LIGHT AND ILLUMINATION.

BY CHARLES P. STEINMETZ, *Member*

Compared with other branches of engineering, as the transformation of electrical power into mechanical power in the electric motor, or the transformation of chemical into mechanical energy in the steam engine, we are at a disadvantage when dealing with light and illumination, because we have not to do strictly with a problem of physics, but are on the borderland between applied physics, that is, engineering and physiology. Light is not a physical quantity, but is the physiological effect exerted on the human eye by certain radiations. There are different forms of energy, all convertible into each other, as magnetic energy, electric energy, heat energy, mechanical momentum, radiant energy, etc. The latter, radiant energy, is a vibratory motion of a hypothetical medium, the ether, which vibration is transmitted or propagated at a velocity something like 186,000 miles per second. It is a transverse vibration, differing from the vibratory energy of sound in this respect, that the sound waves are longitudinal, that is, the vibration is in the direction of the beam, while the vibration of radiation is transverse. Radiant energy can be derived from other forms of energy, for instance, from heat energy, by raising a body to a high temperature. Then the heat energy is converted into radiation and issues from the heated body, as, for instance, an incandescent lamp filament, as a group of radiations of different wave lengths, i. e., different frequencies. All frequencies appear from very low frequencies, that is, only a few millions of cycles per second, up to many times higher frequencies. If desired, much lower frequencies in electromagnetic waves may be produced, such as the radiations sent out by an oscillating or an alternating current; but the radiations which are given by heated bodies are all of extremely high frequency as compared with the customary frequencies of electric currents. At the same time they cover a very wide range of frequencies, many octaves, and from all this group of radiations, of all frequencies, somewhat less than one octave can be perceived by the human eye as light. Light, therefore, is the physiological effect exerted upon the human eye by radiations within a certain narrow range of frequency. Frequencies lower than these, as well as those higher, are invisible. Those frequencies lower than the visible ones are called radiant heat. The higher ones are known as chemical rays. These terms, however, are misleading, and there is no distinction in character between radiations of different frequency. There are no heat rays differing from light rays or chemical rays. Any form of energy when destroyed gives rise to an exactly equivalent amount of some other form of energy. If therefore radiant energy is destroyed by intercepting the beam by interposing an opaque body in its path, then the energy of radiation is converted into some other form of energy, usually into heat. Any radiation when absorbed produces heat, and the amount of heat produced merely represents the amount of energy which was contained in the radiation. If the radiation contains a very large amount of energy, the heat developed by intercepting it may be sufficient to be felt by putting the hand in the beam. If the amount of energy is less, it may not be possible to feel it, though with a sensitive instrument, such as a bolometer, it may be possible to measure the heat. All radiations therefore are convertible into heat, the visible light waves as well as the invisible ultraviolet rays, and the usually more powerful long infra-red rays; but none of the radiations can be called heat, any more than the mechanical momentum of a flywheel is heat, because when destroyed, it produces heat.

Considering the infinite range of radiation issuing from heated bodies, it is found those rays which are of frequency lower than the visible rays will be felt as heat, because they contain a large amount of energy. The rays which are visible represent very little energy, and therefore they do not give as much heat. For instance, in the case of a hot steam boiler, although it sends out no light, the radiation from it can be felt by the heat which it produces when intercepted by the hand held near it. The radiation which issues as green light from the mercury lamp cannot be felt as heat merely because the energy of this radiation is less than the amount of energy in the radiation from a hot boiler; but, while it is less, it happens to be of that frequency which affects the eye and is visible. It results from this that when one speaks of cold light, it is not meant that it is different from hot light; from the light, for instance, given by a hot coal fire, where the radiation is felt as heat; it merely means that what is usually called cold light, as, for instance, the light of the firefly, is radiation containing to a very large extent rays of the visible frequencies and not much energy outside of the visible range; i. e., containing very little total energy, so that the energy when converted into heat, cannot be felt easily, but requires more delicate methods of determination. On the other hand, a very inefficient light, as a coal fire for instance, which gives most of its energy as invisible radiations of low frequency, and very little as visible, can be felt by the heat produced by the interception of the rays, which are mainly the energetic low frequency rays. As stated, then, there is no essential difference between so-called heat waves and light waves, but any radiation can be converted into other forms of energy, the so-called chemical rays of ultraviolet light, the x-ray, as well as infrared and the visible rays, and when converted into heat can be detected as such. Now it just happens that most of the available means of producing radiant energy give high intensities of radiation for low frequencies only, the invisible infrared rays, but it is not now possible to produce anywhere near the same intensity of radiation as higher frequencies.

