THE CONCEPTS AND TERMINOLOGY OF ILLUMINATING ENGINEERING.

PRESIDENTIAL ADDRESS.

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In the infancy of a science the concepts regarding it are necessarily neither very clear nor definite. The terminology of a science always lags far behind the actual state of the science itself. We must have the thing before we have a name for it—we must have the concept before we have a word to express it. An exact terminology, as contrasted with a loose one, is found to be more and more essential in proportion as its concepts develop and as the science itself progresses in exactitude. As long as the treatment of the science is qualitative only, no particular need is felt for an exact terminology. As, however, the science becomes quantitative and involves exact measurements of the quantities entering into it, the need for a terminology which is correspondingly precise is felt. For instance, in the earlier days of the science of mechanics, no strict differentiation was made between the terms force, work and power. At the present time, however, these concepts and the terminology corresponding thereto are very clearly differentiated. The interrelations of things are not seen in the same way when a science is young, as they are when it has, so to speak, reached its maturity. The simplest and most obvious relations are the ones which first are used, and it is only with advancing knowledge that the utility of the less obvious relations comes to be appreciated. This is true for an applied science as well as for a pure science. In the application of scientific principles and industrial products to the uses of everyday life, it usually happens that the practitioner at first proceeds in a purely empirical way. He is likely, however, very soon to find a need for greater exactitude in his work; consequently his terminology, which at first was of the crudest description, becomes more exact and perhaps more complex. His concepts of what he is working with, which at first are inexact and hazy, necessarily become cleared with time; and he finds that the ideas on which he proceeded at first, while they may have been more or less correct, yet are not the ones which are most useful in the more extensive practice which time has brought. It may be useful to illustrate these abstract ideas by a few concrete examples.

Going back into the history of electrical science and of electrical engineering, we find that the earliest electrical conception was that of a force, or tension or pressure. The idea of such a thing as a flow of electricity did not become established until after Volta's discovery and the pioneer work of Davy, Farady, Ohm and others had brought this concept to light, and in Ohm's law a relation between the fundamental electrical qualities was established. It was very many years before the terminology of electricity became in any sense systematized or exact. When, however, electricity ceased to become a pure science and came to be applied to the very practical problem of artificial illumination, so that electric power was generated in large quantities and became a commercial product, the need for a terminology, and for units of measurement and for measuring instruments, all made themselves felt, and the terms volt, ohm, ampere and watt came quickly into existence and into the everyday language of the science.

The science of magnetism furnishes another example. The obvious thing about a magnet is its attractive force for other pieces of iron. This force is concentrated at points near the ends of the magnet, which points received the name of "poles." When investigators began to study magnets critically, the most apparent thing to do was to measure the force or strength of these poles. On measurements of pole strength the whole science of magnetism was based. The theory of magnetism, however, went on in its development, and the ideas of lines of force and of flux of magnetism were introduced. Later, when magnetic calculations became a feature in the commercial design of dynamos and motors, the old concept of pole-strength was found to be too awkward and cumbersome as a basis for making such calculations and had to be abandoned in favor of the newer one of magnetic flux, doubtless to the great temporary inconvenience of those to whom the pole-strength concept was a familiar one and the magnetic flux concept an unfamiliar one, acquaintance with which was to be gained only at the expense of considerable mental effort and inconvenience.

We are led now to ask what is the state or condition of the science of illuminating engineering in regard to its terminology and its concepts. This science is founded on the ancient science of optics. All the optical principles which apply to illuminating engineering have been known for many years. Optics is, in many respects, an exact science. The laws of reflection, refraction, diffraction and polarization have been studied with minute care. The measurement of wave-lengths and angles of rotatory polarization, as well as the computation of lenses, mirrors and other optical apparatus, have been carried to an extraordinary degree of precision. In spite of all this, however, the science of optics has remained in a rudimentary condition in so far as its terminology and concepts relating to light as an output, used for purposes of illumination, are concerned.

Just as in the case of magnetism, where the elementary notion of pole-strength was long regarded as the fundamental point of departure for calculations, so the strength or intensity of light sources has been the principal concept in dealing with light as a product. Until touched by the quickening hand of practical application, until illuminating engineering began to take its place as a quantitative science, measurements of the candle power of luminous sources were all that were required, and by candle power was usually meant the candle power in a given direction. At the present time there are many signs that this branch of optical science is following the same course of progress which magnetism has taken before. Within a very few years the term "mean spherical candle power" has come into use among engineers. This marks a distinct advance in the practical application of illuminating engineering, since it implies a recognition of the difference between a candle power in a given direction and the average candle power in all directions in space. The notion of intensity of illumination, as distinct from intensity of a luminous source, has become a familiar one and an awkwardly named unit for it has been used. These are sure indications of the practical progress of illuminating engineering.

