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TUNGSTEN LAMPS OF HIGH EFFICIENCY—II NITROGEN-FILLED LAMPS

BY IRVING LANGMUIR AND J. A. ORANGE

The first part of this paper outlined principles upon which radical improvements in the efficiency of tungsten lamps may be based.

It was shown that the desired improvement can be obtained by preventing evaporation of the filament or by preventing blackening of the bulb. By the introduction of considerable pressures of such gases as nitrogen, mercury vapor or argon into the lamp the blackening can be practically avoided and the evaporation of the filament reduced very considerably.

By making use of these principles we have been able to construct practical tungsten lamps which, starting at a specific consumption of about 0.40 watt per candle, have run over two thousand hours, the average specific consumption during life being less than 0.5 watt per candle. It should be pointed out at the outset, however, that such a degree of improvement as this has been reached only in lamps taking large currents.

In this second part of the paper we will describe the methods by which these results have been attained.

The early experiments with lamps containing nitrogen at atmospheric pressure were made with ordinary single loop filaments of 0.005 and 0.010 inch diameter placed in long heater lamp bulbs. These lamps were set up on life test at such a voltage that the temperature of the filament was 2850 deg. K.

In order to compare these with ordinary lamps, similar lamps with evacuated bulbs were set up on life test with the filaments at the same temperature.

The nitrogen-filled lamps with the filaments 0.005 inch dia-

meter had a specific consumption of 0.65 watt per candle and had a life of about 90 hours, whereas those with the larger filaments (0.010 inch diameter) had a specific consumption of 0.56 watt per candle and a life of about 300 hours. The bulbs opposite the filaments remained clear, although a slight brown deposit of tungsten nitride collected in the upper part of the bulbs. The candle power of these lamps remained above 80 per cent during their entire life, failure being due in every case to breakage of the filament after this had decreased considerably in diameter.

The vacuum lamps, on the other hand, had a specific consumption of 0.41 watt per candle, but the bulbs blackened rapidly, the candle power falling to 80 per cent in about 40 minutes. Since the filaments of the vacuum lamps burnt out after 2 to 5 hours whereas those of the nitrogen lamps lasted 50 to 100 times as long, it is evident that the rate of evaporation of the tungsten is materially reduced by the presence of the nitrogen.

These results indicated clearly the desirability of using a filament of large diameter. The larger filaments gave not only a better efficiency at any definite temperature, but also a much longer life. Thus doubling the diameter decreased the specific consumption from 0.65 to 0.56 and increased the life from 90 to 300 hours. The improvement in the efficiency, as was pointed out in the first part of this paper, is due to the relatively greater heat loss by convection from small wires. The life of the filament is determined largely by the loss of tungsten from the filament by evaporation and has been found to be dependent on the *relative* decrease in diameter caused by this evaporation. If the rate of evaporation per unit area from large and small wires were the same, the lives of various filaments run at a given temperature would be roughly proportional to their diameters. However, as the evaporation of tungsten in nitrogen is largely a diffusion process, it probably obeys laws similar to those of conduction or convection of heat from a wire; that is, for wires of small diameter, the actual amount of tungsten evaporated would be nearly independent of the size of the wire. The rate of evaporation *per unit area* would thus be approximately inversely proportional to the diameter. The relative lives of very small wires in nitrogen are therefore nearly proportional to the squares of their diameters.

DESIGN OF FILAMENT

These results were decidedly encouraging, for both the efficiency and the life of the lamps can be improved by increasing the diameter of the filament.

It is, however, not desirable to use filaments of very large diameter if similar results can be obtained with smaller ones. The current taken by a filament increases approximately with the three-halves power of the diameter. Thus, for wires of the sizes used in the preceding experiments, the currents needed to maintain a temperature of 2850 deg. were approximately:

Diameter		Current
inches	mm.	amps.
0.005	0.127	3.0
0.010	0.254	8.5
0.020	0.508	24.0

Unless very low voltages are used, the power consumed with the larger wires is so great that only very high candle power lamps can be made.

Therefore it was of vital importance to increase the effective diameter of the filament without decreasing its resistance, and various methods of doing this were tried.

This result may, for example, be obtained by using a tubular filament. The method which has thus far proved most satisfactory, however, is to wind the filament into the form of a tightly coiled helix.

The use of a helically wound filament presents several very interesting features. The life of ordinary single loop filaments is limited by the irregularities in diameter which develop after a considerable amount of tungsten has evaporated. These irregularities, after they first appear, tend to magnify themselves very rapidly, on account of the tendency for the current to overheat any spot which becomes thinner than the rest of the filament. The overheating increases the rate of evaporation and rapidly causes failure.

