

RECENT DEVELOPMENTS IN THE ART OF ILLUMINATION.*

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IN the JOURNAL OF THE FRANKLIN INSTITUTE for the last few years there are to be found a number of papers dealing with certain phases of illumination. These are of especial interest to a limited number of Institute members, but most of them are somewhat esoteric and presumably have been read in detail by but a limited number of Institute members. Consideration of the character of the Institute membership has led the writer to feel that he could perhaps be of some service by endeavoring to outline in a comprehensive way the nature and scope of the art of illumination and by making available a brief review of developments in illumination which will place before the members a general view of the subject in its large features. Accordingly, this paper will be found to contain but little of new interest for the illuminating engineer, being written more especially for the consideration of the membership of the Institute at large.

In the discussion which follows a fragmentary bibliography is included. The references which are noted are intended to direct attention to significant papers, and to furnish an indication of the manner in which the several phases of each division of the subject of illumination are being developed.

Illuminating engineering as a distinct specialty is perhaps not generally understood. The name illuminating engineering as applied to this specialty is perhaps not wisely chosen. It will serve, however, for the purpose of this discussion. Illuminating engineering, then, as a specialty may be represented by the diagram in Fig. 1.

The specialist applies the materials of illumination with the aid of the science of illumination, and practises the art of illumination.

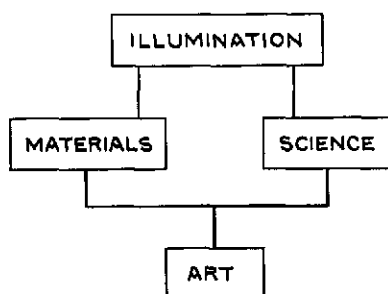
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THE MATERIALS OF ILLUMINATION.

The *materials of illumination* may be classified as illuminants—natural and artificial—lighting auxiliaries, and fixtures.

Considering first *incandescent electric lamps*,¹ it may be noted that increases in the efficiency of light production have been ac-

FIG. 1.



companied by increase in the variety of illuminants both as to types and sizes. Neglecting for the moment other qualities than the efficiency of light production, your attention is directed to the

FIG. 2.

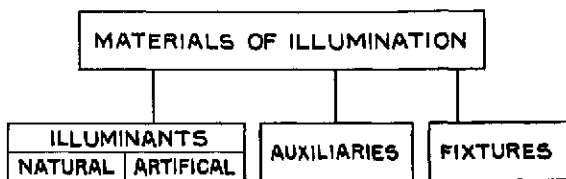


diagram in Fig. 3. This shows improvements in incandescent electric lamps which were made available some years ago and the status of lamps of more recent development. It will be noted that the advances in the efficiency of light production have been

¹ *Incandescent Lamps:*

"A New Carbon Filament," Howell, *Trans. A. I. E. E.*, 1905, p. 839.

"New Types of Incandescent Lamps," Sharp, *Trans. A. I. E. E.*, 1906, p. 815.

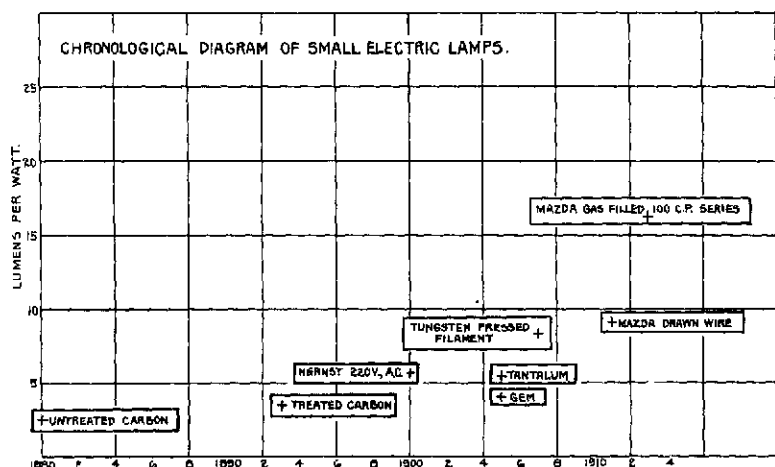
"High Efficiency Lamps," Doane, *Proceedings N. E. L. A.*, 1910.

"Recent Progress in the Art of Lamp Making," Randall, *N. E. L. A.*, 1913.

"Tungsten Lamps of High Efficiency," Langmuir & Orange, *Trans. A. I. E. E.*, 1913, p. 1915.

marked. The carbon filament lamp which had remained without material efficiency improvement from 1893 to 1905 was at that time improved through the development of the so-called "metallized" carbon filament, and in that form remains the most efficient type of carbon filament incandescent lamp. The carbon filament lamp had been the standard form for general electric lighting, and continued to be the standard lamp and the most largely produced lamp until about 1912. Its preëminence was challenged before that time because of the adoption of the metallized carbon filament lamp for free renewal to customers by the

FIG. 3.



larger central stations of the country, and was lost in 1912 as a result of the influence of lamp manufacturers in promoting the sale of the metallized filament rather than the sale of the carbon filament lamp. The substitution of the metallized carbon filament lamp for the earlier form of carbon filament lamp resulted in an increase of the standard of illumination throughout the country, for it consumed the same energy and produced about 20 per cent. more light than did the earlier carbon filament lamp.

In 1905 the various forms of carbon filament lamps were supplemented by the tantalum lamp, an importation from Europe. This lamp never entered largely into American practice, its largest sale in the country probably never exceeding 3 per cent. of the total sales of incandescent lamps. Its inferiority when operated

upon alternating current and the announcement of the invention of the tungsten lamp shortly after its appearance, prevented its attaining a position of importance in our practice.

The tungsten filament lamp, first made available commercially in 1907, was a marked improvement over other lamps then available, although its fragility and relatively high price led to restriction of its use in the earlier years of its history. Through the splendid development work of American lamp manufacturers, this lamp has been rendered much more effective in all respects than it was a few years ago. The substitution of the drawn wire mounted as a continuous filament placed the lamp in a class with the carbon filament lamp in respect to ruggedness. The development of bulb blackening preventives has permitted its operation at somewhat higher efficiencies. These improvements, with notable price reductions, have led to the large use of the tungsten, now known chiefly as the Mazda lamp, so that in 1913 sales of the Mazda lamp exceeded sales of all other types of incandescent electric lamps, notwithstanding the fact that the life standard which it sets is twice that which obtained previously.

During the past year, a new form of tungsten filament lamp has been announced, in which the bulb contains an inert gas which reduces the rate of evaporation of the filament and permits operation of the lamp at a higher efficiency. This gas-filled Mazda lamp is chiefly of importance in the larger sizes, and in effect creates a new lamp of characteristics similar to the incandescent lamp but of power equivalent to the arc lamp. In its smaller sizes it is included on the diagram, marking the highest efficiency attainment in the production of light by small incandescent lamps.

The Nernst lamp was brought to its highest development in 1908 in the Westinghouse Nernst. Its active exploitation practically ceased in 1912, due to the superior qualities of the tungsten filament lamps.

Paralleling the improvement in efficiency of light production by means of incandescent lamps have come improvements in *larger electric illuminants*.² The pure carbon open arc lamp was

² *Arc Lamps:*

"The Invention of the Enclosed Arc Lamp," Marks, *The Sibley Journal of Engineering*, October, 1907.

"Properties and Industrial Applications of the Flame Arc Lamp," Blondel, *International Electrical Congress*, 1904, vol. 2, p. 729.

supplemented in about 1893 by the enclosed carbon lamp, which largely supplanted it in spite of a lower efficiency because of more desirable operating characteristics. This enclosed carbon arc lamp has been for a number of years the standard street lighting illuminant of America, and only within the past two or three years has yielded its position of preëminence in that field to the newer and superior forms of arc lamps. The intensified carbon arc lamp has found considerable application in the lighting of interiors, principally stores. In this lamp pure carbons of relatively small diameter are operated at high current density within a globe which partially restricts the air supply. The resultant light is more nearly white than that usually obtained from the carbon arc lamp and offers some advantages for store lighting purposes.

