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THE EVOLUTION OF ARTIFICIAL LIGHTING.

BY DR. C. V. DRYSDALE

Read before the Optical Society on December 11th, 1906.

AMONG the various branches of optical science there is one which appears to have been strangely neglected by Opticians—that of the production and measurement of the light, with the properties of which they are familiar. In practically every other industry four chief factors enter, the production, measurement, distribution, and utilisation of the article with which it is concerned.

Opticians have practically confined themselves to the last two as concerning light; that is, they study its transmission or distribution by means of lenses, prisms and instruments, and its utilisation on the retina of the eye or in affecting a photographic plate. A very few give some attention to its measurement, and none to its generation. It is as if an electrical engineer should give no attention to batteries or dynamo generators, or a mechanical engineer to boilers and engines.

The “leaving out of Hamlet” in this case may be condoned by the fact that a very large amount of him is provided naturally by the sun, moon and stars, but throughout the history of mankind the production of light artificially has become more and more important. In the following paper, therefore, I propose to deal as briefly as possible with the history of artificial lighting, with the scientific basis of light production, and with the many recent developments.

Historical.

The commencement of artificial lighting dates from the first production of fire, and this is long before historic times. From then until about a century ago the only known method of producing light was by combustion. According to Atheneas†, who wrote in the 4th century B.C., lamps were then not an ancient invention. The lamps used in Greece, or *λυχνος*, generally consisted of a terra cotta cup with handle and two apertures, one for filling and the other, opposite the handle, for the wick, but sometimes a number of wick apertures were provided. These lamps seem, however, to have

† Encyc. Brit. Articles on lamps.

been used rather for religious purposes than for general artificial lighting, and we find that the ancient Persians, Medeans, Assyrians, and Egyptians, had in the temples of Memphis, Thebes, Babylon, Susa, and Nineveh, ceremonies during which the streets were illuminated at short intervals by bronze or stone lamps, each containing about 100 lbs. of liquid fat with wicks about 3 ins. diameter†.

Pliny and Livy mention the use of candles, and in the 4th century A.D., under Constantine, lamps and candles were fairly common. From thence onward the use of candles appears to have died out, and they were not again employed until the 12th century, when they were used for the Roman Catholic Mass. After the Reformation, they began to be used in the castles of the nobles. Sperm candles first made their appearance in the 18th century, while paraffin-candles were devised about 1850.

The principal defect in the old candles was the guttering of the wicks, but in 1826 De Milly found that impregnating them with boric acid, the fusion of this material gave stability to the wick until it was entirely burnt away. At the present time candles are generally made from spermaceti, combined with a certain amount of stearic acid; from Palmitine, a wax derived from palm oil, or in Germany and Austria from ozokerit or *cérésine* wax.

Gas.—Although the so-called “eternal fires” of Baku on the Caspian Sea have existed for ages, and are derived from natural gases, there was no use of gas for lighting purposes until 1792, when Robert Murdoch first produced artificial coal gas. The works of Messrs. Boulton and Watt, in Soho, were lit by gas in 1798, the Lyceum Theatre in 1803, while 1810 saw the inauguration of the Gas Light and Coke Company, and 1813 the gas lighting of Westminster Bridge. From that time the use of gas became very extensive, but until recently the light has been derived from incandescent particles of carbon in the flame itself. This was very uneconomical for two reasons.

Lighting Power of Gas.

In the first place illuminating gas, which is derived from the dry or destructive distillation of coal, is much

† C. R. Bohm. ‘Das Gasgluhlicht.’

more costly to produce than water gas, which is produced by the combustion of anthracite or coke in steam, and which has a high heating, but practically no lighting power.

Secondly, the luminous efficiency of the ordinary gas flame is low, partly owing to the fact that carbon at a certain temperature gives off a larger proportion of useless long waved radiations than other substances, and partly because the carbon particles are probably oxydised before their most efficient temperature is attained. If, therefore, the cheaper non-illuminating water gas could be employed to heat a refractory substance having a tendency to selective emission in the luminous portion of the spectrum, an immense gain should be effected.

