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THE MERCURY VAPOUR LAMP HP 300

Contents. Electrical discharges through mercury vapour at high vapour pressures constitute light-sources with a high luminous efficiency coupled with small overall dimensions. The new mercury vapour lamp "Philora" HP 300, which is designed for connection to alternating current mains, has roughly the same size and shape as an incandescent lamp of the same rating (75 watts) but gives three times the luminous flux. The present article discusses the electrical and illumination characteristics of this lamp, with special reference to the importance and the function of the current-limiting unit (series or leak transformer) and the spectral composition of the emitted radiation.

Introduction

In the history of the technical application of electricity for illumination purposes various periods of development can be distinguished. Neglecting consideration of the arc lamps, the first period may be regarded as starting from the time Edison demonstrated his first carbon-filament lamps and lasting to the beginning of the present century, during which these carbon filament lamps completely held the field. About 1900 there appeared the first Nernst lamps and a variety of metal-filament lamps, first merely as negligible competitors, but later gaining such ground that by about 1912 they had practically ousted the carbon-filament lamp. And today when the field has been held almost exclusively by the tungsten-filament lamp for a period of nearly 25 years, gas-discharge lamps are steadily encroaching on its preserves. In a variety of important directions sodium and mercury lamps have already been adopted on a large scale for practical purposes, principally for street and road lighting and for illuminating shunting-yards and workshops.

In the new "Philora" lamp HP 300 Philips have added a small mercury-vapour lamp, which possesses an exceptionally high efficiency, the output of light being about three times that of a tungsten lamp of the same rating. In the long run, will this lamp be capable of displacing the tungsten lamp in the same way as the latter has completely superseded the carbon-filament lamp?

No, this cannot be anticipated, since the tungsten lamp possesses certain desirable characteristics which are lacking in the new lamp. Thus the tungsten lamp burns at its full brilliancy the moment it is switched on, whilst in the new lamp several minutes must elapse before this state is reached. Moreover, the colour of the mercury light differs from that which one has become accustomed to with the incandescent lamp.

But what may be expected from the new lamp? Wherever the level of illumination is low, a marked increase in this level can be obtained with a lamp of this type for a small extra current consumption. By mixing the mercury light with that of the incandescent lamp a very pleasing tone coupled with a high luminous efficiency is obtained. Thus if tungsten lamps of 200 watts are supplemented by a 75-watt mercury-lamp, the luminous flux is practically doubled, and all colours appear very nearly the same as in ordinary daylight. This mixed light thus offers advantages as compared with the light obtained from each source separately.

Although the carbon-filament lamp during the early years of lighting by electricity made a very important contribution to the development of this branch of electrical engineering, it yet remained to the much more efficient tungsten lamp to popularise the use of electric lighting to a degree which a decade previously no one would have dared to prophecy. In less than 50 years the annual consumption of incandescent lamps has grown to more than a thousand million, accounting for the consumption of about $\cdot 25\ 10^9$ kWh of electricity per annum. Electric lighting has introduced electricity into practically every household.

We are now again on the threshold of an important advance in the increased efficiency of electric lighting. In view of the fact that the level of illumination in practically all applications of electric lighting still is kept very low for economic reasons, it appears that the new lamp will also open up a number of new avenues of application for electric illumination which have hitherto not been accessible to it.

Characteristics of the New Mercury Lamp

Fig. 1 shows the mercury vapour lamp in its natural size. The discharge tube is of quartz, with the liquid mercury contained in the small cupules which surround the electrodes. During operation the pressure of the mercury vapour rises to 20 atmos. The external dimensions of the glass bulb are similar to those of an incandescent lamp of the same rating. The principal electrical and illumination data for this lamp are collected in *table I*.

TABLE I. Characteristics of the mercury lamp HP 300 in stationary operation.