The metallic electrode arc lamp, of which the Magnetite and Metallic Flame lamps are the principal examples, has come into large use in street lighting and more than any other type of lamp has supplanted the enclosed carbon arc lamp. This lamp differs radically from earlier forms of arc lamps in that the light is produced by luminescence and emanates wholly from the arc stream, whereas in the several forms of pure carbon arc lamps the light is produced by incandescence of the electrode ends.

The flame arc lamp (short life form) is the highest achievement in efficiency of light production among commercial electric illuminants. In its earlier forms it suffered from short electrode life, which made its operation costly and practically limited its usefulness in this country to display lighting. In repetition of the history of the pure carbon arc lamp, the flame arc lamp, which is equipped with carbons impregnated with various salts, has been adapted to secure long electrode life by partially enclosing the arc and employing large diameter electrodes. As in the earlier lamp, this operating advantage has been secured at the expense of loss

"The Electric Arc," Steinmetz, *International Electrical Congress*, vol. 2, p. 710.

"The Metallic Flame Arc Lamp," Stephens, *Trans. Illg. Eng. Soc.*, 1907, p. 657.

"Design of Luminous Arc Lamps," Halvorson, *General Elec. Review*, 1911, p. 578.

"Arc Lighting," Steinmetz, *General Elec. Review*, p. 568, 1911.

"Ornamental Luminous Arc Lighting at New Haven," Halvorson, *General Elec. Review*, 1912, p. 220.

"Enclosed Flame Arc Lamp," Chamberlain, *General Elec. Review*, 1912, p. 706.

in efficiency, and the long-burning flame arc lamp is not to be confused with the more efficient short-life flame arc lamp in this respect.

The gas-filled Mazda lamp,³ small sizes of which have been included in consideration of incandescent lamps, has not yet emerged from the developmental stage, but is known to be among the very highest efficiency electric illuminants, especially in its larger sizes.

The mercury arc lamp is available in two types. The low-pressure arc in glass tubes is the earlier form and is in more general use than the high-pressure quartz tube lamp. The latter, however, surpasses it in efficiency.⁴

The Moore tube, filled with nitrogen for general illumination purposes, has been used to a limited extent for special classes of lighting. Smaller sizes in which carbon dioxide replaces nitrogen are used only as artificial daylight.

The Neon tube, as devised by Claude of France, marks a distinct advance in the efficiency of tube lighting. Whereas the Moore nitrogen-filled tube yields light of a pinkish-yellow tinge, the Neon tube gives light which is red.⁵

The diagram, Fig. 4, summarizes and compares the light-producing efficiency of these several large illuminants. The enclosed carbon arc lamps and the Moore tube are the lowest in efficiency. The 4-ampère Magnetite lamp is of substantially the same efficiency as the old open carbon arc lamp. The 6.6-ampère Magnetite and the low-pressure mercury vapor lamp are next in order, just failing to reach the efficiency of the long-burning flame arc lamp, of the quartz high-pressure mercury vapor lamp, and the Mazda gas-filled lamp. A short-burning flame arc lamp producing 36 lumens per watt is distinctly the most efficient of these large illuminants.

³ *Mazda Gas-Filled Lamps:*

"Tungsten Lamps of High Frequency," Langmuir and Orange, *Trans. A. I. E. E.*, 1913, p. 1915.

⁴ *Mercury Vapor Lamps:*

"Notes on the Cooper-Hewitt Lamp," Cooper-Hewitt, *Elec. World and Engineer*, 1910, p. 679.

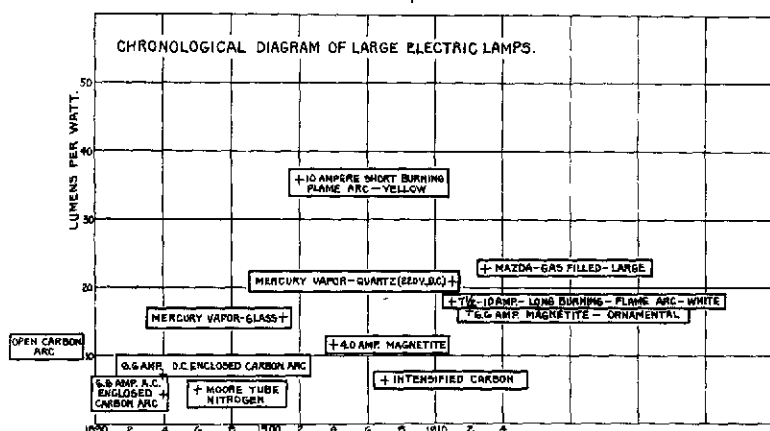
⁵ *Tube Lighting:*

"Light from Gaseous Conductors within Glass Tubes," Moore, *Trans. A. I. E. E.*, 1907, p. 605.

"Neon Tube Lighting," Claude, *Trans. Ill. Eng. Soc.*, 1913, p. 371.

The development of the *gas mantle* by Von Welsbach, in 1884, was the beginning of a new era in gas lighting.⁶ When the mantle burner was introduced, there were available the flat flame burner, producing 1 to 2 candlepower per cubic foot of 16-c.p. coal gas; the Argand burner, producing perhaps 3 candlepower per cubic foot; the regenerative burners producing as much as 7 to 10 candlepower. The Welsbach lamp made available at first 10 and later something like 15 candlepower per cubic foot of gas. Since the early developments of the modern Welsbach lamp in say 1891, no material improvements have been made in the effi-

FIG. 4.



ciency of light production from small mantle burners, though burners, mantles and auxiliaries have been further developed along lines which make for better operating qualities. Beginning with about 1901, the number of sizes of lamps employing mantles was increased and the production of an inverted burner was undertaken. By 1906 the inverted burner had attained a point of commercial success, and there had been produced a variety of sizes of upright mantle lamps, ranging from those consuming $1\frac{1}{4}$ cubic feet of gas up to the multiple burner lamps employed for lighting

⁶ *Gas Lamps:*

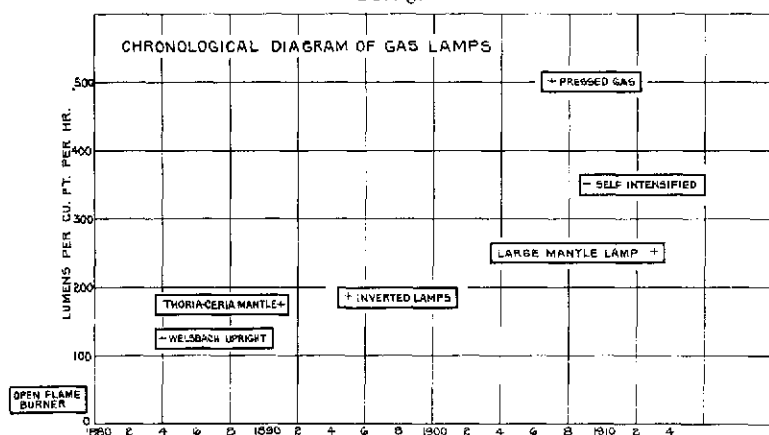
"Inverted Gas Lighting," Whitaker, *Trans. Illg. Eng. Soc.*, 1907, p. 764.

"Modern Gas Lighting Conveniences," Little, *Trans. Illg. Eng. Soc.*, 1908, p. 418.

