RECENT PROGRESS IN TUNGSTEN METALLIC FILAMENT LAMPS.

By H. HIRST, Member.

(*Paper received April* 9, *and read in London on May* 21, 1908.)

During the past few years a great deal of attention has been paid both by chemists and electrical engineers to the construction of metallic filament lamps for incandescent electric lighting. Ever since the advent of the Nernst lamp with its oxide filament, chemists, scientists, and lamp makers have felt instinctively that the supremacy of the carbon filament lamp was seriously challenged. The efforts made have been attended with more or less success, yet it may be news to a large number of electrical engineers of the younger generation that the metallic filament lamp is one of the oldest forms of electric lighting. In fact, incandescent electric lighting commenced with metallic filament lamps, platinum being the incandescent body. Such lamps were made long before the Edison or the Swan carbon filaments were invented. Several inventors worked on these lines, and Edison especially endeavoured to perfect a lamp in which a thin platinum wire raised to white heat by the current formed the illuminating body.

These lamps were, however, never a commercial success, because the melting-point of platinum is only slightly higher than that temperature to which it has to be raised for the economical production of light. In consequence the life of the filaments was short, and the slightest increase in the voltage, which was extremely difficult to prevent in those days, was sufficient to melt the filament. Attempts were made to overcome this defect by automatic arrangements to cut out the lamps should the voltage rise to a point likely to melt the filament.

Even in 1880 we find Edison * trying to further improve the platinum lamp. Maxim † in 1881 describes and claims a thermo-regulator designed to prevent the overheating and consequent melting of the platinum filament. In the same year Maxim ‡ described a process of producing carbon bodies for illuminating purposes which were flashed in carbonaceous vapours with a view of improving them.

It was in 1881 that the carbon filament lamp came to the front and

* U.S. patent No. 227,229, 1880.
† U.S. patent No. 247,380, 1881.
‡ German patent No. 13,383, 1881.

stopped the researches and experiments in connection with the perfection of the then existing metallic filament lamps. It was only after a lapse of nine years that the next American patent dealing with a new metallic filament lamp made its appearance—this was the Poland patent No. 432,710, of 1890, for the iridium lamp.

There were two predominant reasons for the immediate success of carbon as a glow-lamp filament.

1. It could not be melted, and in this respect had an enormous advantage over any of the then known metals. Platinum had at that time the highest melting-point of any of the then available metals which could be made into a thin wire, but this temperature is much lower than that which a carbon filament will stand for a prolonged period in a vacuum.

2. Carbon has also a very high specific resistance as compared with any of the metals then available. The question of the distribution of current was at that time of great importance, and it was even then recognised to be a difficult problem to distribute large currents at a low pressure over a considerable area.

Due to its high specific resistance carbon was found to be a most suitable material from which to produce illuminating bodies to be incandesced by a small current at a high voltage.

When first introduced the carbon filament lamps were made for circuits of 50 to 60 volts, but improvements in manufacture soon increased the standard to 110 volts. The bulk of the pioneering work in central station supply was carried out at this voltage, but it was found that as the distribution networks were extended over large areas the great cost of attaining constant voltage was hampering the spread of electric lighting. The mains absorbed such a large proportion of the total capital outlay of a supply system that it was found necessary to raise the pressure of distribution in order to keep down the cost of electrical energy to a reasonable figure.

The 3- and 5-wire continuous-current systems invented by the late Dr. John Hopkinson, and the high-pressure alternate current with step-down transformers, helped to extend the period during which 110-volt lamps could be used. In spite of these means of reducing the cost of the distributing networks and feeders, the engineers of the electric supply companies and of the municipal authorities encouraged the incandescent lamp makers to develop higher voltage lamps. As a result the 200–250-volt lamps made their appearance in the early nineties, and by the middle of that decade were adopted commercially.

Although these lamps were not as efficient as those for the lower voltages, they saved so much in the cost of distribution that the supply companies were able to reduce the cost of electrical energy to those consumers using them. These lamps have since been so far improved in efficiency as to meet all requirements, and they were officially recognised by the Board of Trade Regulations issued in 1901, which enabled the supply undertakers to enforce their use on all consumers.

Some Recent Inventions and Developments in the Metallic Filament Lamp.

When the carbon incandescent lamps were first introduced they had to compete with the flat-flame gas burners, and a glance through the earlier estimates of the comparative costs of electric and gas lighting shows that these gas burners were then considered as the standard illuminant. With the high price of electricity it was the very great convenience, beauty, and safety of the carbon lamp which enabled electric lighting to make the progress it did. As this price of electricity was lowered with extended use, the carbon lamp had to face a much stronger competitor.

The incandescent gas mantle invented by Auer von Welsbach suddenly reduced the cost of gas lighting to one-third of what it had been before. Electric lighting has survived this blow and made progress, but this progress during the last ten years has been severely handicapped by the cheapness of incandescent gas lighting.

It is worthy of note that a considerable number of gas engineers considered that Welsbach mantles would ruin their undertakings because they reduced the consumption of gas for a given amount of light by one-third. Sufficient time has now elapsed to show how absurd their prophecies were.

It is of far greater interest to electrical engineers to know that Auer von Welsbach by his invention of the osmium lamp has removed the handicap which he placed on the electrical industry. Thus what he has taken away with one hand his inventive genius has enabled him to return with the other.

The existence of incandescent gas lighting has not only had a damaging but also a stimulating influence on the development of electric lighting. The quiet peculiar radiation of the incandescent gas mantle, which, as is well known, consists of thorium oxide containing 1 per cent. of cerium oxide, has been the subject of numerous researches which have furthered the purely theoretical knowledge of radiation. Very careful experiments, especially the now famous investigations of Lummer, have shown that bodies exist which at the same temperature radiate as light a larger percentage of the supplied energy than the so-called "black bodies." The Welsbach mantle owes its high efficiency to this property.

The success of these oxides of the rare earths in gas lighting led to their application to electric lighting, as has been done in the Nernst lamp. The first English patent for this lamp was applied for by Nernst* on August 23, 1897, and in one of the claims it is stated that—

> "A body of magnesia, zirconia, or suitable rare oxide is heated to incandescence by a Bunsen gas flame or otherwise and is then kept incandescent by the passage of electric current through it."

* British patent No. 19,427, 1897.

It is interesting to note that Nernst was endeavouring to dispense with the vacuum, which, of course, would have been an eminent advantage. The chief drawbacks of this lamp are that it requires separate means to heat up the glower in order to render it conductive and also a series ballast resistance. This lowers its economy, and without this resistance the glower cannot be safely used.

There have not been any other important adaptations of the use of oxides for incandescent electric lighting, and it is to the metallic filament that we must turn for those inventions which are enabling electric lighting to compete with the Welsbach gas mantle.

The first commercial metallic filament lamp was the osmium lamp, invented by Auer von Welsbach in 1898, and put on the market in the following years. Its regular commercial supply commenced in 1902.

In this lamp the filament is made of metallic osmium, which has a considerably lower specific resistance than carbon. Due to this increased conductivity doubts were expressed as to whether osmium lamps could be manufactured for the usual voltages.

The osmium lamp consumed per candle-power 1½ watts. Useful life over 1,000 hours. Decrease of candle-power during that period scarcely any. They were hence much superior to carbon lamps taking per candle-power 3½ watts, and after a life of 800 hours decreasing in candle-power 20 per cent.

