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SOME CHEMISTRY OF LIGHT.[1]

BY W. R. WHITNEY.

From the dawn of history, chemistry has had much to do with the production of artificial light, and I wish now to recall to your minds a few illustrations. I will not burden your ears with a long story on physics or mechanics of light, but intend treating the subject of artificial light so as to show you that it has always been largely a subject for chemical investigation. I want to impress upon your minds that it is still a most green and fertile field for the chemist. I have tried to arrange a few familiar experiments to illustrate some of the facts touched upon, and it should be borne in mind that I am trying to interest an audience of chemists from widely different fields, rather than to present a chronological record of recent experimental research.

I cannot tell just when chemistry was first scientifically applied to a study of artificial light. Most cardinal discoveries are made by accident and observation. The first artificial light was not made by design nor was the first improvement the result of chemical analysis. It is supposed that the first lamps were made from the skulls of animals, in which oil was burned. Herodotus, describing events about three centuries before Christ, says of the Egyptians: "At the times when they gather together at the city of Sais for their sacrifices, on a certain night they all kindle lamps many in number in the open air round about the houses; now the lamps are saucers full of salt and oil mixed and the wick floats of itself on the surface and this burns during the whole night." This night was observed all over Egypt by the general lighting of lamps, and these lamps

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[1] Presidential address delivered at the Boston Meeting of the American Chemical Society, December 29, 1909.

were probably the forerunners of the well-known Greek and Roman lamps of clay and of metal which are so common in our museums.

The candle and lamp were probably invented very much earlier. We know that both lamps and candles were used by the priests of the Jewish temple as early as 900 B. C. The light of those candles and lamps was due, as you know, to particles of carbon heated in a burning gas.

It is not fair to the chemists of our early candle-light to skip the fact that great chemical advances were made while candles were the source of light, and so I touch for a moment upon one of the early applications of chemical knowledge. The fats and waxes first used were greasy and the light was smoky and dull. They were capable of improvement and so the following chemical processes were developed and applied to the fats. They were first treated with lime, to separate the glycerol and produce a calcium soap. This was then treated with sulphuric acid, and the free stearic and palmitic acids separated. These acids were then made into candles and gave a much whiter light than those containing the glycerol ester previously used. Similar applications of chemical principles are probably known to you all in the refining of petroleum. The crude distillate from the rock oil is agitated with sulphuric acid and then washed with a solution of sodium hydroxide. This fact accounts, in considerable degree, for the advance of a number of other chemical processes. An oil refinery usually required the presence of a sulphuric acid plant in the immediate vicinity, and this often became a source of supply for other new chemical industries.

Very great advances have been made in the use of fats and oils for lighting purposes, but there is so much of greater interest in later discoveries that we will not consider many of them. The distillation of gas from coal or wood in 1739 was a chemical triumph, and a visit to a gas plant still forms one of the main attractions to the young chemist in an elementary course of applied chemistry. The first municipal gas plant was established in London, just about 100 years ago. The general plan, so apparently simple to us to-day, was at its inception judged impracticable by engineers. In spite of other methods of illumination, the improvements in the making, purification and application of illuminating gas have caused a steady increase in its use. Gas owes its illuminating power to the fact that a part of the carbon in it is heated to incandescence during the combustion of the gas. It must contain, therefore, such carbon compounds as yield a fair excess of carbon, and this knowledge has led to the schemes for the enrichment of gas and for the use of non-luminous water-gas as a base for illuminating gas.

Various schemes were devised in the early part of the 19th century for using gas to heat to incandescence, rods or surfaces of lime, zirconia and platinum. This was not at first very successful, owing to imperfect combustion of the gas. The discovery of the Bunsen-burner principle was made a little later. By thus giving a much higher temperature to the gas flame and insuring complete combustion, this gave new impetus to this branch, and the development of suitably supported oxide mantles continued for half a century.