The oxyhydrogen, or limelight, was in a sense the first step in this direction, and was devised in 1826 by Thomas Hammond, an English officer. Zircon oxide was used by Caron and Linnemann, in 1868. The first application, however, to the non-luminous gas flame seems to have been made by Alexander Cruickshanks, in 1839, who employed quartz or platinum bodies in such a flame, and who actually made a platinum mantle. In 1882 Victor Popp employed a platinum wire net or hat, and platinum and iron wire mantles were used by Jackson, in America, in 1881. Next, in 1883, Fahlenijelm, in Stockholm, introduced rows of needles on thin rods in the form of a comb, of kaolin, quartz, zirconia, lime, or magnesia, into the gas flame.

The final great step in improving the economy of the gas burner was made by Dr. Auer von Welsbach, in 1886, and announced in the German 'Pharmaceutical Post.' He employed an improved Bunsen burner with platinum wire mantle covered with oxides or salts of lanthanum, zirconium yttrium, magnesium or erbium. Since this time the incandescent gas has made immense progress. The mantle principally employed recently has been, according to Professor Fery, a mixture of 98.7 per cent. of thoria with 1.3 per cent. of ceria. The latter plays an important part in the light production, as being dark in colour it radiates more powerfully. Up to a certain point, therefore, it considerably increases the luminosity of the mantle, but if this point is passed the light again diminishes, owing to the cooling of the flame caused by this increased radiation.

It is possible that changes in the quantity of ceria present in the mantle with time account for the great falling off in brightness, which soon occurs with these mantles. There is no doubt, however, that incandescent gas lighting is very low in cost, and it would be more so if gas companies were not compelled to supply illuminating rather than non-illuminating gas.

ARC LAMP.—In 1802, almost immediately after the discovery of the galvanic battery by Volta, Sir Humphry Davy and others experimented upon the spark produced when the current was passed between pencils of different substances. The smallness of the amount of energy available from batteries at first only permitted the formation of intermittent arcs, but in 1809 Sir Humphry Davy showed a continuous arc about three inches long at the Royal Institution. He noticed that the most vivid light was given by carbon pencils, and these have been employed ever since. The first practical use of the arc light was in Paris, in 1878, and with the improvement of the dynamo machine its use has rapidly extended.

Sir Humphry Davy's Discovery.

There is little need to go further into this matter here, as most of the developments were in the mechanism for automatically regulating the lamp, and the recent developments in improving the light will be referred to later.

GLOW LAMP.—Soon after the discovery of the battery it was found that thin metallic wires could be made red or white hot, or even melted, by the passage of the current. This seems also to have been first due to Sir H. Davy, who, in 1810, passed the current from his 2,000 cell battery through a platinum wire one-thirtieth of an inch in diameter and 18 inches long, and stated that this wire instantly became red hot, afterwards becoming white hot and giving off a light of unsupportable brilliancy*.

The incandescence of platinum was afterwards employed in actual incandescent lamps by Edison, who found that by frequent heating and cooling, thus driving out the occluded gases, the platinum would stand a much

* "Electric Lighting by Incandescence," W. T. Hammer, 'American Electrical Review,' March 9, 1907.

higher temperature and give a considerable amount of light. The use of iridium, which has recently come to the front again, seems to have originated with Petrie, and was taken up by Edison and others. The only substance, however, which appeared to combine a highly refractory power, with a suitable resistance, was carbon, which, of course, had to be heated in a vacuum, or, at least, oxygen free space.

The suggestion of using carbon in this way appears to have been first due to Professor Jombard, in 1838, but it was reserved for Edison, in 1879, and Swan to develop it into commercial form. For many years the carbon filament glow lamp was exclusively used, but recently there has been a disposition to revert to metallic filaments, and the more recent improvements will be referred to later.