At first the osmium lamps could only be produced for 37 volts, which necessitated the connection of three lamps in series on a 110-volt circuit. The lamps were very fragile, and had to be burned in a perpendicular position. Their cost was about ten times that of a carbon lamp, due largely to the limited quantities of osmium available.

This did not prevent millions of these lamps being manufactured, but it was evident that it would be impossible to produce them in the quantities required to supply all Europe, which would need between 30 and 40 million lamps per year.

During the following three years the osmium lamp was further improved and made available up to 77 volts, enabling two in series to be used for 110 volts, and three in series for 220 volts.

In January, 1905, shortly after a paper read by Drs. von Bolton and Feuerlein,* the tantalum lamp appeared on the market. It possessed the great advantage that it could be burnt in any position and on a 110-volt circuit. Its economy was slightly less than that of the osmium lamp, and the useful life of the filament was considerably shorter. It was found that this life, when the tantalum lamp was used on alternating-current circuits, was so low that the makers did not recommend their lamps for these circuits. It must, however, be said that in spite of this disadvantage the tantalum lamp would have been looked upon as the lamp of the future had there not been a serious competitor to it even before it was a commercial article.

Many inventors had been working independently on the improve-

* *Electrotechnische Zeitschrift*, vol. 26, p. 105, 1905.

ment of the electric incandescent lamp, using metals with high melting-points, such as osmium, chromium, molybdenum, tungsten, etc., and it is interesting to note the various suggestions as to methods of manufacture which appear in the Patent Specifications.

Thus, Lodyguine * proposed to coat a suitable core of platinum, silver, or carbon with these metals, but he could not obtain incandescent bodies consisting of the pure metals of high fusing-points, as evidently he did not know how to eliminate the interior core of platinum, silver, or carbon on which the filament was built up.

The superiority of tungsten over other metals such as osmium, molybdenum, chromium, zirconium, thorium, tantalum, vanadium, niobium, etc., for the construction of incandescent filaments has now been ascertained by research, but was not proved at the time when Lodyguine made his investigations.

In 1904 Siemens and Halske † endeavoured to extend their drawing process, which had been successful with tantalum, to tungsten, thorium, etc. The brittleness of tungsten and its want of ductility rendered the process inapplicable, and apparently Siemens and Halske have not up to the present time succeeded in producing lamps with drawn tungsten wire.

It was also in 1904 that Drs. Just and Hanaman ‡ applied for a patent for incandescent bodies consisting of pure tungsten. This is the first English patent describing the manufacture of pure tungsten filaments—all previous inventors had failed to produce metallic bodies from this element which were free from oxides, carbon, or carbides.

The second claim of their patent reads :—

> "Process for the manufacture of incandescent bodies in accordance with claim 1, characterised by the fact that tungsten or molybdenum or compounds of these metals are mixed with organic binding media, formed and carbonised, whereupon the carbon is chemically eliminated, substantially as described."

Quite independently of these inventors, the Deutsche Gasglühlicht Aktiengesellschaft (the Auer Company) applied for a patent § which covers a process for the manufacture of pure tungsten filaments. In 1906 and 1907 a large number of British patents were granted both to the Deutsche Gasglühlicht Aktiengesellschaft and to Drs. Just and Hanaman, which describe further improvements in the manufacture of tungsten filaments.

The two patents above mentioned cover what is known as the "paste" process of producing tungsten filaments—another method

* U.S. patent No. 575,002.
† British patent No. 20,277, 1904.
‡ British patent No. 23,899, 1904.
§ British patent No. 19,379, 1905.

called the "coating" process was protected by Drs. Just and Hanaman in their British patent No. 11,949 of 1905.

These fundamental patents appear to protect the processes according to which tungsten filaments can be manufactured commercially at the present time.

Before passing on to the details of manufacture, I desire to mention the patents of some other inventors. Amongst these are—

Heany (American patent No. 839,585) who proposes to use an alloy of tungsten with titanium.

Kuzel (British patent No. 28,154 of 1904) suggests the manufacture of glowing bodies from colloidal metals.

British Thomson-Houston Company (British patent No. 18,749 of 1906 and subsequent patents) describes the manufacture of filaments of tungsten with the help of volatile metals or alloys, chiefly amalgams, which could be drawn into wire. It will be interesting to watch the progress of this suggestion.

Zerning (British patent No. 2,554 of 1906) claims the use of hydrogen and nitrogen compounds of tungsten as the materials from which to construct tungsten filaments.

As far as I know, the hydrogenous compounds of tungsten have never been described by a chemist, and from the information I have been able to obtain the statement of Sir Henry Roscoe still stands. In his famous work "Elements of Chemistry" he refers to the treatment by Berzelius of tungsten trioxide in a current of hydrogen.

I understand that the result of the experiments of this famous scientist, which were confirmed by his French contemporary, Moissan, was the production of nothing but pure tungsten powder without any trace of hydrogenous compound being formed.

As Zerning's experiments were directed towards the same object, it would denote a wonderful achievement if he should have produced a result which is not described in any scientific work and which the above eminent authorities found to be impossible.

The nitrogenous compounds are well known, and it is proved that they cannot exist at the high temperature at which the filaments have to be burned. The patent description is not very clear, but indicates that Zerning intends to make use of the "paste" process, thus producing filaments containing probably carbon or carbide.

After a careful consideration of all the patents on the subject, I believe I am right in maintaining that of the multitude of processes that have been applied for and tried since the first application of the Deutsche Gasglühlicht Aktiengesellschaft and the Just and Hanaman patents, these two alone have during the last two years produced to the world commercial and useful lamps. By this I mean lamps of such characteristics as regards current consumption, life, and light as to inaugurate a new epoch in the electric lighting industry.

It has been ascertained that all metallic filaments burning at a consumption of one watt per candle have been made with tungsten filaments. If ever so small percentages of other substances are added to the tungsten, the economy and useful life of lamps with such filaments suffer immediately.

"Osram" is the name under which the Auer Company introduced the first commercial tungsten metal filament lamp.

The osram lamp is manufactured by the "paste" process, the principle of which consists in preparing from solid substances, such as the metals themselves, in the most finely divided form, a paste with binding or stiffening agents such as the gums, dextrine, and other similar bodies. Such a mass has the consistency of putty, and is then squirted through a very fine orifice in a diamond, with a pressure of several tons per square inch. The result of the squirting operation is that one obtains a somewhat moist thread, which, however, has enough coherence to be formed into filaments that do not break while being dried.

The filaments are first heated under exclusion of air and then possess sufficient strength to be held in metal clamps. They are then subjected to the passage of an electric current which raises them to a high temperature, causing the filaments to sinter. The process of sintering is carried out in gases which chemically attack all the constituents of the binding agent, without the metal being affected, so that eventually a filament of pure metal remains. This filament is dense and homogeneous, but being obtained by a sintering process it is different in structure from the still denser metal which would be obtained from a melted mass.

