CHAPTER VI

THE NERNST LAMP

THE first patents covering the principle of the Nernst lamp were taken out by Prof. W. Nernst in 1897 and 1898, and the lamp was first introduced into this country in 1899 by Mr. Swinburne, who read a paper describing it before the Society of Arts in February of that year. The Nernst lamp, as it was at that date, was only a very crude lamp, the progress that had been made in its development amounting to little more than showing that Nernst filaments could be made, which, whilst consuming only about half as much power per candle as carbon filaments, had nevertheless a reasonably long life. Much further experiment was needed before a commercial lamp could be produced, and the difficult task of carrying this out was taken up vigorously in England, Germany, and America by the three companies interested, their efforts being crowned with success towards the end of 1900. Each company, though proceeding on somewhat different lines, succeeded in perfecting a satisfactory type of lamp, but the English company never manufactured on a commercial scale, and, for reasons connected with the ownership of the English patents, finally abandoned altogether the intention of so doing. The lamp, as it is constructed to-day and sold in England, is, therefore, that developed and manufactured by the Allgemeine Elektricitäts Gesellschaft, of Berlin.

It has undergone but little modification since the first satisfactory types were produced in 1900 and 1901, and it has decidedly failed to achieve the results anticipated at its first introduction, though it has proved a useful and undoubted improvement in many respects.

The essential feature of the Nernst lamp is the employment, as the incandescent body, of an electrolytic conductor. This filament, or glower, as it has been termed, is a short rod composed of a mixture of certain oxides; such a body is not an electrical conductor when cold, but on being heated conducts fairly well. Means have to be provided in the lamp, therefore, for raising the glower to the temperature at which it conducts; this is effected by the use of an electrical heating coil, or heater, fixed in close proximity to the glower. In order to avoid unnecessary waste of current, an automatic cut-out is provided in the lamp, which is operated by the glower current, and which interrupts the heater circuit as soon as current passes through the glower. The glower has the further disadvantage that the voltage and current, at or in the neighbourhood of the working temperature, are not in stable equilibrium, an increase of current being accompanied by a fall in potential difference, and consequently a steadying resistance has to be used in series with the glower, as will be explained more fully presently. In Fig. 46 is shown diagrammatically the scheme of the Nernst lamp.

When pressure is first switched on the glower circuit P G M R N is non-conducting, as the glower G is cold, and current can, therefore, only pass through the heater circuit P H C S N. The temperature of the heating coil H is thereby raised and after a time the glower becomes sufficiently hot to conduct; current now flows round the glower circuit, which includes the magnet coil M and the steadying resistance R. As a result of the energising of the magnet, the spring S is drawn into the dotted position, and the heater circuit broken; S remains in this position until the pressure is switched off, when it returns to the position shown in full in the diagram.

MANUFACTURE.

The Glower.—The glower is composed of a mixture of oxides of the rare earths, which have individually and also when mixed very high melting-points. Various ingredients may be used with equally satisfactory results, the performance of the glower appearing to depend more upon the purity of its components and the method of manufacture than on the actual oxides used. A good mixture, and one formerly (if not still) the standard, is 85 per cent. of zirconia and 15 per cent. of yttria and erbia. Yttria and erbia occur naturally together, and are very similar in chemical properties, their separation being a matter of great difficulty; fortunately, it is unnecessary to effect

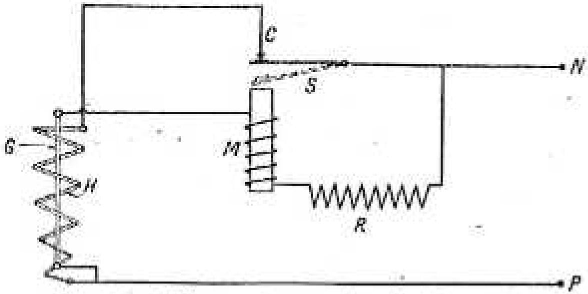

FIG. 46.—Scheme of connections in Nernst lamp.

this, and the mixed oxides can be used in their naturally occurring proportions without any disadvantage. Ceria and thoria may also be used in the mixture. The oxides must be obtained in a very pure state, and also in an extremely finely divided condition. A good method is to prepare pure solutions of the chlorides, and mix these in the proportions necessary to yield on precipitation the mixed oxides in the right proportions. The solution can be precipitated with ammonia, which produces a gelatinous precipitate of the hydroxides, yielding the oxides on calcination. Other methods may, however, be employed. The calcined oxides are mixed to a stiff paste with gum, gum tragacanth being particularly suitable, and about 5 per cent. being sufficient. This paste is forced by a press through a small die, from which it issues in the form of a continuous and fairly strong thread, which soon dries to a stiff rod. For the larger diameter filaments, a needle is fixed in the centre of the die, so that the filament issues as a tube. These rods have now to be baked to a very high temperature, which is best attained by electrical baking. Very good results may be obtained by baking the rods in an electrical tube-furnace, the tube itself being composed of the same material as the glower. Carbon tubes are not very suitable, as they are liable to lead to the formation of carbides. The Nernst tube furnaces are not very satisfactory from a practical manufacturing point of view, and the writer does not know if they are still in use. Filaments can be baked in the oxyhydrogen flame or by passing them slowly through an arc, or indeed in any way in which a high enough temperature can be obtained without introducing impurities. The baked filaments are cut to the required length and mounted; the mounts are formed by winding a skein of fine platinum wire tightly round the filament, as shown in Fig. 47 (*a*), and covering the joint with a paste composed of very finely ground and strongly baked (preferably fused) glower material. This powder is mixed with a little solution of the chlorides of the rare earths to a thin paste, which is applied to the joint and then strongly heated to convert the chlorides to oxides; a very firm joint can be made in this way (Fig. 47 (*b*)). Another method is to fuse the end of the glower in an oxyhydrogen flame or arc and insert into the fused globule a fairly thick platinum wire.

The size of the glowers is approximately as follows: 1 ampere, 1 *m/m* diameter, 32 *m/m* long, for 200 volts; 0·25 ampere, 0·4 *m/m* diameter, 24 *m/m* long, for 200 volts. The length is not proportional to the voltage, on account of the drop in volts and the cooling effects at the mounts.

Fig. 47.—Method of forming mounts on Nernst filament.

The Heater.—In the early days of the Nernst lamp it was proposed to make lamps without heaters, which were to be lighted with a match or spirit lamp, and many excellent lamps were made in this way. They had the advantage of cheapness and extreme simplicity, and it seems a mistake that this type of lamp was not more fully developed. But, for some reason, these lamps did not meet the requirements of the market, and electrical heating devices had to be developed, so as to make the lamps self-lighting. The heater of modern Nernst lamps consists of a porcelain rod, on which is wound a spiral of fine platinum wire. The rods may be squirted in the same way as the filaments from a mixture of china clay and gum, and baked in the usual porcelain kilns. The spiral of platinum is then wound on, and is protected by giving it a coating of kaolin; the rods can be bent to any required shape in a Bunsen flame. The spiral heaters used in the larger lamps may be formed by winding the rods on to a former of the correct shape, the former and rod being kept hot by a blow-pipe flame during winding. The ends of the platinum spiral are secured by nickel wire twisted on to form a mount in the same way as the mounts on the glower are made, the mount being protected by a covering of kaolin.