Having now given a rough idea of the progress of artificial lighting up to a few years ago, it will be well to pause and to consider for a moment the intrinsic nature of the problem. Only by so doing can we realise the recent improvements and see what still remains to be done. It is now universally agreed that light consists of a vibratory disturbance of the ether, which is generally caused by a body whose particles are in a state of rapid agitation. Only such vibrations, however, are termed light which will stimulate the sensation of vision, and it has been found by Angstrom that these lie between 392 and 757 billions of vibrations per second, corresponding to wave lengths in the ether of from 760 to 390 $\mu\mu$.

Since we know in the case of sound that doubling the number of vibrations raises the pitch by an octave, we can say that the whole range of visible vibrations are within an octave. The successive "notes" of this octave are represented by different colours, as in the following table, taken from Barker's Physics:—

Colour		No of Vibrations billions per sec.		Wave length $\mu\mu$	
Ultra Red	370	..	810.0
Red	428	...	700.0
Orange Red	483	...	620.8
Orange	502	...	597.2
Orange Yellow	510	...	587.9
Yellow	516	...	580.8

Colour	No. of Vibrations billions per sec	Wave length $\mu\mu$.
Green	569	527.1
Blue Green	590	508.2
Cyan Blue	604	496.0
Blue	634	473.2
Violet Blue	684	438.3
Violet	739	405.9
Ultra Violet	833	366.0

Vibrations in the Spectrum.

Although these are the limits of the vibrations which affect our vision, it is well known that this is an extremely small part of the total range of possible vibrations of a body. Vibrations from 30 to about 40,000 per second are recognisable as sound, from that up to 400 billions as heat, while above 800 billions they exist as ultra violet light. The lowest number of vibrations detected in the spectrum is 10 billions or 30,000 $\mu\mu$, found by Langley with his bolometer, while Cornu has measured them up to 1,622 billions, or 185 $\mu\mu$.* An incandescent body gives out an immense range of these vibrations extending probably from the lowest frequency up to a number which is higher the greater the degree of incandescence.

It will be easily seen what the real problem of economical artificial lighting is. We require to stimulate a substance to vibrate in such a manner as to give out vibrations within the limits of 392 and 757 billions per second, and none above or below these limits. All vibrational disturbances are communicated to the ether, and imply radiation of energy, so that as far as lighting is concerned all vibrations outside the visible spectrum are useless and wasteful.

On the other hand, it would hardly be satisfactory, even if possible, to produce a vibration of one frequency. This would mean a light of one colour only, and although the efficiency might be perfect, it would give most extraordinary effects with coloured objects. The ideal light must, therefore, have a number of rates of vibration, distributed over the whole range of the spectrum, and of

* Askinass gives 60-70 μ as the greatest, and Schuman 125 $\mu\mu$ as the smallest wave-lengths experimentally determined.

such amounts as to give, approximately, the same appearance to the eye and the same colours as daylight.

To realise more exactly the nature of light we must consider for a moment the nature of the vibration in the ether. It is somewhat difficult to obtain a clear picture of what is going on in this case, but it may perhaps best be understood by a simple analogy. If we take an electrically-charged body, we all know that what are called lines of force, or electric strain, exist in the ether round it, and these lines are in the form of curves starting out from the charged body.

We may, therefore, think of the body as having a number of elastic threads attached to it. Now, suppose that the charged body receives a vibrating motion in a direction at right angles to the line of force considered. The result will be the same as when the end of a string is oscillated. Pulses or waves will travel along the cord or line of force, and these are the transverse electric waves which, when sufficiently rapid, constitute light. As a matter of fact these electric pulses produce magnetic ones at right angles to them, so that we have what are called electro-magnetic waves, such as are always produced by alternating electric currents in conductors, and which are used in wireless telegraphy; the waves thus produced being too slow to affect the eye.