Auer von Welsbach* describes a method for the manufacture of an electrical illuminating body of osmium by sintering the most finely divided metal at such a high temperature that platinum would evaporate, which temperature destroys the binding material used in the manufacture of the threads. The filament so obtained withstands a very high temperature, but it is still of a more or less spongy or porous constitution; very metallic, but nearly solid. The difference of the filament of the osram lamp, which is pure tungsten metal, from the filaments of the osmium lamp, shows itself by the following characteristics. Owing to the higher melting-point of tungsten, an osram filament will stand a temperature at least 100° C. higher than the osmium filament. Their *specific resistance* and *resistance coefficients* differ and there is considerable difference in their *radiation properties*. The *colour* of the osram filament is a steel to a silver grey, whilst the osmium filament has a bluish-grey appearance.

When preparing osram filaments for lamps of 120 volts, 22 to 27 c.p., burning at an efficiency of about 1·1 watts per candle-power, taking 0·2 to 0·25 amperes, the diameter of the filaments is 0·03 mm. The jet from which this filament is squirted is, of course, much larger. As an example:—

* British specification 1,535 of 1898, and German patent 138,135.

The diameter of the jet at point of issue from the diamond is about	0·055 mm.
The thread, after being squirted, shrinks to, when dried	0·050 „
After it has been heated to a red heat under exclusion of air, it becomes a very porous filament, with a diameter of	0·045 „
When this is sintered by the passage of an electric current, which raises it to the brightest white heat, its length is reduced, and it finally shrinks down to a diameter of	0·030 „
The shrinkage is caused by the removal of the carbon and other material forming the organic binding medium, which originally amounted to	84 per cent.
of the volume of the paste.	
It follows that during the whole process 84 per cent. of the original volume must disappear, and the shrinkage corresponds to a linear contraction of	55 „

It is easy to alter the amount of shrinkage by selecting suitable proportions of the binding medium or by adding volatile substances which disappear on heating.

During this *heating process* the filament is fastened in clamps and placed in globes or other arrangements containing certain gases. The heating is effected by the electric current to a gradually increasing amount, and while the thread decreases in length and diameter, it at the same time allows the passage of increased currents. This is due to the sintering of the particles and also to the filament being freed from carbon, which even in minute quantities increases its resistance. The process is controlled by the operator, who has a voltmeter and ammeter to guide him. The current increases rapidly at first, but reaches a constant value within a few minutes. This is common to all sintering processes, and the same phenomena are observed with osmium, iridium, or molybdenum filaments.

The filament so obtained is elastic but brittle, that is, the osram thread, 0·03 mm. diameter, can be bent into a loop of about one centimetre diameter without breaking. After this bending it returns to its original form. Each filament is fastened on to its leading-in wires without the application of any paste.

This is carried out in the following way: The end of the leading-in wire is melted down to a small globule by means of an electric arc. This globule holds the filament securely, and the resistance from the passage of the current from the leading-in wire to the filament is negligible.

The *evacuation of the lamp* is carried out in the same way as with carbon filament lamps. Any process, mechanical or chemical, is suitable, but it is found that any traces of the gases occluded in the tungsten filament escape much more slowly than in the case of the carbon filament. The result is that the evacuation process requires a longer time with the osram than with the carbon filament lamp.

The *other method of constructing tungsten filaments* was developed by Drs. Just and Hanaman simultaneously with, but quite independently of, the Deutsche Gasglühlicht Aktiengesellschaft. Their lamp was introduced commercially under the name "Just-Wolfram." They use what is known as the "coating process," as described in the British patents 11,949 of 1905 and 3,684 of 1906. This interesting process is carried out as follows: Ordinary carbon filaments of very small diameter, 0·02 to 0·06 mm., are raised to a bright red heat by means of an electric current in an atmosphere of volatile tungsten compounds in the presence of hydrogen. The compounds most used are the chlorides and oxychlorides of tungsten.

The heat of the filament causes the hydrogen to reduce the volatile metallic compounds, depositing the metal in homogeneous condition on the carbon filament.

A later patent discloses a process whereby three or more filaments are coated in series at one operation. After the filaments have been coated in this way, their transformation into pure tungsten filaments is carried out as follows:—

The filaments are submitted to the action of an electric current in an atmosphere of highly rarefied inert gas, such as, for example, hydrogen at a pressure of about 20 mm., until they show the clearest white incandescence. This process causes the carbon to combine with the tungsten surrounding it, forming a carbide. This change is so complete that in the resulting filament the cross-section is tubular, and no carbon can be distinguished under a microscope at the point of fracture. The filaments so obtained containing carbon (mostly as carbide) present a glittering white metallic appearance.

In the next process they are raised to a high temperature through the passage of an electric current while they are surrounded by a mixture of hydrogen and a little steam. This causes the carbon to be oxidised by the same reactions which go on in the water-gas process. The carbon may, however, be eliminated by any other method which gives a resulting filament entirely free from carbon. Further improvements of this process, first described in the British patent 11,949 of 1905, have been disclosed in the British patent 3,684 of 1906.

Drs. Just and Hanaman have also obtained patents* protecting the process of *mounting* their tungsten filaments to the leading-in wires. This is effected by means of a paste consisting of finely divided tungsten metal mixed with coal tar or gum. These paste mounts are dried and finally made red hot by any suitable means before the filament is heated in the bulb.

The supports used in these lamps are made of suitable metal.

* British patent No. 9,349 of 1906.

Exhausting is done in a manner similar to that employed for carbon lamps.

The filaments made by this process have a light grey silvery appearance and a little smoother surface than those made by other methods; in fact, they most nearly approach the appearance of a drawn wire.

Though this process is entirely different from the "paste" process, the final result in each case is a pure, sintered filament of tungsten metal. The sole difference is that the filament made by the Just and Hanaman process is tubular. As regards economy, the tungsten or osram lamps produced by either of the above-described processes have identically the same characteristics.

It has been proved that these lamps will burn for from 1,000 to 2,000 hours with a consumption of about 1 watt per candle-power, without any appreciable falling off in the candle-power. Of all the metals which have been experimented with up to now, only pure tungsten has such a life.

In economy, the result is also better than has been obtained with other filaments, thus :—

The osmium filament takes 1·5 watts and the tantalum 1·7 watts for direct current, and somewhat more for alternating.

OUTPUT AND EFFICIENCY.

In the following comparisons between the osram and carbon lamps I have adopted the Hefner candle-power in every case, as this has so far been the standard mostly used when metallic filament lamps have been discussed. At the present it is found next to impossible to try to standardise metallic filament lamps per *candle-power.* It would make the lamp commercially impracticable.

The metallic filament lamps resemble in characteristics more the incandescent gas mantle than carbon filament lamps, and there is, therefore, nothing unreasonable in demanding a similar treatment for them as is accorded to the incandescent gas mantle. The normal efficiency of both osram and Just and Hanaman lamps of all voltages is about 1 watt per candle-power. At such efficiencies they burn 1,000 hours without a perceptible decrease of candle-power.

The following figures give a comparison between the *energy taken and power radiated* from the surfaces of *osram* and *carbon* filaments :—

The filament of a 25-c.p. osram lamp, consuming per mean horizontal candle-power 1·1 watts, has a total surface of about 50 sq. mm., which equals per candle-power 2 sq. mm., or per watt of supplied energy, 1·8 sq. mm. A good surfaced carbon filament consumes per mean horizontal candle-power 3·5 watts = per candle-power 5·5 sq. mm., or per watt of supplied energy 1·57 sq. mm. It results, therefore, that 1 sq. mm. surface of osram filament gives 0·5 c.p., and consumes 0·55 watt. 1 sq. mm. surface of carbon filament gives 0·182 c.p., and consumes 0·63 watt.