Steadying Resistance.—The essential requisite of the steadying resistance is that it shall have a high positive temperature coefficient, so that a very small increase in current is accompanied by a great rise in potential difference. Fairly satisfactory resistances can be made by winding fine platinum wire on porcelain formers, as shown in Fig. 48, the formers being so shaped that the wire is in contact with the former in as few places as possible. The wires must be very fine, and for heavy currents many wires must be used in parallel instead of one thick wire; the wire must be of such a diameter that it is just below a red heat when the normal working current is flowing. Iron wire possesses, however, the necessary properties in a much more marked degree than platinum, and iron wire resistances are now universal. The wire must be protected from the

FIG. 48.—Platinum wire steadying resistance.

oxidising action of the atmosphere by enclosing it in a bulb, which is either exhausted or filled with hydrogen at a low pressure. These resistances have the form shown in Fig. 49; the fine iron wire is wound into a spiral, and fixed on to a nickel wire frame; the whole is enclosed in a bulb, the air is exhausted and the bulb is then filled with pure dry hydrogen at the desired pressure and sealed. The wire is of such a diameter that the normal current raises it to just below a red heat, and the regulation obtained with many fine wires in parallel is far better than that obtained with a single thick wire. These resistances have truly remarkable characteristics, which will be discussed later.

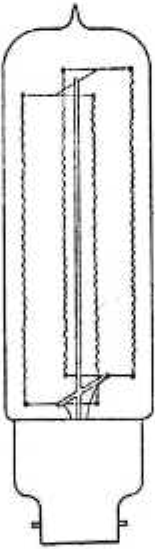

Fig. 49.—Iron wire steadying resistance.

The cut-out does not call for special description. It consists of a small electro-magnet attracting a light spring armature which carries the heater circuit contact. The chief requisites are that it shall absorb as little power as possible, be certain in action, and be silent on alternating current.

The glower, heater, resistance, and cut-out are mounted in a suitable lamp case. The glower and heater are mounted together on a porcelain base, so that they can easily be renewed when either fails, and the resistance is also fixed in such a way that its replacement is easy and can be effected by the user. The cut-out is permanently fixed to the lamp.

PHYSICAL CHARACTERISTICS OF THE NERNST LAMP.

In Figs. 50 and 51 are given typical curves showing the connection between the current flowing through a Nernst filament and the potential difference at its terminals. The curve in Fig. 50 is for a very short filament in order to show the full range of current and P.D. values. It will be noticed

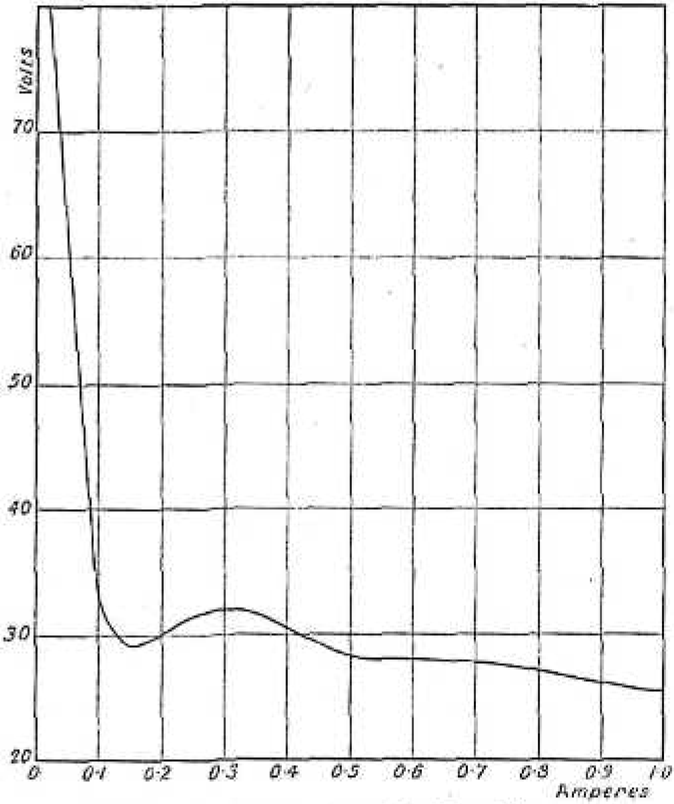

FIG. 50.—P.D.-current curve for Nernst filament.

that as the current is increased the potential difference at first falls very rapidly, then rises and finally again falls, this last fall continuing until the filament fuses. The curve in Fig. 51 is for a filament of normal length (suitable for a 0·25 ampere 100-volt lamp) and shows on a larger scale the most important part of the curve, that in the neighbourhood of the normal working current.

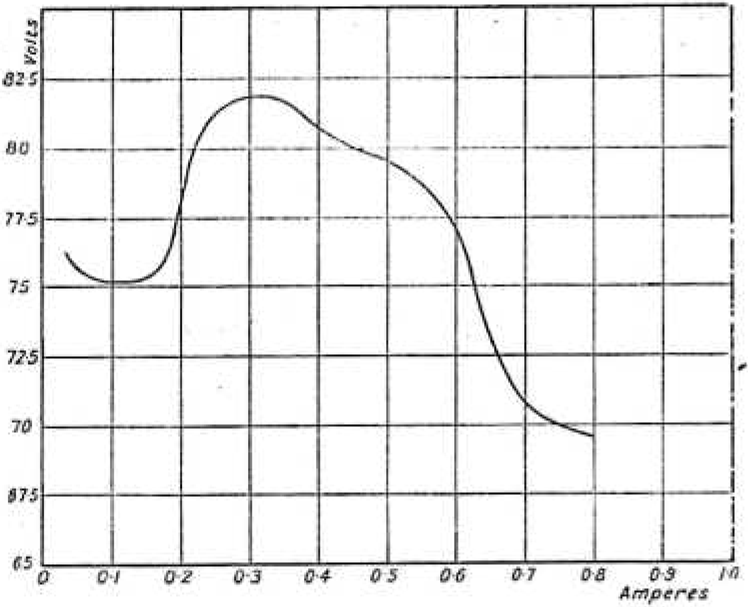

FIG. 51.—P.D.-current curve for Nernst filament.

From the study of these curves the conditions for stability of the filament current can be determined. Suppose in the first case that the glower is connected direct to a generator of E.M.F., E (Fig. 52) and draw the line E A B C corresponding to this E.M.F. cutting the P.D.-current curve at

A, B and C. As there is no fall of P.D. in external resistance the P.D. at the filament terminals must be equal to E and the current must, therefore, have one of the values O A′, O B′ or O C′ corresponding to the points of intersection A, B and C. Of these three values O B′ is the only possible stable value under the given conditions. For, let the E.M.F. rise slightly to the value E_1 and draw the line $E_1 A_1 B_1 C_1$ as before. The new value of the current must be $O A'_1$, $O B'_1$ or $O C'_1$. Now the rise in E.M.F. must occasion an increase in current, since the resistance of the glower is unchanged at the moment the rise takes place, but both