Most prominent in this field is the work of Auer von Welsbach. It was a wonderful series of experiments which put the group of rare-earth oxides into practical use and started a line of investigation which is still going on. The Welsbach mantle practically substitutes for the carbon of the simple gas flame, another solid in a finely divided shape capable of giving more efficient light. This allows all of the carbon of the gas to contribute to the production of a hotter flame. But more interesting than the mechanical success, to my mind, is the unforeseen or scientifically unexpected discovery of the effect of chemical composition. By experiment it was discovered that the intensity and color of the various mixtures of difficultly fusible oxides at incandescence varied over a wide range. Thus a broad field for unforeseen investigation was opened. The samples of Welsbach mantles which you see before you were kindly loaned to me by Mr. H. S. Miner, of the Welsbach Company, and beautifully illustrate the application of advanced chemical work to this industry. The color and intensity of the light varies in an unexplained manner with slight differences in composition of the mantle. The following are the composition and candle powers of the mantles shown:

CANDLE POWER OF MANTLES, RANGING FROM PURE THORIA TO 10 %CERIA.

No.	Per cent. thoria.	Per cent. ceria.	Candle power.
367	100.00	0.00	7
368	99.75	0.25	56
369	99.50	0.50	77
370	99.25	0.75	85
371	99.00	1.00	88
372	98.50	1.50	79
373	98.00	2.00	75
374	97.00	3.00	65
375	95.00	5.00	44
376	90.00	10.00	20
69		La, Zr, Ce, oxides,	30

The methods of making present mantles were also a part of Dr. Auer's contribution to the art. Suitably woven fabrics are dipped into solutions of the rare-earth salts; these are dried and the organic matter burned out, leaving a structure of the metal oxides.

The pure thoria gives a relatively poor light. The addition of the ceria, up to a certain amount, increases the light. This added component is called the "excitant," and as the cause for this beneficial action of the excitant is not known, it is possible that further discoveries along this line will yet be made. There is hardly a prettier field for chemical speculation than is disclosed by the data on these light efficiencies. For some unknown reason, the change in composition by as little as one per cent. varies the luminosity over tenfold, and yet, more than one per cent. of the excitant (ceria) reduces the light. Besides the temptation to speculation, such disclosures of Nature encourage us to put greater trust in the value of new experiments, even when accumulated knowledge does not yield a blazed trail for the pioneer. By giving a discovery a name and attaching to it a mind-quieting theory, we are apt to close avenues of advance. Calling this small amount of ceria an "excitant" and guessing how it operates, is directly harmful unless our guess suggests trial of other substances.

One of the explanations proposed to cover the action of the ceria ought to be mentioned, because it involves catalysis. This is a term without which no chemical lecture is complete. Some think that the special mantle mixture causes a more rapid and localized combustion and therefore higher temperature, by condensation of gas in its material. Others think that this particular mixture permits of especially easy and rapid oxidation and reduction of its metal oxides themselves in the burning gas mixture. The power which catalyzers have of existing in two or more states of oxidation seems to apply also to the ceria of the Welsbach mantle. Whatever the truth may be, it has been shown by Swinton[1] that when similar oxide mantles are heated to incandescence by cathode rays *in vacuo*, the presence of one per cent. ceria produces only a very small increase in the luminosity of thoria. It is interesting to note that in the gas flame pure ceria gives about the same light as pure thoria, while in the cathode rays of the Crookes tube, with conditions under which ceria gave almost no light, pure thoria gave an intense white light. These facts, which are still unexplained, illustrate how little is understood in this field.

I will merely refer to the fact that vapors of gasoline, kerosene, alcohol, etc., are also now used in conjunction with the Welsbach mantles.

The field of acetylene I must also omit with a mere reference to the fact that the manufacture of calcium carbide was a chemical discovery and the action of water upon it, producing the brilliantly-burning acetylene gas, was another.