Voltage-drop across the lamp	230 volts
Current intensity	0.4 amp
Consumption of lamp	75 watts
Losses in connected transformer 5450 G/86	15 watts
Power factor	0.55
Luminous flux	3000 lumens
Net yield of light	33 lumens per watt
Diameter of discharge tube	ab. 4 mm
Distance between electrodes	18 mm
Mean luminous density	420 candles/sq. cm
Luminous density along axis	ab. 1150 candles/sq. cm

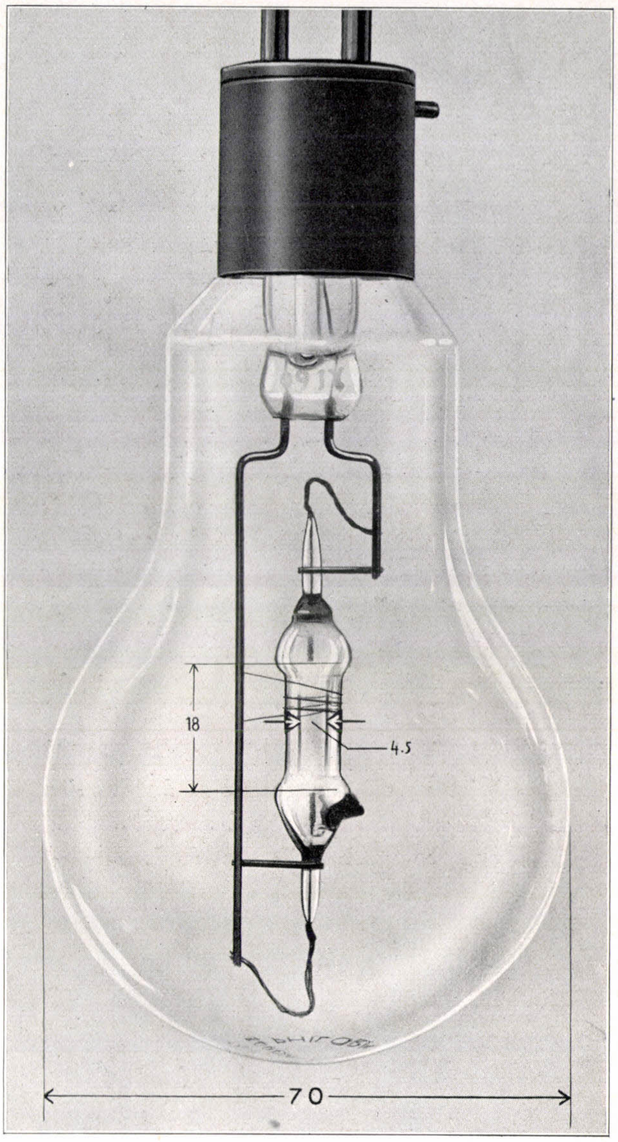

Fig. 1. Mercury vapour lamp "Philora" HP 300 rated for 75 watts and 3000 lumens in natural size.

The lamp is designed for running from an alternating-current mains supply. As with all other gas-discharge lamps, the new mercury vapour lamp also may not be connected directly to the mains, but must be connected in series with a resistance, condenser or a self-induction coil, in order to limit the current. The use of resistances is naturally avoided as far as possible in order to guard against supplementary power-losses. A strikingly simple solution of this problem is offered by the use of a transformer with a high leakage which serves both as a voltage source and as an inductive series resistance. The leak transformer (type No. 5450 G/86) provided for the new lamp is so rated that on the secondary side an inductive resistance of suitable magnitude is obtained and on connecting to a 220-volt mains supply the open-circuit voltage of 410 volts(eff.) for starting up and running the lamp is furnished.

To obtain a closer insight into the operation of this current-limiting unit, oscillograms were registered of the voltage drop U_E across the discharge and U_L across the unit in question, as well as of the total voltage U and the current intensity I (*fig. 2*). These curves show that the total tension is practically of sinusoidal form. On the other hand the voltage-drop U_E at the discharge when represented as a function of the time is roughly of rectangular form. The magnitude of the voltage-drop is thus almost independent of the current intensity, and we will call it the running voltage E_B. The direction of the voltage-drop, however, suddenly reverses when the direction of the current is reserved. The instant after reversal the voltage-drop rises to a higher value E_D, which we will term the re-ignition voltage, as this voltage is necessary to re-ignite the lamp when it becomes extinguished each time after reversing the current. The voltage U_L at the series transformer is equal to the difference between U and U_E. It is therefore not sinusoidal but, as shown in the figure, has a fairly complex form. As the series transformer has an inductive resistance, the following relationship holds between the current intensity I and the voltage U_L:

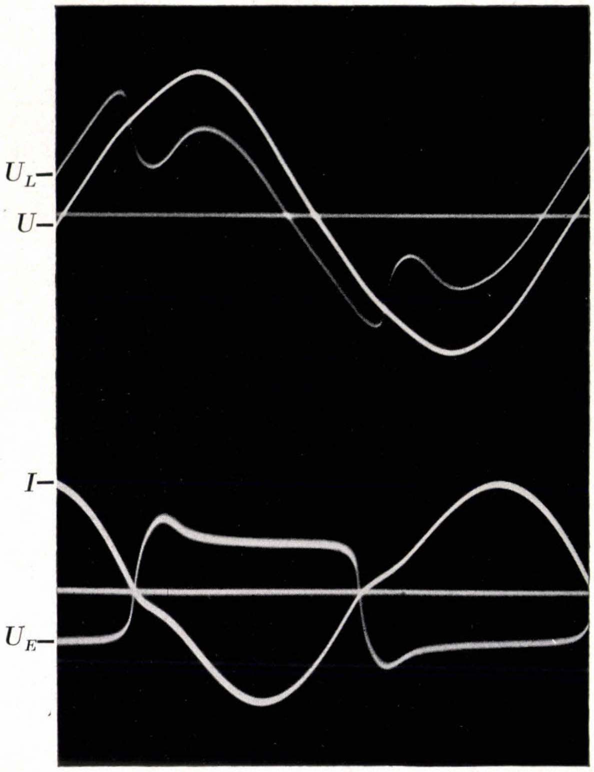

Fig. 2. Oscillograms of mercury vapour lamp HP 300 under normal running conditions. U_E = discharge voltage; U_L = voltage at series unit; U = total voltage; I = current intensity.

$$U_L = L\,\frac{dI}{dt}.$$

This expression indicates in accordance with fig. 2 that the current attains its highest value when the voltage U_L changes sign. Only when this has occurred does the current commence to drop. It is thus found that the current lags behind the feed voltage U, which was to be expected owing to the inductive character of the series transformer, although the currents in question here are not sinusoidal. When the current intensity becomes equal to zero, the voltage-source is already furnishing an appreciable reverse voltage. The magnitude of the re-ignition voltage E_D now determines whether this reverse voltage is sufficient to re-ignite the lamp immediately in the opposite direction after it has been extinguished. This is definitely possible if the ignition voltage is sufficiently low, as in the case shown in fig. 2. But under certain working conditions the lamp remains dead for a finite period, the so-called dark pause, before the current changes direction and before the tension has again reached such a value that re-ignition of the discharge takes place. *Fig. 3* shows the calculated fluctuation of the voltages and the current intensity assuming a sinusoidal total voltage, a rectilinear voltage-drop at the lamp and a purely inductive resistance at the series transformer. The agreement with the oscillograms is very satisfactory.

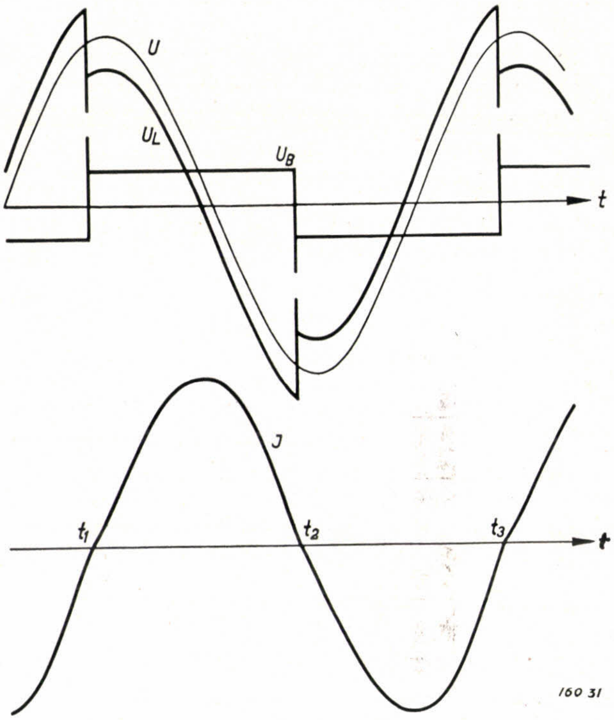

Fig. 3. Calculated current and voltages of the gas discharge and the series unit assuming simplified characteristics for the lamp. The concordance with the oscillograms is very satisfactory.

Shortness of the dark pause is not only advantageous from considerations of better illumination (less flickering) but also enables the lamp to be run with the minimum feed voltages. The re-ignition voltage E_D is indeed not constant but increases during the dark pause, and as a result the running of a lamp with a resistance in series requires higher peak voltages than when using chokes in series.