So, also, when speaking of ultraviolet, or high frequency radiations, such as chemical rays, that does not mean they have a distinctive character in producing chemical action. Any form of energy can be converted, if one knows how, into chemical energy; the long ultrared waves just as well as the short ultraviolet waves. It just happens that those chemical compounds which are easily split up by radiant energy, such as silver salts or salts of gold and platinum, are especially affected by the ultraviolet and violet rays. For this reason, the chemical action of these rays is more noticeable than the other rays. There may, however, be some feature in the constitution of matter, which accounts for the high chemical action of the ultraviolet and violet rays. It is obvious if the radiations are intercepted and destroyed and their energy converted into other forms of energy, if the energy is only high enough, a high temperature results, and so high chemical action is produced by the mere effect of temperature. But there may be a chemical effect by what probably is some kind of resonance phenomenon. The particles of a body, atoms or molecules, must have some rate of vibration of their own. If, then, a ray of radiation impinges upon them which is of a frequency of the same magnitude as the inherent rate of vibration of the atom, by resonance this vibration of the atom must rapidly increase in intensity until the atom breaks away from the others, or the molecule breaks up; that is, the chemical combination is split up. The inherent frequency of oscillation of the atom seems to be about of the same magnitude as the visible radiations, or rather a little higher; that is, if the atoms are left to vibrate freely, as under the influence of an electric current in the arc, then radiations of the frequency inherent to the atom are given off. The general tendency is toward the violet or short wave end of the spectrum. If one assumes that the mass of the silver atom is such as to give a rate of vibration in the range of the violet and ultraviolet, it is easy to understand that a radiation of this frequency will split up the silver salt by increasing the vibration of the atom through resonance, and that shorter or longer waves will have no effect, or one much less. So it may be a mere incident that those chemical compounds on which the chemical action of radiation is marked just happen to be sensitive to the violet end of the spectrum. It is indeed a fact that other chemical changes are brought about by radiant energy, as the formation of ozone from oxygen, which is the splitting up of the oxygen molecule and the forming of the ozone molecule from the atoms and does not take place in the violet or ultra-violet, but requires frequencies much higher, about the highest frequencies which the mercury arc gives at low temperature. Possibly, since the oxygen atom is so much lighter than the silver atom, its frequency of vibration is much higher; which means that resonance effects and destruction of the molecules take place only with a much shorter wave length of radiation.

Inversely, it seems that those frequencies which are chemically active in organic life, which give the energy absorbed from radiation by plants and bring about the chemical activity utilized in building up the growth of vegetation, are at the red end of the spectrum, not at the violet end. It appears that the red and infrared rays produce growth of plants and the chemical activity called life, while the violet and ultra-violet rays kill. Even this can be understood if the chemical activity is considered as a resonance phenomenon, because the metabolism of protoplasm which is called life is based on the existence of unstable structures of carbon compounds. Here it is not atoms which are combining with each other but groups, chain and ring formations, which are of larger mass and therefore have a lower rate of vibration and so should be expected to respond to lower frequencies or to red light, as indeed seems to be the case. The violet and ultraviolet light do not split up the organic matter into groups, which recombine to form complex bodies, and so represent the changes called life; but due to their higher frequencies, resonance occurs with the atoms, and the organic compound splits up into atoms and so disintegrates, which means death.

Thus it can be understood that the chemical activity of different radiations may be different, the chemical activity of long rays give life to vegetation and the short waves death; one splits the compounds up into carbon groups and the other carries destruction down to the atom.

Thus, the popular distinction between heat waves, chemical waves, light waves, is not a physical distinction, as all are radiant energy of the same character and differ merely in wave length. The visible range is somewhat less than one octave rather at the upper end, at the higher frequencies which are difficult to produce.

The problem of investigating and dealing with light is difficult for the engineer, because it is not a physical quantity which can be measured accurately, as in the case of power or velocity, but it is a physiological effect. The total energy of radiation from a heated body may, indeed, be measured very accurately, but the total energy of radiation is not light; only a very small part of it is visible. It is possible to go further and split up the total radiation issuing from a hot body, as from an incandescent lamp filament, into its different wave lengths of different frequencies, by resolving it into a spectrum by means of a prism, and then to collect all of the radiation within the visible range by a lens or other means and measure the energy of these radiations. Or, still simpler, some medium, such as glass or water, which absorbs the invisible long rays and invisible short rays, and which transmits all, or nearly all, of the visible rays, may be interposed in the beam of radiation. In this manner the energy of the visible radiations may easily be measured and compared with the total energy radiated. That would give a physical measure of the efficiency of the process of producing visible radiation, but it would not be a measure of the efficiency of producing light, since unfortunately the different wave lengths of the visible radiation have very different physiological effects. A given amount of energy as visible radiation, giving the effect of green light, represents an entirely different amount of light and causes a much greater physiological effect than the same amount of energy in rays of the wave lengths which give the impression of red light. It follows from this that the physiological effect, or light-equivalent of mechanical energy within the visible range, is a function of the wave length and varies with the color. That really is obvious, because the energy radiated at low frequencies represents no light whatever and has no physiological equivalent; it is invisible. Coming to the visible range, there is a physiological into the visible range the physiological equivalent must pass from effect, that is, light. Therefore, in passing from the invisible zero into a finite value and must necessarily pass continuously. At the extreme end of the visible range, the light equivalent of energy must be extremely low, and the further one goes into the visible range, the greater it is. The maximum is reached in the middle of the visible range, in the green and yellow. Then it decreases down to zero at the violet end of the visible rays; beyond that, at still higher frequencies, the physiological equivalent of energy is zero also. Or, inversely, the mechanical equivalent of light is a minimum in the middle of the visible range where one candle power of light represents the lowest amount of energy, and increases toward the ends of the spectrum of the visible range, reaching infinity at the ends. In other words, the efficiency of light production is a function of the wave length, that is, of the color, and is at its maximum in the middle of the spectrum, where the same amount of power, measured in watts, gives the largest amount of light measured in candle power.