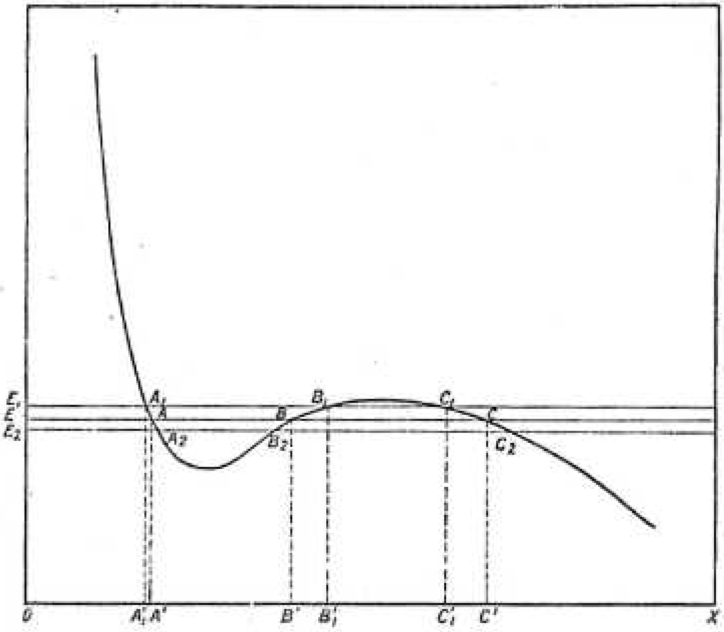

FIG. 52.—Conditions for stability of filament current.

the currents O A'_1 and O C'_1 are less than the original currents O A′ and O C′, and in order that the current should assume these values after the rise in E.M.F. it would be necessary for this rise to produce a fall in the initial current. In the same way it can be seen that a fall in E.M.F. from

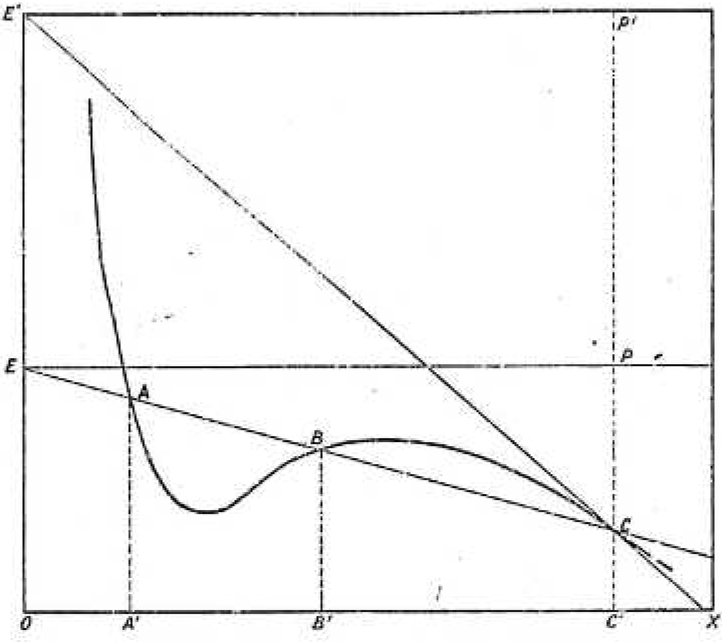

FIG. 53.—Stability of filament current with resistance in series.

E to E_2 cannot occasion the *increase* of current from O A′ to O A'_2 or from O C′ to O C'_2. The inclination of the P.D.-current curve at B is, however, in the right direction; the value of the current corresponding to a higher P.D. after the change being greater, and that corresponding to a lower P.D. smaller, than the initial value of the current.

If a resistance is connected in series with the filament there will be a fall in P.D. in this resistance. Draw the line E P (Fig. 53) as before, corresponding to the generator E.M.F. and plot *downwards* from this line the values of the P.D. drop in the series resistance with different currents, thus obtaining (for a constant resistance) the line E A B C. Exactly the same argument as before will show that the current corresponding to the point of intersection B is again the only stable current under these conditions.

In general, when the *resistance line* E A B C cuts the P.D.-current curve from above (as at B), the condition represented is stable, but when it cuts the P.D.-current curve from below (as at A or C) the position is unstable.[1] It is sometimes erroneously stated that the instability of the Nernst filament is due to its possessing a negative temperature coefficient. A carbon filament possesses a negative temperature coefficient, its resistance being lower when hot than when cold, but is nevertheless stable. The criterion of stability is not the temperature coefficient but the slope of the P.D.-current curve: when a small *rise* in P.D. $d\,V$ is accompanied by a small *rise* in current $d\,A$, *i.e.*, when $\frac{d\,V}{d\,A}$ is positive, the condition is a stable one: when a small *rise* in P.D. is accompanied by a small *fall* in current, *i.e.*, when $\frac{d\,V}{d\,A}$ is negative, the condition is unstable. In order to determine the stability of a circuit containing both filament

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[1] The argument is precisely the same as that applied by M. Blondel to explain an exactly similar phenomena in the electric arc, and very fully and lucidly explained by Mrs. Ayrton: *The Electric Arc*, Chapter VIII. The case of the Nernst filament is peculiar as the curve possesses one stable and two unstable regions.

and resistance it is necessary to find the sign of $\frac{d\,V}{d\,A}$ for the combined circuit. This can be done by plotting a curve the ordinates of which are equal to the *sums* of the P.D.'s of filament and resistance; if this curve slopes upwards from left to right the condition is stable, if downwards unstable. A more simple method is to see whether the resistance line cuts the P.D.-current curve from above or not. Thus in Fig. 53, whereas the point of intersection C is unstable when the generator E.M.F. is E, it is stable when the generator E.M.F. is E′, and a resistance is used in series with the filament over which with current O C′ there is a P.D. = P′ C. It will be seen therefore that to obtain all the points on the P.D.-current curve it is necessary to use an E.M.F. very high compared with the actual P.D. between the ends of the filament. For this reason a very short filament was used to obtain the curve in Fig. 50, and even though the normal P.D. between the ends of this filament was only about 32 volts, a generator E.M.F. of 300 volts was necessary in order to obtain the points on the first part of the curve.

The P.D.-current curve is also very interesting in connection with the lowest burning current and the lighting-up temperature of the glower. It is evident from what has preceded that the lowest current at which a given filament will burn steadily depends simply on the E.M.F. available and the resistance in series with the filament. The lowest burning current is determined by the position of B, Fig. 53, and in order that E B may cut the P.D.-current curve from above at a point corresponding to a small current, O E must be great and the angle P E B large. The greater therefore the potential difference over the external resistance the smaller the value of the lowest burning current. In confirmation of this the following experiment may be described. Three filaments of the same diameter and material were mounted so that the lengths between the mounts were 5 *m/m*, 12·5 *m/m* and 24 *m/m* respectively, and all three were tested on a 200-volt circuit. This was equivalent to testing a filament of fixed length on circuits of different voltages. It was found that the lowest burning currents were 0·015, 0·07 and 0·10 amperes respectively. The normal working current for these filaments was 0·5 amperes. Since the P.D.-current curve rises rapidly as the current approaches zero, the E.M.F. necessary to maintain a very small current steadily flowing is very large: if the curve eventually becomes parallel to the axis of P.D. there is a lower limit below which no current can be maintained, however high the available E.M.F.