What should be, or are likely to be, the lines of further development? These may be determined, in some directions, largely by action which our Committee on Nomenclature and Standards may take. In other directions this committee will be impotent, since it cannot enforce the adoption of its recommendations in practice. The practitioner must feel the need of some novel term or idea before he will adopt such term or idea. Such a need is sometimes unfelt because the practical value of novel terms and concepts is not clearly enough recognized by those to whom they would be useful. Having this in mind, I desire to bring to your closer attention the bearing of some terms and concepts which have not, I believe, established themselves in the practice of illuminating engineering to the extent to which their practical convenience and utility entitle them.

At the present time, in his quantitative work, the illuminating engineer deals chiefly with candle power in its various aspects and with intensity of illumination. He does not, as a rule, employ any term which expresses directly the quantity of light which is being emitted by the source with which he is dealing. This is surprising, for the quantity of light which he had at his command is of vital importance to him. The distribution of this light he can arrange according to his own wishes by the use of various devices. Now the proper term for the quantity of light is easily found by a consideration of the physical nature of light itself. Light consists in ether waves propagated with a velocity of 300,000 kilometers per second. A source of light is simply a wave-maker. It agitates the ether continually and sends out a constant stream or flow of such waves in all unobstructed directions. If we take any transparent plane on one side of which is a source of light, we may think of a continual flow of wave-trains in the ether across this plane. If we surround our source of light by a closed, transparent surface, say an imaginary sphere, the total flow of ether-trains through this surface measures the luminous output of the source. For the sake of uniformity with the usages of other branches of physics, etc., the wave-flow is referred to by using the Latin name for flow, namely "flux."

We should form a concept, then, of all sources of light, whether primary or secondary, as the starting points of a luminous flux, and of all spaces surrounding such sources of light as traversed by this luminous flux. Having formed the concept of luminous flux, the following definitions and relations are a direct consequence: The output of any lamp is measured by the total luminous flux which it emits; the brightness of a diffusely reflecting or transmitting surface is proportional to the luminous flux which it emits per unit of area; the reflecting or transmitting power of such a surface is the ratio of the luminous flux which it emits to that which it receives; the intensity of illumination on any surface is the flux which it receives per unit of area. All the above quantities are of vital importance in illuminating engineering, in view of which fact it would be surprising if the concept of luminous flux should not prove itself to be very useful in the everyday work of the illuminating engineer.

It is necessary first to define a unit in terms of which luminous flux is to be measured and to establish its relation to the unit of luminous intensity, the candle power. This is done in a way analogous to that employed in magnetism and electrostatics; that is, unit flux is defined as the flux emitted by a light of unit intensity, or one candle power, in a unit solid angle. A unit solid angle is the solid angle subtended at the center of a sphere by a portion of the surface of the sphere bounded by four lines, each equal in length to the radius of the sphere. There are 4Π or 12.57 such solid angles in the entire sphere. This being the case, we have approximately the relation that a unit solid angle is the one subtended at a point by a surface one foot square, one foot distant from that point, or by a surface one metre square one metre distant from the point, or a surface one yard square one yard distant from the point, etc. If at the apex of such a solid angle a light source of one candle power be placed, a unit luminous flux will pass through any transverse plane through the solid angle, no matter what the inclination of the plane or its distance from the light. In terms of this unit, luminous flux is measured.

The relation between the total luminous flux of a source of light and the mean spherical candle power of that source is at once seen. If we consider a source of light having an intensity of one candle power in all directions, its mean spherical candle power would be one; and since there are 4Π solid angles in a sphere surrounding that source, the total flux from it will be $4\,\Pi$ units of flux. If the mean spherical candle power of a source is I_s, its total flux will be equal to $4\ \Pi\ I_s$, or Φ equals $4\,\Pi\, I_s$ where Φ represents the total flux and I_s the mean spherical intensity. Thus the total flux is numerically equal to 12.57 times the mean spherical candle power of the source.

We have next to consider the relations existing between flux of light and intensity of illumination. As we have seen, the flux falling on a plane surface one foot square placed one foot distant from a light of one candle power is approximately a unit flux. But the illumination on that surface is unit illumination if we measure in English units. If the same plane surface is removed to a distance of two feet from the light, only one-fourth of the total flux falls on it and the illumination is one-fourth as intense. In other words, the intensity of illumination on any surface is measured by the luminous flux per unit of that surface or by the flux density. This relation may be expressed thus: $E = \frac{\Phi}{s}$, where s is the area and E the intensity. From this relation the familiar inverse square law may at once be deduced.