"Symposium on High-Pressure Gas Lighting," Goodenough, Klatte and Zeek, *Trans. Illg. Eng. Soc.*, 1912, p. 506.

large areas, and consuming 12 to 18 cubic feet of gas per hour. Since that time this range of lamps has been realized in the inverted type and various improvements have been made in structural features and operating qualities. Regenerative lamps have been produced and have entered to a limited extent into service in this country. These attain efficiencies of the order of 28 candlepower per cubic foot per hour. Highest efficiencies from illuminating gas have been obtained by the use of pressed gas systems, used largely abroad for street lighting, but not as yet introduced extensively in this country. These yield light-producing efficiencies of the order of 35 candlepower per cubic foot per hour.

FIG. 5.



The progress in efficiency of light production indicated by the record of the manufacturer of gas illuminants is shown in Fig. 5.

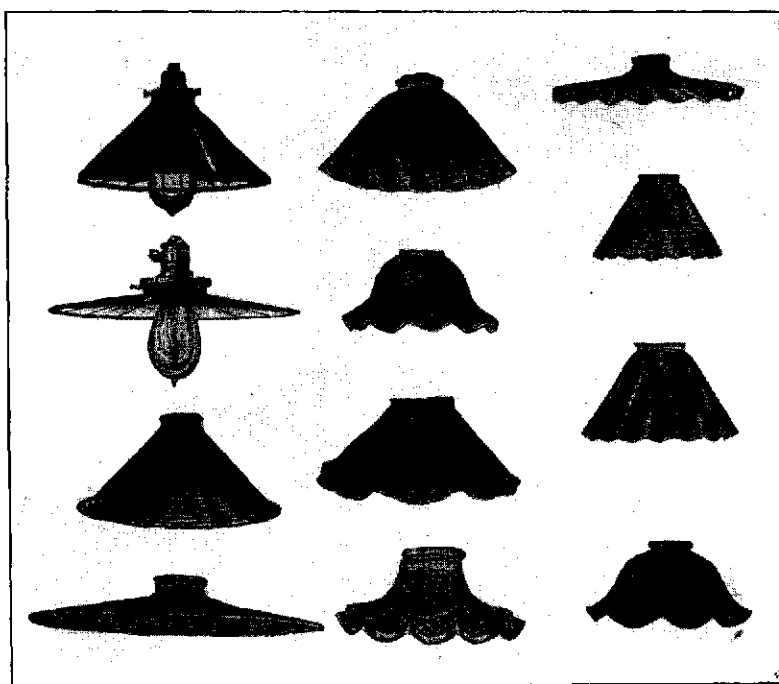
Among *other illuminants*² the kerosene oil lamp is, of course, the most important. Its earlier form was improved by the substitution of a round wick, centre draught lamp for the flat wick burner. The incandescent mantle has been applied to the kerosene lamp but without such success as to command general substitution in oil-lamp lighting. Acetylene lighting, filling a limited part of the general illumination field, is not understood to be making any considerable advance in efficiency of light production. The same is true of gasoline lighting.

² *Miscellaneous Illuminants:*

"The Progress of the Gas Industry," Morrison, *Trans. Illg. Eng. Soc.*, 1909, p. 36.

One illuminant has been produced which yields light of a color closely approximating what may be considered to be average daylight. That is the Moore carbon-dioxide tube. Mazda lamps, the intensified carbon arc lamp, and gas mantle lamps have been equipped with color screens intended to modify the light to pro-

FIG. 6.



Reflectors of a decade ago.

duce artificial daylight.⁵ Some of these duplications of natural light are excellent and are being employed with good effect for commercial purposes. Other illuminants or equipments for illu-

⁵ *Artificial Daylight Illuminants:*

"A Standard for Color Values—The White Moore Light," Moore, *Trans. Illg. Eng. Soc.*, 1910, p. 209.

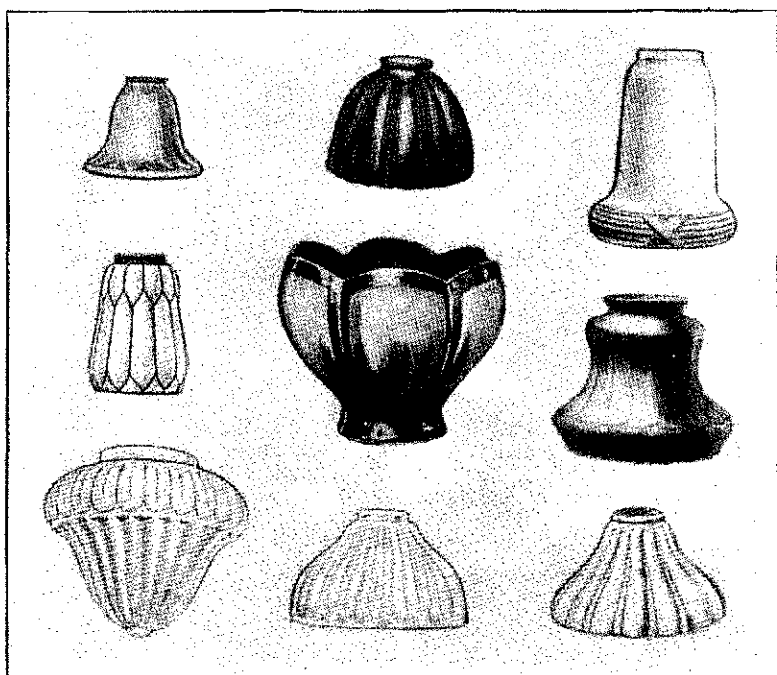
"A Lamp for Artificial Daylight," Hussey, *Trans. Illg. Eng. Soc.*, 1912, p. 73.

"Subtractive Production of Artificial Daylight," Ives and Luckiesch, *Electrical World*, 1911, p. 1092.

"A Gas Artificial Daylight," Ives and Brady, *Lighting Journal*, 1913, p. 131.

minants have been announced as the equivalent of daylight or as having daylight qualities. Unfortunately, however, there has been much misrepresentation connected with this, and so far as the writer is aware, only the efforts named above should be regarded seriously in this connection.

FIG. 7.



Various forms of modern reflectors and globes.

Lighting auxiliaries,⁹ including reflectors, globes, shades, etc., have been greatly improved in recent years. Fig. 6 illustrates some types of reflectors typical of those which were sold to to 15

⁹. *Auxiliaries*:

"The Principles of Shades and Reflectors," Bell, *Trans. Illg. Eng. Soc.*, 1909, p. 723.

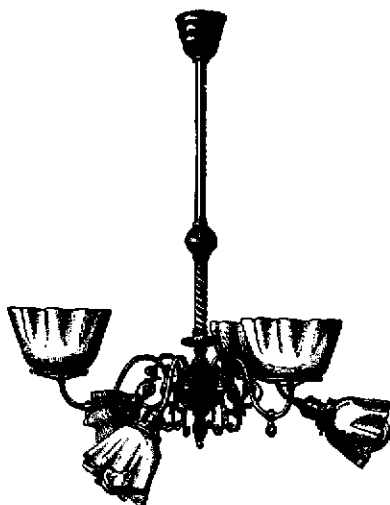
"Scientific Principles of Globes and Reflectors," Lansingh, *Trans. Illg. Eng. Soc.*, 1910, p. 49.

"Symposium on Illuminating Glassware," Jones, Marshall, Young and Hibben, *Trans. Illg. Eng. Soc.*, 1911, p. 854.

years ago. Fig. 7 shows an assortment of modern reflectors which surpass those previously available in appearance, and in that they conceal the light source and diffuse the light. They excel also in efficiency of light redirection.

The design and manufacture of *fixtures*¹⁰ may be divided into two classes; namely, fixtures of distinctive design and stock fixtures. The former cannot well be generalized; the latter, which, of course, are more largely used, have been improved somewhat with the improvement in taste in regard to design which is grad-

FIG. 8.



Typical stock fixtures of a decade ago.

ually being wrought among the public at large. At least, it may be said, that the atrocious fixtures which were placed in moderate priced houses twenty years or so ago are now supplanted by more tasteful fixtures.