Consider now the question of the lighting-up temperature. When a Nernst lamp is lighted the filament is heated by external means until it attains a certain temperature at which it will have a definite resistance g_1. Let the external E.M.F. be E, Fig. 54, and the resistance in series with the filament r. Then a current will flow equal to $\frac{E}{r + g_1}$, which will itself heat the filament to a higher temperature at which it will have a resistance less than g_1. The current will consequently increase until a steady condition is reached, at which the filament has a resistance g_2. The steady current flowing will now be equal to $\frac{E}{r + g_2}$. Let this current be represented on the diagram by O A′. Draw E A as before such that *tan* P E A = r, and O A such that *tan* X O A = g_2. The point of intersection A of E A and O A determines the position of A′. Since the filament is hotter than it would be if heated solely by the current O A′ its resistance must be lower than it would be as a result of the

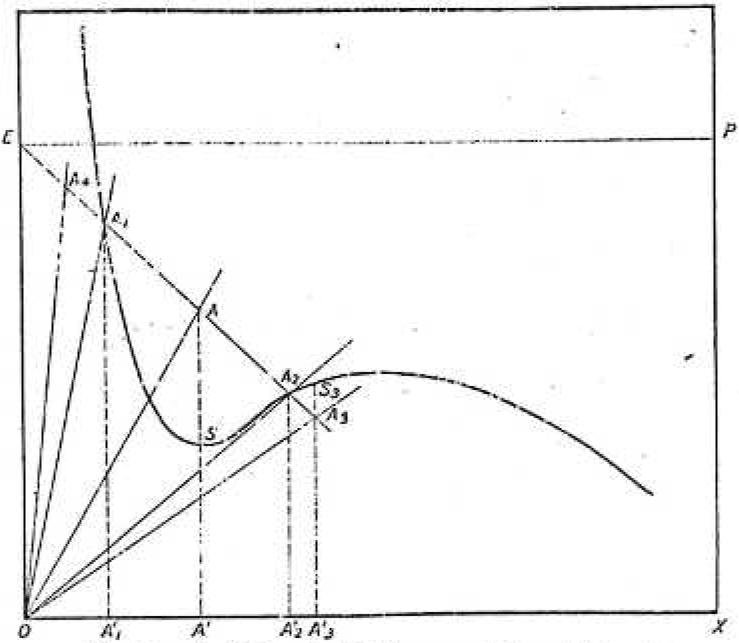

FIG. 54.—Conditions for lighting-up of Nernst filament.

electrical heating alone. The P.D. at its ends must therefore be less than that required to maintain the current O A′ without external heating. But this P.D. is S A′. Hence A A′ the actual P.D. at the ends of the filament must be less than S A′, *or the point A must lie below the P.D.-current curve.* The position shown is therefore clearly impossible:

under these conditions the current would go on increasing until it finally attained a steady value such as OA'_3 for which the condition that $A_3A'_3$ must be less than $S_3A'_3$ is satisfied. If the resistance line EA cuts the P.D.-current curve at A_1 and A_2 it will be seen that A can lie anywhere on EA except between A_1 and A_2. The current which flows through the filament whilst the external heating is still applied must be therefore either *less* than OA'_1, or *greater* than OA'_2, and the resistance of the filament (due to the electrical and external heating) must be either *greater* than *tan* XOA_1, or *less* than *tan* XOA_2. Suppose the resistance is greater than *tan* XOA_1, say equal to *tan* XOA_4, and let the external source of heat be now removed. As the filament cools the current will fall in a manner determined by the movement of A_4 along A_4E. As A_4 in moving along A_4E never meets the P.D.-current curve a value of the current is never reached at which the filament can burn under the given conditions of E.M.F. and resistance, since for all such values A_4 must lie on the P.D.-current curve. As a result the current falls to zero and the lamp goes out. When however the resistance is less than *tan* XOA_2, say equal to *tan* XOA_3, and the external heating is removed, A_3 in moving along A_3E eventually comes to the P.D.-current curve at A_2, and at the current corresponding to this position (OA'_2) the filament will continue steadily burning. Hence in order that the filament may light up, the initial current must have a value greater than OA'_2, and it has already been shown it will attain such a value provided it attains a value greater than OA'_1. The resistance of the filament due to the external heating combined with the heating produced by the starting current as it grows must therefore fall to a value less than *tan* X O A_1, and in the limiting case we may say that the resistance due to the external heating *alone* must be less than *tan* X O A_1. The lighting-up temperature is therefore determined by the position of A_1, the *first* point of intersection of the resistance line and the P.D.-current curve. This depends upon the P.D.-current curve, the E.M.F. and the external resistance. There is therefore no such thing as an absolute lighting-up temperature for a given filament: it will be seen at once that the higher the applied E.M.F. and the lower the external resistance, the lower the temperature at which the filament starts up. For given external conditions the lower the

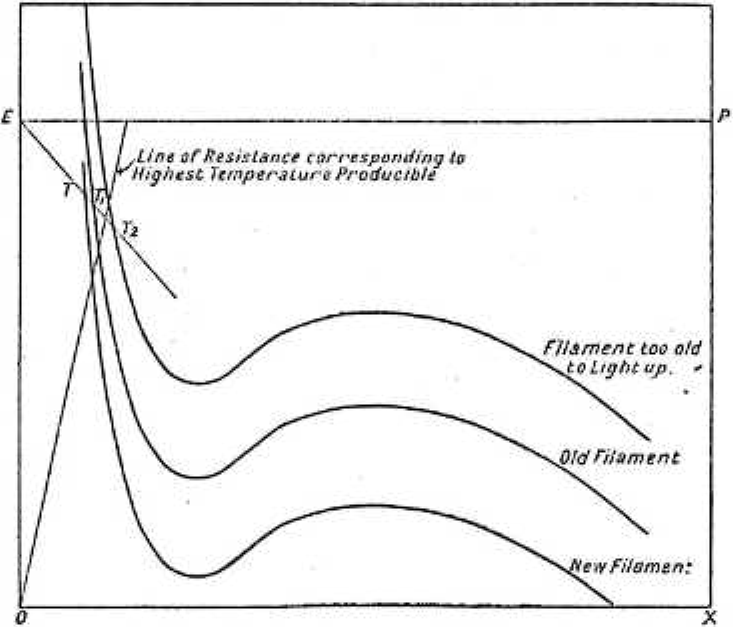

FIG. 55.—Ageing of Nernst filament and lighting-up temperature.

resistance of the filament (or more accurately the lower the P.D.-current curve) the lower the lighting-up temperature. This explains a phenomenon often observed with Nernst lamps that, as the lamps grow old, the time taken to light up increases until eventually the filament will not light up at all. As the filament ages its resistance increases, and the P.D.-current curve rises bodily, the point T (Fig. 55) moving from left to right along the axis of current until eventually it corresponds to a temperature higher than that which the heater can produce, as is shown diagrammatically in the figure.

TABLE XIV.

Filament Resistance at 0·4 amperes.	Thermocouple Reading at lighting-up Temperature.
400	37
425	40
440	50
560	Greater than 57

Some experiments made by the writer which confirm these conclusions may be quoted. Four filaments of the same diameter and material were made of different lengths so as to have different resistances. A small electrical furnace was constructed in which the filament to be tested could be completely enclosed, and a thermocouple was inserted in this furnace as close as possible to the filament. The filament was connected in series with a fixed resistance on a supply of definite E.M.F., and the furnace slowly heated up. Readings of the thermocouple indications were taken every two minutes until the filament lighted up; the lighting-up could be quite definitely determined by watching an ammeter connected in series with the filament; the

Polarity.—That the conduction in Nernst filaments is essentially electrolytic in nature is shown by the fact that even a few minutes running on direct current is sufficient to give the filament properties indicating the existence of a definite polarity, and if the current is now reversed the filament in all probability breaks at the original positive end. This breakage does not always occur, and is less liable to occur the shorter the period for which the filament has been run before reversal. It will usually be found that if the filament survives the first few hours' running after reversal its polarity appears to be reversed and it continues to burn quite satisfactorily. Nevertheless it is obvious that the greatest care must be taken to avoid reversal, and lamps must always be connected up with the correct polarity as marked on the lamp by the manufacturers. For similar reasons direct current filaments must not be used on alternating current circuits; the reverse process is less objectionable. At one time different compositions were used for alternating and direct current filaments; the writer is not aware if this is still the case. It is, however, quite possible with proper precautions to make filaments of the same composition equally satisfactorily for direct or alternating current. The polarity of the filament is further evidenced by the greater heating which always occurs at the positive mount, and the greater drop of potential at this mount.