Unfortunately, the physiological equivalent of power, or the physiological effect of light, varies not only with the wave length, but also with the absolute intensity. If it be required to compare red, yellow and green lights, or any lights of different colors, great difficulties are met. Suppose one candle power is wanted in light as red, yellow, or green. The different colors cannot be compared directly, since there is no physical measure of light. Lights are compared with a standard lamp, which has a certain color, usually a yellowish white. Lights of the same color can be compared exactly. If the color is not much different, an approximate comparison may still be made; but with widely different colors not even an approximate comparison can be made. One can not say when the two sides of the photometer screen, one illuminated by green light, the other by red light, are equal in intensity. Thus there can be no direct comparison of different colored lights. It is necessary to go one step farther and consider that light is used for illumination, is used to see by, and this gives a fair method of comparison: let it be observed at what distances from the two lights, red and green, there is the same ease in reading the same print; or, to measure more exactly, get the maximum distance at which a certain size of print can just be read by each light. At these distances the two illuminations are the same, and so the two lights have intensities inversely proportional to the squares of the distances. In this manner lights of different color can be compared.

Necessarily, the comparison has not the accuracy of a photometrical comparison. This can not be expected, since physical quantities are not compared, but only physiological effects on the eye, and different observers may have different personal constants. The eye of the one may be more sensitive to green, and the eye of the other to red, and therefore the comparisons may be different. However, these individual differences are not great, and different observers, even with widely different colors of light, do not give results differing much from each other; so that a comparison of intensities of different colored lights, and thereby a measurement of the intensity of different colored lights in candle power, is feasible, by some such method.

It is found, however, with a green light and a red light, which at a certain distance appear equally brilliant to the eye, when approached the red light appears much brighter than the green, and receded from the green light appears brighter, and at greater distances the green light may still be fairly bright when the red light is almost invisible. That is, the relative physiological effect of different wave lengths varies, not only with the wave lengths, but also with the absolute intensity of illumination, and while throughout the whole range the sensitivity of the eye for green light is much greater than for red light, the difference is far greater for low than for high illuminations. That is, the ratio of sensitivity for green compared with that for red is greater for faint illuminations than for intense illuminations. If it be desired to express lights of different colors in candle power, it seems necessary also to give the distance, or the intensity of illumination at which the observations were made. In other words, the light from the middle and the short wave end of the spectrum gives a better and more efficient illumination when the total intensity of illumination is low than the long or low frequency rays of red, orange and yellow, but the latter colors give a much more brilliant effect at high intensities than the same amount of light of shorter wave length.

This is of importance for the illuminating engineer, because when it is desired to get high intensity effects, as in decorative lighting or in advertising, better results are given by the low frequency end of the spectrum, by orange and yellow light, whereas when a low intensity of illumination is satisfactory, as in street lighting, better results are given by the short wave end or the middle of the spectrum, by the greenish-yellow of the Welsbach gas lamp and the bluish green of the mercury lamp. Therefore the white light of the carbon arc gives better results in street lighting than the yellow of the incandescent lamp, even at equal intensity of illumination. These features have been of small importance until recent years, since the available sources of light were all approximately of the same color, varying from orange yellow, to yellow and yellow white, to white; from the orange-yellow color of the gas lamp, kerosene lamp and tallow candle to the yellow incandescent lamp, the yellowish white arc, the yellowish white sunlight, to the white diffused daylight. This was a fairly limited range. It is only in the last few years that illuminants of high efficiency have been brought out which give marked and decided color differences and are available in units of suitable size and of high efficiency; such, for example, are the greenish yellow Welsbach gas lamp, the bluish green mercury lamp, and the orange yellow flaming arc. Hence these questions of color are increasing in importance.

II.