The above equation becomes of practical importance in computing average illumination results. If, for instance, we know that from a given source or sources of light a certain flux falls upon the plane of reference, we can determine at once the average illumination on this plane by dividing the flux by the area of the plane. Thus the average illumination is determined without direct reference to the candle power of the sources. Conversely, measurements of illumination on a given plane enable us to determine the flux of light falling on that plane. This is a quantity of great importance, since it leads us to a value for what we may term the net efficiency of the installation, or the efficiency of ultilization of the light. By the net efficiency of the installation, or the efficiency of utilization, would then be meant the ration of flux which falls upon the horizontal plane of reference, to the total luminous flux emitted by the lamps in the room.

In order to make the use of the notion of luminous flux, a convenient one in practical work of the computation of illumination, it is necessary to use it also with reference to the sources of light employed. In other words, when we wish to arrive at average values for illumination rather than exact illumination curves, we may ignore the candle power and the distribution of the luminous intensity of the lamp and may start out from a value for the flux of light which the lamp, together with its reflector or globe, sends in the direction of the plane of reference. Multiplying this flux by the number of lamps, and dividing it by the area of the plane, we have approximately the illumination on the plane, neglecting reflections from walls and other objects. The effect on the flux of multiple reflections by the walls of the room can be found according to the usual procedure, that is, the flux must be multiplied by $\frac{1}{1-k}$, where k is the average coefficient of reflection of the walls and ceiling, and where this value is subject to large modifications according to the location of the lamps in the room. The maximum and minimum points of the illumination in a given installation can usually be told at a glance, and the values of these illuminations can be computed if required. The advantage of the procedure outlined above is that it gives an average value for the illumination over the entire plane of reference without the necessity for going through the computation of the actual illumination at a large number of points in the room.

The procedure for determining the value of the luminous flux from a lamp, either its total flux or the flux within a certain solid angle, is similar to that pursued in determining the mean spherical candle power and mean hemispherical candle power, etc. For instance, the well known Rousseau diagram, so generally employed for the determination of mean spherical candle power, is really a flux diagram. If the Rousseau diagram extends over 180 degrees polar distance, the total area which it encloses is proportional to the total flux of light from the lamp and the part which is enclosed between any two angles as marked on the axes of the abscissas, is proportional to the flux from the zone or from the solid angle. Consequently, any method which will yield the mean spherical, mean hemispherical, or mean zonular candle power will give, with practically no modification, the luminous flux corresponding thereto. The Matthews integrating photometer may be calibrated so as to give directly the total luminous flux from the lamp measured by it, or other integrating devices may be employed. By the use of such devices as are at hand to-day, it would not be at all impossible to rate lamps according to their total luminous flux rather than according to their candle power. Thus at one stroke the difficulty would be cleared up which arises from the actual difference in performance of incandescent electric lamps, which are rated alike according to our present arbitrary method. Using one of the methods indicated above, it is a matter of no difficulty to determine what the total flux of light will be, for instance, from a lamp with a conical reflector inside the angle subtended by the sides of the cone. Imagine, then, a number of lamps with such reflectors illuminating a room, and so placed that the angles of the cones of the reflectors do not in any case fall outside the boundaries of the plane of reference. Then the total amount of light which these lamps are throwing on the plane of reference will be approximately equal to the number of lamps multiplied by the flux which is sent out inside this plane, and as said above, the average illumination is obtained by dividing this flux by the area of such plane. This method is of such extreme simplicity that it seems that it ought to be developed in practice. It is concededly approximate, but since any method yields results which are so strongly affected by the reflections from walls and ceiling, it is a question whether an approximate method like this might not in the end yield results which are quite as reliable as those which are obtained by the more laborious calculations involved when illumination curves are computed.

Having pointed out certain reasons why the notion of luminous flux should find extensive application in illuminating engineering work, let us consider for a moment the question of terminology. We have at the present time a name for the unit of luminous intensity. We call that the candle, and we measure luminous intensities in candle power.