Fig. 8 shows a cluster of electric lamps which is typical of those sold ten years ago. Contrast them with the view in Fig. 9

¹⁰ *Fixtures:*

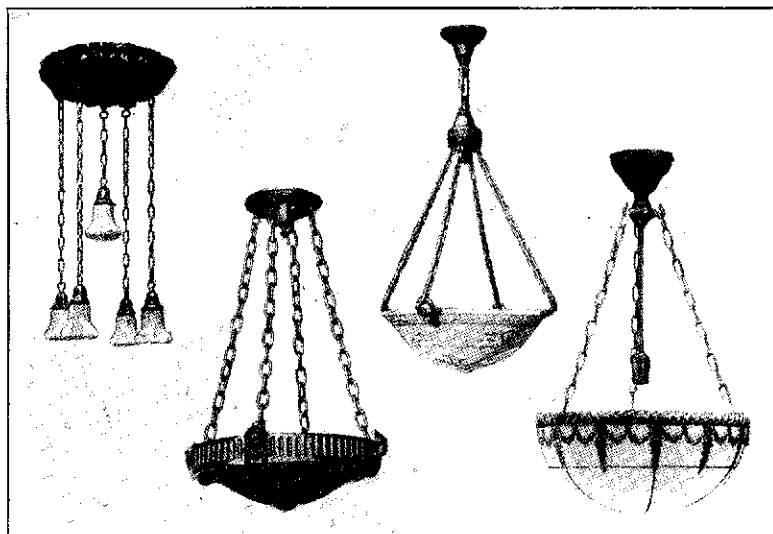
"Fixture Design," Lausingsh and Heck, *Trans. Illg. Eng. Soc.*, 1907, pp. 728-784.

"The Relation of Fixture Design to Modern Illuminating Practice," Hopton and Watkins, *Trans. Illg. Eng. Soc.*, 1910, p. 310.

of modern fixtures designed for the same class of use. The latter are superior in almost every respect, and while possibly more costly, yield a much better service return upon the investment.

It is thus apparent that progress in recent years in the design and construction of materials of illumination has been rapid, and that the report of recent developments must be considered to be

FIG. 9.



Modern fixtures.

encouraging in so far as the materials of illumination are concerned.

THE SCIENCE OF ILLUMINATION.

The *science* of illumination may be considered to comprehend engineering, vision, and aesthetics.

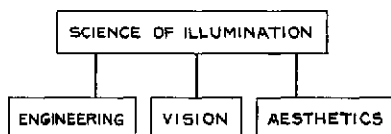
Principles of Engineering.—Considering first the principles of engineering in so far as they form a part of the science of illumination, it may be said that the subject of *supply* falls properly under the headings of electrical or gas engineering. The lighting practitioner must have a working knowledge of usual systems of supply, but no special knowledge is essential.

In the matter of *installation*¹¹ the practitioner needs to be somewhat more skilled. The electrical contractor, plumber, etc., are prepared to handle installations effectively, but are in need of guidance of the illuminating expert; hence, the latter requires a good working knowledge of the subject.

A thorough knowledge of the design, construction, lighting qualities, and operating characteristics of *artificial illuminants* is essential, and this subject has not been neglected in the literature of the art. *Daylight*¹² also has been studied as to direction, diffusion, intensity, color, etc. Very complete information regarding sources of illumination is thus available to the practitioner.

The study of *auxiliaries* from the several viewpoints of light distribution, light absorption, color modification, dust deprecia-

FIG. 10.



tion, etc., has been an important part of recent developments in the field of illumination. The light distribution curve has become a familiar part of manufacturers' data and has been influential in emphasizing the importance of correct design and low light absorbing qualities for reflectors and globes. It has been shown that there have been marked improvements in the design of lighting auxiliaries. Likewise, there has been a notable growth in the knowledge of the use of such devices and in the discriminating selection of the best available for given purposes.

¹¹ *Operating Characteristics of Illuminants:*

"Deterioration of Gas Lighting Units in Service," Pierce, *Trans. Illg. Eng. Soc.*, 1912, p. 677.

"The Relation of the Incandescent Lamp to the Lighting Service," Cooper and Campbell, *National Elec. Light Assn.*, 1913, p. 400.

"The Proper Lamp for a Circuit," Campbell and Cooper, *N. E. L. A.*, 1912, vol. 3, p. 338.

¹² *Daylight:*

"Daylight Illumination," Marsh, *Trans. Illg. Eng. Soc.*, 1908, p. 224.

"The Intensity of Natural Illumination Throughout the Day," Lewin-son, *Trans. Illg. Eng. Soc.*, 1908, p. 482.

"The Distribution of Luminosity in Nature," *Trans. Illg. Eng. Soc.*, 1911, p. 687.

"Daylight," Nichols, *JOURNAL OF THE FRANKLIN INSTITUTE*, 1912, p. 315.

The literature of the art is rich in discussions of the *physics*¹³ of light production, optical principles, color, etc. Knowledge of these subjects has been distributed rather rapidly through numerous presentations before organizations of men interested in lighting.

In the *measurement of light* notable progress has been made in recent years. The measurement of total flux and light distribution in the laboratory and the measurement of illumination intensity and brightness in lighting installations has been developed and now forms a standard part of illuminating engineering practice.

Beyond the introduction of certain refinements which have promoted accuracy of results, there have been no important developments in the practice of commercial photometry during recent years. Probably the most important development in this field has been the reduction in the size of photometers, which has resulted in making *portable photometers* available for the study of illumination. A recent broadening of the scope of such study has included the measurement of brightness as an important branch of photometry.¹⁴

¹³ *Physics and Chemistry:*

"Transformation of Electric Power into Light," Steinmetz, *Trans. A. I. E. E.*, 1906, p. 789.

"Color Values of Artificial Lamps," Stickney, *Trans. Illg. Eng. Soc.*, 1907, p. 282.

"The Theory of Flame and Incandescent Mantle Luminosity," Fulweiler, *Trans. Illg. Eng. Soc.*, 1909, p. 635.

"Luminous Efficiency," *Trans. Illg. Eng. Soc.*, 1910, p. 113.

"Some Chemistry of Light," Whitney, *General Elec. Review*, 1910, p. 101.

¹⁴ *Photometry:*

"The Integrating Photometer," Matthews, *Trans. A. I. E. E.*, 1902, p. 39.

"Illumination Photometers and Their Use, Millar, *Trans. Illg. Eng. Soc.*, 1907, p. 548.

"A New Universal Photometer," Sharp and Millar, *Elec. World*, 1908, p. 181.

"The Integrating Sphere in Industrial Photometry," Sharp and Millar, *Trans. Illg. Eng. Soc.*, 1908, p. 502.

"Color Measurements of Illuminants," Ives, *Trans. Illg. Eng. Soc.*, 1910, p. 189.

"Illumination Tests," Sharp and Millar, *Trans. Illg. Eng. Soc.*, 1910, p. 391.

"Photometry of Large Light Sources," Stickney and Rose, *Trans. Illg. Eng. Soc.*, 1911, p. 641.

"Photometry at Very Low Intensities," Bell, *Trans. Illg. Eng. Soc.*, 1911, p. 671.

A number of investigators are engaged in the study of the problem of *photometry by non-ocular means*. The thermopile and the photo-electric cell with possibly some alternatives are looked to for assistance in the future. While nothing of commercial practicability has yet demonstrated its value, progress is being made.

