The Theory of Cold Light*

Can Light Be Produced Other Than By Temperature Radiation

By Wilder D. Bancroft, Professor of Physical Chemistry

WHEN opaque substances such as carbon, platinum or earthenware are heated sufficiently they emit light, the quality and intensity of which depends on the temperature and not on the nature of the substance heated. Radiation of this sort is called temperature radiation. An opaque gas would also emit light if heated to a suitable temperature. Iodine vapor, for instance, glows[1] when heated to above 500 deg. Cent. While this may not be entirely a temperature radiation, it is usually so considered. The law of temperature radiation holds only for opaque substance, which are sometimes called perfect radiators. An absolutely transparent substance would give no temperature radiation. At the end of the eighteenth century Wedgwood[2] showed that heated air is not luminous. Subsequent experiments have confirmed this conclusion of Wedgwood's.

Most artificial lighting is due to temperature radiation from solid particles. In the kerosene lamp the light is due to glowing particles of carbon. The difference between the kerosene lamp and the gas jet is that the temperature of the latter is higher. If all the solid particles are burned, as in the Bunsen burner, a so-called non-luminous flame is obtained, even though the temperature is much higher than in the burner with a lumnious flame. The brilliancy of the lime light is due to temperature radiation from intensely heated lime. In the Welsbach mantle and in the Nernst lamp there are suitable mixtures of rare earth oxides instead of the calcium oxide used in the lime light. There is some question whether the light from the Welsbach mantle is exclusively due to temperature radiation, but it is unnecessary to go into that matter now.

At first one would suppose that the incandescent lamp would give the most efficient temperature radiation known because graphite melts at a higher temperature than any other known substance. The carbon lamp can be made to give an extraordinary light efficiency, but its life is extremely short under these conditions. The graphite vaporizes or disintegrates and the filament breaks.[3] There has, therefore, been a systematic search for substances with high melting points and low vapor pressures. As a result, there have been produced successively the osmium, the tantalum, and the tungsten lamps. In the nitrogen-filled tungsten lamp the thermal radiation has been cut down and consequently less power is needed to heat the filament to a given temperature.

While it would be foolish to claim that the limit of efficiency has been reached, it must be remembered that a large number of very able men have been attacking this problem of temperature radiation systematically and that consequently the limit of efficiency is probably being approached. That brings up the question whether light may not be produced in other ways than by temperature radiation and, if so, whether it is possible to produce cold light. The possibility of cold light cannot be disputed because the firefly produces it. Langley's studies of the firefly have shown that the insect gives about 95 per cent efficiency, meaning thereby that 95 per cent of the radiations are in the portion of the spectrum visible to the human eye while only about 5 per cent of the radiations are in the ultra-red portion of the spectrum and what are popularly called heat rays. The light of the firefly cannot be due to a temperature radiation because the firefly does not burn up instantaneously. It is not a question involving life because the abdominal portion of the firefly can be dried, pulverized in a mortar, and kept for two years. At the end of that time the powder will glow if moistened and exposed to oxygen. It is simply an oxidation process. The firefly has the power of secreting a substance which burns with a luminous, cold flame. If one were to make in the laboratory the unknown substance which the firefly makes, it would behave in exactly the same way as the natural product. It would be amusing to do this; but that is all that it would be, because the product would be too expensive to use as a source of light. Nobody claims for the firefly a low cost of production. In fact, it is not known how one would estimate the firefly's cost of production.

Under certain circumstances cold light can be produced in the laboratory. Angström[4] has calculated that he gets about 95 per cent light efficiency when he passes a current through nitrogen under 0.1 mm. pressure. The losses at the electrodes and at the walls of the tube cut the working efficiency down to about 8 per cent. From this work of Angström's, it seems probable that the Moore light is not a temperature radiation but is due to chemical reactions.

Phosphorescing substances, such as zinc sulphide, emit light at low temperatures and do not involve temperature radiations. As yet, however, such substances as Balmain's paint, etc., have to be exposed to light before they will emit light. Until some other way of stimulating them is found, they are of more theoretical than practical importance. At present very little is known about the chemical reactions involved, because these substances have been studied chiefly by physicists.