In the gas-filled lamps, however, when helically wound filaments are employed, a new factor is introduced which entirely counteracts this tendency to overheat in spots. In designing the filaments of these lamps, it is evidently desirable to wind the filament on as large a mandrel as possible, in order to obtain the advantage of the large diameter. Since tungsten is a relatively soft material at the operating temperature of these lamps, too large a mandrel should not be used, as otherwise the weight of the filament pulls out the helix very materially in a few

hours, and the heat lost by convection may thus become greater than if a helix of smaller diameter had been used. In actual practise the filament is designed so that the amount of sagging during life will be perceptible, but not enough to cause too great a change in the characteristics of the lamp.

If, during the life of the lamp, any part of the filament should, for any reason, evaporate more rapidly than the rest, so that the filament becomes somewhat thinner, this portion will have less mechanical strength than the rest and will therefore sag more rapidly. The helix will therefore open out wherever the filament becomes thin or becomes overheated. This will cause increased heat loss both by convection and radiation, and thus prevent local overheating or spotting.

The use of helically wound filaments increases the life of the lamp many times beyond the life that would be obtained with a straight filament running at the same efficiency. This is especially true of the smaller sizes of wire.

Besides the helically wound filament, various other forms have been tried, and, for special purposes, many of these have decided advantages.

DESIGN OF BULBS AND LOCATION OF FILAMENTS

In the ordinary evacuated lamp, the choice of a suitable bulb is a comparatively simple matter. It must be of convenient size and shape, and provide sufficient room for the proper mounting of the filament. Furthermore, it must have as large an inside surface as possible, so that the density of the deposit of evaporated tungsten will be small. It is also desirable to have the bulb at a sufficient distance from the filament and so related to the power input into the lamp that the bulb does not become overheated. This latter is not only desirable from the point of view of safety (in case of lamps for domestic service), but because it is difficult to remove water vapor so thoroughly from the bulbs that the life of the lamps will not be greatly shortened by an overheating of the glass.

In the nitrogen-filled lamps, however, several other factors must be considered, especially in the lamps of high candle power.

In ordinary lamps about 20 per cent of the energy radiated from the filament is intercepted by the glass and causes heating of the bulb. In the nitrogen lamp, beside this radiated heat, there is an additional amount of heat carried to the bulb by convection—an amount varying with the type of lamp and

ranging from 6 to 40 per cent of the total input. The convection currents carrying this relatively large amount of heat travel vertically upwards from the filament and strike a relatively small area of the bulb, which thus tends to become greatly overheated. Unless special precautions are taken, this overheating will cause the liberation of enough water vapor to cause attack of the filament and consequent blackening of the bulb. It is thus highly desirable, in ordinary cases, if small bulbs are to be used, that the filament should be placed in the lower part of the bulb. This has the further advantage that it allows sufficient surface of glass in the upper part for the deposition of the tungsten nitride.

For a similar reason it is generally desirable, although not necessary, to make the bulbs with their height considerably greater than their horizontal diameter.

By special design of the bulb, satisfactory lamps have been made with bulbs of only one-half to one-third as large a volume as that of evacuated lamps of the same wattage. This means that for bulbs of the same volume the nitrogen lamps give roughly from five to ten times the candle power of evacuated lamps. The bulbs of such lamps naturally run much hotter than those of ordinary lamps. The upper parts of the bulbs are often at 100 to 200 deg. cent. or more, while the lower parts are sometimes much cooler than this, although closer to the filament.

Several special varieties of heat-resistant glass have been used for the bulbs, which can thus be made smaller, while it becomes easier to get rid of water vapor. Transparent quartz bulbs have been tried, but do not seem to have sufficient advantage over some of the special glasses to offset their present high cost.

LEAD-IN WIRES AND SUPPORTS

For some of the larger size lamps which take heavy currents (20-30 amperes) it has been necessary to devise special types of lead-in wires. The ordinary platinum leads have been discarded entirely, even in the smaller sizes. Several types of heavy current leads have been successfully used. Most depend on the use of special alloys which have the same coefficient of expansion as the glass. Bulbs of special glasses into which tungsten or molybdenum wire can be sealed directly, have also been used.

In many of the larger lamps the lead-in wires pass through the lower end of the lamp. In this case they can be made

short. In others, however, the leads are brought in from the top. This requires more care in the construction of the seal if it is exposed to the heat from the convection currents. Screens are sometimes used to protect the seal or other glass parts from direct contact with the convection currents, and to reduce convection.