RADIATION.

It will be seen from the above figures that the osram filament radiates only 87 per cent. of the energy radiated by an equal surface of the carbon filament, but gives 275 per cent. of the light given by the carbon filament.

If the kind of radiation were the same in both cases the carbon filament ought to get hotter than the osram filament by about 60° C., because of the higher total radiation per unit of surface. On the other hand, considering the greater light emanating from the osram filament, it ought to exceed the carbon filament by about 200° C.

These contradictory conclusions show clearly how different is the radiating power of the osram filament as compared with the carbon filament. The latter behaves much more like the "black body" of the radiation theory.

From approximate calculations the temperature of an osram filament burning at 1·1 watts per candle-power is about 250° C. higher than that of a carbon filament burning at 3·5 watts per candle-power. If a carbon filament were to be overrun to such an extent as to consume only 1·1 watts per candle-power, its temperature would then have to be raised by 360° C.

The favourable radiating properties of the osram filament, therefore, mean that its temperature is 100° lower than that of a carbon filament of the same efficiency. If it were not so possessed of this radiating property it would have to be burnt at an efficiency of 1·5 to 1·6 watts per candle-power, in order that it might have the same life it actually possesses at 1·1 watts per candle-power.

A further favourable property possessed by all tungsten filaments is their *high positive temperature coefficient of electrical resistance.* If one takes the resistance of carbon, tantalum, osmium, and tungsten filaments at ordinary temperatures, the resistances at those temperatures which, in a vacuum, correspond to 1·5 watts per candle will be as follows:—

For a carbon filament ...	... 0·55 of the original.
For a tantalum filament	... 5·70 times.
For an osmium filament	... 8·50 times.
For a tungsten filament...	... 11·00 times the original.

At temperatures of about 2,200° C. absolute, each increase of temperature of 10° increases the resistance of a tungsten filament about 0·45 per cent.

If the pressure is raised from 100 to 104·5 volts, the current rises from 1 to 1·027 amperes.

For a carbon filament the amount of the increase would be from 1 to 1·05 amperes.

The total energy supplied, therefore, rises in the former case about 7·3 per cent., and in the latter about 9·7 per cent.

Near the normal conditions the light of a carbon filament lamp rises and falls with the 6·3 power, that of a tungsten filament lamp with the 3·6 power, of the voltage.

The latter differences are too great to be explained by the increase of energy caused by the change of pressure.

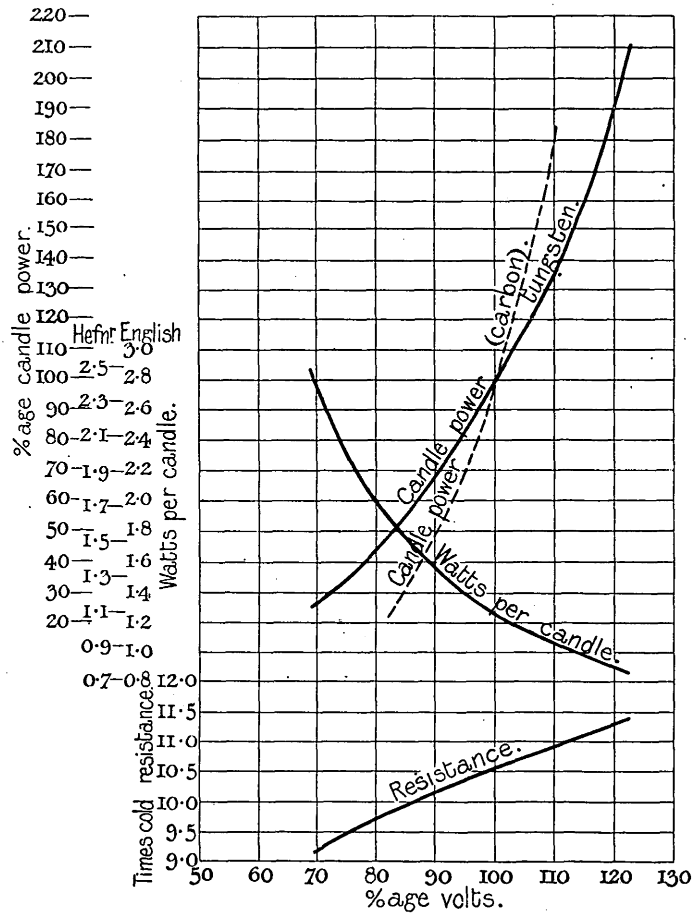

FIG. 1.

The small changes in the *light* of the osram lamp, as compared with a carbon lamp for the same change of voltage, can only be completely explained by the supposition that with a change of energy the radiated light is altered in a different way with the two lamps. A simple calculation shows that near the normal efficiency the light of a carbon lamp changes with the third power of the energy, whilst such change for an osram lamp progresses with 2·3 power of the energy. These proportions have a very important practical consequence, which is clearly shown by the accompanying curve (Fig. 1) and Table I.

TABLE I.

	Osram.	Carbon.
Increase of light due to 10 per cent. increase in voltage	36 per cent.	84 per cent.
Decrease of light due to 6 per cent. decrease of voltage	21 "	34 "

It will be seen that the osram lamp is much less affected by changes in voltages. Thus, if the pressure is decreased by 6 per cent. from the normal, the light from a carbon filament lamp is reduced so much that it is a considerable drawback, whilst the reduction of light from the osram lamp is not considerable.

HIGH-VOLTAGE LAMPS.

High-voltage metallic filaments of the osram type have recently been put upon the market, manufactured both by the D.G.A. and the Just-Hanaman processes. A number of these have been tested in commercial use and under special conditions to ascertain their life. From the results obtained, the average life of a 1-watt 1-c.p. lamp seems to be between 800 and 1,000 hours. During this period there is no appreciable drop in candle-power, and the lamps have shown themselves to be equally good as the low-voltage osram or Just lamps. These high-voltage lamps, made for from 200 to 250 volts, require double the number of filaments used in the low-voltage lamps. It is evident, therefore, that they cannot be produced for small candle-power. Up to the present 40- to 50-c.p. is about the lowest unit that has been obtained in a commercial lamp, and some extraordinary development or discovery will have to be made before that candle-power can be largely reduced.

THE USE OF 110-VOLT LAMPS ON 220-VOLT CIRCUITS.

In so far as the lamp is different from the carbon lamp, it will, therefore, always be necessary to rely on *series running* whenever low units of light are required on high-voltage circuits; thus, for public lighting (especially for the lighting of large spaces), the convenience of one lamp will be apparent, and people will stretch a point to use 50-c.p. for such purposes whenever they can; but for the use of private houses and confined spaces it will always be necessary to revert to lamps burning in series.

To meet this demand, elaborate arrangements have been made at the Osram Works for testing lamps that will run in series. They are tested to one-hundredth of an ampere, and sorted out in from five to seven series numbers according to the type of lamp and carefully marked, and the reference numbers (ranging from, say, 28 to 38, which are marked on the caps of all lamps singled out for series burning) practically mean the consumption of current is 0·028, 0·029, 0·030, 0·031, etc., of an ampere.