Until a few years ago, until the development of the Welsbach gas mantle, practically all methods of producing light were based on incandescence. That is, by impressing energy on a solid body, either the chemical energy of combustion, or electric energy in the incandescent or carbon arc lamp, the temperature is raised to such a high value that among the total radiation issuing from the heated body a certain very small percentage appears within the fraction of an octave of visible light. With increasing temperature of the radiating body, the average wave length of radiation decreases; that is, the average frequency of radiation increases, and so approaches nearer to the visible range, although even at the very highest temperature which can be produced the average wave length of radiation is very far below the visible. This means that the higher the temperature reached by an incandescent body, the higher is the average frequency of radiation, and so a larger percentage of the total energy of radiation is within the visible range and is light. Thus, the problem of efficient light production by incandescence is the problem of reaching as high a temperature as possible in the luminous body. In the gas flame and the kerosene lamp, this temperature is the temperature of combustion, and is rather limited. In the incandescent lamp it is limited also. In the latter case the temperature which can be reached is limited by self-destruction of the incandescent body.

Probably the highest temperature which can be reached is the boiling point of carbon; it is reached in the crater of the carbon-arc lamp, and therefore the carbon arc gives the most efficient incandescent light. It is incandescent light because it comes from the incandescent crater and the arc flame or the vapor conductor does not appreciably contribute to the amount of light issuing from the lamp. Very much lower, necessarily, is the temperature of the carbon filament of the incandescent lamp.

The problem is to find materials which can stand very high temperatures, to increase the temperature of the gas flame as well as of the incandescent filament. The temperature of the gas flame has been increased by using a gas of higher chemical energy, as acetylene. The acetylene flame is white; the ordinary gas flame is yellow. The temperature of the carbon filament has been increased by replacing the carbon with some more refractory material, such as tantalum, osmium, tungsten, etc., and thus a higher efficiency is obtained. The temperature of the gas flame may be increased by increasing the rapidity of combustion. The temperature of the carbon filament in the incandescent lamp may be increased by increasing the energy input, but if the temperature of the carbon filament be increased, it is more rapidly destroyed. The temperature of the gas flame has been increased by more rapid combustion to a certain extent by having the gas issuing, not from a round hole, but from a flat slit, so as to give a larger surface to the flame. By going still further and mixing the gas with air, a still higher temperature and a more rapid combustion are obtained, but the incandescent body is destroyed, because the incandescence of the gas flame is the light given by carbon or heavy hydro-carbon particles floating in the gases of combustion. The efficiency of the gas flame may be increased by mixing the gas with air, as in the Bunsen flame, but it is then necessary to insert a luminous body of some other material in place of the carbon produced by the gas by its dissociation. This may be done by a skeleton of platinum wire. In no case, however, can very high efficiencies by incandescence be reached, because of the temperature limit.

However, the efficiency of light production might be increased if an incandescent body be found which does not radiate in the same manner as the carbon filament or the so-called black body, but which gives an abnormally low radiation in the low frequency range, or an abnormally high radiation in the high frequency or visible range. Such a body may be said to give selective radiation, because the distribution of energy amongst the different frequencies of radiation in the spectrum is not the same as it would be with an ordinary black body at the same temperature. If a body be found which gives an abnormally low radiation in the visible range, or abnormally high radiation in the invisible range, this body would be an abnormally inefficient light producer. Inversely, if a body give abnormally high radiation of short wave lengths in the visible range, or abnormally low radiation of long waves of low frequency, this would be an abnormally efficient incandescent body. Such bodies exist and the enormous progress in gas lighting made by the introduction of the Welsbach mantle is based on such selective radiation; that is, the oxides do not radiate the same range and intensity of waves as a black body, the incandescent carbon, but give an abnormally large amount of visible rays compared with invisible rays; that is to say, they give a larger percentage of high frequency light rays compared with the low frequency invisible rays. Possibly, and even probably, some of the highly efficient metal filaments, like the Tungsten filament, also owe their high efficiency of one watt per candle power to selective radiation.

When discussing selective radiation, it is necessary first to come to an agreement on what is understood by selective radiation. The question whether an illuminant owes its high efficiency to selective radiation, depends largely on the definition of the term "selective radiation." This is a case similar to the much discussed problem of the "counter electromotive force of the electric arc." Whether the electric arc has a counter electromotive force or not, entirely depends on the definition of counter electro motive force. In the same way the decision on the question of selective radiation depends on what is defined as selective radiation. If selective radiation be defined as any radiation in which the intensity of radiation is distributed through the total spectrum differently from that of the theoretical black body, then the Welsbach mantle shows selective radiation. If, however, selective radiation be defined as the radiation of a body which gives spectrum lines, or bands, or absorption lines and bands, that is, sharply defined narrow ranges in the spectrum, of abnormally high or abnormally low intensity, then the Welsbach mantle shows no selective radiation. So all discussions and statements on selective radiation have rather little meaning if the writer does not give his definition of selective radiation. In the following I define as selective any radiation which differs in the distribution of its intensity from the radiation of the theoretical black body.