The Series Resistance.—It has already been shown that it is possible to burn a Nernst filament without any resistance in series though under very unstable conditions. In discussing the P.D.-current curves it has been assumed that a constant resistance, *i.e.*, a resistance which remained of the same value for all values of the current, was used in series with the glower. It is easy to see, however, that such a resistance is unsuitable; take for example the P.D.-current curve in Fig. 57 for a filament in series with a resistance equal to *tan* P E A. If the E.M.F. rises above E_1, the filament will fuse, and if it falls below E_2 the filament will go out. The permissible variations in supply voltage under these conditions are accordingly very small, and, moreover, the alterations in current even when the voltage does not vary beyond these limits is excessive. To avoid this, it is necessary that the resistance line E A should be as nearly vertical as possible at the working current. This could be secured by using a very high resistance and a very high

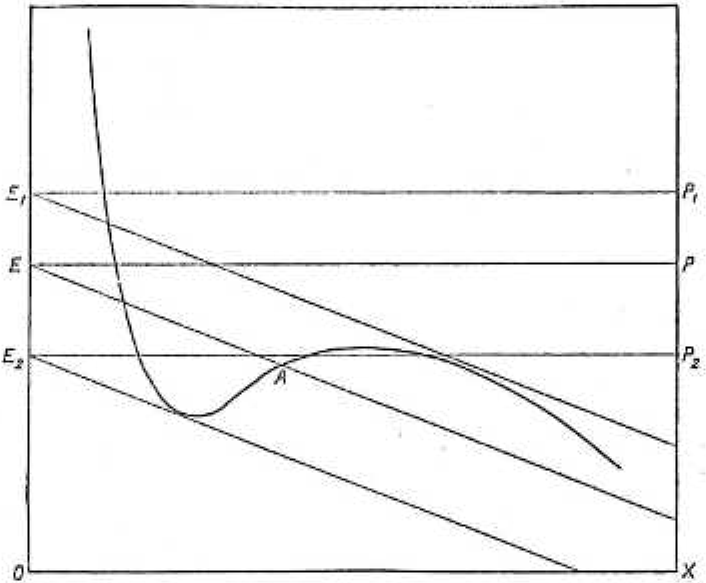

Fig. 57.—Stability of Nernst filament with constant series resistance.

E.M.F., but such a course is obviously undesirable, as the power wasted in the resistance would then be very great. The line E A can be made nearly vertical at the working current in another way by using a resistance having a very high temperature coefficient. A very small increase in the current will then, by slightly raising the temperature of the resistance wire, cause a great rise in the potential difference between its ends. The iron resistances, and to a

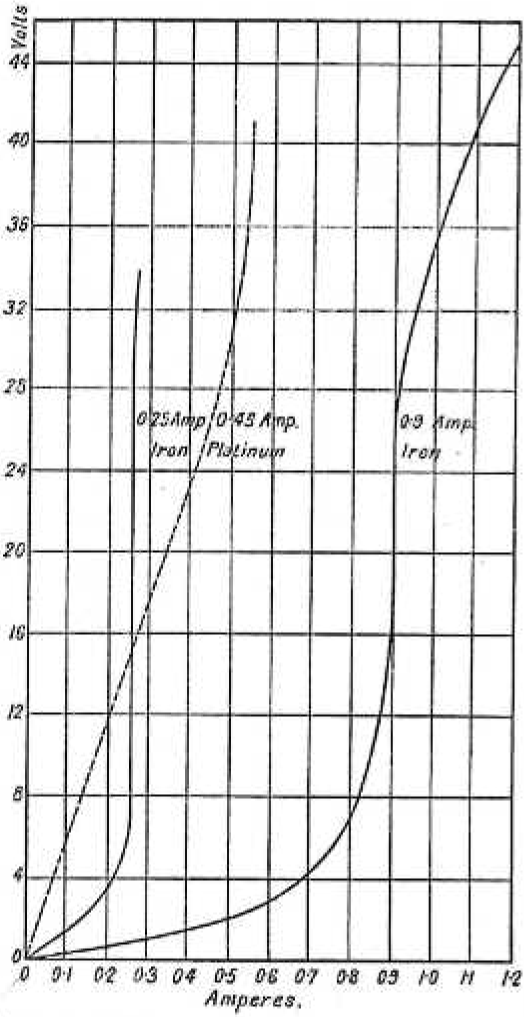

Fig. 58.—P.D.-current curves for iron and platinum series resistances.

lesser extent the platinum resistances, already described, possess this property to a remarkable degree in the neighbourhood of a red heat. In Fig. 58 are shown the P.D.-current curves for two iron resistances, and by way of comparison a similar curve (dotted) for a platinum resistance. It will be seen that with the iron wires the P.D. rises at first slowly, then more rapidly, and then so quickly that the curve becomes almost vertical; finally the P.D. rises less rapidly, the curve bending over towards the horizontal. The sudden sharp rise is particularly interesting; practically for a certain value of the current it will be seen that the P.D. may have any value over a considerable range. This value of the current is the correct working value for the resistance, and may be called the regulating current. The conditions for a filament in series with such a resistance are shown in

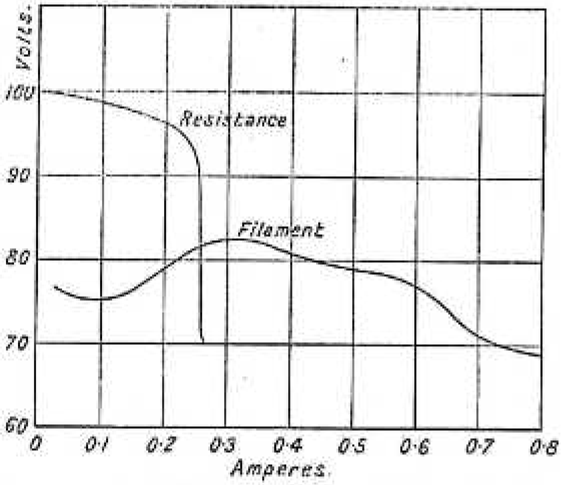

FIG. 59.—Nernst filament in series with iron steadying resistance.

Fig. 59. It will be seen that the value of the current through the filament is practically determined by the resistance, and that a very considerable rise or fall of the supply voltage would produce only a very slight alteration in the current. The analysis already given of the consequences of the shape of the filament P.D.-current curve applies equally well when a series resistance of this type is used, though for simplicity it was assumed in discussing these consequences that a constant resistance was in series with the filament.