In order to produce these waves of light we have, therefore, two courses open to us. We may either attempt to produce these electro-magnetic vibrations in the ether directly by alternating currents with frequencies of 400 to 800 billions per second, or we may excite electrical and magnetic vibrations in the particles of a substance which impart them to the ether. The first is the more scientific procedure, but it has hitherto shown no prospect of success.

The Cause of Light.

The most rapid electro-magnetic oscillations yet produced have been of the order of one-eighth of a billion per second, instead of 400 billion, which is the minimum necessary for light. These vibrations are produced by causing sparks to pass between little spheres, thus causing oscillations within them, but it can be shown mathematically that the spheres would have to be reduced to about the size of atoms to produce oscillations of sufficient frequency. In fact, the light emitted by any substance

is undoubtedly due to electro-magnetic vibrations in its molecules.

The only other course open to us, therefore, is to stimulate the vibrations by agitating the molecules of a substance, and this can be effected either by heating the substance, by passing an electric current through it, by vibrations of other rates, or by causing a shower of particles at a very high velocity to impinge upon it. Modern investigation has proved almost beyond all doubt that instead of substances being composed of indivisible atoms each of these atoms is composed of 700 or more smaller particles, called electrons. The atoms, in fact, may be considered as aggregations of electrons, like mulberries, or, rather, like swarms of bees, each swarm keeping in one body, although they may move relatively to one another.

These electrons really revolve round their common centre of inertia like planets round the sun, and whenever such groups collide their internal motions may be accelerated. It has long been known that the heating of a body consists of imparting a vibratory motion to it, and thus making its particles move at a higher speed, and collide with each other more frequently; and if these collisions are sufficiently rapid and violent the motion of the electrons in the atoms will be rapid enough to produce light waves in the ether.

Principle of the Arc Lamp.

Whenever an electric current passes through a substance it implies that a stream of electrons travels from the negative to the positive pole. Each atom is supposed to have one or more electrons (six being the maximum) which can be detached, and in the case of a conducting body these detachable electrons are continually handed on from one atom to the next, thus constituting the current. These interchanges are naturally accompanied with rapid motion, manifested as heat, or as light, if the current is very strong. This is the principle of the electric glow lamp, or arc lamp.

Thirdly, we have a method of stimulating certain vibrations in a body by means of other vibrations of a different rate. This is illustrated in the two phenomena of calorescence and fluorescence. Each compound substance being made up of molecules composed of various numbers of various sorts of atoms, will have

a definite time or times of vibration which it will most easily respond to, and it may even vibrate at these rates when stimulated by other vibrations of quite different rates. As an example, a pier in the sea, when struck by the waves at intervals of a few seconds, may tremble at a very high rate.

This is akin to the phenomenon of calorescence, where some bodies, when heated to a comparatively low temperature, will give out a light of quite a high frequency. In fluorescence we have almost the same effect, except that visible light is sometimes emitted by a substance, when illuminated by a light of higher frequency, such as that we term ultra-violet light. In phosphorescence the result persists for some time after the exciting cause is removed.

Lastly, we may provoke the natural vibrations of the body by impacting upon it a shower of particles at an extremely high velocity. This was first done on any considerable scale by Sir W. Crookes, who found that when a tube was exhausted to a high degree, and a discharge was passed through it, substances placed opposite the negative pole or cathode became intensely luminous. He came to the conclusion that this was due to a stream of what he termed "radiant matter," which was projected with high velocity from the negative pole, and stimulated the vibrations of the substance on which they impinged.

It is now supposed that this radiant matter consists of electrons projected off the negative pole with a velocity approaching that of light, and that in consequence of the small number of air molecules present, these are able to traverse long distances. This method of producing light by the impact of showers of electrons is termed "luminescence," and it has been greatly studied on the continent by Wiedemann, Plucker, Lenard, Hittorf, and many others. The recent researches on the radio-active bodies, radium, polonium, etc., have shown that these bodies are continually projecting electrons which will cause luminescence in suitable substances.

With the foregoing in mind we may now pass to the recent remarkable developments in artificial lighting.