In an incandescent lamp filament a definite pitch, or definite frequency of vibration, is not given, but there is an infinite number of different waves. The reason is, perhaps, that in a solid or liquid body the vibrating particles are so close together as to interfere with each other. If a body could be set in vibration, in which the vibrating particles, atoms or molecules, are so far apart as not to interfere with each other, as, for instance, in a gas at low pressure, then they would execute their own periods of vibration, and the light from such a body would not be a radiation of all wave lengths, but a radiation of only a few definite wave lengths, or a line spectrum. Thus incandescent or luminous sodium vapor gives only one kind of light, a yellow spectrum line, and in addition thereto a number of infra-red and ultra-violet rays.

Since the spectrum light is based on the non-interference of the vibrating particles, it is easy to understand that when the atoms or molecules are brought closely together, as at atmospheric pressure, interference may begin, and the lines of the spectrum become confused and blur into bands. Thus the mercury arc spectrum, which is at low vapor pressure, consists of a small number of definite sharply defined lines. In the calcium spectrum of the flame carbon arc there is a large number of lines blurring into each other and forming an almost continuous spectrum; so it is also in the white spectrum of the magnetite-titanium arc.

When a gas or vapor is set into vibration, it vibrates at its own frequency, independent of the temperature, and it is merely a question of the character of the material whether a very large percentage of the total energy of radiation happens to be within the visible range or outside the visible range. Temperature does not come in as a factor, because the frequency of radiation is no longer a function of the temperature, but is independent of it; sodium vapor gives the same frequency of radiation, the same yellow line when the sodium vapor is at low temperature or at high temperature. Some spectrum lines may increase in intensity with an increase of temperature faster than others, and the color of light may change with the temperature, may change from yellow to white or blue, or from green toward white or red, as the mercury light does with increasing temperature, but that is merely a characteristic feature of that particular body, and not a general temperature effect. The possibility therefore exists of finding materials which, when energized as vapor or gas, give a spectrum with a large amount of energy in the visible range, thus giving an efficiency of light production far in excess of that available by incandescence.

So far the only materials which give these characteristics are mercury, calcium and titanium. These three metals give spectra which contain such a large percentage of the total radiation in the visible range that the amount of light measured physiologically in candle power is far in excess of that which possibly could be produced by incandescence, even with the assistance of selective radiation. Their industrial applications are represented by the mercury arc, the yellow flame carbon, and the white magnetite-titanium arc lamps, and these have a higher efficiency than any incandescent lamp.

Considering these three illuminants only, there is a considerable color scale; from the orange-yellow of the flame carbon, which is about the longest wave length which could be used, to yellow and yellow-white in the acetylene flame and the tungsten filament. Then there is the greenish yellow of the Welsbach mantle, due to selective radiation. Next are the bluish green in the mercury arc, the yellowish white of the carbon arc, and the clear white of the titanium arc. Each of these can be modified. The titanium arc may be given all colors from yellow-white to bluish white by the addition of materials which give either yellowish or bluish spectra. The yellow calcium arc may be modified from the orange yellow of calcium fluoride down to the yellowish-white of calcium borates. It is possible to get nearly any color, with the exception perhaps of a clear blue or violet: no means have been found to get approximately the same efficiency in these colors of very short wave length.

This feature makes the effect of color discussed before, the variation of the physiological effect with the brilliancy of illumination, of more importance now than years ago when the only method of producing light of any color was by the absorption of all other colors.

III.

After all however, it is not light that is wanted but illumination; it is not the amount of visible rays issuing from the source of light, the incandescent lamp or gas flame, which is of importance, but the amount of light which reaches the objects desired to be seen, that is, the illumination produced by the light. In this respect, a mistake has been made for many years, by the gas industry, as well as the electric lighting industry, by devoting all energy to the production of light, to the development of the lamp, while it was left almost entirely out of consideration that the production of an efficient light is not the only important problem, but of equal importance is the arrangement of the light so as to get efficient illumination, that is to get the greatest benefit from the light produced. This feature has been usually left to the tender mercies of the architect or the decorator, who placed the lights wherever he thought they would look artistic, everywhere there are cases of artificial illumination where the lamps have been arranged so that they give a very poor illumination from a large amount of light. It is the object of this society to overcome these defects, to study the problems involved between the production of light and the physiological effect produced by the light on the eye, and it requires as careful study as any other engineering problem. It is of importance to consider, not only the amount of light issuing from the flame, but the amount of light which reaches objects to be seen by the illumination.