The value of the regulating current and the sharpness of the regulation of an iron resistance depend on the size of wire used, the pressure of gas in the bulb, and the way in which the wire is fixed. It has already been mentioned that the regulation is sharper the finer the iron wire, and for this reason when the current is great two or more wires in parallel are preferable to a single wire. The regulation is also sharper the better the vacuum in the bulb, but the better the vacuum the lower the current at which the wire becomes red hot; some compromise must, therefore, be made, sufficient pressure of gas being used to enable wire of a reasonable diameter to be employed. A pressure of 12 to 14 c.m. of mercury is very satisfactory. The wire should also be fixed as freely as possible; it is generally wound in a very open spiral, as shown in Fig. 49, p. 144. The more open this spiral the sharper the regulation, but here again a compromise must be made in order to get the necessary length of wire into the bulb. The small resistances used in the smaller lamps are always less satisfactory on account of the necessary crowding of the wire. The nearness of the wire to the bulb and the position of the bulb in the lamp also affect the regulating current; this can be readily understood since the regulation takes place at a particular temperature. Anything, therefore, which affects the temperature of the bulb will affect the value of the regulating current.

The remarkable characteristics of these resistances suggest their application to other uses. Their use in series with standard incandescent lamps has already been mentioned (p. 133), and they may well be employed in other cases in which a constant current is required. Similar resistances have recently been adapted for use in series with flame arcs; the writer suggested their use with arc lamps in 1903.[1] It may be mentioned that though these series resistances are classified according to current and voltage, *e.g.*, 0·5 amps. 15 volts, the value of the voltage is obviously to a certain extent only nominal.

POTENTIAL DIFFERENCE AND CANDLE-POWER.

The Nernst lamp consisting of a combination of the filament and the series resistance, its behaviour under varying conditions of voltage depends naturally on the characteristics of these two components. It has been thought better, therefore, to discuss each of these separately, but there remains the question of the variation of candle-power with variation of voltage, which it is better to consider for the lamp as a whole. Variation of candle-power depends on variation of temperature, and this must be always regarded in incandescent lamps as directly dependent on

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[1] *Journal of the Institution of Electrical Engineers*, Vol. XXXII., p. 532.

the current and only indirectly dependent on the voltage. There will be a great change in the candle-power for a given change in the voltage when this voltage change produces a great change in the current. Since, therefore, the regulating resistance keeps the current through the Nernst lamp practically constant over a large voltage range the candle-power will also vary very little over this range; above and below this range the variation will be more rapid. These conclusions are fully borne out by the curves in Fig. 60, showing the variation of candle-power and watts per candle with voltage. These may be advantageously compared with the similar curves for carbon filaments on p. 112.

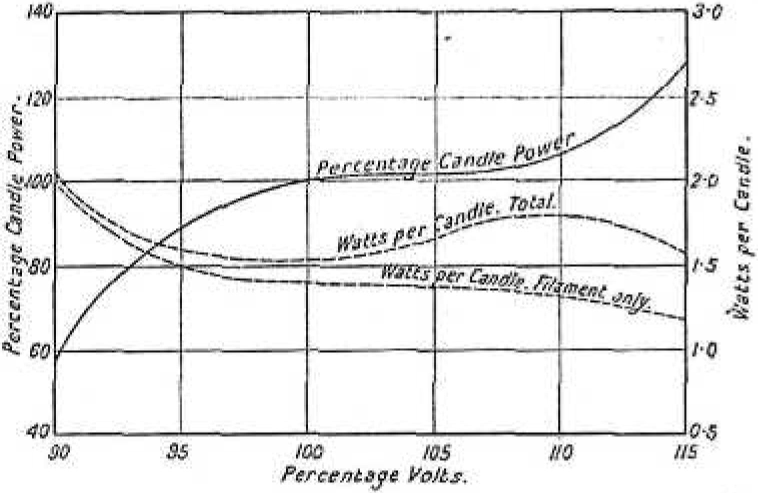

FIG. 60.—Candle-power and watts per candle variations with Nernst lamp.

The watts per candle will vary somewhat differently to the candle-power, since the watts absorbed by the non-light-giving resistance have to be taken into account. In some cases these may increase so rapidly that there is an actual increase in the total watts per candle when the lamp is overrun, as shown in Fig. 60, although, of course, when the watts absorbed by the filament only are considered, there is a steady fall in watts per candle as the voltage is increased. By overrunning a carbon filament lamp one obtains always a worse life at a better efficiency; by overrunning a Nernst lamp it is possible that the worse life is obtained without any advantage in efficiency.

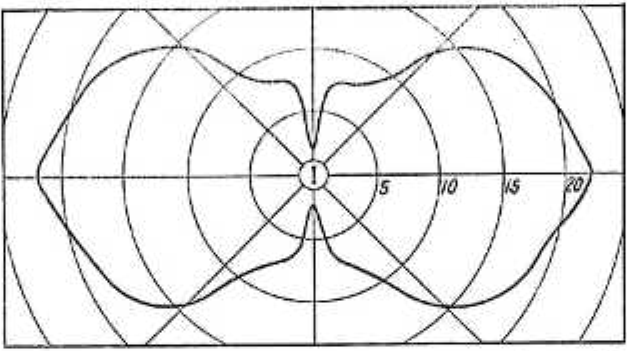

Fig. 61.—Horizontal distribution curve. Nernst lamp with straight horizontal filament.

Distribution of Light.

In Fig. 61 is given the horizontal distribution curve for a Nernst lamp with straight horizontal filament, and in Fig. 62 the vertical distribution curves for the same lamp, the full curve showing the distribution in the plane at right angles to the filament, and the dotted curve that in the plane of the filament. There is naturally a very marked difference between these two curves. A method for obtaining a mean vertical distribution curve for a lamp of this type has been given in Chapter IV., p. 78. The exceedingly low values of the candle-power in the two directions along the actual axis of the filament are due to the presence of the mounts and supports at each end. In Fig. 63 is given the vertical distribution curve for a lamp with straight vertical filament; the normal horizontal distribution curve for a lamp of this type may be regarded as a true circle. The curves are all for lamps without globes; a clear globe modifies the shape of the curve but little; a frosted globe smooths out the more marked inequalities. When the heater surrounds the filament (as in the case of the lamp in Fig. 63), a certain amount of the light amounting to from 2 per cent. to 5 per cent. is cut off, and the light in certain directions is modified by the heater shadows.

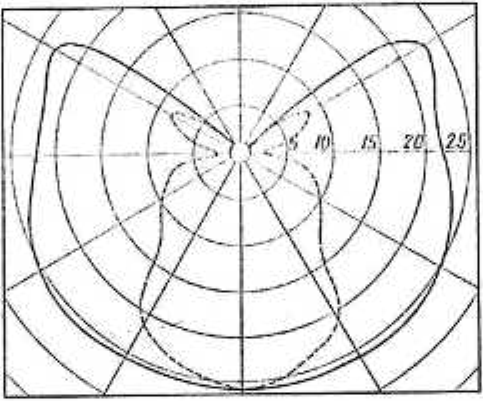

FIG. 62.—Vertical distribution curves. Nernst lamp with straight horizontal filament. *Full curve*, in plane at right angles to filament. *Dotted curve*, in plane of filament.

RATING AND LIFE.

Nernst lamps are rated by the manufacturer according to voltage and current, the candle-power varying according to the voltage. Thus lamps are made for 0·25 amperes and say 200 and 220 volts; the 200-volt lamp will be 32 candle-power and the 220-volt lamp 35 candle-power. This rating by current is to a certain extent necessitated by the fact that resistances and burners have to be sold separately, but apart from this it is in many ways preferable to the candle-power rating. If all lamps were rated in this way the consumer would know what he is going to pay for energy for burning each lamp, and he could tell approximately himself which lamp suits him best, lasts longest, or gives him the best return in illumination for the money spent. But when he buys two lamps, each of 16 candle-power, he has no idea how much current each is taking, and it is a very difficult, or even impossible, matter for him to find out which is the most economical from his lighting bills.