This running of osram lamps in series can be avoided to a very large extent in those areas where the supply is given on the alternate-current system. In such cases, where the wiring of the premises to be lighted is carried out on the *sub-circuit principle* (as recommended in the wiring rules of this Institution), it is an easy matter to group up the circuit into two halves, and to connect these halves in series. If it could be insured that there would be always an equal number of lights burning in each of the groups of circuits connected in series in this way, nothing further need be done. As this is not possible in most cases, an auto-transformer has to be added, and connected up as shown in Fig. 2. These tungsten filament lamps burn equally well on either continuous or alternating current, and are quite independent of both frequency and wave-form.

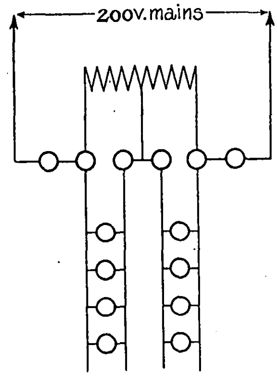

FIG. 2.

THE EFFECT OF METALLIC FILAMENT LAMPS ON SUPPLY SYSTEMS.

Fears have been expressed by some electrical engineers that the introduction of these osram lamps will seriously affect the finances of supply undertakings. As I pointed out in the introduction of this paper, exactly the same fears were expressed by gas engineers when Welsbach mantles were introduced, which enabled the gas required to produce a given quantity of light to be reduced to one-third of that previously used. These fears proved groundless, and the demand for gas increased instead of decreased. I feel confident that the same result will follow the commercial use of the metallic filament lamp. It seems likely that the introduction of these lamps *will mean an increase of* 100 *per cent. in the unit* adopted for electric light. Sixteen-c.p. carbon lamps will be replaced by 25 to 35 watt tungsten lamps, and those places in which a low illumination is desired will still be supplied with carbon filament lamps of 2½, 5, and perhaps 8 c.p. As it is not practicable at present to make osram lamps for 110-volt circuits of a lower candle-power than 25, it is likely that in small rooms greater illumination will have to be used. Where larger spaces have to be lighted, it is easily possible to obtain the present illumination by using fewer lamps, but I think that, with the cheaper light, the general tendency will be towards higher illumination.

Generally speaking, I do not think that the metallic filament lamp will decrease the current consumption of existing consumers to the extent expected, but will, instead, lead to a large increase in the amount of illumination. At the same time the high efficiency of the lamp, compared with all other forms of lighting, will turn the scale in the favour of the use of electric light rather than other illuminants. Station engineers will find that the increased load from new consumers will more than make up for the decreased consumption of existing ones. This conclusion has already been proved to be correct by Mr. C. P. Sparks, Mr. A. H. Seabrook, and others.

As has been the case with so many new inventions, so the tungsten lamp on its introduction had to run the gauntlet of many reproaches on the part of the more conservative elements in our profession. I think it well to allude as fully as possible to what have been termed the disadvantages of the lamp. Amongst these is the *burning in vertical position*, which up to now has been insisted upon by the manufacturers. This problem is already solved in different ways, and lamps can now be supplied to burn in any position.

The price of these lamps is for the moment a trifle higher, but before many months I believe they will be supplied at the same price as the others.

The *price* itself is naturally held up as a disadvantage, especially when a consumer is displacing old lamps for new ones. The outlay then appears serious, but Table II. shows that the saving in current for given illumination rapidly wipes off this expenditure.

Much has been made of the brittleness of the metallic filament and of the percentage of *breakage* in certain instances. I have no experience of what the makers of tantalum lamps have found in this respect, but from the moment it was understood how to pack the osram lamp the breakage in bulk has been a negligible quantity. It now only affects the supply of the lamps in small parcels of one half-dozen to one dozen. This problem is now being dealt with, with every prospect of an early success.

Another point about which there has been considerable outcry is the *blackening* of individual bulbs which occasionally occurs. It is at present thought that this blackening is due to some extent to the great sensitiveness of the filament to small changes in vacuum. Other theories exist as to the cause of this, but what for the moment mainly interests the users is that if a lamp is going to blacken it usually happens at a very early period of its life, when the makers are prepared to deal with the matter generously. It is quite different in this respect to a carbon lamp, in which a blackened bulb means as a rule that the lamp has been kept on circuit for an indefinite period, far exceeding its useful life.

Having dealt with these points, I would call attention to the other data on Table II. and to the following curves (Figs. 3, 4, 5, and 6), showing some characteristic tests of osram, tungsten, and tantalum lamps made by various independent testing authorities.

TABLE II.

Life Test Results

No. of Test.	Type.	Cost per Lamp.	Tested by	Starting. Watts.	Starting. C.P.	Efficiency in W./C.P.	Number of Lamps.	Duration of Test.	Average Useful Life.	Mean Efficiency.	Average C.P.-hours.	Cost per 1,000 C.P.-hours. Renewals.	Cost per 1,000 C.P.-hours. Energy at 4d. per Unit.	Cost per 1,000 C.P.-hours. Total.
	Low Voltage.	d.						Hours.	Hours.	W./C.P.		d.	d.	d.
I.	Osram	48	Faraday House	35·7	36·3	0·99	12	2,000	1,520	1·12	48,700	0·98	4·48	5·46
II.	Osram	48	Westminster Testing Laboratory	35·8	29·7	1·22	12	1,500	1,360	1·29	36,600	1·31	5·16	6·47
IIA.*	Osram	48					12	3,350	2,850	1·42	70,800	0·67	5·68	6·35
III.	Osram	48	T. R. Charlottenburg	34·7	1·0	1·12	(?)	1,000	1,000	1·11	31,100	1·54	4·44	5·98
IV.	Osram	48	Robertson E. L., Ltd.	35·0	27·7	1·26	6	1,800	1,720	1·36	45,600	1·06	5·44	6·50
V.	Wolfram	48	Robertson E. L., Ltd.	38·0	30·7	1·24	2	1,000	1,000	1·27	28,900	1·66	5·08	6·74
VI.	Tantalum	33	Westminster T. L.	39·1	22·0	1·78	6	1,000	700	1·84	15,000	2·19	7·36	9·55
VII.	Carbon	12	—	59·0	18·7	3·15	10	1,000	1,000	3·25	18,000	0·67	13·00	13·67
	High Voltage.													
VIII.	Wolfram	90	Robertson E. L., Ltd.	63·4	53·7	1·18	10	880	720	1·12	42,500	2·12	4·48	6·60
IX.	Carbon	12	—	68·0	18·9	3·6	10	1,000	1,000	3·95	18,200	0·66	15·80	16·46

NOTE.—For the purpose of comparison *all* the above results have been expressed in terms of the "Hefner" unit of candle-power.

* This is a continuation of Test II. to 3,350 hours to show that it pays to burn osram lamps to the limit of life.

The samples of osram lamps were selected at efficiencies corresponding to the limits of sorting, that is, 1·0 to 1·25 watts per candle-power, so that they represent the lowest and highest efficiency at present on the market.