The variety of color values of the several important illuminants and the other color values which for scientific purposes must be measured, create a requirement for standards of light of several widely different color values. There is a great need for a series of such standards which shall be authoritative by reason of the auspices under which they have been derived as well as by official designation. A number of laboratories are engaged in the study of this problem of heterochromatic photometry and while concrete results in the establishment of such standards are not available yet, progress must be recorded in that the need for such standards is now definitely established and work is under way, which should result ultimately in meeting this need. Present indications are that a range of *calibrated color screens* offers a most practical solution of this problem.¹⁵

*Standards of light*¹⁶ may be classified as primary, representative, and working standards. Primary standards, or those reproducible from specifications, are at present flame standards, respectively candles, the Hefner lamp and the Pentane lamp. There have been no important developments in the way of primary

¹⁵ *Photometrical Laboratories:*

"Photometrical Laboratories of National Bureau of Standards," Stratton and Rosa, *Trans. A. I. E. E.*, 1905, p. 999.

"A Testing Laboratory in Practical Operation," Sharp, *Trans. A. I. E. E.*, 1905, p. 1051.

"Photometrical Laboratory of the United Gas Improvement Company, Bond, *Trans. Illg. Eng. Soc.*, 1909, p. 619.

"Physical Laboratory of the National Electric Lamp Association," Hyde, *Trans. Illg. Eng. Soc.*, 1909, p. 631.

¹⁶ *Standards of Light:*

"Standards of Light," Nichols, International Electrical Congress, 1904; Steinmetz, *Trans. A. I. E. E.*, 1908, p. 1319.

"Report of the Committee on Nomenclature and Standards, *Trans. Illg. Eng. Soc.*, 1909, p. 520.

"Heterochromatic Photometry and a Primary Standard of Light," Ives, *Trans. Illg. Eng. Soc.*, 1912, p. 376.

standards of light in recent years, although certain means of arriving at a superior primary standard have been suggested and some research work has been done with that end in view. It is generally recognized that none of the existing primary standards of light is entirely satisfactory and that there is need for the development of a new and superior standard. Representative standards have been adopted and the so-called international candle is the official unit of light in England, France, and the United States. It is the result of standardization work of the past few years and the unit is now represented by groups of seasoned, calibrated incandescent electric lamps held at the official laboratories of these three countries. These form a reasonably accurate and safe standard for light of one color value. From them working standards are derived which accurately duplicate the value of the standard lamps and which are now available for general use of all who require them.

A start toward adopting a reasonable system of *units and nomenclature*¹⁷ was made at the Geneva Electrical Congress in 1896. The Committee on Nomenclature and Standards of the Illuminating Engineering Society has been actively engaged in the furthering of this work. That considerable progress has been made will be testified by the several annual reports of the committee to be found in the Transactions of that Society. The subject of nomenclature is especially vexing, and the art is fortunate in having the services of so distinguished a committee to assist in the adoption of sound definitions, symbols, and nomenclature. Pressure is being exerted with a view to the adoption of the metric system and some little progress appears to have been made toward this end.

The principles of physical optics and of magnetic flux underlie many *calculations*¹⁸ made in illuminating practices. Marked im-

¹⁷ *Units and Nomenclature:*

"Reports of the Committee on Nomenclature and Standards, *Trans. Illg. Eng. Soc.*, to date.

"The Concepts and Terminology of Illuminating Engineering," Sharp, *Trans. Illg. Eng. Soc.*, 1907, p. 414.

¹⁸ *Calculations:*

"A Rectilinear Graphical Construction of the Spherical Reduction Factor of a Lamp," Kennelly, *Trans. Illg. Eng. Soc.*, 1908, p. 243.

"The Calculation of Illumination by the Flux of Light Method," Cravath and Lansingh, *Trans. Illg. Eng. Soc.*, 1908, p. 518.

petus was given to calculations of illumination by the application of the idea of luminous flux in commercial illumination design. In recent years, the mathematics of the subject have been set forth repeatedly and it may be said that calculations involved in illuminating engineering work are perhaps farther along toward complete development than is any other branch of the subject.

The subject of *costs*¹⁹ is a fundamentally important feature of the science of illumination, and questions of first cost and operating cost, including maintenance and depreciation, must have the careful attention of the practitioner. The literature of this subject is rather meagre, because of the difficulty of generalizing due to the marked influence which local conditions often exercise upon costs and due to the invidious form which cost discussions are likely to take.

So much for the purely engineering aspects of the illuminating art. The engineering features are important, indeed essential, but other aspects are equally so. The subject of *vision* in all its ramifications forms an integral part of the science of illumination, a fact which is being given due recognition. Light must be correct in respect to intensity, direction, diffusion, color, and steadiness; and to the study of these qualities a knowledge of visual processes and methods of perception is essential.²⁰ Shade perception and visual acuity together with color perception have been

"Calculating and Comparing Lights from Various Sources." Hering, *Trans. Illg. Eng. Soc.*, 1908, p. 645.

"The Law of Conservation as Applied to Illumination Calculations," McAllister, *Trans. Illg. Eng. Soc.*, 1911, p. 703.

¹⁹ *Costs*:

"The Analysis of Performance and Cost Data in Illuminating Engineering," Harrison and Magdsich, *Trans. Illg. Eng. Soc.*, 1911, p. 814.

²⁰ *Visual Processes*:

"Effects of Light upon the Eye," Seabrook, *Trans. Illg. Eng. Soc.*, 1908, p. 157.

"Eye-Strain and Artificial Illumination," Krawell, *Trans. Illg. Eng. Soc.*, 1908, p. 212.

"Artificial Illumination from a Physiological Point of View." Standish, *Trans. Illg. Eng. Soc.*, 1908, p. 254.

"Eye-Strain," Pyle, *Trans. Illg. Eng. Soc.*, 1909, p. 447.

"Physiological Effects of Radiation," Steinmetz, *Trans. Illg. Eng. Soc.*, 1909, p. 683.

"The Psychology of Light," Woodworth, *Trans. Illg. Eng. Soc.*, 1911, p. 437.

studied and discussed to an extent which begins to make known some of the more important facts pertaining to vision.

In this connection also the subject of *contrast* may be considered. A knowledge of the behavior of the human eye under various conditions of contrast is all essential to the science of illumination. Therefore the study of reflection and absorption of light and of brightness of surfaces is a prominent feature of the most recent advance in the science of illumination. Glare both from light source and from reflecting surfaces is largely a question of contrast and its suppression in order to promote ocular welfare is one of the principal aims of the lighting practitioner to-day.²¹ Excessive brightness means excessive contrast with surrounding objects.²² Sometimes a light source, which is so bright as to occasion discomfort amid dark surroundings, becomes innocuous when amid bright surroundings. The general recognition of the need for contrast limitation has been effective in reducing contrast in the more recent installations.²³

Glare is intimately connected with diffusion of light. It is a subject to which a great deal of study has been given within the

²¹ *Methods of Perception:*

"Some Physiological Factors in Illumination and Photometry," Bell, *Trans. Illg. Eng. Soc.*, June, 1906, p. 3.

"Allowable Amplitudes and Frequencies of Voltage Fluctuations in Incandescent Lamp Work," Ives, *Trans. Illg. Eng. Soc.*, 1909, p. 709.

"Physiological Points Bearing on Glare," Cobb, *Trans. Illg. Eng. Soc.*, 1911, p. 153.

"Notes on Spectral Character of Light upon the Effectiveness of Vision," Luckiesch, *Trans. Illg. Eng. Soc.*, 1912, p. 135.

²² *Brightness:*

"Intrinsic Brightness of Lighting Sources," Woodwell, *Trans. Illg. Eng. Soc.*, 1908, p. 573.

"The Measurement of Brightness and its Significance," Ives, *Trans. Illg. Eng. Soc.*, Volume 9, No. 3.

²³ *Light Absorption and Reflection Coefficients:*

"Coefficients of Diffuse Reflection," Bell, *Trans. Illg. Eng. Soc.*, 1907, p. 653.

"Some experiments on Reflection from Ceilings, Walls and Floor," Lansingh and Rolph, *Trans. Illg. Eng. Soc.*, 1908, p. 584.