Incandescence Methods.

From what has been said as to the producing of vibrations by heating it is fairly obvious that little economy

can be expected from this method under ordinary circumstances. The blind agitation or joggling of the particles produces vibrations, it is true, but (in the case of most solid bodies) of every sort mixed together. Below a temperature of about 400° C., although a considerable amount of energy is radiated, it is below the limits of vision, and as the temperature is raised and visible radiation is produced, there is yet a great increase of the invisible radiation.

It was first stated by Stefan, and it has been since confirmed by the researches of Boltzmann, Lummer, and Pringsheim, Rosa, and Féry, that the total radiation is proportional to the fourth power of the absolute temperature. For an absolutely black body Kurlbaum has stated that the radiation is .01763 calories per square cm. from a surface at 100° C. to one at 0° C.* We have also the important law of Wien, which states that the dominant wave-length, or wave-length at which the greatest energy is radiated, is inversely proportional to the absolute temperature. Calculations which the writer has made from the results of Paschen and Wanner give for the dominant wave length in 1,000ths of a millimeter $\lambda = \frac{2888}{T}$. Hence, for a wave-length of $.54 \mu$, which is approximately the most luminous part of the spectrum $T = \frac{2888}{.54} = 5,350^{\circ}$ C. absolute, or $5,075^{\circ}$ C. on the ordinary scale, which is given by Féry as about the temperature of the sun.

From these considerations it is easily seen that almost the only possibility of obtaining a reasonably efficient source of light by incandescence is to have a very high temperature. The following table, from Dr. Fleming's "Electric Lamps and Electric Lighting," shows the approximate temperature corresponding to various degrees of incandescence.

			Centigrade.
Bodies just visible in dark	...	...	400
Dull red heat at	...	...	700
Dull cherry-red	...	...	800
Full cherry-red	...	...	900

* Dr. C. Féry, 'Rayonnement Calorifique et Lumineux,' p. 69, gives $4.74 \times 10^{-12} T^4$ as the radiation in watts per square cm. from a carbon filament.

Centigrade.

Melting point of silver	945
Clear red heat	1,000
Melting point of gold	1,045
White cast iron melts	1,040
Orange red heat	1,100
Bright orange	1,200
White heat	1,300
Steel melts at	1,300
Bright white heat	1,400
Dazzling white heat	1,500
Palladium melts at	1,500
Wrought iron melts	1,600
Platinum melts	1,775
Iridium melts	1,950

Experiments have been made by Langley, by Merritt and Marks, and by Nicholls, at the Cornell University, upon the proportion of light to total energy in various sources.

Source of Light.	Watts per candle.	Ratio of Luminous to total energy.	Effective Watts per c p
Candle . . .	86	2 to 3%	1.7 to 2.6
Oil lamp . . .	57	3%	2.7
Petroleum lamp	42.8	3%	1.8
Argand gas lamp	68.8	2.4% 4%	1.65 to 2.8
Electric glow la'p	3½	Langley. 3 to 7%	.105 to .245
Electric arc . . .	.8	5 to 15%	.04 to .12
Magnesium wire		15% Fleming 35% Rogers	
Electric discharge in gases . . .		33%	
Sun (Langley) . . .		35%	
Mercury vapour lamp . . .	.52	60%	.34
Firefly (Langley)		nearly 100%	

The Welsbach Lamp.

As far as flame incandescent lamps are concerned, it is evident that the chief requisite is a highly refractory substance which will stand an extremely high temperature without rapid deterioration, and a flame of high

temperature. This is what has been done in the case of the oxyhydrogen light, and in the modern Welsbach lamp, in which a thoria mantle is used. It is not sufficient, however, that a large proportion of the radiation should be luminous, we must also have a good emissivity. It has been shown by Swinburne, as before stated, that a certain proportion (about $\frac{1}{2}$ per cent.) of cerium oxide, which is dark in colour, is necessary in order that the radiation is sufficient. Above this amount the efficiency is diminished, and this is attributed by Swinburne to the increase of radiation actually lowering the temperature of the mantle.