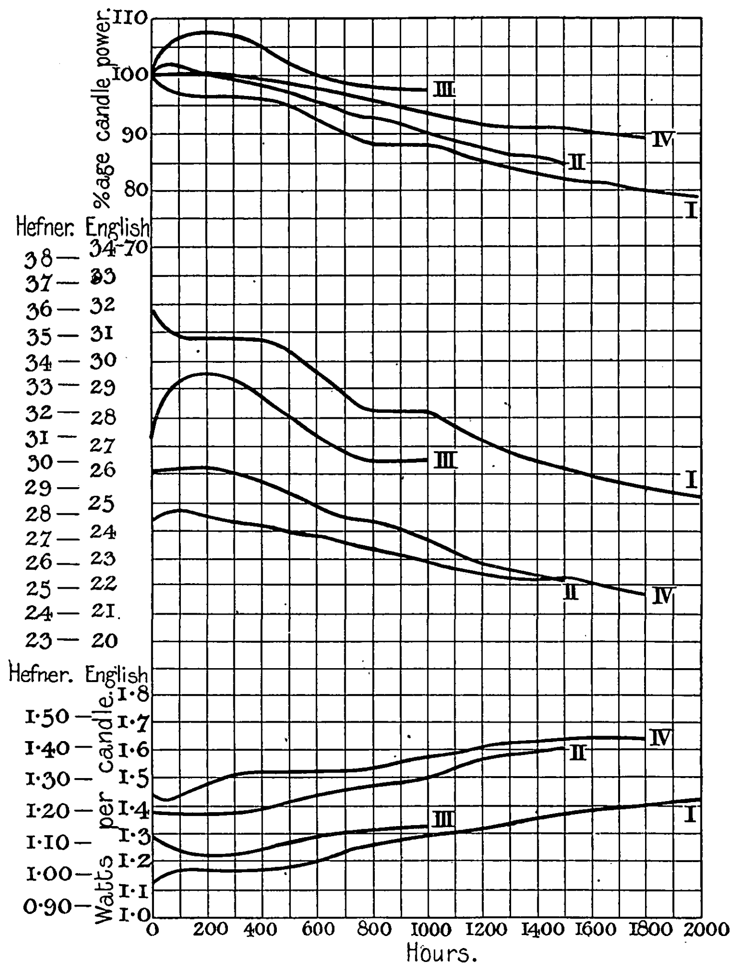

FIG. 3.—"Osram" Average Life Test Curves, etc.

Test I. on Table II. and Fig. 3 is a good example of an osram lamp. This was made by Faraday House on an ordinary commercial lighting circuit, alternating current, with a variation of voltage of about 3 per cent. each way. Twelve lamps were tested, and nine gave a life of 2,000 hours, with a 20 per cent. drop in candle-power. The first failure took place at 900 hours, the other two failures following between 1,200 and 1,400 hours. The cost of lighting with such lamps comes out at the very low figure, including renewals, of 5¾d. per 1,000 c.p.-hours.

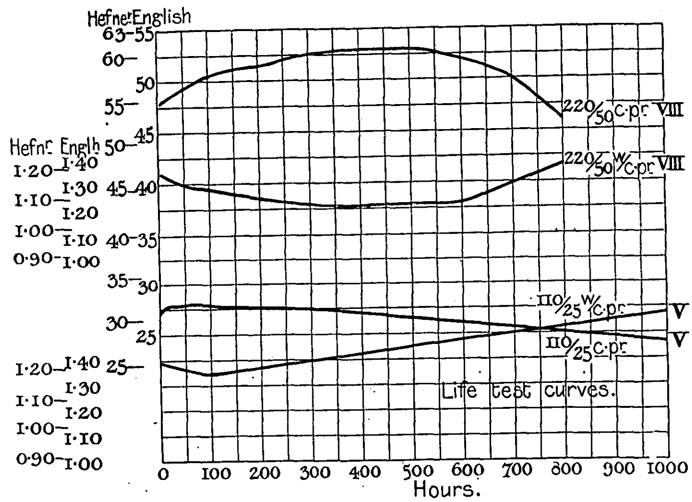

FIG. 4.—"Just-Wolfram."

Tests II. and IIA. on Fig. 3 are other examples of osram lamps burnt at a slightly lower efficiency, and after 1,500 hours' use the drop

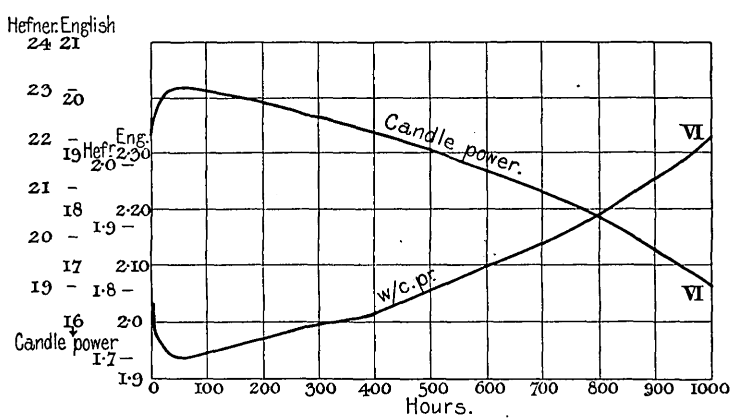

FIG. 5.—Tantalum Lamps.

in candle-power only amounted to 11 per cent. This test was continued to 3,350 hours, when nine lamps were still good. Their average candle-power was then 70 per cent. of the initial candle-power. It is interesting to note from this test that it pays to run these lamps to a point when the candle-power has dropped 30 per cent., as will be seen from the table.

The test No. V. on Fig. 4 of tungsten lamps made by the Just-Hanaman process shows that these lamps are quite as good as the osram.

The test was only carried to 1,000 hours, but it is quite possible that the lamp could have lasted up to 2,000 hours or more, with a proportionate reduction in the cost of renewals. After the 1,000 hours the

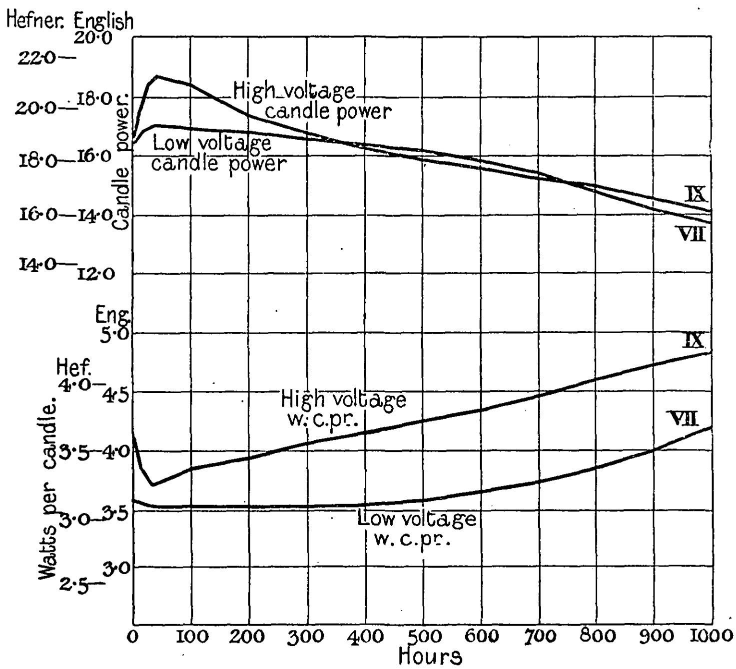

FIG. 6.—Carbon Lamps.

drop in candle-power was exceedingly small, amounting to only 3 per cent.

The tantalum tests, No. VI. on Fig. 5, give a much less favourable result than the above figures.