Heating-up and Stability

The voltage-drop E_B and the power output W of the mercury-vapour discharge both increase with the vapour pressure. If W is represented as a function of E_B, nearly a straight line as shown in *fig. 4* is obtained for the HP 300 mercury lamp. The curves N_1, N_2 and N_3 give the inputs of the lamp fed through the series unit, also as a function of the voltage drop, for an opencircuit voltage U

of 410 volts$_{\mathrm{eff}}$ and various settings of the leak transformer. Expressed as a function of the voltage-drop the power input has a maximum value. This may be readily understood, for at $E_B = 0$ the voltage-drop disappears and at $E_B = 580$ the current disappears. Actually the curve already breaks off at $E_B = 350$ volts, as the re-ignition voltage then exceeds the maximum open circuit voltage (580 V).

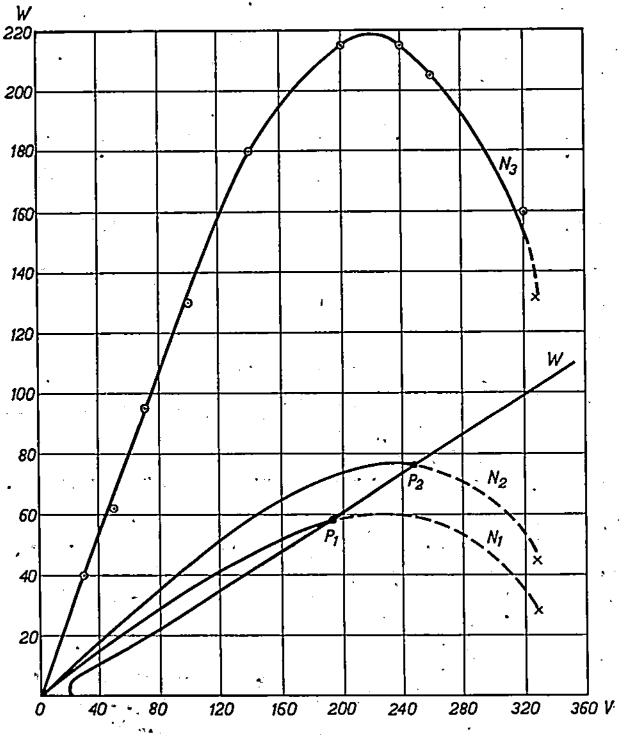

Fig. 4. The power output W of the mercury lamp HP 300 plotted as a function of the voltage-drop E_B under normal cooling conditions. The curves N_1, N_2 and N_3 show the inputs of the lamp with a total voltage of 410 volts$_{\mathrm{eff}}$ and various settings of the leak transformer. The points P_1 and P_2 correspond to stable working states of the lamp. If the energy input is that corresponding to the top curve N_3 no stable working point is obtained. The lamp becomes heated and goes out as soon as the re-ignition voltage rises above the maximum voltage applied to the lamp.

On switching on the cold lamp, the input power N is initially greater than the total output W. As a result the lamp heats up, whereupon its voltage-drop E_B, and hence also the power output W according to fig. 4 increases. The input power expressed as a function of E_B is represented by the curve N_2 for a load slightly higher than normal. In this case the heating-up stage terminates at $E_B = 250$ volts in the stationary working state P_2, in which the energy input N_2 and the radiation emitted W are equal.

Consider now the heating-stage curve N_3 which was obtained with a lamp running on a heavy overload. The output in this case too follows the curve W. As the input of energy is always in excess, the temperature as well as the re-ignition voltage rises until (at $E_B = 350$ volts) the maximum feed voltage is insufficient to ignite the lamp. The discharge is then extinguished, the temperature drops, the lamp is re-ignited after the elapse of a short interval and so on.

When the lamp is running on a subnormal load (heating-stage curve N_1) no abnormal behaviour is observed. The difference between the heat input N_1 and the output W is, however, very small as shown in the diagram, so that the time taken to reach the stationary state on reducing the power input increases very considerably. Moreover, owing to the small angle between the curves N_1 and W the position of the working point P_1 (stationary state) is very susceptible to slight displacement of these curves, i.e. small changes in the working conditions.