Turning now to electrical methods of generating light, we find the chemist early at work. Sir Humphry Davy and others, at the dawn of the 19th century, showed possibilities which since that time have been developed into our various types of incandescent and arc lamps. We naturally attach Mr. Edison's name to the development of the carbon incandescent lamp, because it was through his indefatigable efforts that

[1] *Proc. Roy. Soc., London* (*A*), 65, 115.

a practicable lamp and illuminating system were both developed. It had long been known that platinum, heated by the current, gave a fair light, but it melted too easily. A truly enormous amount of work was done in attempts to raise the melting-point of the platinum, and the effect of occluded gases, of annealing, of crystalline condition, etc., etc., were most carefully studied, but the results were unsatisfactory. He was therefore led to the element carbon as the next most promising conductor of high melting point. Edison's persistent and finally successful attempt to get a dense, strong, practical filament of pure carbon for his lamps, is one of the most encouraging lessons to the chemist of to-day. This history needs to be read in the light of the knowledge of carbon at that time and the severe requirements of a commercially useful carbon filament. It illustrates the value of continued effort when it is based on knowledge or sound reasoning. The search was not the groping in the dark that some of us have imagined, but was a resourceful search for the most satisfactory, among a multitude of possible materials. From our point of view, all subsequent changes in choice of material for incandescent lamp filaments have been indicated by the knowledge that high melting point and low vapor-tension were the first requirements. If you will consult the curve of the *melting points* of all the *elements*, as plotted against their *atomic weights*, you will see at once that the desired property of high melting point is a periodic functionof the atomic weight. And it is this fact, which was independently disclosed as a general law by Meyer and Mendeléeff, in 1863, that has aided in the selection of all the new materials for this use. You will notice that the peaks of the curves are occupied by such elements as carbon, tantalum, tungsten, osmium, etc., which are all lamp materials.

A study of the laws of *radiation* also soon played.a part in incandescent lamp work. The early rough and black filament of bamboo was first replaced by a polished black carbon filament, and later by one which had a bright, silver-gray coat of graphite. A black body at any temperature radiates the maximum possible energy in all wave lengths. Heated to incandescence, it will *radiate more invisible and useless infra-red rays than any other* opaque material at the same temperature. A polished metal is therefore a more efficient light source than the same metal with a black, or even rough surface. This is derived from Kirchoff's Law of Radiation and Absorption, which was early established.

It may seem like penetrating too far into detail to consider for a moment the changes in structure and surface which the carbon filament of our incandescent lamps has undergone, but the development of such an apparently closed problem is instructive because it has yielded to such simple methods of attack. The core, or body, of the carbon filament of to-day is made by some one of the processes based on dissolving and reprecipitating cellulose, such as are used in artificial silk manufacture. The cellulose solution is squirted through a die into a liquid which hardens it into dense fibers. These cellulose fibers are then carbonized by being heated, out of contact with the air, at as high a temperature as possible with gas furnaces. All of this is also merely the application of chemistry which was first worked out in some of the German chemical laboratories. This plain carbon filament, the result of this simple process which might have been satisfactory in the early days, would be nowadays useless in a lamp, as its practical life is only about 100 hours at 3 watts per candle. In a subsequent process of manufacture it is therefore covered with a steel-gray coating of graphite, which greatly improves the light-emitting power. This coat is produced by heating the filament in an atmosphere of benzene or similar hydrocarbons. The electric current which heats the filament is of such an intensity that the decomposition of the hydrocarbon produces a smooth, dense deposit of graphite. With this graphite coat the filament now burns about 500 hours; but the simple graphite coat can itself be improved. It is improved by being subjected, for a few moments, in the electric furnace, to a temperature of about 3500°, so that the life now becomes about 1500 hours under the same operating conditions as before. The product of this treatment is known as the metallized filament, because its temperature coefficient of resistance is by this last step made similar to that of the metals.

A case is shown on the table which contains illustrations of the.carbon incandescent lamp manufacture in the shape of cellulose solution, squirted cellulose fiber, carbonized fiber, etc.