The test is a typical performance on a direct-current circuit. The cost per thousand candle-hours works out at 9½d., or 73 per cent. more than the osram lamp.

The carbon filament lamp results, test No. VII. on Fig. 6, were selected from a large number of tests, and represent the average English-made lamp.

A comparison of the figures in the last column of Table II. shows that the total saving from the use of osram lamps over carbon lamps when equal voltages are compared is 60 per cent.

Test No. VIII. in Table II. shows the high-voltage trials of tungsten lamps, which were made on an ordinary alternating-current lighting circuit, 50 cycles, with a voltage variation of 5 per cent., most of the variation being up. The figures show that, even paying 7s. 6d. for these 65-watt lamps, there is a saving of over 60 per cent. over the average high-voltage carbon lamp (test No. IX. on Fig. 6) when all the factors of the cost are considered.

In all of the above examples the price of current has been taken as 4d. per unit, which is a fair average for lighting at the present time. Of course with higher prices per unit the saving from the use of tungsten metallic filament lamps is still greater.

As an instance of the life of osram lamps for public lighting, I append figures showing the life of the lamps installed in the streets of Canterbury, which have been kindly furnished by the Borough Engineer, Mr. C. A. Blascheck.

CANTERBURY.

LIFE OF OSRAM LAMPS ERECTED IN THE STREETS, MARCH, 1908.

OSRAM LAMPS.

St. George's Place.	*(Lamps in Open.)*
Post No. 37...	1,357 hours burning.
	*2,434 ,, ,,
Post No. 38...	1,971 ,, ,,
	2,036 ,, ,,
	93 ,, ,,
Post No. 39...	*2,434 ,, ,,
	*2,434 ,, ,,
Post No. 40...	1,779 ,, ,,
	*2,434 ,, ,,
Post No. 41...	*2,434 ,, ,,
	*2,434 ,, ,,
Post No. 42...	1,665 ,, ,,
	*2,434 ,, ,,
Post No. 63...	974 ,, ,,
	2 ,, ,,
	*2,434 ,, ,,
16 lamps	29,349 total hours burning.

Average hours = 1,834.

NOTE.—Those marked * are still burning, therefore the actual average life on completion of test will be considerably higher.

Dover Street and Oaten Hill.	*(Lanterns enclosing the Lamps.)*
Post No. 179	1,402 hours burning.
	1,500 " "
Post No. 180	484 " "
	*2,464 " "
Post No. 181	829 " "
	*2,464 " "
Post No. 182	*2,464 " "
	*2,464 " "
Post No. 183	*2,464 " "
	*2,464 " "
Post No. 184	*2,464 " "
	*2,464 " "
Post No. 185	*2,464 " "
	*2,464 " "
Post No. 205	*2,464 " "
	*2,464 " "
Post No. 206	2,315 " "
	*2,464 " "
Post No. 207	712 " "
	800 " "
	639 " "
	1,068 " "
Post No. 208	430 " "
	736 " "
	736 " "
	1,960 " "
	1,403 " "
Post No. 255	*2,464 " "
	*2,464 " "
29 lamps	51,974 total hours burning.

Average hours = 1,792.

NOTE.—Those marked * are still burning, therefore the actual average life on completion of test will be considerably higher.

SPECIAL APPLICATIONS.

25-volt Osram Lamps.—What I have said as to the likelihood that the metallic filament lamps will raise the standard of illumination, owing to the impossibility of making small candle-power lamps, applies only to those cases in which the lamps are connected on to standard supply systems at 110 volts, or two in series across 220-volt circuits.

The advantages of the pure tungsten filaments can be obtained with small candle-power lamps when a lower voltage of supply is adopted.

As an example of this, osram lamps for 25-volt circuits have been standardised for both 10 and 16 c.p. These lamps consume respectively 10 and 16 watts, and for this consumption give the same candle-power as the ordinary carbon filament lamps taking 40 and 60 watts. It is somewhat difficult to make use of these low-voltage lamps when only continuous current is available from the public mains. Then, in order to reduce the voltage, motor-generators, double commutator balancers, or rotary converters have to be used.

While these are quite serviceable commercially when large numbers of lamps have to be supplied, the low efficiency of small sets, and the attention which the additional rotating machinery involves, will limit the extensive application in this direction.

When alternating currents are distributed the case is entirely different, as static transformers can be used which require no attention and have high efficiency. The low voltage required for these small candle-power lamps can then be obtained at a cost which brings them into effective competition with the incandescent gas mantle for private house lighting.

The opinion has often been expressed, and is still held by many, that the cost of the transformer, together with the losses in the same, would more than nullify the saving from the use of metallic filament lamps. The iron loss in such transformers is constant, and goes on whether the lights are burning or not. Hence, to get the best result, these transformers, like those still largely used for reducing high pressure to, say, 220 volts for house lighting, must be designed with a minimum of iron loss so as to obtain a high all-day efficiency.

For use with these lamps special transformers have been constructed on the above lines, from which the following figures have been obtained on test :—

The iron loss on the transformer designed for 300 watts output is as low as 5 watts.

The following table shows the units taken per year by this and two other transformers of a larger size to overcome iron losses :—

TABLE III.

Details of Iron Losses of Small Transformers.

Output of Transformer in Watts.	Number of 16-c.p. Osram Lamps Alight at one Time.	No Load.	Iron Losses.	Units Taken per Year.	Cost per Year at 4d. per Unit.
		Watts.	Percentage.		£ s. d.
300	19	5	1·67	44	0 14 8
750	47	10	1·33	88	1 9 4
1,500	94	17	1·13	149	2 9 8

The cost per year at 4d. per unit is given in the last column.

The copper losses in these transformers are not large, and only occur when the lamps are being used. The total loss in the copper of the transformer, and in the wires between the transformer and the lamps, will not be appreciably higher than the copper losses in the cables alone when carbon lamps are used.

The following table shows the financial results from the use of these 25-volt 16-c.p. osram lamps in a private house requiring 25 lamps. I have assumed that the smallest size of transformer in the preceding table will suffice, as 19 lamps alight at one time is about the extreme maximum load in such a house. The total saving in current shown in the last column varies with the number of hours the lamps are in use; at 500 hours' use the saving in current is £6 4s. 9d. on a yearly bill of £9 10s. when carbon lamps are used. The current account is thus reduced 65 per cent., but the bill for lamp renewals will be somewhat higher.

TABLE IV.

Annual Costs for Current on an Installation of 25 16-c.p. Lamps, of which 19 are Burning at one Time.

(16-watt Osram Lamp *v.* 60-watt Carbon Lamp.)

No. of Hours per Annum at Maximum Load.	Maximum Load in Watts.		Units used per Annum with Osram Lamps.			Units used for Carbon Lamps.	Cost of Current at 4d. per Unit.		
	Osram Lamps.	Carbon Lamps.	Osram Lamps.	Trans-former.	Total.		Osram Lamps.	Carbon Lamps.	Saving.
							£ s. d.	£ s. d.	£ s. d.
300	304	1,140	91	44	135	342	2 5 0	5 14 0	3 9 0
400	304	1,140	122	44	166	456	2 15 3	7 12 0	4 16 9
500	304	1,140	152	44	196	570	3 5 3	9 10 0	6 4 9
600	304	1,140	182	44	226	684	3 15 3	11 8 0	7 12 9
700	304	1,140	213	44	257	798	4 6 6	13 8 0	9 1 6
800	304	1,140	243	44	287	812	4 15 6	15 4 0	10 8 6

Table V. shows the complete balance sheet obtained by adding the cost of current to the lamp renewal charges for both carbon and osram lamps.