Under certain operating conditions (intense cooling and subnormal load), it may even happen that a lamp will not become heated to the normal working state. Such a case is shown in *fig. 5*. The stationary working point is P with a voltage E_B, but this working level is not attained. During heating, the lamp does not get beyond the first point of intersection P_0 of the curves N and W, so that at the very low running voltage E_0 it remains at the stage corresponding to a low-pressure discharge. To get it into a proper working condition, the vapour pressure must be raised by suitable means, e.g. by external heating, to such a level that the running voltage rises above the second point of intersection P' of the curves W and N. In this case the input energy will again exceed the output energy, so that the lamp will continue to heat itself and tend to attain its stable end state.

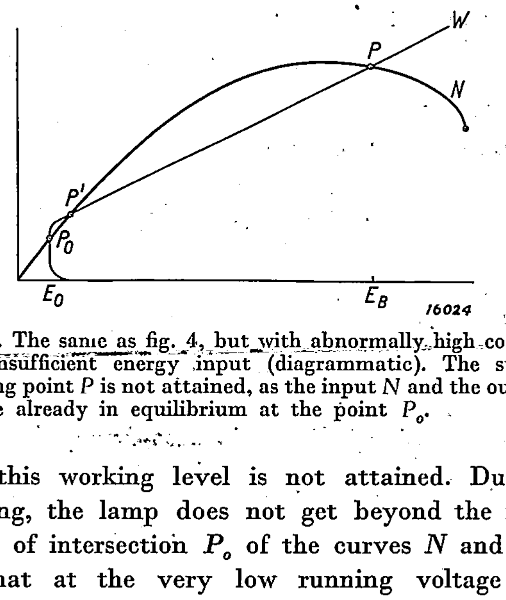

Fig. 5. The same as fig. 4, but with abnormally high cooling and insufficient energy input (diagrammatic). The stable working point P is not attained, as the input N and the output W are already in equilibrium at the point P_0.

It can thus be generally concluded that the normal load of the lamp is fixed within certain limits. With a subnormal load the temperature rises too slowly, whilst with a very heavy overload no stable working point is obtained. The mean heating curve is obtained when using the leak transformer 5450 G/86 for an output of 75 watts in the end state. The curves in *fig. 6* show the heating process as a function of the time.

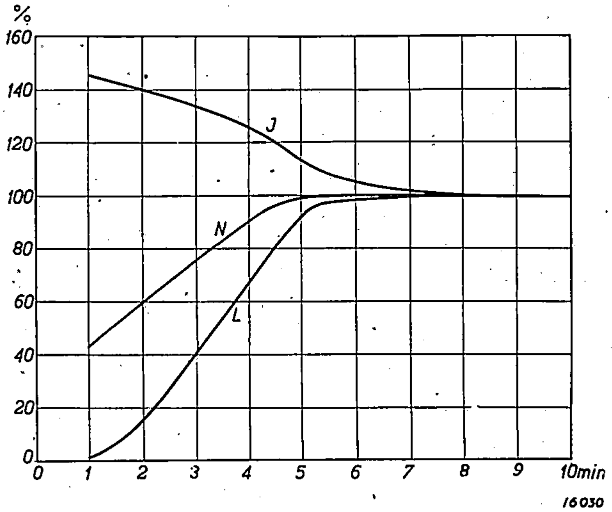

Fig. 6. Current intensity I, power N and luminous flux L of the mercury lamp HP 300 expressed in percentages of their end values and plotted as a function of the time after switching on. After the elapse of about 5 minutes the lamp gives about 90 per cent of its total luminous flux.

Illumination Characteristics

The luminous flux of the new mercury vapour lamp on a normal load is 3000 lumens. As the current-limiting unit itself absorbs about 15 watts, the light yield is 33 lumens per watt [1]). The spatial distribution of the light emitted by a lamp suspended vertically and with an opal globe is shown in *fig. 7*. A detailed discussion of the spectrum of the mercury-vapour discharge has already been published in a previous issue of Philips techn. Rev. (1, 5, 1936), where it was indicated that the distribution of spectral intensity was determined by the vapour pressure of the mercury. In general it may be assumed that the higher the vapour pressure the richer will be the spectrum in long-wave (red and infra-red) radiation, and hence the stronger will the ultra-violet lines be absorbed by the vapour. In addition the lines are broadened to an increasing extent and a continuous background appears between the lines especially in the visible region. *Fig. 8* shows the intensity distribution of the new mercury-vapour lamp in the visible spectrum. The figures at the peaks of the curves indicate the percentage contribution of the corresponding lines to the total luminous flux. As could be expected, this lamp already has a definite continuous background as well as an appreciable proportion of red light. Nevertheless the spectral distribution still deviates very considerably from that of daylight and the light given by incandescent lamps.