VARIOUS TYPES OF NITROGEN-FILLED LAMPS

We have seen that at constant temperature, both the efficiency and the life improve as the diameter of the wire is increased. With very large wires (0.020 to 0.040 inch diameter) which take 20-60 amperes, the specific consumption may be as low as 0.40 watt per candle and probably even less, and yet give a life over a thousand hours. It will probably be worth while, in some cases, to use nitrogen in low-current lamps, even if an efficiency no better than that of vacuum lamps is obtained, in order to gain certain other advantages of the nitrogen-filled lamps, such as better color of the light, higher intrinsic brilliancy, etc.

The principal limitation of the new type is therefore that of current. There is no practical upper limit to the current, provided the voltage is not lowered to keep constant power consumption.* With increasing current, larger and larger filaments are used and the specific consumption may be lowered towards the limit of 0.20 watt per candle, which is fixed by the melting-point of tungsten. Unless special expedients are employed, the cooling effect of the leads lowers the efficiency of the lamps by an amount that is inversely proportional to the voltage and nearly independent of the size of the wire or the current strength.

With voltages of 20 volts or more, this effect is not serious, but for voltages as low or lower than 10 volts, it may become very important.

For the particular type of nitrogen-filled lamp which has at present been furthest developed, it may be said that a life of over 1500 hours is obtained at a specific consumption less than 0.50 watt per candle only in large units taking over ten amperes. Lamps running at 0.6 to 0.7 watt per candle have been made in units taking at least 5 amperes.

No serious difficulty has been met in making high-voltage

*As an example, a lamp taking 60 amperes and giving 6600 candle power at 0.40 watt per candle has been successfully run.

lamps. In nitrogen at atmospheric pressure with properly constructed lamps there is no tendency toward arcing, even at 250 volts. Many lamps taking 6 or 7 amperes at 110 volts have been made up and run at 0.6 to 0.7 watt per candle, with a life of over 1000 hours.

A number of special types of nitrogen-filled lamps have been made and tested. Among these the most interesting, for the present, are perhaps the following:

1. *Large Units of Very High Efficiency* (0.4 to 0.5 watt per candle with a life of 1500 hours or more). These take currents of 20 to 30 amperes and (except in units over 4000 candle power) are therefore best run from a-c. circuits by means of small transformers or auto-transformers giving a voltage depending on the size of unit desired. Thus, with 30 volts and 25 amperes, the power would be 750 watts and this, in a lamp at 0.45 watt per candle, would give 1670 candle power. Higher or lower candle power may be obtained by using other voltages. Typical lamps of this kind are shown in Figs. 1 and 2.

2. *Small Units of Low Voltage*. These take currents of ten amperes or less and voltages as low as four or five volts. The specific consumption with 1000-hour life ranges from 0.6 to 1.0, or even 1.25 watt per candle, according to the current used.

These lamps are adapted for series street lighting on 6.6-ampere circuits (at 0.6 to 0.7 watt per candle), for stereopticon lamps, automobile headlights and in general wherever a source of high intrinsic brilliancy, steadiness and white color is needed.

3. *Lamps to Run on Standard Lighting Circuits* (110 volts). Large units of this type (several thousand candle power) have a specific consumption of 0.5 watt per candle or less. With smaller units the efficiency is ordinarily not so high.

A lamp of this type is illustrated in Fig. 3. The leads may be brought in from the top, in which case they are preferably made longer so that the filament remains in the lower part of the bulb.

SPECIAL ADVANTAGES OF THE NITROGEN-FILLED LAMPS

Besides its high efficiency, the features of the new lamps which may, at least for certain purposes, prove of advantage, are:

1. *Color of the Light*. The temperature of the filament being 400 to 600 deg. higher than that of ordinary lamps, causes the light to be of a very much whiter color, so that it comes closer to daylight than any other form of artificial illuminant except the d-c. arc and the special Moore tube containing carbon dioxide.

The color is almost exactly like that which can be had for a few minutes by running an ordinary tungsten lamp at double its rated voltage.

Work is at present under way to develop special color screens

FIG. 1—HIGH EFFICIENCY NITROGEN-FILLED LAMP FOR LOW-VOLTAGE CIRCUIT

FIG. 2—HIGH EFFICIENCY NITROGEN-FILLED LAMP FOR LOW-VOLTAGE CIRCUIT

which, when used with this light, will give a true daylight color (corresponding to the radiation from a black body at 5000 deg. cent.). From measurements with the spectrophotometer, it can be calculated that the screens which will accomplish this

purpose will absorb from 65 to 75 per cent of the light, so that the net specific consumption will be about 1.5 to 2.0 watts per candle for a pure daylight color. At present, to accomplish this purpose with ordinary tungsten lamps, screens must be used which absorb so much light that the total specific consumption is between 10 and 12 watts per candle.