The luminescence of salt flames are of great importance theoretically. By putting different salts into the non-luminous flame of a Bunsen burner different colored flame are obtained: yellow with sodium, pink with lithium or strontium, blue or green with copper. Since the temperature of the flame is about the same in all these cases and since one cannot very well claim selective absorption in each case, it seems certain that the colors of these flames are not due to temperature radiation and the problem is to find out what does produce the luminescence.

One usually gets the same yellow color with different sodium salts and one is consequently tempted to say that the yellow color is due to the sodium atom when heated to a suitable temperature. This is not true, however, because sodium salts emit little or no yellow light in the hydrogen-chlorine flame, even though this is fully as hot as the flame of the Bunsen burner.[5] The next assumption is that the yellow color is due in some way to sodium metal and that the metal is present in one flame and not in the other. The presence of free metal in the flame is not impossible. Almost all salts are formed with evolution of heat and consequently will dissociate if the temperature is high enough. It, therefor, becomes a question of fact whether a given salt dissociates in a given flame or not. To test this, use has been made of a modification of Deville's hot-cold tube. Cold water was run through a porcelain tube and the chilled porcelain tube was held in the colored flame. With salts of copper, cadmium, tin, silver, lead, bismuth, zinc, antimony, and arsenic in the Bunsen flame, mirrors of the metals were obtained on the porcelain tube.[6] With salts of mercury a gray deposit was obtained consisting of drops of mercury. No experiments were made with gold or with the platinum metals. No mirrors of tungsten or molybdenum could be obtained from oxides of these metals in the Bunsen flame, but good mirrors were obtained with the hotter oxhydrogen flame. From the cooler portions of the oxyhydrogen flame tungsten blue and molybdenum blue were precipitated on the tube. When sulphur dioxide was led into the hydrogen-air flame, sulphur was precipitated on the porcelain tube. No copper was obtained when copper salts were fed into the hydrogen-chlorine flame, showing that the amount of metallic copper present in this flame is at any rate very much less than in the Bunsen flame.

It is not to be expected that mirrors of metallic sodium and potassium would be produced. There is, however, some evidence that the metals are actually precipitated. The sodium chloride is distinctly alkaline when precipitated from the hottest flames. This is probably not due to hydrolysis in the heated gases, because caustic soda is more volatile than sodium chloride and consequently should be found in larger amounts in the outermost portions of the flame. This is not the case, for the sodium chloride from the outside of the flame is neutral. The greatest alkalinity is obtained under the conditions under which one should expect to have the largest amount of free metal. While this is not absolutely conclusive in itself, it is pretty satisfactory when taken in connection with the behavior of the other metals.

It is evident that a number of reactions are taking place simultaneously in a flame colored with a salt. It is now believed that all reactions tend to emit light[7] and that they all emit light if made to take place very rapidly, the critical reaction velocity varying enormously in different cases. It is known that increasing the rapidity of a reaction which emits light increases the intensity of the light[8] without producing much change in the quality. While the vaporized salts are sometines colored, as in the case of cupric chloride, and may, therefore, give temperature radiation to some extent, it is clear that most of the light emitted by salt flames is due to chemical reactions and is to be classified as chemiluminescence.

Some progress has been made in determining the reaction corresponding to a given color. The following results[9] were obtained for copper salts in the Bunsen flame:

I. Cuprous ion to cuprous salt = red.
II. Copper to cuprous ion = green.
III. Cuprous ion to cupric salt = blue.

The first conclusion is based on the action of cathode rays on cuprous iodide, the third on the combustion of cuprous chloride in chlorine, and the second on the combustion of copper in oxygen. A number of experiments were made on the rapid reduction of cupric and cuprous salts with sodium and aluminium as reducing agents. No characteristic luminescence could be obtained, presumably because these reverse reactions were not made to go sufficiently rapid. However that may be, it is clear that reductions play no important part as regards the light emitted by copper salts in the Bunsen flame.