These tables clearly show that private houses in those areas over which electricity is distributed in the form of alternating current can at once realise to the full the exceptional radiating properties of the tungsten filament.

As some engineers may object to my statement above as to the

TABLE V.

No. of Hours per Annum of Maximum Load.	Osram Lamps.		Carbon Lamps.		Total.		Total Saving with Osram.	
	Current.	Lamp Renewals.	Current.	Lamp Renewals.	Osram Lamps.	Carbon Lamps.		
	£ s. d.	£ s. d.	£ s. d.	s. d.	£ s. d.	£ s. d.	£ s. d.	%
300	2 5 0	1 10 0	5 14 0	7 1	3 15 0	6 1 1	2 6 1	38
400	2 15 3	2 0 0	7 12 0	9 6	4 15 3	8 1 6	3 6 3	41
500	3 5 3	2 10 0	9 10 0	11 10	5 15 3	10 1 10	4 6 7	43
600	3 15 3	3 0 0	11 8 0	13 3	6 15 3	12 1 3	5 6 0	44
700	4 5 6	3 10 0	13 6 0	16 7	7 15 6	12 2 7	6 7 1	45
800	4 15 6	4 0 0	15 4 0	19 0	8 15 6	16 3 0	7 7 6	45½

copper losses of the transformer being small, I give below a formula which will enable them to calculate what the comparative cost of osram and carbon lamps would be if these copper losses are also taken into account.

Using the following symbols :—

a = open circuit loss in watts.
b = number of lamps.
c = candle-power.
d = cost per unit.
e = average hours of running per year.
f = copper loss on average load.

The cost of lighting with osram lamps per year works out at—

$$8{\cdot}76\, a\, d + \frac{b\,c\,e\,d}{1{,}000} + \frac{f\,e\,d}{1{,}000}.$$

The yearly cost of lighting with carbon filament lamps as against this, works out to be—

$$3{\cdot}5\,\frac{b\,c\,e\,d}{1{,}000}.$$

This under the assumption of an efficiency of 1 watt per Hefner candle for the osram lamp and 3·5 watts for the carbon filament lamp. The saving in running cost, therefore, is per year—

$$3{\cdot}5\,\frac{b\,c\,e\,d}{1{,}000} - 8{\cdot}76\,a\,d - \frac{b\,c\,e\,d}{1{,}000} - \frac{f\,e\,d}{1{,}000}$$

$$= d\left(\frac{2{\cdot}5\,b\,c\,e - f\,e}{1{,}000} - 8{\cdot}76\,a\right).$$

If we take the cost of an actual installation as an example, and figure on 25 16-c.p. lamps (*b* equal to 25, *c* equal to 16) and take from actual measure—

a	= 5
f (to be on the safe side the maximum copper loss has been taken, not the average) ...	= 12
d	= 4d.
e	= 1,000.

Under these conditions the saving works out, as per above formula, to £15 14s. 9d. on a total of £23 6s. 8d., equivalent to a *saving of* 67·4 *per cent.*

If we had not transformed down, but taken the smallest obtainable candle-power, namely 28-watt osrams (against 16-c.p. carbon lamps), the saving would have been £11 13s. 4d., equal to 50 per cent.

If we take further into consideration the cost of renewals and the additional cost of the transformer, we find :—

	£	s.	d.
First cost of transformer	2	2	0
Amounting to an annual outlay (reckoning on five years' amortisation) about ...	0	9	0
Cost of renewals for osram lamps 25 × 3s.	3	15	0
Cost of renewals for carbon lamps 25 × 1s. 3d.	1	11	3
Difference	2	3	9

The actual saving is therefore £15 14s. 9d. minus £2 12s. 9d. = £13 2s., which is equivalent to 56·2 per cent.

The no-load losses have decreased the original saving in running cost by 4·5 per cent.; the copper losses by 1 per cent. (therefore from 67·4 per cent. to 62 per cent.).

An unexpected objection has arisen to the use of these small transformers from certain central station engineers—they find that the iron losses are so small that they will not keep the meter running. If this is the case, these iron losses, which should be borne by the consumer, fall on the station—which is obviously incorrect.

There is no reason why this should not be done if the station engineer is allowed to charge for the same.

With the high-pressure distribution, using transformers in consumers' houses, which was common practice ten years ago, the electricity meters were always placed on the low-tension side of the transformer, and the price per unit was fixed with due consideration of this fact. I would suggest, therefore, that those supply engineers who wish to make use of osram lamps to extend their private-house load should themselves supply these small transformers and charge the consumers a slight increase per unit to cover the iron losses, and also the capital expenditure involved.

There is another large field for these low voltage lamps in connection with isolated plants for the supply of country houses, workshops, etc. Where small units of light are quite sufficient, the cost of the generating plant can be reduced very largely as the output required falls in the ratio of the efficiency of the filaments used in the lamps. Thus the maximum load in any given case falls in the ratio of $3\frac{1}{2}$ to 1, and neither the factory inspector from the Home Office nor the fire insurance company claims that supply at 25 volts is dangerous.

The same reduction in the cost of generating plant in mains can be realised when designing electric lighting equipment for the numerous small towns and villages within the United Kingdom yet to be supplied with electrical energy. In such undertakings the capital burden to be borne by the relatively few consumers obtainable is the chief deterrent.

While the saving from the use of the metallic filament lamp may not bring the capital down quite in the above ratio, it will make many schemes feasible which hitherto have been passed by.

DISCUSSION.

Mr. HAYDN T. HARRISON : I think we are to be congratulated that Mr. Hirst has been able to read this paper, since he has a more intimate knowledge of the possibilities of the tungsten filament lamp probably than anybody else in this country. On page 645 he compares, as everybody probably will have done, the tungsten lamp with the gas mantle, but there is one point which he does not call attention to, and that is that the gas mantle differs in a most important feature; that is, in the first 100 hours of burning the candle-power of the average gas mantle drops 20 per cent., and in 500 hours from 40 to 50 per cent.; whereas the tungsten lamp has this peculiarity, that in 1,000 hours it drops less than 10 per cent. So that the tungsten lamp is nearly equal in efficiency as far as cost per candle is concerned, and it is more than equal in efficiency as regards steadiness in illumination. On page 648 Mr. Hirst says that it will require some extraordinary developments or discovery to produce a tungsten filament lamp of lower candle-power for higher voltages. In his remarks just now he referred to a patent of the General Electric Company of America, a mercury process, but I believe that in that very same application they also mention another point—namely, that tungsten when increased in temperature, even below that of oxidisation in the atmosphere, becomes ductile, and therefore they refer to a process of drawing it down. I want to ask the author whether he thinks that this is practical or not. These filaments, as has been explained, are not drawn filaments, but if tungsten is ductile at a temperature below oxidation, of course there may be considerable possibilities in that particular idea. The author states that elaborate arrangements are being made for testing the lamps to $\frac{1}{100}$ of an ampere, but as the lamps only take $\frac{3}{10}$ of an ampere that is rather a

Mr. Harrison.