2. *High Intrinsic Brilliancy of the Filament.* At the operating temperature of the nitrogen-filled lamps the intrinsic brilliancy

FIG. 3—NITROGEN-FILLED LAMP
FOR 110-VOLT CIRCUIT

FIG. 4—LAMP AND SCREEN USED
FOR CALIBRATION OF BLUE GLASS

of the filament is about 1200 candle power per sq. cm. In ordinary tungsten lamps, on the other hand, running at about 1.25 watts per candle, the filaments have a brilliancy of only about 150 candle power per sq. cm. The brilliancy of the filament of the nitrogen lamp is thus about eight times that of the ordinary lamp.

This feature, combined with the high degree of concentration

preferably used, renders these lamps particularly useful for projection work, such as for headlights or for stereopticons.

3. *Constancy of Characteristics During Life.* It is often possible so to design these lamps that their ampere-, volt-, candle power characteristics remain practically fixed during the greater part of their life. In any case, however, since there is no deposit on the bulb to cut off the light, the candle power practically never falls below 75 per cent (this decrease sometimes being due to sagging). The lamp usually fails by the breakage of the filament with the candle power well above 80 per cent of its original value.

APPENDIX I

Light Distribution of Nitrogen-Filled Lamps. In the preceding paper, wherever the specific consumption of lamps has been given, it is expressed in watts per horizontal (international) candles measured in the direction perpendicular to the plane of the filament if this is in the form of a single loop.

Careful measurements have shown that with helically wound filaments the distribution of light in a horizontal plane is almost perfectly uniform, therefore the specific consumption that has been given may be considered to represent also watts per mean horizontal candle.

The spherical candle power of many of the lamps has been measured. The ratio of mean spherical to maximum horizontal (practically mean horizontal also) candle power has been found to average about 84 per cent for the lamps made with single loops of helically wound wire.

APPENDIX II

Method of Photometry for Nitrogen-Filled Lamps. The usual practise in dealing with incandescent lamps is to determine volts, amperes and candle power either at a predetermined value of one of these quantities or else at a predetermined efficiency by the "cut and try" method. In the case of a lamp which presents so many variables as does the nitrogen-filled lamp, however, it is more systematic to regard temperature as the fundamental variable.

The method that has been adopted for these lamps is not essentially novel, although it does not appear to be as well known as it deserves to be.

First: The temperature has been defined by the equation

$$T = \frac{11,230}{7.029 - \log H}$$

where T is the absolute temperature and H is the intrinsic brilliancy of the filament in international candle power per sq. cm. (projected area).*

Second: A most useful criterion in practise for equality of temperature of tungsten filament is that of color-match.

A little practise with the Lummer-Brodhun photometer enables one to judge equality within about 5 deg. if the illumination is good. The most convenient way of setting up temperature standards is to select a number of well-seasoned lamps of high-voltage type in which the anchors are tightly pinched onto the filaments so as to prevent variable cooling effects at the contact. It is best to standardize these, not on a basis of candle power and filament dimensions, but by the aid of a special lamp and diaphragm as shown in Fig. 4. This lamp is arranged at one end of the photometer with the diaphragm in front of and at a known short distance from it. The filament is preferably stout (say 10-mil or 0.025-cm.) so as to admit of good micrometer measurements.

The diaphragm enables one to disregard the end portions of the filament and select a known length of the part which is at uniform temperature. Of course a simple geometrical correction based on the position of the screen is necessary.

It is thus possible to set up the special lamp at any temperature desired by getting the appropriate candle power per sq. cm. from the filament. The standard lamps are brought to color-match with this arrangement and in this way a set of lamps with known relation between voltage and effective temperature is obtained. The life of the ordinary standard lamps would be very short indeed if they were run at the same temperature as nitrogen-filled lamps. For this work, therefore, the standards cannot be used directly as color-standards. For this reason a most important accessory is introduced in the form of a set of special blue glasses. It is not easy to get a blue screen which will perfectly facilitate color-match of tungsten filaments at dif-

*(The derivation of this formula together with a description of other methods of obtaining the temperature of filaments will soon be published, probably in the *Physical Review*.)

ferent temperatures, but a special blue glass has finally been obtained which answers exceedingly well.