It is usual in this country to express illumination in terms of the candle, and of the foot as the unit of distance. We have no suitable name for this unit of illumination; by some it is called the candle-foot, by others the foot-candle. Some make the plural candle-feet, others make it foot-candles. The name is inappropriate and awkward, since ordinarily, when we place two words in conjunction like this, we mean the product of the two quantities involved, as for example in foot-pounds, where we mean the product of the feet by the pounds. The foot-candle or the candle-feet, however, means candles divided by, not feet, but feet squared; consequently the term is doubly inappropriate. It would, therefore, be very desirable, if we are going to adhere to this unit of illumination, to have a suitable name for it. If we use the metric system, a name for the unit of illumination is at once at hand. In this system the candle may be the unit of luminous intensity, but the meter is taken as the unit of length. The illumination produced by one candle at a distance of one meter is called the "lux." On account of the relation existing between the foot and the meter, it happens that the lux is about ten times the size of the foot-candle. To be more exact, it is $(\frac{39.37}{12})^2$ or 10.8. The use of the lux, however, involves the use of an unaccustomed unit of length and it is consequently found awkward. This is all a matter with which the Committee on Nomenclature and Standards will undoubtedly deal.

When it comes to the unit of flux of light, as we have seen, the unit of length does not enter. The unit of flux depends only upon the chosen unit for luminous intensity and consequently we may adopt the name which has already been suggested and used for this purpose, namely, the "lumen." By the lumen we mean the flux of light emitted by a source of one candle-power through a unit solid angle, and, as we have seen, the number of lumens falling on a surface, divided by the area of the surface in square feet, will give the illumination in foot-candles, or the number of lumens falling upon a surface, divided by the area of that surface in square meters, will give the illumination on that surface in lux. It would, therefore, seem to be an obvious thing to do to adopt the lumen as the name for the unit of luminous flux.

A point in terminology, which it may not be out of the way to bring up at the present time, relates to the use of the term "efficiency" in illumination work. We have in this kind of work at least three kinds of efficiency to consider. We have, first, the efficiency of the illuminant as such; second, the efficiency of the illumination installation irrespective of the lamp (this may be called the net efficiency of the installation, or the efficiency of utilization of the light); and, third, the efficiency of the installation including the lamp (this may be called the gross efficiency of the installation). The efficiency of the lamp, if it be an electric lamp, would properly be determined by its lumens per watt; this term has not come into use, but deserves to do so. Instead of lums per watt, we speak of watts per candle. Watts per candle measures for a given type of lamp, the specific consumption of that lamp. True specific consumption would be measured by watts per lumen. The term watts per candle, while a very convenient one from the lamp-maker's point of view, is not so good a term for the use of the illuminating engineer. It is to be hoped, therefore, that in time lamps will be designated by their efficiencies, and the efficiencies will be expressed in terms of lumens per watt. What we ordinarily at the present day call a sixteen candle-power 3.1 watts per candle lamp would, under that system, have a rating of 163 lumens and an efficiency of 3.3 lumens per watt. In the case of gas lamps, the efficiency could be expressed in terms of lumens per cubic foot per hour.

Going next to the net efficiency of the installation, irrespective of the lamp. This is the efficiency which it is the especial province of the illuminating engineer to attend to. Given any illuminants whatever, there is some best way to equip and to arrange them so as to produce a maximum result in illumination. This efficiency may be expressed in terms of the lumens received on the horizontal plane of reference, divided by total lumens emitted by the lamps. The gross efficiency includes the efficiency of the lamps themselves. This is the efficiency with which the user of the installation, the man who pays the bills, is most interested. This efficiency can be expressed in terms of lumens on the plane of reference per watt, or per cubic foot per hour expended in feeding the lamps. In the *Transactions* of this Society it has appeared that the need is felt for an expression of the gross efficiency of an installation, since the term foot-candles per watt per square foot has been used for this purpose. Those who have used this term have recognized its awkwardness as well as its usefulness, and it has even been proposed to give a name to this unit. If we stop, however, to analyze this expression, we see that foot-candles per watt per square foot is equivalent to foot-candles multiplied by square feet, and divided by watts. But, as we have seen, the foot-candles multiplied by the square feet gives the luminous flux in lumens, consequently the expression foot-candles per watt per square foot is equivalent numerically to lumens per watt; so that here again the introduction of the notion of luminous flux, and of the term lumen, justifies itself by reducing an expression of unusual complexity to one of very great simplicity.

This address as a treatise on the concepts and terminology of illuminating engineering is necessarily indefinite and incomplete. Its purpose is to point out the utility of certain ideas and names which should prove useful in the pursuit of the theory and practice of illuminating engineering. What the ultimate developments will be in concepts and terminology of the science cannot be foretold; the most obvious steps in advance are those outlined above.

DISCUSSION.

President Sharp.—Gentlemen, it gives me pleasure next to invite the Past President of the Society, the Vice-Presidents of the Society who are present, and the members of the council to occupy seats on the platform.

The next order of business will be the discussion of the President's address, during which time I will ask Mr. Pope, Senior Vice-President, to take the chair.

(Vice-President Pope in the chair.)