Carbon-filament lamps with a chemical transport cycle

At the beginning of this century nearly all electric lamps had a carbon filament, but by about 1910 the carbon filament was almost entirely superseded by the tungsten filament. Carbon-filament lamps of the traditional type are now only produced on a limited scale, for special purposes. The main reason for the switch to tungsten was that it has a much slower rate of evaporation than carbon at the same temperature. This means that under the same operating conditions, the bulb of a tungsten-filament lamp does not blacken nearly as quickly as that of a carbon-filament lamp. The difference between carbon and tungsten can also be seen from fig. 1, which shows their vapour-pressure curves.

Nevertheless the carbon-filament lamp does have its virtues. In principle a carbon filament can operate at much higher temperatures than a tungsten filament, because carbon sublimes at about 4100 K whereas tungsten melts at a temperature four hundred degrees lower. Fig. 2 shows the temperature dependence of the luminance and luminous efficacy for both carbon and tungsten. At the same temperature, the efficacy of the carbon-filament lamp is rather worse than that of the tungsten lamp, but the carbon filament has a greater luminance. For applications requiring high luminance, carbon would therefore seem to have the advantage over tungsten. Another reason for taking a new look at the carbon-filament lamp is that much more information is now available about the various kinds of carbon and the ways in which they can be manufactured and shaped. Finally there is the question of possible shortage of materials; there is some risk of this with tungsten, but not with carbon.

A primary object of the investigation — to which we shall confine ourselves here — was to find a way of preventing the bulb from blackening at filament temperatures considerably higher than those used in the traditional incandescent lamp (2100 K) while maintaining an acceptable life.

We tried to see whether this could be done by filling the bulb with a gas that react with carbon and functions in much the same way as iodine or bromine in...
halogen lamps\(^2\). A gas of this kind would have to convert carbon into stable gaseous compounds at the bulb wall and close to it. These compounds would then be transported by diffusion and convection to the filament, where the carbon would be released again because of dissociation due to the high temperature — and in the ideal case would completely regenerate the filament. The 'transport gas' released on dissociation would then diffuse to the bulb wall again. A lamp in which a mechanism of this type is operative can operate at higher temperatures, giving a higher luminance and efficacy.

The occurrence of a chemical transport cycle and its properties can in principle be predicted for any gas

![Fig. 3. Model of a (chemical) transport reaction in a carbon-filament lamp.](image)

\(V_1, V_2\) each contain solid carbon and gas. The temperature in both volumes is assumed to be uniform \(T_W\) is about 500 K, \(T_F\) is 2500-3000 K). It is assumed that both volumes contain equal numbers of bonded or free atoms of the reactive element. After exchange of the gas in the two volumes the original composition of the gas phase is restored. In this process an effective transport of carbon takes place from the solid phase in the one volume to that in the other.

![Fig. 4. a) Calculated composition of the gas in the heterogeneous system carbon-fluorine as a function of absolute temperature \(T\). The partial pressure \(P_p\) of the compounds formed is plotted vertically. \(C_2\), \(C_3\), \(C_4\), \(C_5\), \(C_6\) are carbon molecules; \(C\) and \(F\) are atomic carbon and atomic fluorine respectively. The calculations were based on a total quantity of fluorine corresponding to a constituent pressure of \(2 \times 10^3\) Pa. No data relating to kinds of molecule at pressures lower than 10 Pa are included. b) Calculated carbon total vapour pressure \(\Sigma p_C\) of the heterogeneous system carbon-fluorine as a function of \(T\). The parameter used is the total number of bonded or free fluorine atoms, characterized by the constituent pressure \(P_F\). Curve a: a lamp with this variation of \(\Sigma p_C\) will still have a clear bulb, at least at filament temperatures between 2300 and 2900 K, since \(\Sigma p_C\) is then lower near the filament than at the wall; for curve b somewhat higher temperatures are possible, up to 3000 K. In the case of curve c carbon transport goes towards the bulb wall at all filament temperatures above 2000 K.](image)


a given temperature can then be calculated from the available thermodynamic data relating to the (heterogeneous) equilibrium between the solid carbon and the reactive transport gas.

If there are many kinds of molecule the composition of the gas will be rather complex. For instance, in the case of the heterogeneous system carbon-fluorine, which we shall now consider, we have to contend with the molecules \( \text{C}_2, \text{C}_3, \text{C}_4, \text{C}_5, \text{CF}, \text{CF}_2, \text{CF}_3, \text{CF}_4, \text{C}_2\text{F}_2, \text{C}_2\text{F}_4, \text{C}_2\text{F}_6 \) and \( \text{F}_2 \), as well as the atoms \( \text{C} \) and \( \text{F} \). The composition of the gas phase of this system is given as a function of temperature in fig. 4a.

From the curves in fig. 4b the direction of carbon transport — towards the bulb or away from it — can be determined for a given temperature distribution in the lamp. Here we assume that two volumes of gas with equal numbers of bonded or free fluorine atoms are exchanged between the region near the relatively cool bulb and the region near the much hotter filament. (In reality the exchange takes place by diffusion and convection.) After the exchange the original equilibrium is restored, which means that the composition of the gas phase is now the same as it was before the exchange. In proportion to the difference in total va-

The extent to which a gaseous medium takes up the carbon in a bonded or free form may be expressed by a kind of total vapour pressure \( \Sigma \rho_c \). This is done by summing the partial pressures of the gaseous carbon compounds, taking into account the number of carbon atoms present in the various kinds of molecule. Fig. 4b shows a plot of \( \Sigma \rho_c \) for the carbon-fluorine system as a function of temperature. The parameter \( \rho_F \) is the constituent pressure, a quantity that characterizes the total number of bonded or free fluorine atoms.

![Fig. 5. Blackening of the bulb in four experimental carbon-filament lamps with a carbon-fluorine transport cycle.](image-url)

I gas filling (at room temperature) \( 65 \times 10^3 \) Pa of Xe + \( 1.3 \times 10^3 \) Pa of \( \text{CF}_4 \) (see curve a in fig. 4b). II gas filling \( 65 \times 10^3 \) Pa of Xe without \( \text{CF}_4 \). When the photograph was taken, both lamps had operated for six hours at a filament temperature of 2750 K.

III gas filling as in I. IV gas filling \( 53 \times 10^3 \) Pa of Xe + \( 1.3 \times 10^3 \) Pa of \( \text{CF}_4 \) (see curve c in fig. 4b). Lamp III has operated for fifty hours at 2560 K, lamp IV for only two minutes.

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near the minimum in the curve. If the fluorine content is high enough for curve c to apply, the mechanism will transport carbon to the bulb, and the lamp will not be usable. Our experimental results agree with these predictions (fig. 5) [3].

A life of several hours has already been achieved with experimental carbon-filament lamps operated at a filament temperature of 3000 K, and a life of the order of several tens of hours has been reached with a filament temperature of 2500 K. These are promising results.

The calculations have also shown that a transport cycle that keeps the bulb clear is feasible not only with fluorine but also with chlorine or hydrogen. This has been confirmed in the meantime by experiments [4].

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Open-air laboratory for road lighting

A short piece of roadway at a Philips establishment at Acht, near Eindhoven, has been arranged as a lighting laboratory. The road surface is 250 m long by 17 m wide, and the equipment provided can be used for investigating the performance of experimental lanterns and the associated optical equipment. The 'lamp posts' can be moved on rails. The lanterns can be mounted at any height up to 16 m above the road surface, and their position in the horizontal plane can also be varied.