Four distinct screens of different intensity are used, each carefully finished as a uniform plate, and any or all of these may be combined with a tungsten filament run at any temperature and the result will color-match correctly against another tungsten filament at a higher temperature.

It may be shown theoretically and experiment confirms that the following relation holds:

If T is the temperature of a filament which is viewed through screens A , B , C , etc.,

T_1 is the temperature of a filament which matches the above.

$$\text{Then } \frac{1}{T} - \frac{1}{T_1} = a + b + c \text{ etc.}$$

where a , b , c etc. are constants for the screens A , B , C , etc. Thus one only needs to maintain one standard temperature by means of standard lamps and that temperature can be so low that great permanence is insured.

The constants for the four glasses once determined, there are available a number of standard temperatures ranging from 2250 deg. to 3600 deg. K.

By the use of these screens it is an easy matter to set a lamp up at a voltage such that the filament has a standard temperature, say 2850 deg. To do this it is simply necessary to adjust the voltage so that the color of the light from the lamp is the same as that which comes from the standard lamp when viewed through one of the special blue screens.

Since the efficiency in vacuum is very simply related to the color of the light, this method of photometry gives a very simple and direct way of knowing the exact effect which the nitrogen has on the efficiency of the lamp.

DISCUSSION ON "TUNGSTEN LAMPS OF HIGH EFFICIENCY—I AND II" (LANGMUIR AND ORANGE), NEW YORK, N. Y., OCTOBER 10, 1913.

John B. Taylor: I would first like to make a few remarks, to give the audience a few moments' time in which their eyes may become accustomed to the great difference in brilliancy between the filaments they have just been looking at and the enlarged projected image, which, perhaps, will have a brilliancy of something in the order of one-millionth part of the brilliancy of the lamps at which you have been looking.

I can testify to the satisfaction that this lamp gives in projection work after using the lamp with a projecting microscope and also for photomicrographic work, particularly color photography. The steadiness of the lamp as compared with an arc lamp, either hand-fed or automatic, leaves the worker absolutely free to give all his attention to the subject or specimen and the

FIG. 1

photographic plate. A switch turns on the lamp and the light source is always exactly in the same position. Its intensity will always be the same, and repeated exposures will give similar results. The color value is good, as it is almost as white as a carbon arc. In projection work half of the light is thrown backward, but a large portion of this can be conserved by the use of a reflecting mirror, properly placed so that the reflected image practically coincides with the source of light. The projection arrangement I have here will show this. This reflector arrangement is of no value in the case of the carbon arc, as the electrode casts a shadow backwards. As shown in Fig. 1, the reflected image is inverted with respect to the direct image.

(Mr. Taylor then threw the projection on the screen.)

I ask Dr. Langmuir if he can tell us anything of the ratio of the resistances of the filament hot and cold in the nitrogen-filled lamps. This may be an important factor when the lamp is switched on if there is a momentary overload of fifteen or twenty times normal.

John W. Howell: Dr. Langmuir has made an analysis of the residual gases in tungsten lamps, and has devised an apparatus for the making of qualitative analyses in determining the five constituents in one cu. mm. of gas. That is a marvelous achievement. During all the years we have been working on incandescent lamps we have been interested in residual gases, we have known they were there, and we had a general idea what they must be, but we never had the initiative to try to measure them in quality and quantity as Dr. Langmuir has done.

The first summary of Dr. Langmuir's, on page 1932, reads* as follows: "The efficiency at which tungsten lamps may be profitably run, is limited principally by the blackening of the bulb." Dr. Langmuir should have drawn that statement more carefully, so that it would refer to large lamps. It is true of large lamps, but it is not true of the small lamp. Forty-watt lamps and all smaller standard lamps blacken so little that they break before the blackening becomes objectionable and their useful life is their total life. These lamps constitute over 75 per cent of all lamps sold. In large lamps the efficiency is limited by the blackening of the bulb. There are two reasons for this. The small lamps have thin filaments. If these filaments waste away by evaporation, and one spot is hotter than the other, the hottest spot will waste fastest, and it will break there. This wasting will break a thin filament in shorter time than a thick filament, consequently the thin filaments break before the evaporation has proceeded far enough to blacken the bulb. We test in the laboratory all 40-watt lamps at 0.9 watts per candle. Their total life at 0.9 watt per candle is about 400 hr., and at the end of that time they are not blackened sufficiently to render them objectionable or make us take them down. Large-diameter lamps will live longer. Another reason why lamps with thick filaments blacken more than those with thin filaments is that thick filaments are used for high candle power lamps and in these lamps, for practical reasons, the bulb area is not nearly so large relative to the candle power or filament surface as in thinner filament lamps, and as the evaporation from a filament is proportional to its surface, these larger lamps with less bulb surface per unit of filament surface would get blacker in a given time. This difference in bulb surface in relation to filament surface is very great and causes large lamps to become useless by blackening before the filaments break.