In electric glow lamps the refractory nature of carbon, combined with its conductivity, has made it appear, until lately, the only possible material, and research was almost stopped in that direction for many years. It has been found impossible to raise the efficiency of the ordinary carbon filament much above three watts per c.p. owing to the throwing off of carbon particles and the blackening of the bulbs*.

According to Dr. Fleming,† Mr. Meritt, of Cornell, found the following for the luminous efficiency of a 16 c.p. Edison glow lamp at different voltages:—

Working volts.	Candle power.	Power absorbed in Watts.	Watts per candle power.	Luminous radiation in Watts.	Luminous efficiency %	Luminous radiation Watts per candle.
74.2	.9	34.6	38.0	.18	.5	.20
91.6	4.8	56.2	12.0	.68	1.2	.142
97.3	7.3	64.6	9.0	1.13	1.7	.155
100.3	8.9	69.3	7.8	1.62	2.3	.180
107.6	14.6	81.6	5.6	2.97	3.6	.204
109.3	16.3	84.4	5.2	4.57	5.4	.280
124.1	38.2	115.4	3.0	7.46	6.5	.195

* The G.E. Co. of America has recently made filaments of an efficiency of $2\frac{1}{2}$ watts per c.p. by taking an ordinary treated filament and heating it to 3,000 or 3,700° C. in an electric furnace.

† 'Electric Lamps and Electric Lighting,' J. A. Fleming, F.R.S., p. 83. The figures in the last column have been calculated by the present writer.

In an American publication, 'The Cyclopædia of Applied Electricity,' the following is given as the temperature of a glow lamp filament at different efficiencies.

Glow Lamp Temperatures.

Temperature.	Watts per candle.	Temperature.	Watts per candle
1200	9.8	1275	4.5
1225	7.5	1300	3.5
1250	5.75	1325	2.8

The variation of efficiency and life of these lamps is given by the same authority as follows: —

Voltage % normal.	Candle power % of normal	Watts per c.p	Life % normal
90	58	5.36	—
95	73	4.26	310
100	100	3.5	100
105	129	2.95	39
110	169	2.53	16

These figures show both the extreme importance of correct voltage for carbon filament lamps and the hopelessness of attempting to secure a much higher efficiency from them, without radical change in their construction.

The large amount of research on luminous radiation on the continent has, however, led to the attempt to gain higher temperatures with the most remarkable results.

The first of these was obtained by Dr. Nernst*, in 1899, who, considering that it would be impossible to

* "Nernst Electric Lamp," J. Swinburne, 'Soc. Arts Journal,' 47, pp. 253-260, 1899. E. de Fodor ('Zeitschrift Electrochem Wien,' 17, pp. 172-178, 1899) states that Jablochkoff, in 1877, patented a lamp consisting of a strip of kaolin 38 by 10 by 2 mm., and Edison did the same with other refractory substances, and used a heating spiral.

obtain metallic filaments of a sufficiently high melting point, tried some of the infusible oxides used in the limelight and gas mantles, and found that they were conductors at high temperatures. He adopted a mixture of zirconia and yttria, in the form of a small rod, which is electrically heated at starting by a small coil, which is automatically switched out when the filament begins to conduct. These lamps seem to average about two watts per candle with a life of 500 hours. Messrs. Drake and Gorham have kindly lent me some of the most recent of these lamps.

It has now been found that a number of metals will serve as filaments for these high temperatures. Dr. Auer von Welsbach was the first to use osmium, and these lamps have been on the market for some time. They are only made, however, up to about 25 volts, requiring four in series on 100 volt circuit. Next, Bolton, at the works of Messrs. Siemens and Halske, produced the Tantalum lamp, which is coming into extensive use. Tantalum appears to have a melting point of about $2,250^{\circ}$ C., and can be drawn into wire. It makes a very long and delicate filament, but seems to work well on direct currents up to 110 volts, with an energy consumption of about 1.5 watts per candle, and a useful life of 500 hours. With alternating currents, however, the lamps blacken and the filament soon breaks.