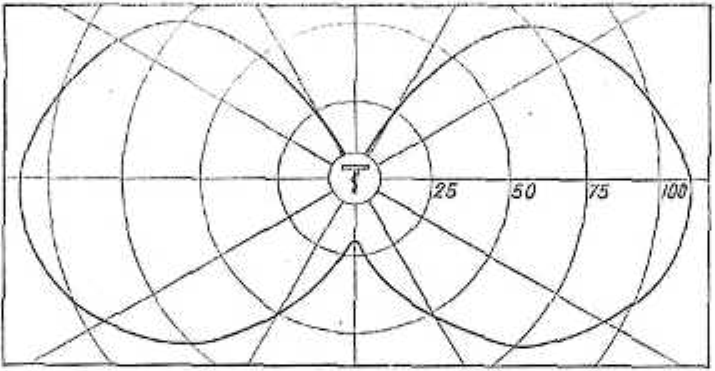

FIG. 63.—Vertical distribution curve. Nernst lamp with straight vertical filament.

The Nernst lamp is at present made in various sizes; the standard filaments take 0·25, 0·5, and 1·0 amperes respectively. The quarter and half-ampere filaments are mounted in lamps that can be fitted into the ordinary lamp-holders as used for carbon filament lamps; the one-ampere filaments are mounted in lamps which have to be separately suspended in the same way as arc lamps, and the half-ampere filaments can also be obtained mounted for this type of lamp. Multiple filament lamps are also made having three half-ampere or three one-ampere burners. The candle-power varies, as already stated, with the voltage, and may be calculated approximately on the basis of a power consumption of 1·5 watts per candle for the larger and 1·75 watts per candle for the smaller lamps.

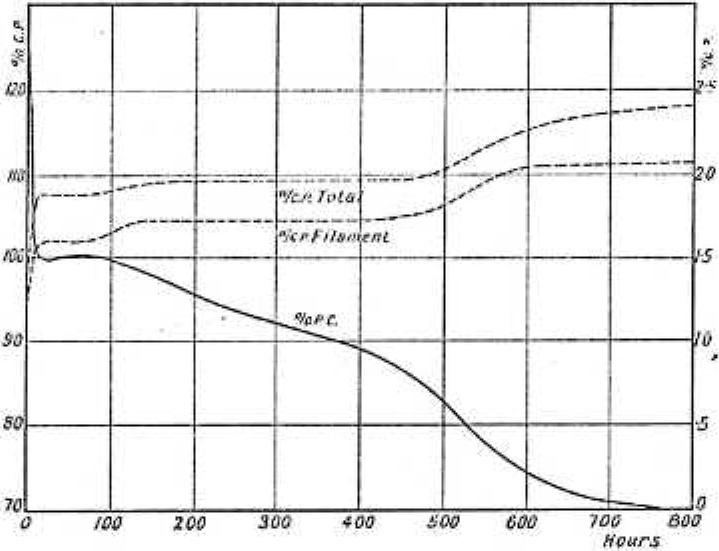

FIG. 64.—Life test curve for 200-volt one-ampere direct-current Nernst lamps.

The life of Nernst lamps is very variable, so much so that it is possibly better to define their useful life as the life till failure, rather than the life till the candle-power has fallen 20 per cent. Some lamps will fail after a few hours, others may last only 30 to 50 hours, and others again run for 500 to 1,000 hours. Roughly, the average life may b taken as about 500 hours for direct-current lamps and 300 hours for alternating-current lamps.

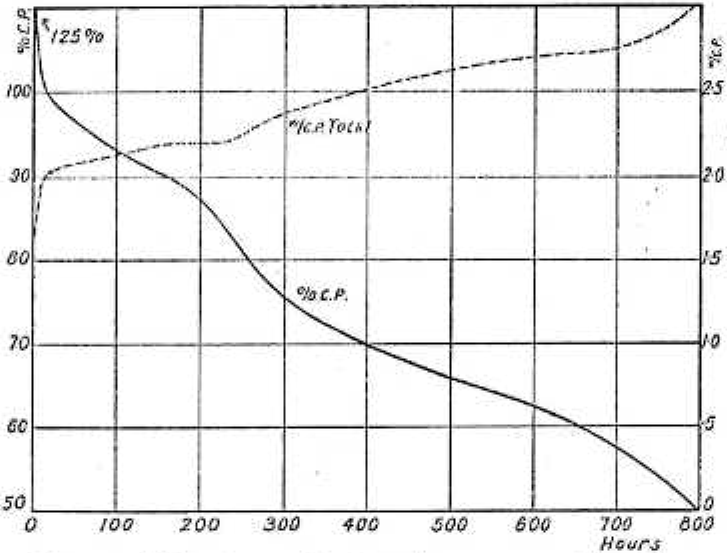

FIG. 65.—Life test curve for 200-volt one-ampere alternating-current Nernst lamps.

In Figs. 64 and 65 are given typical life test curves for direct and alternating 200-volt one-ampere lamps. It is generally characteristic of Nernst lamps that there is a very marked fall in candle-power during the first few hours' burning, as is shown in these curves, but this characteristic is not always present. On account of this the percentage candle-powers in Figs. 64 and 65 have been calculated in reference to the actual candle-power after 20 hours' use, instead of in reference to the true initial candle-power. It will be seen that there is a continuous falling off in candle-power during life, which becomes steeper towards the end of the life. The average life (till failure) for the five direct-current lamps (Fig. 64) was 750 hours, and for the five alternating lamps (Fig. 65) 700 hours, but the corresponding useful lives (20 per cent. fall), it will be seen, were only 520 and 260 hours respectively.

On account of the uncertainty in life, it is difficult to give a true estimate of the cost of lighting with Nernst lamps. Firstly, a decision has to be made as to whether the life till failure or the "useful" life will be taken as the basis of comparison; secondly, the question of the renewal of other parts than the burner (*i.e.*, filament and heater) has to be considered; and finally, the costs of maintenance and depreciation, items by no means negligible with Nernst lamps, have to be taken into account. It seems better for the purpose of this book, however, to neglect these last items, as charges of this sort vary immensely according to the precise conditions of the installation. Thus Nernst lamps used for outdoor street lighting will cost very much more for upkeep, and will involve much heavier depreciation charges, than when used for interior lighting.

As a basis for the calculation of the lighting cost, independently of these charges, we may take the curves in Figs. 64 and 65 and work out the cost, firstly, when the lamps are run only for the period of their useful life, and secondly, when they are run till failure. From these curves we get the following data :—

DIRECT-CURRENT LAMPS.

Useful life, 520 hours at 1·9 watts per candle.
Life till failure, 750 hours at 2·1 watts per candle.
Life of resistance, say, 1,000 hours.

ALTERNATING-CURRENT LAMPS.

Useful life, 260 hours at 2·2 watts per candle.
Life till failure, 700 hours at 2·4 watts per candle.
Life of resistance, say, 1,000 hours.

We may take the following renewal costs as a basis for calculation :—

	Burner.	Resistance.
¼ ampere	12*d*.	6*d*.
½ ,,	16*d*.	8*d*.
1 ,,	20*d*.	8*d*.