"Effect of the Variation of the Incident Angle on the Coefficient of Diffuse Reflection," Gilpin, *Trans. Illg. Eng. Soc.*, 1910, p. 854.

"Reflection Coefficients," Bauder, *Trans. Illg. Eng. Soc.*, 1911, p. 85.

"Some Reflecting Properties of Painted Interior Walls," Jordan, *Trans. Illg. Eng. Soc.*, 1912, p. 529.

last few years. In a paper before this Institute, Sweet presented the results of some laboratory experiments on the effect of glare due to the presence of a light source within the field of vision. While the conditions which he employed were extreme and the effect was exaggerated beyond that met in practice, yet the consequences experienced in ordinary installations differ from those found in his experiments only in degree. Glare due to exposed light sources means diminished seeing ability, discomfort and possible injury to the eyes. Another effect also known as glare is that attending specular reflection from polished surfaces. This is a subject which has received especial attention during recent years. Glare of this kind is again a matter of excessive contrast. One views the imperfectly reflected image of a light source upon the page of a book, brightness of the image being far in excess of the immediate surroundings and the general surroundings. The same means which are effective in reducing contrasts between the light source and its surroundings are naturally effective in reducing the contrast between the reflected image of the light source and its surroundings. Thus in avoiding glare due to exposed light sources, glare due to specular reflection is likewise avoided.²⁴

The engineering aspects, together with those aspects which pertain to vision, in large part constitute the science of illumination. *Æsthetics* as comprehended in the principles of design, ornamentation, and decoration may, in a sense, be grouped under the science of illumination, and to the extent that it is so considered, it is essentially important. Obviously, however, *æsthetics* is so much a matter of artistic feeling that the entire subject cannot be classed under this heading.²⁵

A growing appreciation of the artistic possibilities of lighting

²⁴ *Contrast, Glare, etc.:*

"Physiological Points Bearing on Glare," Cobb, *Trans. Illg. Eng. Soc.*, 1911, p. 153.

"Artificial Illumination as a Factor in the Production of Ocular Discomfort," Black, *Trans. Illg. Eng. Soc.*, 1911, p. 166.

"The Effectiveness of Light as Influenced by Systems and Surroundings," Cravath, *Trans. Illg. Eng. Soc.*, 1911, p. 782.

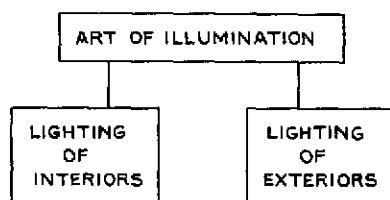
²⁵ *Æsthetics, Architectural Principles, etc.:*

"Electric Light as Related to Architecture," Walker, *Trans. Illg. Eng. Soc.*, 1907, p. 596.

"The Relation of Architectural Principles to Illuminating Engineering," Jones, *Trans. Illg. Eng. Soc.*, 1908, p. 9.

and the growing demand for artistic execution in lighting design are gradually introducing more pleasing features, glassware, and lamps. It is one of the gratifying and encouraging features of the situation that there is nothing inconsistent in the requirements of good illumination whether they be requirements of efficiency, ocular hygiene, or æsthetics. It appears that in promoting the one, natural impetus is given to one or both of the others. The more efficient light sources are likely to be more brilliant and to carry with them the need for concealment from view. In meeting this need, design along the lines of least resistance results in dif-

FIG. 11.



fused light from larger areas, forming secondary sources which do not disturb ocular comfort. In the design of such systems of lighting, opportunities for the creation of pleasing and artistic effects thrust themselves upon the designer in a manner which was never encountered when less efficient illuminants of lower brilliancy were placed in rooms without adequate concealment.

The *art* of illumination²⁶ is the lighting of interiors and of

"Modern Methods of Illumination from the Architectural Standpoint," Castor, *Trans. Illg. Eng. Soc.*, 1908, p. 271.

"The Relation of Illuminating Engineering to Architecture from the Illuminating Engineering Standpoint," Elliot, *Trans. Illg. Eng. Soc.*, 1908, p. 280.

"Architecture and Illumination," Perrot, *Trans. Illg. Eng. Soc.*, 1908, p. 619.

"Illumination and Architecture," Furber, *Trans. Illg. Eng. Soc.* 1910, p. 822.

"The Architect and Illuminating Engineering," Trimble, *Trans. Illg. Eng. Soc.*, 1912, p. 51.

²⁶ ART OF ILLUMINATION.

Decorative Aspects:

"Light and Color in Decoration," Hunter, *Trans. Illg. Eng. Soc.*, 1908, p. 190.

exteriors. The specialist applies daylight and artificial illuminants employing lighting auxiliaries and fixtures conforming to correct engineering, ocular and æsthetic principles in the lighting of interiors and exteriors. The art of illumination may be improved only as better materials of illumination are made available and as the science of illumination is advanced. In the lighting of interiors, more or less in accordance with established illuminating principles, much experience has been gained and recorded in recent years and considerable advance in practice has resulted. In the Transactions of the Illuminating Engineering Society alone there are more than 50 papers dealing with the illumination of interiors, many of them containing definite photometric data on the results obtained. This experience covers a wide variety of installations ranging from the illumination of churches and theatres through illumination of stores and factories to the simpler problems of lighting garages and stable.

That remarkable advances have been made in the *lighting of interiors* during the last five years will probably not be denied. Better materials of illumination are available and knowledge of correct principles of illumination has increased rapidly. Experiments in the design of lighting equipment and its installation have

"The Relationship of Decoration to the Illuminating Engineering Practice," Clifford, *Trans. Illg. Eng. Soc.*, 1910, p. 179.

Church Lighting:

"Church Lighting," Perrot, *Trans. Illg. Eng. Soc.*, 1908, p. 369.

"Indirect Lighting in Auditoriums," Wheeler, *Trans. Illg. Eng. Soc.*, 1912, p. 163.

"Church Lighting," Ely, *Trans. Illg. Eng. Soc.*, 1912, p. 613.

Lighting of Auditoriums and Theatres:

"The Illumination of Hammerstein's Philadelphia Opera House," Spillman, *Trans. Illg. Eng. Soc.*, 1909, p. 385.

"Theatre Illumination," Vaughn and Cook, *Trans. Illg. Eng. Soc.*, 1911, p. 961.

Office Lighting:

"The Illumination of the Building of the Edison Electric Illuminating Company of Boston," Bell, Marks and Ryan, *Trans. Illg. Eng. Soc.*, 1907, p. 603.

"Illumination of the Engineering Societies' Building, New York," Knox, *Trans. Illg. Eng. Soc.*, 1907, p. 445.

"Illumination of the Office Building of the Philadelphia Electric Company," Bartlett, *Trans. Illg. Eng. Soc.*, 1908, p. 555.

"Indirect Illumination of the General Offices of a Large Company," Aldrich and Mailia, *Trans. Illg. Eng. Soc.*, 1914, p. 103.

sometimes failed to give satisfaction, but usually have given some lesson which has added to the total experience in lighting practice. Developments which in themselves have not achieved permanent success have in some cases been stimulative, and have promoted the best development of lighting practice.

In the *lighting of exteriors* there has been some advance also. Street lighting is so largely dependent upon municipal appropriations that its development is sometimes hampered unduly by lack of funds. Merchants' associations have found in street lighting a means of promoting trade, and have had recourse to display street lighting to supplement the lighting provided by the city. Thus, tungsten cluster lighting has been installed in many cities, particularly the smaller cities of the country, with a very beneficial effect upon street lighting as a whole. More recently a competitive form of illumination, known as the "Ornamental Arc Lamp System," in which an inverted arc lamp is employed, has commanded much attention and is experiencing notable growth. General civic street lighting is improving slowly, the average standard of intensities being increased, and somewhat better de-

"Some Engineering Features of Office Building Lighting," Edwards and Harris, *Trans. Illg. Eng. Soc.*, 1914, p. 164.