A Remarkable Achievement.

A number of other lamps have been produced with iridium, tungsten, molybdenum and zirconium filaments. The Osram lamp consisting of osmium and tungsten has been found to have a consumption of about 1.08 watts per candle *after* running 1,000 hours. This is a most remarkable achievement, and means that the consumption of energy is only one-third or one-fourth of that in the ordinary carbon filament lamps. Incidentally it should be mentioned that these lamps are much less sensitive to fluctuations in voltage, and this should make them good secondary standards for photometric work.

A most interesting point in the construction of these lamps is that many of the filaments are made from colloidal solutions or suspensions of the metals, the state of which is rendered visible by the ultra microscope. Many of you will remember the exhibition of this instrument

by Messrs. Siedentopf and Zigmondy, in 1904. Messrs. Reichert, of Vienna, have just introduced a simplified form of this device, and Mr. J. H. Baugh has kindly arranged to show you a colloidal solution of silver with it this evening.

Attempts have been recently made to improve the efficiency of the arc lamp. This has been effected in the case of the flame arc lamps, in which calcium and magnesium salts are introduced, which give in some cases two or three times or more light for the same energy consumption. I have some doubt whether this is due to increase of temperature or whether it is not more probably a form of calorescence or fluorescence. On examining the spectrum of such an arc we generally find a number of very bright lines indicating that there is a well marked selective emission bringing a much larger proportion of the radiation within the spectrum. The combination of the use of these materials with improved disposition of the carbons enables one to get a mean hemispherical candle-power of about 2,000, or more, for an expenditure of 500 watts, or more than 4 c.p. per watt.

As to luminescence lamps the only practicable one yet devised is the mercury vapour lamp of Cooper-Hewitt, Bastian, and others. The luminous efficiency of this lamp is said to be as high as 60 per cent., but it is somewhat difficult to reconcile this with the energy consumption which has been stated from tests made at the Reichsanstalt to be .52 watts per c.p. without, and .88 watts per c.p. with, the necessary resistance, thus making it appear little more efficient than the more recent incandescent lamps. The fact is that experimental tests of the luminous efficiency are very liable to be deceptive, and much more work is needed in this direction. The great difficulty with the mercury vapour lamp, however, has been with its extraordinary colour distorting effects, and many attempts have been made to introduce fresh lines into its spectrum. The only devices, however, which have been at all successful, are those of employing cadmium or by the fluorescence of rhodamine.

Many minerals fluoresce somewhat brilliantly in a cathode stream, chief among these being corundum, or silicon carbide, barium platinocyanide, scheelite, or calcium tungstate, willemite, dolomite, and zinc blende. None of them, however, appear yet to be within practi-

cal politics, not so much on account of efficiency or colour, as on account of the costly nature of the cathode ray-form of energy. This difficulty should not be unsurmountable when the importance of the subject is realised. The recent work of Paulsen in the production of undamped electrical oscillations of high frequency opens up new possibilities already.

Finally, I should like to plead for a greater interest in this important subject in this country, both by Opticians and by others. Although much has been done in the past, much yet remains to be done for human beings to catch up the firefly. Surely there is more human and commercial advantage to be gained from conquering these problems, than in wrangling over optical politics. It is time that we united in an effort to show other nations that instead of quarrelling among ourselves while they do the work and reap the advantage, we are doing something worthy of the country we live in.

MR. ROSENBERG said that progress was also being made in gas-lighting. Experiments were being made with organo metallic compounds such as magnesium, calcium, or aluminium, in the form of an ethyl, ethylate, or methylate, or similar silicate compound; the gas was passed over these volatile compounds, and on ignition gave the same effect as the ordinary mantle, and the light-giving power did not decrease with use.