As to the second paragraph in Dr. Langmuir's summary, I have recognized for some time that there are three different kinds of blackening in a tungsten lamp, and that the ordinary blackening which proceeds very slowly and is uniform throughout the bulb is caused by the evaporation of the filament. I believe that same thing of carbon lamps, and if you will refer to the *TRANSACTIONS* of this Institute for March, 1894, you will find a paper written by Prof. Anthony on "Incandescent Lamps Containing Heavy Gases." Prof. Anthony concludes with the statement that the blackening of the carbon lamp is caused by the evaporation of the filament, and Prof. Elihu Thomson, and Prof. Robb, of Hartford, and Mr. Doane agreed, in discussing the paper, that the blackening was due to this cause.

In discussing that paper I said that there were two kinds of blackening, one was due to evaporation, I believed, and the other was not. Now, the other kind of blackening, which I thought was not due to evaporation, is always irregular in its deposition on the bulb. In carbon incandescent lamps we fre-

*As first printed, previous to presentation.

quently met an irregular blackening which we call mottling, and mottling always occurs in a lamp which has a defective vacuum. Of course, there are different kinds of defective vacua, but only a few kinds of defective vacua that produce that mottling. There is one condition which always produced a mottled discoloration of the carbon lamp, and that was in the case of lamps which we made at one time, in which we put a little clay in the anchor clamp to hold the filament. These lamps were always discolored irregularly and with mottling. That same mottled discoloration is found in tungsten lamps. This lamp (exhibiting lamp) illustrates a mottled lamp, but the discoloration is not black.

It is a lightish discoloration, caused by oxygen, by air. That is a mottled discoloration. I believe that any residual gas in a lamp which attacks the filament will produce a mottled discoloration.

The other kind of blackening in lamps is due to water vapor. We have believed for a good many years that the gas which comes from the glass of the lamp as it is heated was water vapor, but we did not know it. Dr. Langmuir proves it and now we know it. It is impossible, I think, to exhaust out of a lamp with a mercury pump all of the water vapor which comes off the glass when you heat it. The only way in which we can take it out is by the use of phosphoric anhydrid.

Water vapor in a carbon filament lamp does not cause the lamp to blacken as in a tungsten filament lamp. Here are two tungsten lamps (exhibiting lamps) that were made in the spring of 1907. When we made these lamps we exhausted them together in the same way. After they were exhausted and sealed up as finished lamps, I took one lamp and with a gas torch heated the bulb hotter than it had been heated in exhaustion, and then the two lamps were put up on a life test and burned over night, and the result of one night's burning was that the lamp that had been heated to drive the water vapor off the bulb into the lamp was black the next morning and the other one remained perfectly clear. We discovered also that when we heated the bulb during exhaustion the water vapor was sufficiently removed so it did not come out any more afterward.

Away back, about 1890, there was a lamp put on the market called the novak lamp, a carbon lamp with one mm. of bromine in it. The lamp was not commercially successful because the bromine had, as nitrogen has, bad effects and good effects, but in that carbon lamp the bad effects were greater than the good effects, and the result was a disadvantage and the lamp did not live.

At that time I made a lot of experiments on the effects of gases in lamps. I made measurements with four gases, nitrogen, hydrogen, bromine and chlorine. The lamps I used were first exhausted with a very good vacuum, and then increasing amounts of each one of these gases, separately, were admitted to the lamp, and the change made in the specific consumption of the lamp

by the cooling effect of the gas was noted, and these changes were plotted in a curve which showed the effects of any amount of either one of these four gases in the lamp. At first it was impossible to make a lamp which would burn well with any gas in it. It was only when we realized the absolute necessity of dryness in the gas that we succeeded, but when we got these gases absolutely dry, neither one of them had any ill effects on the lamp. I mean as to making it black; but they all cooled the filament and this cooling effect is what we measured.

The effect of water vapor in a carbon lamp is to render the filament sooty and black. This makes it a very excellent radiator of heat, so that it is cooled by radiation to such a degree that the candle power falls away down, and yet the bulb remains clear.

Farley Osgood: The question that interests the operating engineer is, what is the hope of the development of this lamp in small units? As Mr. Howell has said, 75 per cent of the lamps used are in small units.