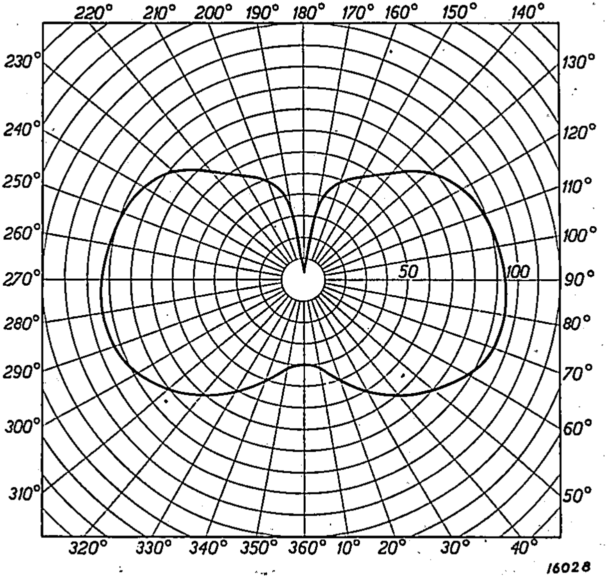

Fig. 7. Spatial distribution of the luminous flux of the new mercury lamp with opal globe.

To obtain a convenient survey of the spectral distribution the scale of wave-lengths has been subdivided in *table II* into four ranges, these ranges being of such extent that they contribute equal proportions of luminous flux in the case of a spectrum of constant intensity in the wave-length scale (so-called equal energy spectrum). As indicated by table II, solar radiation is distributed almost uniformly over the different ranges selected. The

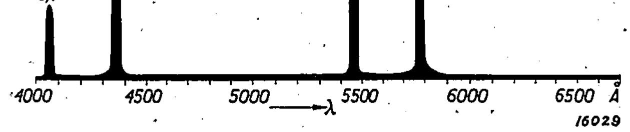

Fig. 8. Intensity distribution of the radiation of the new mercury lamp in the visible spectrum. The figures at the peaks of the intensity curve represent the percentage contribution of the respective spectral lines to the total luminous flux.

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[1]) With the same power, the efficiency of an incandescent lamp is approximately 13 lumens/watt.

TABLE II. Distribution of luminous flux of various light-sources over four spectral ranges of visible light expressed as a percentage of the total light output.

Range of wave-lengths Å	Equal energy spectrum	Sun	In-cand. lamp	Mercury vapour lamp HP 300	Mixed light. G and H denote the luminous flux of the incand. lamp and the mercury vapour lamp resp.	
					$G/H = 1/1$	$G/H = 2/1$
	%	%	%	%	%	%
4000—5300	25	26	14	8	10	12
5300—5580	25	26	22	58	40	34
5580—5880	25	25	28	31	30	29
5880—7000	25	23	36	3	20	25

incandescent lamp contains a higher proportion of long-wave radiation and a less proportion of short-wave. The mercury-vapour discharge is made up mainly of yellow and green light. The blue lines, owing to their very short wave-length (4358 Å and 4047 Å), contribute only very little to the total luminous flux. Although long-wave radiation ($\lambda =$ above 5880 Å) is indeed present as a continuous background it is by no means sufficient to produce a natural impression.

Control of the Spectral Composition of the Light

Experiments have shown that the impression given by coloured surfaces on illumination with mercury vapour lamps can be considerably improved by the admixture of red radiation. This may be done in various ways, e.g. the use of red-fluorescing reflectors or the addition of light from incandescent lamps, which as we have seen has an excess of red radiation as compared with daylight. In order to give a numerical instance of the degree of adaptation, two cases of mixed illumination are included in Table II. Favourable adaptation appears to be obtained when about $^2/_3$ of the light is furnished by incandescent lamps and $^1/_3$ by the mercury vapour lamp. In this case the proportions of yellow and red radiation compare favourably with those of sunlight, although there is an excess of green and a corresponding lack of blue radiation. Perfect adaptation to the spectral intensity distribution of sunlight can naturally not be achieved and is possibly not desirable at all. It is indeed, quite probable that the eye requires a different distribution of spectral intensity with artificial light than with daylight owing to the necessarily lower brightness. The best mixture of glowlamplight and mercury vapour light can therefore only be determined by experiment.

Compiled by G. HELLER.