The dimensions are given in mm.

unknown source. When the bulb shown in fig. 4 is used the optical focussing through the plane windows is able to satisfy high requirements. By the oblique position of the window in the way shown in the figure disturbing reflections from front

Assembly and dimensions of the ribbon

The assembly is carried out in general as follows. Each end of the ribbon is welded to a nickel pole which must be relatively thick, since otherwise the temperature of the nickel at the weld would exceed the maximum permissible temperature for this metal.

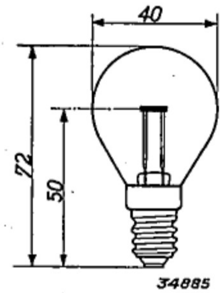


Fig. 5. Ribbon lamp with small spherical bulb.

The temperature at the ends of the ribbon naturally exhibits a sharp gradient due to the flow of heat toward the poles. In certain measurements these cooler end pieces might have a disturbing effect. In order to prevent this the ribbon is bent at both ends as shown in *fig. 6*. In this way the cooled ends are screened by the middle section of the ribbon whose radiation is to be used. By this means it is also brought about that the expansion of the ribbon upon heating has practically no tendency to cause disturbing stresses or deformations. The length of the ends bent under is always 5 mm. The useful length of the ribbon may be 10 or 20 mm, and its width 1 or 2 mm, in some cases 0·5 mm.

In choosing the most suitable ribbon lamp for a given application from the models given in *table II*, various factors must be considered. For spectral photometric uses the conditions of the desired optical focussing will be decisive. If the image of the ribbon is focussed transversally across the slit, a short ribbon is sufficient. If a vertical ribbon must be focussed on the slit a long ribbon is usually preferable.

In any case the ribbon should always be chosen as small as possible in order to avoid unnecessary consumption of current. For many applications it is desirable that a certain point on the ribbon, usually the middle, should be indicated. In all lamps with a useful ribbon length of 20 mm such indication may be introduced in the form of a point of wire at one side in the plane of the ribbon.

Table II

Bulb	Width of ribbon in mm	Position of ribbon	Useful length of ribbon in mm
Cylindrical model of heat resistant glass or quartz	2 or 1	horizontal or vertical	10, 10 or 20*
Horn-shaped model with one plane window of heat resistant glass or quartz	2 or 1	horizontal or vertical	10 or 20*
Model with two oblique windows of heat resistant glass or quartz	1	horizontal	20*
	0.5	horizontal	10*
Small spherical model of calcium glass	0.5	horizontal	10

*) With index at the middle of the ribbon if desired.

Vacuum lamp or gas-filled lamp

The tungsten ribbon lamps may be vacuum lamps or gas-filled lamps. In general a gas-filled lamp will be preferred because with the same life a higher working temperature and thus a greater brightness can be obtained than with a vacuum lamp. For spectral photometric work in the blue and ultra violet this is an important advantage.

As we have already seen the gas has no harmful effect on the reproducibility of the radiation in the course of time if the lamp is always allowed to burn in the same position. The gas does, however, have some influence on the temperature distribution of the ribbon. In the vacuum lamp this temperature distribution is determined by accidental slight irregularities in dimensions and properties of the ribbon and by the flow of heat toward the poles. In the gas-filled lamp the flow of the heated gas is also an influential factor. In the most unfavourable case, namely that of a gas-filled lamp with a vertical ribbon 2 mm wide and 20 mm useful length, at an average temperature of 2 500 °K, the upper end of the ribbon is not more than 25° warmer than the lower end. This difference in temperature is however not important.

Due to the dissipation of heat by the gas a larger current must be used to obtain a given temperature with a gas-filled lamp than with a vacuum lamp. For example, in the case of the gasfilled lamp with a ribbon 2 mm wide, a normal working temperature of 2 800 °K is reached with a current of 17.5 A, a temperature of 2 300 °K with 12.8 A. In the case of a vacuum lamp a normal working temperature of 2 300 °K is reached with a current of 10.8 A.

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