The demands of illumination are mainly of two classes, general illumination and local or concentrated illumination. Many places require general illumination, as a meeting room, where it is desired to see equally well everywhere, that is, to get the same intensity of illumination throughout the whole illuminated area. This is also the case in a draughting room, a school room, the hall of a house and the streets of a city. A uniform fairly high intensity is needed in a draughting room or school room, an intensity relatively low but as nearly as possible uniform in the streets of a city. It is true, street lighting is usually very far from uniform, but that merely means that the problem of proper street lighting is usually not solved in the most efficient and satisfactory manner. In other cases concentrated lighting is required, as, in domestic lighting, in the dining room, the living room, etc., where light is desired on the table for working, eating or reading. In such cases, the general illumination of the room is of lesser importance, and is not needed to any extent, or is frequently undesirable, because a room with a very low intensity of general illumination frequently is considered more homelike, especially by the feminine part of the human race. In still other places general illumination may be directly objectionable, as in a sick room, Most cases, however, require a general illumination of moderate intensity, and a far more intense local illumination, as over the desks in an office, or the reading tables in a library. In such cases merely a general illumination would be sufficient if very intense, but this is uneconomical and to some extent objectionable on account of the blinding glare, which is disagreeable. Therefore a combined general and local illumination is more efficient and more satisfactory.

In producing illumination either direct lighting or indirect lighting may be used. That is, the rays issuing from the source of light may either pass directly to the illuminated objects, or they may pass to a reflecting surface, and be reflected from this surface to the object, or they may pass through a refracting body, as the frosted incandescent lamp globe, or the opal globe of the arc lamp, and so reach the illuminated object. In general, it is obvious that any method of indirect lighting by refraction or reflection wastes a considerable amount of light. That means, the total amount of light which reaches the illuminated object must necessarily be less with indirect lighting, as compared with direct lighting, with the same total amount of light.

Indirect lighting can be done by reflection or refraction by some attachment to the lamp, as a reflector or a Holophane or frosted globe, or by reflecting the light from the ceilings and walls of the room on the objects to be illuminated. In the latter case it is obvious that white walls give the highest efficiency of reflected light. It is easy to observe that the same source of light in a room with white walls gives several times the intensity of illumination which it gives in a room with black or non-reflecting walls. That means the total amount of illumination is increased several-fold by reflection from white walls. In a draughting room or schoolroom, the best efficiency of illumination may be got by using as light walls as possible.

It is not always feasible to have light walls, especially in machine shops or foundries, and other places where the walls do not remain white, but change to some darker color. The color of almost everything which is changed by age is due to either iron or carbon. In most cases of discoloration by age the reddish-brown color of iron and the brownish-yellow color of carbon are seen. This is the color most objects gradually assume. This color of age is in the long wave or low frequency end of the spectrum. To get the benefit of reflected light from walls which cannot be kept perfectly white, a source of light rich in the long low frequency waves, or of a yellowish tinge is therefore more efficient as it gives more reflection from the walls than a source of light rich in short or high frequency waves such as bluish-white. This effect is very marked when the mercury arc lamp is compared with the flame carbon lamp. The illumination given by the mercury arc lamp in a draughting room is very satisfactory, but the same illumination in a foundry or machine shop is far less satisfactory, because of the marked absence of reflected light. Even the black-begrimed walls of a blacksmith shop reflect a considerable amount of light with an orange-yellow source of light, but reflect practically none of the bluish-green light of the mercury lamp.

Thus the shade of color of the illuminant may be very essential in getting efficient illumination. In the interior of a city, the walls usually have a reddish-yellow color. In that case white or yellowish lights are superior. Outside of the city the greenish-yellow light of the Welsbach lamp and the bluish-green of the mercury arc, give much larger amounts of reflected light from vegetation than do the yellow of the incandescent lamp and a better illumination results. Vegetation absorbs the long waves, the low frequency radiation, so that with a yellow source of light there is practically no reflection from living vegetation. On the other hand, there is reflection of the long waves from dead vegetation, and in the light of the incandescent lamp or the flame arc all vegetation appears very poorly, because the dead parts are brought out prominently. The reverse is the case where the light is deficient in the red and yellow, and rich in the green and blue; the green shows prominently, but the dead leaves are not visible.

IV.

It is however not the amount of light which reaches the illuminated objects, that is to say the physical itensity of illumination, which is of importance, but the amount of light from these illuminated objects which reaches the eye. With a given intensity of illumination, the amount of light entering the eye will vary widely with the opening or contraction of the pupil of the eye. The eye automatically adjusting itself to intensity of the light. This is the reason one sees well in sunlight and in the light of the full moon, although the former is many thousand times more intense than the later. The eye can accommodate itself to intensities varying over an enormous range. It does this partly by the fatigue of the nerves of vision, and partly by the contraction or opening of the pupil. This is undoubtedly a protective device. It follows that if there is in the field of vision a source of high intrinsic brilliancy, the eye protects itself by contracting the pupil and thus receives much less light than it would if the source of light were taken out of the field. By eliminating the source of light from the field of vision and thereby eliminating the contraction of the pupils resulting from the high intrinsic brilliancy of the illuminating body, a larger amount of light is actually sent into the eye, although only the same amount of light strikes the illuminated object; that is to say, a higher physiological efficiency is obtained. Even though a much less amount of light reaches the illuminated objects, more light may reach the eye. That means that the intrinsic brilliancy of the illuminant may be reduced by indirect lighting or by diffusing the light, and thus a considerable amount of light may be lost, yet a larger amount of light enters the eye.