When a solution of cupric chloride in aqueous hydrochloric acid is sprayed into the Bunsen flame, there is a red or violet tip to the flame and when the flame is burning steadily one can often see a violet sheath around the flame. This is not a true luminescence, though it looks like one. It is merely the color of cupric chloride vapor. It can be obtained in mass by heating copper in an electric furnace and then running in chlorine or by volatilizing cupric chloride.

When cupric chloride is sprayed into a hydrogen-chlorine flame or when a mixture of cupric chloride and hydrochloric acid is sprayed into a Bunsen flame, the hydrochloric acid cuts down the dissociation of the cupric chloride and there is a reaction from cuprous ion to cupric salt but not the reaction from copper to cuprous ion. Consequently the flame is blue and not green. The same result ought to be obtained without the acid if one used a flame the temperature of which was not sufficient to dissociate cupric chloride into free metal and chlorine. The alcohol flame is just on the dividing line. Cupric chloride colors a hot alcohol flame green and a cooled alcohol flame blue.

Since the yellow of the sodium flame is due to the reaction from sodium to sodium ion, the hydrochloric acid from a hydrogen-chlorine flame will force back the dissociation and cause the yellow to disappear practically completely.[10]

Since the bulk of the light in salt flames is due to chemical reactions and not to temperature radiation, there is a possibility of duplicating the effect, if one can cause the reactions to take place sufficiently rapidly at low temperatures; in other words, if they are done electrolytically. Some years ago Schluederberg[11] showed, in the Cornell laboratory, that light is emitted when an alternating current is passed through lead electrodes in sulphuric acid. Later, Wilkinson[12] obtained flashes of light with a number of metals as anodes, using a direct current. Owing to film formation, the light could only be seen for an instant. By pressing a tooth brush against a rotating anode, it is possible to remove the film as it gets too thick and thus to obtain light continuously for an indefinite period, ten minutes for instance. So far we have not been able to obtain an electrolytic flame with copper which could be shown to a large audience, but we can do this readily with mercury.[13]

When mercurous bromide or mercury is burned in bromine an orange light is emitted. When mercurous or mercuric bromide is exposed to the cathode rays a similar orange light is obtained. When mercury is made anode in a cold, fairly concentrated, potassium bromide solution (25 per cent, for instance), with an anode current density of about 2 amperes per square decimeter, the mercury first becomes coated with a film of bromide and then appears to glow with a brilliant orange light. This will last for at least ten minutes, at the end of which time the film of bromide will have become so thick as to prevent the light being seen. By looking carefully from the side, light can still be seen between the film and the surface of the mercury. The light can be obtained at as low a voltage as 3 volts, but the intensity is then very

---

*A paper read at a meeting of the Pittsburgh Academy of Sciences and the Illuminating Engineering Society.

[1] Salet; *Ann. Chim. Phys.* (9) vol. 28, p. 34; 1873. Cf. Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 295; 1914.

[2] *Phil. Trans.*, vol. 82, p. 272; 1892. Cf. Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 281; 1914.

[3] Werner von Bolton obtained 0.3-watt per candlepower for a moment with a tantalum lamp.

Wied. Ann., vol. 48, p. 493; 1893.

[5] Cf. Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 19, p. 310; 1915.

[6] Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 261; 1914.

[7] Bancroft; *Jour. Franklin Inst.*, vol. 175, p. 129; 1913.

[8] Trautz, *Zeit. Elektrochemie*, vol. 10, p. 595; 1904. *Zeit. Phys. Chem.*, vol. 53, p. 108; 1905.

[9] Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 323; *Trans. Am. Electrochem. Soc.*, vol. 25, p. 123; 1914.

[10] Bancroft and Weiser; *Jour Phys. Chem.*, vol. 19, p. 310; 1915.

[11] *Jour. Phys. Chem.*, vol. 12, p. 623; 1908.

[12] *Ibid.*, vol. 13, p. 695; 1909.