Among the incandescent lamps which are before you I have one containing a platinum wire filament. You will see, as I turn on the current, that the intensity of its light is not very great, even when the current is sufficient to melt the wire. A much greater luminosity is produced by a plain carbon filament, and a still greater by the graphite coated and metallized carbon before they are destroyed. In the case of carbon, the useful life of the lamp depends much more on the vaporization of the material than on its melting point, and these lamps, as shown, will operate for a short time at very much greater efficiencies or higher temperatures than is possible when a practical length of life is considered. Thus, besides the physical effect of surface quality, we have evidence of differences in the vapor pressure of different kinds of carbon. It looks as though carbonized organic matter yielded a carbon of much greater vapor pressure for given temperature than graphite, and that even graphite and metallized graphite are of quite distinctly different vapor pressures at high temperatures. It may be interesting to note here that if the carbon filament could withstand for 500 hours the maximum temperature which it withstands for a few moments, as shown in the experiments, then the cost of operating incandescent lamps could be reduced to nearly a fifth of the present cost.

It was discovered by Auer von Welsbach that the metal osmium could be made into a filament, though it could not be drawn as a wire. The osmium lamp was the first of the recent trio of metallic filament incandescent lamps. The tantalum lamp, in which another high melting point metal replaces the superior but more expensive osmium, has been in use six or eight years. This surpasses the carbon in its action, and on running up to its melting-point it shows still brighter light than carbon. More recently the tungsten filament lamp has started to displace both lamps. At present this is the element which withstands the highest temperature without melting or vaporizing, and on being forced to its highest efficiency in a lamp you see that it reaches higher luminosity and that there is a similarity to carbon and tantalum in that an enormously greater efficiency may be produced for a very short time than can be utilized for a suitable length of life. The inherent changes at these temperatures, distillation or whatever they are, quickly destroy the lamp. The lamp will burn an appreciable time at an efficiency fifteen times as great as that of the common operating carbon incandescent lamp (at 3 watts per candle). In other words, light may be produced for a short time at an energy-cost one-fifteenth of common practice, so that there is still a great field for further investigation directed towards merely making stationary those changing conditions which exist in the burning lamp.

While it is generally true that the light given by a heated body increases very rapidly with rise of temperature above 600°, the regularity of the phenomenon is commonly overestimated. A certain simple law covering the relation between the temperature and the light emitted, has been found to apply to what we have called a black body. This so-called Stefan-Boltzmann law states that "the total intensity of emission of a black body is proportional to the fourth power of the absolute temperature." There are, however, very few real black bodies in the sense of the law. The total emission from a hole in the wall of a heated sphere has been shown experimentally to follow the law rigidly, but most actual forms and sources of illumination do not. Most practical sources of artificial light are more efficient light producers than the simple law requires. This may be said to be due to the fact that these substances have characteristic powers of emitting relatively more useful energy as light than energy of longer wave length (or heat rays). Most substances show a power of selective emission and we might say that an untried substance, heated to a temperature where it should be luminous, could exhibit almost any conceivable light effect. It is still less possible to predetermine the proportionality between luminous and nonluminous emission. A simple illustration will serve to make this clear: if a piece of glass be heated to 600°, it does not emit light. If some powder such as zirconia or thoria be sprinkled upon it, light is emitted and the proportion of light at the same temperature will depend upon the composition of the powder. Coblentz has shown, both for the Auer mantle and for the Nernst glower, that the emission spectra are really series emission bands in that portion of the energy curve which represents the larger part of the emitted energy. This is in the invisible infra-red part, and so the laws which govern the emission at a given temperature depend upon the chemical composition of the radiant source. Silicates, oxides etc., show characteristic emission bands.

One of the most attractive fields of artificial light production has long been that of luminous gases or vapors. It has seemed as though this ought to be a most satisfactory method. The so-called Geissler tubes in which light is produced by the electrical discharge through gases at low pressure are familiar to all. The distribution of the energy emitted from gases is still further removed than that of solids from the laws of a black body, and a large proportion of the total electrical energy supplied to a rarefied gas may be emitted as lines and bands which are within the range of the visible spectrum. These lines, under definite conditions of pressure, etc., are characteristic of the different elements and compounds. The best known attempts to utilize this principle are the Moore system of lighting, in which long tubes of luminous gas are employed, and the mercury lamps, which, while more flexible on account of size, are still objectionable because of the color of the light. A simple form of mercury arc is shown.

It is rather interesting that the efficiencies of all of these various sources of electric light are not nearly so widely different as one would expect from a consideration of the widely divergent methods of light production employed.