J. E. Randall: You have had here an exhibition of this new development and a demonstration of the operation of these lamps during a period of a few moments. I presume that I am the last person in this hall to have seen any lamps of this kind operated in the Research Laboratory at Schenectady. I saw some lamps there today and identified them as those that I saw operating under the same conditions a number of weeks ago. They have been operating continuously since the first time I saw them. Therefore, I think we can say that this development is successful. The development will be beneficial because it marks a long step in the energy efficiency of a device that is notoriously inefficient.

If we grade the quality of lamps by the initial efficiency, that is, filament temperature at which they will show a certain performance, the so-called nitrogen lamp will take a very high rank. If we establish as a standard of performance, the initial efficiency at which a lamp will develop 90 per cent of its theoretical candle hours during one thousand hours of burning, candle maintenance and mortality both considered; and if, on this basis, we call the raw carbon filament lamp 100, the various types will rank as follows:

Raw carbon filament lamp.....	100
Treated carbon filament lamp.....	119
Gem filament lamp.....	149
Tantalum filament lamp.....	206
Tungsten filament lamp.....	359

I have not complete data for the new lamp
but it surely would have a rating of..... 600

We should not consider these developments as extending the lives of lamps. Their success should rather be gaged by their energy saving. The real advantage of any improvement in the incandescent lamp is utilized by raising efficiency rather than by prolonging life.

The way for the new lamp was to a great extent prepared by the production of ductile tungsten. Methods of shaping the drawn tungsten wire into helical coils have been so developed that they are of signal assistance. Accuracy of control of wire diameter, which, one may say, has almost reached perfection, will doubtless add speed to the commercial development of this latest lamp.

William McClellan: I ask whether Dr. Langmuir in closing will say a word about frequency in connection with the lamps, especially low frequencies, with low-voltage lamps. Is there any difference between that and the ordinary tungsten lamp?

Irving Langmuir: Different frequencies of alternating current?

William McClellan: Yes. The point is that the ordinary carbon lamp at 25 cycles, low wattage, does not flicker so that it can be noticed. When you come to the tungsten lamp it flickers considerably. I am interested in knowing whether the new type of lamp will be different from the tungsten, or practically the same.

John W. Lieb, Jr.: The question naturally arises, what is going to be the effect of this great movement forward in lamp efficiency on central station service, and what is its effect going to be on the general question of improvements of efficiency and life of incandescent lamps? Undoubtedly these new lamps will necessitate a revision of our criteria which have prevailed hitherto as to what should be considered as the useful life of the lamp. Useful life, as we know, has been established in accordance with general agreement that when the lamp has depreciated in candle power to 80 per cent of its initial value the useful life of the lamp has ended; it has reached the "smashing point." Now, with these new developments in the lamp, and the increased efficiencies which have been attained, it will be necessary for us to modify our figure, or at least give it new consideration in the light of the electrical data which these new lamps present. The central stations have long ago passed that period when they could afford to exhibit any fear as to the ultimate result of an improvement in the art, in any direction in which the art might progress. This new development will help to reach that consummation which we have all been hoping for, that the electric light will reach the humblest home and be as easily accessible to the humblest of our citizens as kerosene.

Another question which is raised by these lamps is, what will become of the arc lamp? I think it is no empty prediction that the arc lamp under the impulse which this new development produces, will achieve further advances to put itself in line to continue the contention with its new competitor.

M. G. Lloyd: We are told that the nitrogen is at about one atmosphere pressure. I ask the reason for using that particular value. I should like to know whether it is considered objectionable to have a higher pressure than one atmosphere inside the bulb.

H. M. Fales: Telephone companies are interested in the success of the tungsten lamp for street lighting purposes. The present carbon arc lamps produce variations in the lighting circuit of such frequencies that serious disturbances are often caused inductively in telephone circuits located on the same street. With tungsten lamps this is not the case. The disappearance of inductive disturbances in telephone circuits has already, in a number of cases, been traced to the substitution of tungsten lamps for arc lamps.

Farley Osgood: I might suggest that Dr. Langmuir in closing say a word about the stability of these lamps. Our friend Mr. Lieb has indicated the possibilities of it for arc use, which is very interesting to operating engineers.

Irving Langmuir: The difference in brilliancy, pointed out by Mr. Taylor, between the inner and outer portions of the helix as thrown on the screen, is due, I think, principally to reflected light from the inner sides of the turns. In other words, the conditions in the interior of the helix more nearly approach those in a so-called "black body" furnace. The difference in temperature between the inner and outer part of the wire may be approximated by calculation, and is found to be less than 10 degrees, an amount too small to account for the large difference in brilliancy.