[13] Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 762; 1914.

low. With increasing voltage—or really with increasing current density—the intensity of the light increases, the upper limit coming when visible sparking takes place. The phenomenon is shown very well with a voltage of 24–28 volts.

This is not cold light. It is not even a very efficient light. The importance of it lies in the fact that it is a striking illustration of the principle that reactions emit light and that a high temperature is not essential. To obtain cold light one must find a reaction which can be made to go rapidly, which absorbs heat or evolves but a small amount of heat, and which has a high conversion factor for light. A number of other requirements come in, if it be stipulated that the light shall be suitable for commercial purposes. There is no immediate prospect of the present methods of lighting being superseded; but the theoretical feasibility of cold light and the general conditions under which it is to be obtained have been demonstrated.

Your Lighting Bill for 1925

By Albert W. Deininger

Wonderful progress has been made in the science of illumination in the past ten years. What will be achieved in that field in the next decade?

Let us examine briefly the recent progress, and, knowing the present tendency, predict if we can the future of illumination.

Table I gives the recent achievements in gas lighting while Table II considers electric lighting for a corresponding period.

TABLE I.—GAS LIGHTING.

Burner.	Relative Amounts of Gas for Same Amount of Light.
Prior to 1905—Open flame	1.00
1905 to 1910—Upright mantle with fluted flat cone reflector	0.26
1910 to 1915—Inverted mantle with prismatic reflector	0.11

From Table I it will be seen that an inverted mantle burner with a prismatic reflector uses only one ninth as much gas as an open flame burner giving the same amount of light.

The common open flame burner consumes 5 cubic feet of gas per hour while the ordinary inverted mantle burner consumes 3 cubic feet. It naturally follows, therefore, that the gas consumption will be reduced 40 per cent and the intensity of illumination be 5.4 times as great if open flame burners are replaced by inverted mantle burners with prismatic glass reflectors.

TABLE II.—ELECTRIC LIGHTING.

Incandscent Lamp.	Relative Amounts of Electricity for Same Amount of Light.
Prior to 1905—Carbon filament with opal cone reflector	1.00
1905 to 1910—Gem lamp with opal cone reflector	0.82
1910 to 1915—Tungsten filament with prismatic glass reflector.	0.36

Thus, at the present time using tungsten lamps with prismatic reflectors we obtain 2.8 times as much effective illumination for the same power as we could obtain using carbon lamps with opal cone reflectors.

While the relative increase in efficiency of gas and electricity as illuminants is interesting, the thing that interests the consumer is the most economical method of lighting. Table III gives the cost per thousand lumen hours of gas and electric lighting for the three periods of time considered. The costs of gas and electricity are the averages for the periods, the methods of lighting being as given in Tables I and II. The walls of the room considered are of medium color, neither very light nor very dark.

TABLE III.—COST OF ILLUMINATION PER THOUSAND EFFECTIVE LUMEN HOURS.

Prior to 1905.

Gas $1.50 per thousand cubic feet. Electricity $0.20 per kilowatt hour.

	Power.	Cost.	Relative Cost.
Gas	61.00 Cub. ft.	9.15 Cents.	1.00
Electricity	0.70 kw. hrs.	14.00 Cents.	1.53

1905 to 1910.

Gas $1.25 per thousand cubic feet. Electricity $0.15 per kilowatt hour.

	Power.	Cost.	Relative Cost.
Gas	16.00 Cub. ft.	2.00 Cents.	1.00
Electricity	0.57 kw. hrs.	8.55 Cents.	4.28

1910 and including the present time.

Gas $1.00 per thousand cubic feet. Electricity $0.10 per kilowatt hour.

	Power.	Cost.	Relative Cost.
Gas	6.80 Cub. ft.	0.68 Cents.	1.00
Electricity	0.25 kw. hrs.	2.50 Cents.	3.68

It will be noted in Table III that gas lighting costs only 7.4 per cent of the cost prior to 1905, and that electric lighting costs only 18.2 per cent of the cost prior to 1905. At present electric lighting costs 3.68 times as much as gas lighting, the replacement cost of gas mantles and tungsten lamps being very nearly the same.