From the light of a vapor or gas to that of an open arc is not a wide step, but the conditions in the arc are apparently quite complex and there is a great deal of room for interesting speculation in the phenomena of an arc. Briefly, there are two kinds of arcs to be considered in lighting. One has been in use for a century, the other for a few years only. The first is the successor to Sir Humphry Davy's historical arc between charcoal points. In this kind of arc the current path itself is hardly luminous and the light of the lamp is that given by the heated electrodes. In case of direct current it is the anode, or positive electrode, which gets the hotter and gives far the greater part of the light. In the carbon arc shown, it will readily be seen that the light is emitted by the heated solid carbon of one electrode. This gives a steady source of light, but is not so efficient as an arc in which material in the arc stream itself is the source of light. The arc may be made to play upon rare earth oxides, and these, being heated to incandescence, increase the luminosity, but this has not proved useful. The more common way is to introduce into the carbon electrode certain salts which volatilize into the arc and give a luminous effect. Here cerium fluoride, calcium fluoride, etc., are used, and the color of the arc, just as in the case of gas mantles, may be varied by varying the composition of the electrodes. This is seen in the arc from the carbon electrodes containing such salts.

I have arranged several different kinds of arcs and before each is a magnifying lens, to throw the image of the arc upon a screen. This permits our seeing the phenomena of the arcs and observing the characteristics of each. The very essential difference between the plain carbon arc and the luminous or flaming arc is readily noticed. In the latter case the greater part of the light is due to the incandescent metallic vapors in the space between the electrodes. Substitution of one chemical for another in such flaming arc electrodes has covered quite a wide range of chemical investigation. Salts are chosen which give the greatest luminosity without causing the formation of too much ash or slag. Some compounds of calcium, for example, are practicable, while others are not, though all of these would, under suitable conditions, yield the calcium spectrum.

If such salts as calcium fluoride were conductors at ordinary temperature, useful electrodes for flame arcs would probably be made from them. Such conducting materials as iron oxide, carbides, etc., have been used for flame arc electrodes, and a great many of the so-called magnetite arcs are now in use. The electrodes in this case are largely magnetic oxide of iron, with such other ingredients as titanium and chromium oxides, to increase the intensity of light, to raise the melting point of the mixture, etc.

As will be seen from observing this arc, the light is very white and intense and is generated by the heated vapors of the arc proper. A great many modifications of this arc principle are possible. Titanium carbide and similar substances give characteristic arcs, and some of them are very intense and efficient. For purposes of comparison, I have added to this illustrating experiment an arc of titanium carbide and one of copper.

The Nernst Lamp.

A distinct species of electric incandescent lamp is that invented about 10 years ago by the well-known physical chemist, Professor Nernst. This employs for filaments a class of bodies which are not electrical conductors at all at ordinary temperatures, and which, at their burning temperatures, do not conduct the current as metals and carbon, but as a solution does. This kind of conductivity, the electrolytic, involves electrochemical decomposition at the electrodes, and in the case of the Nernst filaments these otherwise destructive reactions are rendered harmless by the continual oxidizing action of the air. For this reason this type of lamp will not burn *in vacuo*. For its most perfect utility the principle of the Nernst lamp seems to require a mixture of oxides, because a single one is not so good a conductor nor so luminous. It uses oxides because these are the most stable compounds known, and it uses the rare-earth oxides because they have higher melting points than other oxides. As the efficiency very rapidly rises with the temperature, there is a great advantage in using the most infusible base possible. For that reason, zirconia, thoria, etc., are usually employed.

In this lamp a rod or filament of an oxide mixture, much like those used in Welsbach mantles, is heated by the current externally applied until it reaches a temperature at which it becomes a good conductor itself. Here again the peculiar laws of light radiation are illustrated, the light emitted at a given temperature being determined by the nature of the substance. Just as the pure thoria gives a poor light compared to the mixture with one per cent. ceria, so a pure zirconia rod, heated by the current, gives much less light than a rod containing a little thoria, ceria or similar oxide.