Similar methods had also been used to improve the candle—the organo-metallic compounds being mixed with the fats or paraffin.

MR. LEON GASTER said that the tantalum lamps had stood the efficiency and life tests on direct current, but were not satisfactory on alternating current, more particularly with the higher frequencies.

The "Osram" lamp and the Zircon "Z" lamp worked satisfactorily on both circuits, and efficiencies of 1 watt per candle were claimed.

The lecturer having referred to the Cooper-Hewitt mercury vapour lamp, he would like to mention also another vapour lamp, which was Macfarland Moore's invention. This vacuum lamp worked only with alternating current at high voltages and at very high frequencies, and consisted of a glass tube of convenient diameter, and of any desired length, having electrical conductors, her-

metically sealed into the opposite ends, and the air within exhausted to such a degree as to bring it to the point of conductivity for electric current of available pressure. The passage of the current raised the rarefied gases to a state of incandescence, and the lighting so produced commended itself on account of the low intrinsic brilliancy and consequent avoidance of retinal fatigue, the diffusion obtainable being far more perfect than with light sources of a point character, the efficiency of the system was claimed to be very high. He was only mentioning this method in order to indicate the direction of researches worthy to be more closely followed in the future.

Although the paper dealt exhaustively with the evolution of artificial illumination, he ventured to think that the question of the influence of artificial light upon sight would have, in the future, to receive a greater attention than it had in the past. The physiological factors in illumination and photometry ought to be investigated from more than one point of view, and for that purpose the Optical Society seemed to be best suited to have such work undertaken by its members. He took that opportunity to suggest that oculists, when examining their patients, should also try to keep a record regarding the nature of the light used by their patients; valuable results might be obtained from comparing such data, and perhaps a more corroborative conclusion could be drawn showing the relation between the strength and colour of the illuminants, and the diseases of the eyes.

The question as to what was really the best and most suitable method for artificial illumination, and the determination of the minimum amount of light necessary for different purposes, would be very useful. He should like to mention that at a recent meeting of the "Illuminating Engineering Society" of the United States, a discussion, in which a great number of oculists took part, took place on the physiological aspects of the subject, but the opinions expressed did not seem to be quite corroborative, proving that the subject had not as yet been sufficiently investigated. The introduction of many new lamps and improved methods of illumination was only of recent date, and, therefore, the subject would have to be more closely studied now. Anything the Optical Society could do in that connection he was sure

would be much appreciated by all concerned with the use of artificial illumination.

MR. V. H. MACKINNEY said that he had made a series of life tests on lamps, including 12 Osmium and 12 Tantalum lamps; the results showed an average life of well over 1,000 hours, the efficiency was 1.2 watts per candle at the beginning, and 2 watts after 1,000 hours for the Osmium, while the Tantalum lamps were rather less efficient after 1,000 hours owing to blackening.

The Osmium lamp showed no blackening if it were not run above its *nominal* voltage, while the Tantalum gave a black band just in front of the filament. This uneven blackening necessitated a modification of the mean spherical reduction factor for different times in the life. This difficulty could be avoided by the use of an "Ulbricht sphere," but on Mr. Howe's suggestion the sphere was replaced by a one meter cube and the results were quite satisfactory. He considered that the difficulties of obtaining accurate comparisons of the different coloured lights had been exaggerated, and claimed an accuracy of 2 to 3% for his own observations.

Mr. Chalmers thought that as a compromise between the line spectrum and the continuous spectrum, it might be possible to form a spectrum consisting of a number of *wide* bands; this, though probably not so efficient as a line spectrum, might be, physiologically and practically, more desirable.

DR. DRYSDALE, in reply, said that the use of refractory materials in enriching gas was most interesting, though the loss of the refractory materials limited the application. The physiological questions raised by Mr. Gaster were of the utmost importance, and would require careful investigation. The ideal light of the future would, he thought, consist of a number of bands in the visible spectrum.