School Lighting:

"Schoolhouse Illumination," Hatch, *Trans. Illg. Eng. Soc.*, 1907, p. 359.

"Public Schoolroom Lighting," Knight and Marshall, *Trans. Illg. Eng. Soc.*, 1910, p. 553.

Library Lighting:

"Design of the Illumination of the New York City Carnegie Libraries," Marks, *Trans. Illg. Eng. Soc.*, 1908, p. 538.

Store Lighting:

"The Lighting of a Large Store," Law and Marshall, *Trans. Illg. Eng. Soc.*, 1911, p. 186.

"Department Store Lighting," Shalling, *Trans. Illg. Eng. Soc.*, 1913, p. 17.

"Distinctive Store Lighting," Law and Powell, *Trans. Illg. Eng. Soc.*, 1913, p. 515.

"Present Practice in Small Store Lighting," Law and Powell, *Trans. Illg. Eng. Soc.*, 1912, p. 435.

Factory Lighting:

"Factory Lighting," Marks, *Trans. Illg. Eng. Soc.*, 1909, p. 805.

"Mill Lighting," Stickney, *Trans. Illg. Eng. Soc.*, 1911, p. 478.

"Factory Lighting," Flexner and Dicker, *Trans. Illg. Eng. Soc.*, 1913, p. 470.

sign of the illuminants and systems being noted in the more recent installations.

There is some little development in the way of lighting exteriors of buildings. Outline lighting of expositions was first carried out in a notable manner at the Columbian Exposition in 1893, attaining perhaps its highest development at the Pan-American Exposition in Buffalo in 1901. The Jamestown Exposition struck a new note in lighting building exteriors, and in the Panama-Pacific International Exposition in San Francisco, 1915, we are promised a fuller development of the lighting of buildings by concealed sources.

These occasional remarkable installations are, of course, few in number. There is no general tendency to light the exteriors of buildings, though a few creditable attempts have been made in this direction.

PROGRESS IN ILLUMINATION.

Having reviewed briefly the recent developments in the field of illumination, allow me to direct your attention briefly to the subject of progress and to the forces which have been responsible for improvements in the past and to which we must look for further development.

The illumination which is provided depends not only upon the

Show Window Lighting:

"Show Window Lighting," Henninger, *Trans. Illg. Eng. Soc.*, 1912, p. 178.

"Show Window Lighting," Wheeler, *Trans. Illg. Eng. Soc.*, 1913, p. 555.

Residence Lighting:

"Residence Lighting," Cravath, *Trans. Illg. Eng. Soc.*, 1906, p. 164.

"Some Home Experiments in Illumination from Large Area Light Sources," Ives, *Trans. Illg. Eng. Soc.*, 1913, p. 229.

"The Lighting of a Simple Home," Powell, *Trans. Illg. Eng. Soc.*, 1914, p. 45.

Passenger Car Lighting:

"The Lighting of Railway Cars," Hulse, *Trans. Illg. Eng. Soc.*, 1910, p. 75.

"Illumination of Passengers Cars," Minick, *Trans. Illg. Eng. Soc.*, 1913, p. 214.

"Modern Practice in Street Railway Illumination," Hibben, *Trans. Illg. Eng. Soc.*, 1913, p. 589.

"The Illumination of Street Railway Cars," Porter and Staley, *Trans. Illg. Eng. Soc.*, 1914, p. 25.

status of the art but also upon the degree to which practice conforms with the art. It has been stated that the art of illumination is improved as the materials of illumination are bettered and as the science of illumination is advanced. It may now be added that illuminating practice is improved as individuals, manufacturers in the lighting field, contractors in the lighting field, and lighting companies better their practice. It is to be regretted that in a review of recent progress in the field of illumination, note must be taken of the fact that illuminating practice has not advanced as rapidly as the development of the materials of illumination and the advance of the science of illumination would appear to make possible. The art of illumination has made rapid strides. Manufacturers, contractors, and lighting companies have improved their practice in many instances. Unfortunately, however, their influence is largely confined to new installations in stores and to some large manufacturing establishments. Where the commercial incentive is clearly discernible, old installations have been brought up to date very generally. With these exceptions the older installations, dating back ten years or more, compare unfavorably with the best that the art affords.

General:

- "Indirect Illumination," Curtis and Morgan, *Trans. Illg. Eng. Soc.*, 1908, p. 740.
- "Daylight Illumination," Marsh, *Trans. Illg. Eng. Soc.*, 1908, p. 224.
- "Symposium on Indirect, Semi-Indirect and Direct Lighting," Rolph, Henninger and Hibben, *Trans. Illg. Eng. Soc.*, 1912, p. 234.

Street Lighting:

- "A Method of Street Lighting by Incandescent Lamps," Underwood and Lansingh, *Trans. Illg. Eng. Soc.*, 1906, p. 115.
- "Lighting of Streets by the Incandescent Mantle Burner System," Westermaier, *Trans. Illg. Eng. Soc.*, 1906, p. 122.
- "Street Lighting," Bell, *Trans. Illg. Eng. Soc.*, 1908, p. 400.
- "Street Lighting by Tungsten Lamps," Rhodes, *Trans. Illg. Eng. Soc.*, 1909, p. 54.
- "Some Neglected Considerations Pertaining to Street Illumination," Millar, *Trans. Illg. Eng. Soc.*, 1910, p. 653.
- "Street Lighting with Ornamental Luminous Arc Lamps," Halvorson, *Trans. Illg. Eng. Soc.*, 1913, p. 88.

Lighting of Building Exteriors:

- "The Lighting of the Buffalo General Electric Company's Building," Ryan, *Trans. Illg. Eng. Soc.*, 1912, p. 597.

Broadly speaking, a review of recent developments throughout the entire field must prove encouraging to all who are interested in the subject of illumination, with the single exception that means

FIG. 12.



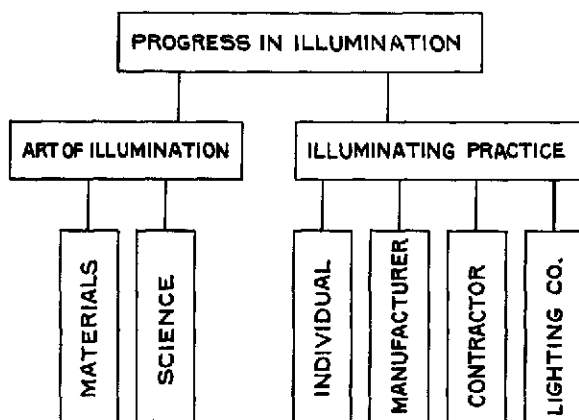
Building of the Denver Gas and Electric Company as lighted at night.

have not yet been devised for bringing old installations up to date and into conformity with present day knowledge of lighting principles.

FORCES TENDING FOR BETTERMENT IN THE ILLUMINATION FIELD.

The progress of the past few years in the field of illumination is largely traceable to definite sources, and consideration of these sources warrants the belief that recent progress may be taken as an earnest of further progress to be anticipated for the near future. The Illuminating Engineering Society is a forum for the discussion of lighting questions. It fosters study in the field, collects in its transactions most of the important literature of the art, and seeks to disseminate information regarding illumination. The Johns Hopkins University Illuminating Engineering Society

FIG. 13.



lecture course on illuminating engineering laid the groundwork for educational courses devoted to the subject, and a Committee on Education of the Illuminating Engineering Society is now seeking to further pedagogic interest and activity along this line. The national associations of electric companies and of gas companies are doing educational work in this field. The Illuminating Engineering Society is conducting a campaign of popular education. All of these efforts have made for progress, and may be looked to for future progress. The manufacturers of illuminants and accessories in this country are remarkably progressive. Their researches and investigations and educational work are bringing large results throughout the entire field. Lighting companies are awakening to the importance of illumination. While perhaps the power business in both the electric and gas industries

is assuming greater importance than the lighting business, yet it is the lighting business upon which the reputation of the company for furnishing good service or poor service is most likely to depend, and which offers far more opportunity for cultivating public good-will through acceptable service than does the power business. Most large electric and gas companies now have on their staff one or more illuminating engineers, and are devoting more attention than formerly to the subject of good illumination.