Work done by Coblentz on the energy-emission of such rods shows the emission spectra, at least in the infra red, to vary with the nature of the substance. In general, the spectra are not continuous like the spectra of metals and black bodies, but seem to occupy an intermediate position between these and luminous gases, which we know have usually distinct line spectra.

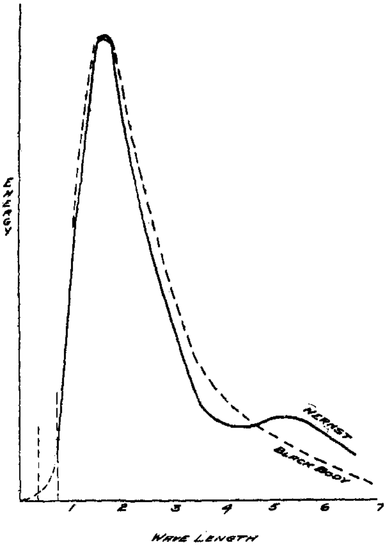

Fig. 1.

This recalls the subject of selective emission. Coblentz has shown selective emission in the long wave lengths for a Nernst glower. This is shown in comparison with the emission of a black body, in curve Fig. 1. The two sources, when compared at the temperatures where they exhibit the same wave length for maximum emission, differ very considerably in emission in the infra red, the black body giving more energy at the blue end, and less at the red end of the spectrum.

This is still more noticeable in the curves for such substances as porcelain, magnesia and glass, as shown by Coblentz's curves (Fig. 2).

The curves of wave length and radiant energy which are shown are, with slight modifications, taken from work of Lummer and Pringsheim and of Dr. Coblentz. The curve for the ideal, or black-body radiator, gives a picture of the total energy and its distribution over the different wave lengths. It is the peculiarity of the black body to radiate more energy of any given wave length than does any other body at the same temperature. Therefore, in case of all substances acting as thermal radiators, the black body will always give the greatest brilliancy. Since this body at the same time radiates a maximum in *all* wave lengths, it will be surpassed in light *efficiency* by any substance which is a relatively poor radiator in the invisible or non-luminous part of the spectrum.

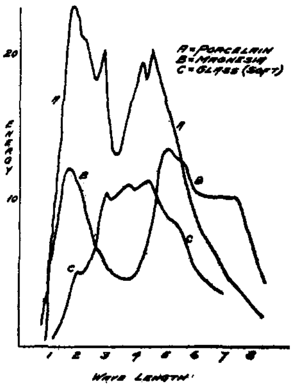

Fig. 2.

In the energy curves shown it is to be noticed that the visible part of the energy is practically only that between 0.4 and 0.8 thousandths of a millimeter. Consider the black lines in Fig. 3 for a moment. These show the emission of a black body at centigrade temperatures noted on the curves. Evidently the energy emitted rises very rapidly with the temperature; *i. e.*, as the 4th power of the absolute temperature. It will be noted also that the point of maximum energy or wave length corresponding to maximum energy shifts gradually toward the left or towards the visible wave lengths.

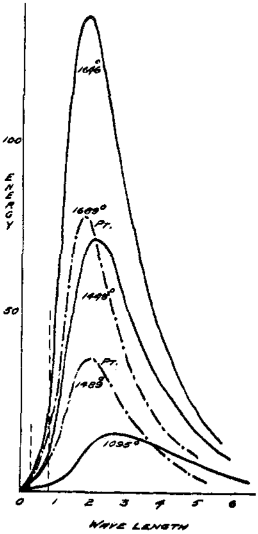

Fig. 3.

It is this rapid shifting of the position of maximum energy which makes the search for substances which can withstand even only slightly higher temperatures, of such great interest.

The curves for the black body and for platinum (dotted lines, Fig. 3), are not greatly different in general appearance, but the total amount of energy emitted at a given temperature from the black body is shown to be more than for the platinum, and it can be seen that at about the same temperature the platinum is the more economical light source. Prof. Lummer has said that at red heat, bright platinum does not radiate *one-tenth* the total energy which the ideal black body radiates at the same temperature, and at the highest temperature still less than one-half. The deviation of platinum from the black body law is a step in the direction of getting improved light-efficiency without corresponding increase of temperature. This method is practically without limit in its extension, for there seems to be no limit to the forms of energy curves which different substances may possess. The curves are apparently determined not only by physical state, but also by the chemical composition of the emitting substance.