It follows from this that in efficient illumination, it is of the greatest importance to arrange the illuminant so as not to have excessive an intrinsic brilliancy in the field of vision. The proper place for the illuminant is outside of the field of vision. Where it can not be so put, its intrinsic brilliancy should be reduced by diffusion. This is the reason for indirect lighting. Even though a large amount of light is thrown on any object in a room, if the eye be fatigued by seeing the source of light, very little light will enter it.

It appears, however, that this automatic protective faculty of the eye was developed through the ages as a protection, not against light, but against energy; apparently the eye is protecting itself against the energy of the radiation, and not against the physiological effect, and since the energy of radiation is mainly in the ultra-red, in the long waves, the frequencies which cause the protective reaction are those of the long wave end of the spectrum, the red and yellow; they make the pupil contract. This action is much less for the green and blue rays, which is the reason the eye does not react to the mercury lamp to any great extent. Therefore a green light, such as is given by the mercury or Welsbach lamp, may be placed more freely in the field of vision, without causing the contraction of the pupil and thus reducing the physiological effect. This is of importance in places where the light can not well be taken out of the field of vision, such as in street illumination. Here all the sources of light must be arranged along the street and so must be in the field of vision. By cutting off the red end of the spectrum the contraction of the pupil may be eliminated and the full benefit of the illumination between the lamps be obtained. It is otherwise with a yellow source of light, such as the incandescent or arc lamp. The physiological effect of the lighting by a green illuminant is, in such cases, superior to that by a yellow illuminant; the illumination appears brighter and more uniform.

A light devoid of red and yellow rays is at the same time the safest and the most harmful. It is the safest and gives the most uniform illumination, if its intrinsic brilliancy is sufficiently low to be below the danger limit of energy of radiation; but is harmful if above that, because the eye does not protect itself against it, probably because these lights have not existed throughout all the ages during which this protective action was being developed, when sunlight and fire were the only sources of light, both of which are rich in red rays. This accounts for the rather contradictory effect observed, that green or blue light, such as given by the Welsbach mantle or the mercury lamp, is a very good light to work by, superior even to the yellow kerosene lamp; and at the same time there is suspicion that it may be harmful to the eye. It may well be that when it is of very high intensity, the automatic action of the eye is not sufficient to protect it against such light. Where such sources of light are used, the benefit of the absence of the contraction of the pupil may be obtained, but the illumination must be arranged so as not to get the harmful effects against which the automatic protection of the eye fails. All of these blue and green lamps are superior for illumination if they have intrinsic brilliancies, but are somewhat questionable if they have extremely high intensities.

V.

It is, however, not even the actual amount of light which enters the eye which is of importance in illumination, but the differences in this light. If in the illuminated area the light is of uniform intensity, and everything of the same color, nothing but a glare of light will be seen. Seeing takes place by the recognition of differences in color and in intensity. Difference in intensity includes shadows. Shadows are thus an essential feature in seeing things.

Considering, then, the seeing by shadows and seeing by color differences, illumination may be divided into directed and diffused illumination. In diffused illumination light comes in all directions with approximate uniformity, and shadows do not exist; in directed illumination, shadows exist. In some cases shadows are objectionable. In others shadows are necessary for clear distinction, and diffused illumination in such cases would not be satisfactory.

Where definite color distinctions are required, the sharpness of vision may be intensified by selecting that color of light best suited to bringing out the colors desired. Where the color conditions to be distinguished are those of age, due to iron and carbon then that light which is deficient in red and yellow, and which therefore shows the colors given by iron and carbon as black gives a much sharper distinction. The light of the mercury lamp makes blemishes and dirt much more pronounced than a white light. Again, the sources of light which are rich in red and yellow rays emphasize the colors due to iron and carbon less, and make less noticeable blemishes of a slight amount of dirt. Where the color distinctions are those due to these two most prominen elements, their appearance will be greatly softened in the yellow light. Under the green light they will be made harsh and sharp If it is desired to soften effects, as in a ballroom, it would be fiendish to use mercury lamps, but where the object is to search out a spot that is soiled, it is wrong to use a dull yellow incandescent lamp or gas flame. Rather use the green Welsbach light or better still the bluish green mercury arc, which gives sharp distinction where white light shows little and yellow light nothing

Where it is desired to see all colors in about the same relation as by daylight, obviously a white light is necessary.