The question naturally arises as to whether further increased lighting efficacy is possible. It unquestionably is possible and highly probable. The inverted mantle gas burner gives out as light only one half of one per cent of the energy in the gas consumed and the tungsten incandescent lamp only about 5½ per cent of the electrical energy consumed as light.

The latest and most efficient incandescent lamp is the inert gas or nitrogen filled incandescent lamp. It has a tungsten filament but the bulb is filled with nitrogen—an inert gas. At present, the lamp is used commercially only in large sizes of several hundred watts. The nitrogen-filled tungsten lamp is, in large sizes, about twice as efficient as the ordinary tungsten lamp, and if made in small sizes, will cause ordinary illumination by electricity to cost only about 80 per cent greater than illumination by inverted mantle gas lights if the relative cost of gas and electricity remains the same as at present.

Lighting has passed through a combustion stage where illumination was obtained by burning tallow, oil and finally gas. We are now in the incandescent era, light being obtained by the incandescence of the mantle of the gas lamp and the filament of the incandescent electric lamp. The limit of illuminating efficiency by incandescence is believed to be at hand. The next era is believed to be one of luminescence in which light will be obtained by causing a gas in a bulb to glow by passing an electric current through it. The efficiency of the luminescent lamp is expected to be very high.

Gas, as an illuminant, will probably have but a small place in the luminescent era if the expected efficiency is realized in the luminescent lamp. Gas would still be used, but chiefly as a power gas, as it would not be an efficient illuminant. A similar condition existed in the period during which the open flame gas burner and the carbon filament indandescent lamp were in use, it being possible to use a given amount of gas in a gas engine driving an electric generator lighting carbon incandescent lamps and obtain twice as much light as the same gas would give from open flame burners. The introduction of the mantle type of gas lamp alone prevented gas from being discarded as an illuminant. The efficiency of the gas lamp has been improved three times as much as the electric incandescent lamp since that time so that that condition no longer holds.

One hundred per cent increase in the efficiency of the electric incandescent lamp, which is expected in the nitrogen-filled lamp of ordinary size, should make it more profitable to operate electric incandescent lamps from a generator driven by a gas engine than to burn the gas in inverted mantle gas burners in a fair sized building.

Neglecting interest, depreciation, and attendance charges 100 per cent increase in the efficiency of the electric incandescent lamp would cause electric lighting by incandescent lamps using purchased power to be 80 per cent more expensive than gas lighting by inverted mantle burners, or 140 per cent more expensive than illumination obtained from incandescent lamps lighted by a generator driven by a gas engine if the relative charge for gas and electricity remains the same as at present.

It is unlikely that the efficiency of gas lighting will be improved materially. Gas, as an illuminant, will have to compete with electricity by lowering the charge per thousand cubic feet. When the open flame burner is discarded the price of gas may be lowered considerably as the mantle type of lamp requires heat only and therefore a cheap gas of low illuminating efficiency may be used.

Thus it will be observed, that within a few years we may expect electric incandescent lighting bills to be cut in two because only half the power used at the present will be required, and gas lighting bills to be considerably lower because cheaper gas will be in use.

Now, take your guess as to your lighting bill in 1925, and by the way, will it be for gas or electricity, and if for gas will you burn it or use it in a gas engine driving a generator that lights incandescent lamps?