You see before you a vacuum incandescent lamp which contains a ribbon of platinum, in the shape of a loop. While the section of the platinum is the same throughout, one-half of the loop is blackened by depositing a little platinum black upon it. This greatly affects the light efficiency as shown. The blackened portion, being more nearly a black body, radiates at each temperature relatively more energy of long wave length (*i. e.*, heat) than the bright portion; so for about equal total energy radiated the ribbon radiates less as light from the blackened surface.

In the production of artificial light, the tendency will always be in the direction of increasing the practical efficiency; *i. e.*, reducing the cost of light. We have seen that there is still much room for this. In the case of the kerosene oil lamps we know that much less than one per cent. of the energy of combustion of the oil is radiated as light from the flame. In the case of the most efficient source, the electric incandescent lamp at highest efficiency, we are still far from ideal efficiency. A still higher temperature would yield a yet higher efficiency. We do not know exactly how much light might possibly be yielded for a given consumption of energy, but one experimenter concludes that it is about ten candles per watt. If this is true, even the most efficient light you have seen this evening is less than half as efficient as it might be. Fortunately, it is not now clear just how the chemist is to realize all the advances which he will make in more efficient lights.

No consideration of this part of the subject is complete without a brief reference to the efficiency of the firefly. The source of his illumination is evidently chemical. This much is known about the process.

The light-giving reaction is made to cease by the removal of the air, and to increase in intensity by presence of pure oxygen. It is extinguished in irrespirable gases, but persists in air some time after the death of the insect. Its production is accompanied by the formation of carbon dioxide. These all indicate a chemical combustion process. Prof. Langley has shown that such a flame as the candle produces several

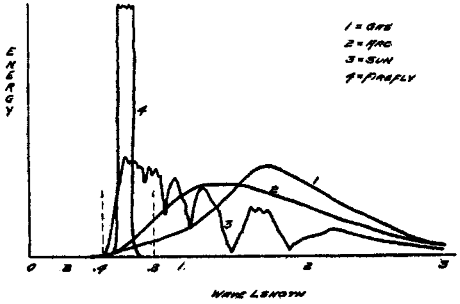

Fig. 4.

hundred times as muchus eless heat as the total radiation of the firefly for equal luminosity. In other words, the firefly is the most efficient light source known. This is illustrated by the energy distribution curves from several light sources taken from Prof. Langley's work (Fig. 4). The difficulties attendant upon the accurate determination of the curve for the firefly are so great that we ought not to expect very great accuracy in this case. These curves, which in each case refer to the energy after passing through glass, which cuts off energy of long wave lengths, represent the same quantities of radiant energy. While the sun is much more efficient than the gas flame or carbon arc, it still presents far the largest part of its energy in the invisible long wave lengths (above 0.8), while the firefly seems to have its radiant energy confined to a narrow part of the visible spectrum.

GENERAL ELECTRIC COMPANY,
SCHENECTADY, N. Y.

[CONTRIBUTION FROM THE RESEARCH LABORATORY OF PHYSICAL CHEMISTRY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, NO. 46.]

THE HYDROLYSIS OF AMMONIUM ACETATE AND THE IONIZATION OF WATER AT HIGH TEMPERATURES.

BY A. A. NOYES, YOGORO KATO AND R. B. SOSMAN.

Received November 30, 1909.

Contents.

1. Outline of the Investigation.

In a paper from this laboratory published six years ago[1] an apparatus and method were described by which accurate measurements of the electrical conductivity of aqueous solutions could be made at temperatures up to 306°. In a second paper[2] were presented the results of the measurements of the conductivity of aqueous solutions of various salts, bases, and acids, and the ionization relations of these substances were discussed. The pürpose of the research to be described in this article was to study another phenomenon—that of the hydrolysis of salts into

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[1] THIS JOURNAL, 26, 134–170 (1904).

[2] *Ibid.*, 30, 335–352 (1908).