It is therefore important for the illuminating engineer, in selecting the shade or color of the light, to study the requirements of each case which comes into his charge. It would be just as wrong in one case to use an incandescent lamp, if the mercury lamp would be better, as to do the reverse.

It is necessary, therefore, to distinguish between general illumination and local illumination, between direct illumination and indirect illumination, and between directed illumination and diffused illumination. These three different classes or distinctions to a certain extent overlap. It would be wrong to mistake them, and a serious mistake in the design of a system of illumination can thus easily be made. For instance, general illumination and diffused illumination may be confused. The problem may be to get uniform intensity throughout a room. This may be done by distributing a large number of small units around the cornices and reflect the light from white walls and ceilings, thus getting a very diffused illumination. Or a general illumination may be obtained with the intensity of illumination everywhere the same in a moderate sized room, from one source of light by using one source of light such as an incandescent lamp with a reflector which gives a uniform distribution. The former arrangement gives diffused light, the latter directed light. The intensity of illumination may be the same all over the room in both cases, but in the former case there are no shadows, and in the latter absolutely black shadows. Probably for domestic use lighting by the former method would be unsatisfactory and trying to the eyes, because, due to the lack of shadows, objects are not distinct. In the latter case with directed lighting from one source, the lighting will be unsatisfactory because of the very dark shadows in which nothing can be distinguished. The eyes are tired by trying to see in the shadows.

It is necessary to consider how much directed light and how much diffused light are required. In some cases only diffused light may be desired. In the general lighting of a draughting room directed light is not wanted, since there must be no shadows, because if the ruler casts a shadow, it is trying to the eyes to distinguish between the edge of the ruler and the edge of the shadow.

and mistakes may be made. In this case, one sees only by differences in color and in intensity, and not by shadows. A satisfactory illumination is given by many small units or by indirect lighting by reflection from white walls and ceilings. An unsatisfactory illumination is obtained from a few units even when properly distributed to give uniform intensity all over, but giving little reflected light. In other cases a general illumination everywhere equal in intensity may be required, but directed illumination may be needed so as to see by the shadows. A good draughting room illumination would not be suitable for a foundry, where all the objects assume more or less the same color. Here shadows are necessary. What is needed is a number of units of light to get directed illumination. But this must not go so far as to make it impossible to see in the shadows. There must be some diffusion, or overlapping of the different beams of light. A satisfactory foundry illumination placed in the draughting room, even if the intensity were sufficient, it would be entirely unsatisfactory, and so would be the reverse. It is therefore not merely the distribution of the intensity of the light, which is essential, but also the character, whether diffused or directed light, or how divided between diffused and directed light.

In different lighting problems these questions of concentrated and general illumination, of directed and diffused illumination ,are met. In domestic lighting a high intensity may be obtained by reflected light from white walls and ceilings. The illumination may be increased several fold over that given directly by the source of light, yet the illumination may be unsatisfactory and tiring to the eyes. In the home a room with white walls is not as agreeable as one with darker walls. There seems to be too much light. But there is not too much light, because there is not anywhere near the same amount of light as there is during the daytime out of doors. There is too large a percentage of diffused light. The intensity of the diffused light is too great as compared with the directed light. The shadows are lost and that is tiring to the eyes.

The problem of domestic lighting is to get sufficient directed and sufficiently low diffused lighting so as to give the best vision. That is, to get sufficient shadows to see by. But the shadows must not be so dark as to make seeing objects in the shadows themselves tiring to the eyes. During the daytime there is directed light from the windows and diffused light reflected from the walls. To get the proper proportion between directed and diffused light is what fixes the shade of the walls, and in general it is necessary to have the walls of somewhat darker color. But when lighting in the evening with a source of light like the incandescent lamp or the gas lamp, which sends out light in all directions, the diffused light as compared with the concentrated or directed light is greater than in the daytime for the colored walls, due partly to the color of the light, which is yellow and reflected more but largely because the directed light coming through the window forms a much larger percentage of the total light than that of the lamp, where only a small part is concentrated light. It is not comfortable to have this strong diffused light, and therefore the walls are shaded so as to absorb three-quarters of the light. That means waste, however, and the light which is not used must be paid for. Proper illuminating engineering then is to secure the correct distribution of light so as to give the desired amount of concentrated lighting on the dining or reading table, and to give only as much diffused lighting as is compatible with the amount of direct light used. The problem of domestic lighting, from the illuminating engineering point, is to determine the proper illumination over the entire area, and also the character of illumination, whether directed or diffused, and how much of the light should be concentrated, and how much should be directed. Another important feature is the question of colors and shades as was discussed before.

Practically nothing has yet been done in this direction systematically and intelligently. Problems are solved by trial, which usually means producing more light than is necessary, and throwing away the excess of the diffused light by absorption.