Triplex Glass

One of the most recent French productions is known as "triplex glass," and it is claimed to afford a remarkable security against breakage of glass panes, especially as regards accidents due to projected fragments of glass. This new invention is the outcome of considerable research, and consists in the makeup of a glass pane which uses two plates of glass with a sheet of transparent celluloid between them, the whole being suitably cemented and pressed together. Such combination glass has some remarkable properties in the way of strength, but at the same time it is quite as transparent as ordinary glass. Before this time a product known as reinforced glass was brought out, consisting of a pane having wire netting of large mesh imbedded in it. This was a step in advance, but was far from solving the problem, as will be seen from the fact that the amount of fragments projected by a shock of equal force upon a glass pane is for ordinary glass 80 per cent of the surface, for armored glass 30 and for the new triplex glass only 2 per cent. Great safety is thus obtained, and especially for automobile use. Statistics show that over half the number of wounds to chauffeurs and occupants come from projection of glass fragments due to a collision or from a shock, this latter being either direct or recoil. Even passers by are wounded in this way. Mortal wounds by veritable blades which pierce the body like a poignard, or less grave ones where the face is mutilated, are on record. Reinforced glass was tried for this purpose, and here the danger is much less, and the quantity of fragments smaller, though as above seen, it is still considerable. But for automobile use such glass is scarcely practicable because of its unesthetic appearance which gives a cage-like effect, and a still greater drawback is that when placed before the driver it causes difficulties of vision, these being still further increased by sunlight or rain.

The new triplex glass appears to solve the problem of an extra strong as well as a perfectly transparent glass, and there is no fear of the celluloid becoming yellow with time, for this coloration is due to contact with the air and cannot now be produced because the celluloid is hermetically sealed between the two panes. But once given the idea, it was not by any means easy to realize in practice, and the inventors worked at it for over two years in order to elaborate the process; this consists in the preparation of the glass panes and the celluloid sheet, cementing together, pressure under hydraulic press and cutting into shape. Even in the shop the cutting is difficult, which shows its great strength. Each glass pane is run over by the diamond, but the pane is as yet far from being cut as a whole. It is placed upon a heating table so that the cut will widen by expansion, then it is bent back and forth a number of times as for a cardboard sheet so that the celluloid is detached by breakage along the edge. This applies to straight line work, but for curved pieces, such must be made up by assembling three pieces of the right shape beforehand, for it is practically impossible to cut out such shapes in the assembled triplex glass. Very good protection against burglars is thus afforded.

Some experiments were made to show the strength of the glass against shocks from a projectile. In a stout wood frame were placed in turn three plates about 8 inches square, the first in ordinary glass 0.2 inch thick, the second in 0.28-inch reinforced glass and the third in triplex glass of only 0.16-inch thickness. Shocks of the same value are given to each pane by hanging a metal ball of about 1 pound weight from the ceiling on a 13-foot cord and using a suitable release device at the ceiling so that the ball swings down and strikes the glass with considerable force. The results afford an instructive comparison. For the ordinary glass, there remained but few fragments in the frame, and splinters were projected for 15 feet. The reinforced glass suffered much less, but its center was torn out and shattered, debris being found 18 feet distant. A great difference was seen for the new glass, and it was simply cracked in the part lying around the point of impact, the ball stops without penetrating the pane, and a few fragments (not over 2 per cent) fall at less than 8-inch distance. It is easy to see what would be the case in an accident. As to a recoil shock, the new glass holds up remarkably well here. For instance, a glass door is violently closed, in which case the pane flies in pieces, but with the new glass it is simply cracked in zigzag without detaching any pieces. A still more remarkable effect is seen by using two triplex glasses laid together and mounted in a frame, and here an unusual strength is obtained. The hardest hammer stroke only produces star-shaped cracking, but does not cause pieces to separate, and no splinters are produced. Revolver firing also proved its great strength. A double pane was mounted in a frame at 20 inches in front of a 2-inch plank, and this served as a target for revolver firing at 20-foot range. The ball made a hole in the glass without splintering, and struck the wood; but the resistance due to the glass was so great that the ball could not penetrate the plank and only left a mark on the surface. Such a result is unusual and is worthy of attention, for in the absence of the glass, the ball easily perforates the plank. The uses of the new product appear to be numerous. As it is refractory to the diamond, panes for show windows are safe against burglars. Because of its high resistance to recoil shocks, it is good for use in window sashes or glass doors which are subject to sudden closing. Another use is for greenhouse sashes, and especially for horticulturists and market gardeners this gives a good protection against hail, even in the case of severest storms. But the new glass will no doubt find its most practical application in carriage work, and especially for automobiles, and in this field there is a great need for a product of this kind in order to avoid the frequent accidents which are caused by breakage of glass.