It might at first sight appear that the imprisonment of light by reflection back and forth between the adjacent turns of a helix causes a waste of light energy. In a sense, this is true, but since the heat energy is also imprisoned to nearly the same degree, the power needed to heat the filament is decreased in about the same ratio as the light. The efficiency at any given temperature is therefore not seriously affected by the helical winding. Experiments confirm this.

Mr. Howell's criticism that the failure of small lamps is due principally to breakage and not to blackening is, I feel, quite correct. In writing the paper I had in mind lamps of 40-watt size, or larger. Although under the usual operating conditions the failure of 40-watt lamps running at normal efficiency is, as Mr. Howell points out, rarely due to blackening, yet our experiments have shown clearly that as soon as the specific consumption of such lamps is lowered to about 0.8 watts per candle, the bulbs blacken relatively rapidly and the candle power often falls to 50 per cent of the initial candle power, or lower, before failure occurs.

I did not mean to claim in the paper that we were the first to find that water vapor in lamps is injurious, or to suggest evaporation as a cause of blackening. I know that the presence of water vapor has been considered extremely harmful, in both carbon and in tungsten lamps, from the early days of their manufacture. I have pointed out that evaporation as a cause of blackening was one of the theories often applied to the blackening of lamps.

I feel, however, that evaporation was considered as a *possible explanation*, rather than as the *known cause* of blackening in well made lamps.

It has been my experience that the men in lamp factories always endeavored to explain every particularly good or "freak" lamp by assuming that the vacuum in the lamp had been better than usual, thereby directly inferring that the presence of residual gases limited the life of ordinary lamps.

Many of the German lamp factories have carried on very careful scientific investigations as to the cause of blackening of tungsten lamps, but so far as I know, have not found evaporation to be the cause.

The prevalent theory among these investigators seems to be that the blackening is primarily due to electrical disintegration. This theory has sometimes been discarded in favor of the evaporation theory, because the rate of blackening apparently did not perceptibly depend on the voltage of the lamp, but did rise rapidly with the temperature of the filament, according to a curve resembling a vapor pressure curve. These were Prof. Anthony's main reasons for concluding that evaporation was the cause of blackening. Investigations during the past ten years, however, have shown that the electrical discharge (thermionic current) from a hot wire in vacuum is independent of the voltage and does rise with the temperature, according to just such a curve as that observed for the rate of blackening. Thus both of the main reasons which had led Prof. Anthony to conclude that evaporation was the cause of blackening fall to the ground.

On the other hand, the objections to the electrical theory which have previously seemed most serious, disappear.

The real reason for our conclusion that evaporation and thermionic currents are not related, is based on actual measurements of these thermionic currents, which are being published elsewhere (*Phys. Review*, Dec., 1913).

What Mr. Howell has said about the uniformity of the deposits caused by evaporation is in accord with our experience. The blackening due to water vapor, however, is not always, or even usually, irregularly deposited, although in some cases it may be so to a marked degree. In some cases we have observed that blackening by water vapor is limited to the hottest portions of the bulb. In fact, if heat is applied locally to a part of the bulb, this alone may blacken. Sometimes blackening in presence of gas is influenced by electrical discharges. But it is more usual even in presence of water vapor, to obtain very uniform deposits, which in appearance cannot be distinguished from those due to normal evaporation.

I may have conveyed a false impression in the paragraph on the effect of argon. That paragraph refers only to argon at very low pressures. Argon at high pressures is just as good, if not better than, nitrogen. The results so far indicate that argon will probably be substituted for nitrogen in the lamps as

soon as it becomes readily available. The gas is very hard to make on a small scale, but on a large scale it can be made very cheaply, comparatively speaking.

In regard to the flicker of these lamps when used on alternating current, I may say that this depends entirely on the size of filament used; in other words, on the current taken by the lamp. With lamps taking 6.6 amperes on 25-cycle current, the flicker is just barely noticeable. With lamps taking larger currents, it cannot be detected by the eye.

The pressure of gas used in the lamps is preferably as high as is consistent with safety. In order to avoid all possibility of explosions, we aim to employ such an amount of gas that the pressure will be about atmospheric pressure during the normal operation of the lamp. The gain in efficiency which could be obtained by using higher pressures is entirely negligible.

The stability of the lamps is as good as that of ordinary lamps. Of all the lamps shipped from Schenectady to New York for this meeting, not one was broken.

In conclusion, I should like to say that I consider the real credit for this work is due to Dr. W. R. Whitney, who, by the encouragement he has given and the wonderful spirit of coöperation he has created in the laboratory, has made the result possible.