FIG. 14.

ADVANCES IN SCIENCE OF ILLUMINATION DURING RECENT YEARS

CONCEALMENT OF BRILLIANT LIGHT SOURCES.

KNOWLEDGE OF QUALITIES OF ILLUMINANTS AND AUXILIARIES.

CONCEPT OF LIGHT FLUX.

COLLECTION OF PHOTOMETRIC ILLUMINATION DATA.

AVOIDANCE OF EXTREMES IN CONTRAST.

APPRECIATION OF ARTISTIC REQUIREMENTS.

FIRST GLIMMERINGS OF RECOGNITION OF PSYCHOLOGICAL REQUIREMENTS. (1914.)

IMPORTANCE OF THE SUBJECT.

In conclusion, allow me to enter a plea for more general attention to the subject of illumination. It is one of transcending importance whether viewed from a humanitarian or a commercial standpoint. Some estimates for the year 1913 of its commercial importance in this country have recently been published.²⁷ According to these the manufacturer's sales of materials employed directly for illumination in the electric lighting industry alone aggregated \$65,000,000, while the sales of machinery involved in the generation of electricity for lighting purposes aggregated perhaps half of this amount. The revenue of central stations derived from the electric lighting business is estimated as exceeding \$300,000,000. These figures suggest in some measure the importance of the electric lighting industry and of course are in need of supplement by corresponding figures representative of the gas lighting industry and of the miscellaneous lighting business of the country. But if all such figures were available, they would only begin to suggest the commercial importance of arti-

²⁷ Editorial, *Lighting Journal*, January, 1914.

ficial illumination to the country. Who shall attempt to estimate the colossal additions to the wealth of the nation which it makes possible through extending the hours of industry?

The importance of artificial illumination in another sense is difficult to overestimate.

"*Health* in the home is dependent upon proper sanitation. 'Cleanliness is next to Godliness'; without proper light, cleanliness is next to impossible! Adequate illumination promotes cleanliness.

"Ophthalmologists tell us that inadequate or otherwise improper illumination occasions eye-strain which often results in headache and other nervous disorders. These, if prolonged, sooner or later undermine general health. So, good illumination affects general health by promoting sanitation and avoiding nervous strain.

"Good illumination has a more direct bearing upon the health of the eyes. If the eyes are closely employed upon detailed work, as in sewing or reading, under conditions of illumination which are improper, the eyes are fatigued, and if the occupation is continued, in spite of the fatigue, vision is impaired at least temporarily, and possibly is injured permanently. As compared with our forefathers we are distinctly a nocturnal people. We use our eyes a greater number of hours per day. Oculists' records testify, and the prevalence of eye-glasses evidences, the deleterious effects upon the vision of the people as a whole. Who shall say what part of the prevalence of impaired vision is attributable to improper illumination, that is to say, to the misuse of light?

"Physiologists tell us that the human eye is naturally adapted for distant vision; that when focused upon nearby objects, as in most of the work in which it is applied in our modern life, the muscles are contracted and the focal mechanism of the eye is subjected to strain. They tell us also that, just as children are physically, intellectually, and morally more susceptible and pliant than adults, so the visual organs of children are delicate and especially liable to injury if used under adverse conditions. In modern life children are called upon for a large amount of home-work in connection with the school systems. This involves application of the eyes in exacting near vision to which they are not naturally adapted, and at a time of life in which they are peculiarly liable to injury. When to these untoward conditions there is added that

of poor illumination, is it any wonder that we are becoming a bespectacled race? Of these conditions which operate against ocular welfare some may be beyond our control, but that of poor illumination is a menace for the existence of which there is no excuse, since the remedy is understood and is available to all.

"Light has a marked bearing upon the *usefulness* of our lives. Artificial light extends the hours in which we may labor. It makes possible intellectual improvement; it permits added achievement; it makes actual life of fifty years equivalent to a much longer life in the period antedating the perfection of our modern light sources. Yet, though these statements are in general correct, it remains true that the precise measure of added usefulness which artificial light makes possible depends upon the merits of the illumination. With good illumination one may labor to better effect, may produce more largely, and the product will be more nearly perfect than with poor illumination. These facts may be applied to the industries and to the arts, to manufacture, to the pursuit of knowledge, or to the development of artistic talent.

"Artificial light is an important factor in promoting *happiness*. In extending the hours of activity beyond those which are ordinarily devoted to the duties of life, it affords opportunity for the pursuit of pleasure. Light reveals the beauties of nature and of art, whether it be sculpture, painting, or architecture. It is particularly important in the home where so much effort is expended for the comfort and pleasure of the family. Few homes are so humble but that some effort is made to render them attractive. The home usually reflects in its decorations the personality of the home-maker, and, within the limits of the tastes and means of the family, attempt is generally made to render it homelike and charming. Much of the beauty and charm are lost in the evening if the rooms are not properly illuminated."²⁸

Considering the immense importance of artificial illumination as a factor in the progress of the country, every advance in the science of illumination, every improvement in the materials of illumination, and all progress in the art has a special significance—even a minor improvement in materials or in the science may have a large general influence if embodied in standard practice. It is

²⁸ Mrs. P. S. Millar, Froebel Society, Brooklyn, November, 1913.

therefore of interest to consider the improvements which have been brought about in the recent past, the discrepancy between some of the present practice and the best that the art affords, and the opportunity which each one of us has to influence one or more lighting installations for good. Considering the importance of the subject and the progress being made, it is a gratifying task to undertake to report upon recent developments, even though such report is recognized as being but little more than suggestive as to the facts.

Influence of the Casting Process on Wrought Non-ferrous Materials. ANON. (*Amer. Mach.*, xli, No. 8, 329.)—In a discussion before the American Society for Testing Materials it was pointed out that the surface of molten brass becomes instantly covered with a thick film of oxide on exposure to the air, and this oxide must be prevented from becoming incorporated in the solidified metal. Two instances will illustrate the importance of proper casting. Ingot copper of the finest character, as received from the refining furnace, is neither very ductile nor malleable when cold, but when properly melted and cast from a crucible it becomes highly so. A properly cast billet should show no pipe at the upper end, but when improperly cast a considerable pipe may occur. The casting process, when properly performed, leaves the bar, billet, or ingot free from blow-holes, gas cavities, or dirt, and from surface imperfections.

Luminosity of Neon Tubes as a Function of Their Diameter. G. CLAUDE. (*Comptes Rendus*, clviii, 692.)—The author has verified the law of variation of fall of potential as a function of the diameter of neon tubes along the luminous column of those tubes. The object of the present experiments is to ascertain the consequences of this law from the point of view of luminosity. The table of results shows that the lighting power, with equal current densities, does not increase in proportion to the sections, but barely as the diameters. Now, if the current increases as the square of the diameter, the fall of potential in the column decreases inversely as the diameter, so that taken altogether the electric power absorbed in the column increases only as the diameter, and, as the lighting power increases approximately according to the same law, it follows that the quantity of light produced is connected with the energy expended. When considering the output of the luminous column only, both very large and very small tubes are at a disadvantage. Quite satisfactory results, however, can be obtained with tubes of diameters 40 mm. to 10 mm. The lighting power furnished by a tube of given length diminishing very nearly as its diameter without the output suffering, it is therefore possible to arrange a very economic form of lighting.