On these assumptions Table XVI. has been worked out showing the cost per 1,000 candle-hours, with energy at various prices per unit. If the figures in this table are examined closely it will be seen that so far as the direct-current lamps are concerned it is practically immaterial whether the lamps are run till they fail or whether they are replaced after the candle-power has fallen 20 per cent., but with the alternating-current lamps it is more economical in all but a few cases (those of the high candle-power lamps when the cost per unit is high) to run the lamps till failure. It is a fairly safe general rule, therefore, to run Nernst lamps until they fail, and this conclusion is supported by the fact, already mentioned, that lamps differ so much in their individual behaviour that any estimate of the cost of lighting can only be regarded as approximate.

TABLE XVI.

TOTAL COST OF LIGHTING PER 1,000 CANDLE-HOURS. NERNST LAMPS.

Cost per B.O.T. Unit.		1d.	2d.	3d.	4d.	5d.	6d.	7d.	8d.
		d.	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
Direct-current lamps run till 20 per cent. C.P. fall.	100 V. ¼ ampere	4·1	6·0	7·9	9·8	11·7	13·6	15·5	17·4
	100 V. ½ ,,	3·4	5·3	7·2	9·1	11·0	12·9	14·8	16·7
	100 V. 1 ,,	2·8	4·7	6·6	8·5	10·4	12·3	14·2	16·1
	200 V. ¼ ,,	3·0	4·9	6·8	8·7	10·6	12·5	14·4	16·3
	200 V. ½ ,,	2·6	4·5	6·4	8·3	10·2	12·1	14·0	15·9
	200 V. 1 ,,	2·3	4·2	6·1	8·0	9·9	11·8	13·7	15·6
Direct-current lamps run till failure.	100 V. ¼ ampere	3·9	6·0	8·1	10·2	12·3	14·4	16·5	18·6
	100 V. ½ ,,	3·3	5·4	7·5	9·6	11·7	13·8	15·9	18·0
	100 V. 1 ,,	2·8	4·9	7·0	9·1	11·2	13·3	15·4	17·5
	200 V. ¼ ,,	3·0	5·1	7·2	9·3	11·4	13·5	15·6	17·7
	200 V. ½ ,,	2·7	4·8	6·9	9·0	11·1	13·2	15·3	17·4
	200 V. 1 ,,	2·5	4·6	6·7	8·8	10·9	13·0	15·1	17·2
Alternating - current lamps run till 20 per cent. C.P. fall.	100 V. ¼ ampere	6·7	8·9	11·1	13·3	15·5	17·7	19·9	22·1
	100 V. ½ ,,	5·2	7·4	9·6	11·8	14·0	16·2	18·4	20·6
	100 V. 1 ,,	4·1	6·3	8·5	10·7	12·9	15·1	17·3	19·5
	200 V. ¼ ,,	4·5	6·7	8·9	11·1	13·3	15·5	17·7	19·9
	200 V. ½ ,,	3·7	5·9	8·1	10·3	12·5	14·7	16·9	19·1
	200 V. 1 ,,	3·1	5·3	7·5	9·7	11·9	14·1	16·3	18·5
Alternating - current lamps run till failure.	100 V. ¼ ampere	4·6	7·0	9·4	11·8	14·2	16·6	19·0	21·4
	100 V. ½ ,,	3·9	6·3	8·7	11·1	13·5	15·9	18·3	20·7
	100 V. 1 ,,	3·3	5·7	8·1	10·5	12·9	15·3	17·7	20·1
	200 V. ¼ ,,	3·5	5·9	8·3	10·7	13·1	15·5	17·9	20·3
	200 V. ½ ,,	3·1	5·5	7·9	10·3	12·7	15·1	17·5	19·9
	200 V. 1 ,,	2·8	5·2	7·6	10·0	12·4	14·8	17·2	19·6

CAUSES OF FAILURE.

It must be remembered that there are several possible causes of failure in Nernst lamps, and also that both the filament and resistance alter with life, so that it is hardly to be expected that the results of life tests should be so uniform as with carbon-filament lamps. The filament itself always rises in resistance as it gets older, the chief part of this rise being at the mounts. The drop of volts at the positive mount, which is always higher than that at the negative mount, especially tends to rise, and failure very frequently occurs at this mount in consequence of over-heating. The life of the filament is to a very large extent controlled by the amount of platinum put into the mounts; the more platinum used the cooler the mount and the longer the life of the filament. It is in fact possible to predetermine the average life with fair accuracy in this way. The filament also becomes crystalline and much more transparent as it grows older, the crystallisation beginning at the negative mount and gradually spreading along the filament. Under these conditions the filament is a worse radiator; certain impurities increase this effect in a marked manner, the writer having made filaments which, after a few hours' running, gave practically no light for over half their length, starting from the negative mount. The iron resistances are also liable to fail or to alter in the value of their regulating current and the sharpness of their regulation, thus causing failure of the filament. Filaments and resistances must of course be carefully matched; if filaments fail frequently in a particular lamp the fault lies very probably with the regulating resistance, which either does not regulate sharply enough, or regulates at too high a current. Overrunning, or using the lamp on a circuit the voltage of which is normally too high, is more severe on the resistance than on the filament, since the extra voltage is absorbed by the resistance which is consequently continuously running at too high a temperature. The resistance should normally absorb only a few volts, about 15, so that there is plenty of elasticity towards rise of voltage, fall of voltage being naturally less injurious. For this reason, when the circuit on which the lamps are to be used is known to be normally overrun the sum of the marked voltage on resistance and glower should be greater than the nominal voltage of the circuit. For example, a 190-volt or 195-volt glower should be used in series with a 15-volt resistance for a circuit of (nominal) 200 volts instead of an 185-volt glower.

Another cause of filament failure is the cut-out. Sometimes this gets out of order and does not operate, thus allowing the heater to remain in circuit. In addition to the waste of current, the over-heating of the glower then soon causes failure, or the heater itself may fail. A somewhat similar defect occasionally met with is the following. The heater circuit remains normally broken, but with a slight fall in voltage the filament current drops to a value below that necessary to hold off the cut-out armature; this may be due to the cut-out not operating at a low enough current or to faulty regulation of the filament current. This defect is difficult to detect, but may be suspected if a particular lamp gives bad results with different glowers and resistances. The heaters rarely fail unless due to defective cutting out; failure to light up is not due to defective heaters as a rule, but, as pointed out on p. 155, to ageing of the filament.

Considering the complexity of the Nernst lamp, the number of details in connection with which failure may occur or difficulties arise, and the fact that the lamp does not give light immediately it is switched on, it is not surprising that its use has not become very general. It is true that the mechanism is less complicated and requires less attention than that of an arc lamp, but it must be remembered that an arc represents a much larger light source, and expense which may be economical in connection with such a source may no longer be justified with the smaller Nernst lamp. In addition, the arc consumes less energy per candle-hour and thus leaves a bigger margin for maintenance expenses. At first it was hoped that the Nernst lamp would effectively displace the carbon-filament lamp, but this it has quite failed to do. It would seem, however, that there should exist a distinct field for the use of the lamp where light units of about 100 candle-power are required, as for example in the lighting of large interiors or of side streets. To a limited extent the Nernst lamp has occupied this field, but it is very questionable whether it will be able to maintain the position long against the competition of the more efficient and less complicated metal filament lamps; possibly its suitability for high voltages and the lower cost of renewals may enable it to withstand this competition for some time, but eventually, unless radically improved, it would seem that it must inevitably yield.