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CONTRIBUTIONS OF SCIENCE TO THE LIGHTING ART[1]

SCIENTIFIC work is so varied in viewpoint and objective and it is so complexly interwoven with human interpretations and technical and commonsensical applications of knowledge that it is impossible—at least in a brief paper—to establish a definite boundary between science and any of its fields of usefulness, such as a branch of engineering. Even in the scientific realm itself there is now no definite boundary between what have been termed *pure science* and *applied science*—a distinction which, in the last analysis, is now largely hypothetical. Wherever the distinction exists or is useful, perhaps the distinguishing factor is the immediate objective of the individual or of the institution which is prosecuting the work. I should define *pure science*, in the relatively rare cases where a useful purpose is served by doing so, as work done solely for the purpose of advancing knowledge. However, I have no patience with the implication of exalted purpose, as has been openly declared by some of the past members of the aristocracy of science and is still more or less delicately implied by the few remnants of that threadbare aristocracy. The old-fashioned idea of the purification of scientific work by intending and hoping and praying that it would never be put to the vulgar use of benefiting the multitude has almost completely atrophied—from lack of any use for it. Now scientific workers are rare whose viewpoint—if not their objective—is not the eventual usefulness of knowledge. Unless blinded by tradition one sees on every hand the benefits of applications of scientific knowledge. This commendable change in viewpoint and objective has also contributed toward the obliteration of the boundary line already referred to.

With gracious thanks for the knowledge inherited from pure science, the scientific worker, with increased happiness of mankind for his objective, may proudly stand alongside the so-called pure scientist. The latter follows his curiosity, overcoming obstacles or diverting his course as he wishes. The former with a definite objective before him requires not only the mental equipment of the former, but he must also be an interpreter of this knowledge into every-day usefulness and he must surmount the obstacles encoun-

[1] Abstract of an address before Section M, American Association for the Advancement of Science, Philadelphia, December 29, 1926.

tered if he is to reach the definite objective which he has chosen. And as he follows this course he does a great deal of scientific work and contributes much to the fund of knowledge. The so-called purely scientific worker increases knowledge, but it is the practical-minded interpreter who advances progress. Both are needed but, if the one is inclined to imply exalted purpose, the other may be assured that increasing human happiness, by utilizing knowledge which unused is of no value, is the most exalted purpose in human affairs.

Perhaps the foregoing may aid in demonstrating the impossibility of hewing close to the line suggested by the title of this paper and at the same time may aid in appraising the scientific contributions to the lighting art. Now let us look at the lighting art. Here again a complex web of scientific aspects confronts us. We not only have the interwoven physical sciences to consider in the production of radiant energy which is utilized in vision, but as soon as this energy produces the sensation of light we find ourselves in the extremely complex psycho-physiological realm—much of which is quite unexplored. At best in this brief paper only a few illustrative glimpses may be presented.

As in other fields of application of knowledge, we might close the discussion at this point by stating that all the accumulated knowledge since man began to think is drawn upon in some way or other in the development of the lighting art. But it would be futile to attempt to go back beyond the beginning of modern science—a few centuries ago. The possibilities of lighting increase in proportion to the safety, the convenience, the efficiency and particularly the controllability of light from adequate light-sources. Comparing the tungsten filament lamp, for example, with other light-sources in respect to the foregoing characteristics, we find that it justly deserves its overwhelming favor at the present time. A new light-source of greater luminous efficiency would also have to compete successfully with the safety and convenience of the tungsten lamp. On the other hand, no more convenient light-source has ever been produced than the candle—a portable lighting plant—but it has succumbed to greater safety, adequacy, efficiency and controllability of other light-sources. Of course, even now it has special applications where its extreme portability makes it supreme. Thus there are practical aspects which may outweigh scientific ones and *vice versa*.

In treating this subject one is confronted with great scientific principles and epochal discoveries and also with numberless details. In the first class let us begin with Newton's explanation of the spectrum of light in 1666. Who can appraise the influence of this scientific contribution? The spectral distribution of energy is the very foundation-stone of lighting. It is important in the production, the measurement and the utilization of light. Then there are the laws of radiation—of Wein, Planck, Stefan-Boltzmann and others—established during the past fifty years. These have been and are used daily in studying the spectral distribution of energy from light-sources and are intimately involved in the searching investigations of emissivity, selectivity and temperature of radiators and, consequently, of the luminous efficiency of light-sources. The electron theory likewise is found at every turn, particularly in vapor and gas conductors such as arcs and so-called vacuum tubes. Metallurgical science is drawn upon heavily in the development and improvement of filament materials. But let us be content with this glimpse for the present lest we become hopelessly involved and discouraged with the magnitude of the task of giving science its due.

Let us turn to some details of gas-lighting. William Murdock about 1790 is usually credited with the first production and use of coal gas for lighting. He heated coal in closed iron containers and burned this gas in his home as it emerged from small iron pipes. However, in searching the literature we find that Clayton distilled coal in a retort at least a century before and noted that the gas emitted was inflammable. This well illustrates how unlikely the original scientific contributor of the more distant past is to receive credit, even though one were genius enough to unravel the complex web of knowledge with its threads leading into many highways and byways of science in any specific development. However, in the modern sense no outstanding achievements appear in flame light-sources until Bunsen mixed air with coal gas. The Bunsen burner revolutionized gas lighting as well as heating.

Gurney in 1826 had found that a cylinder of lime became very brilliant when heated with an oxy-hydrogen flame. Drummond immediately applied the idea to obtain powerful light-sources which he wanted in his work of surveying Ireland. The lime-light was used so widely for fifty years—particularly on the stage—that language has been enriched with the phrase, "in the limelight." Much scientific work was done along this line which eventually led to the development of the gas-mantle. Talbot in 1835 found that finely powdered lime became brilliant in the flame of a spirit lamp. He also soaked blotting paper in a solution of lime salt and incinerated it. The ash glowed brilliantly when heated. Gillard in 1848 made a mantle of fine platinum gauze which lasted only a few days. The idea was revived from time to time and it received quite an impetus after the Bunsen burner was applied to gas lighting. Welsbach was conducting spectroscopic researches on rare earths in Bunsen's laboratory. After soaking cotton in solutions of these metallic salts and burning it, he found a replica of the original fibers remained, consisting of the oxide of the metal. This ash glowed brilliantly in a Bunsen flame. He then evolved the idea of using cotton fabric and patented the commercial mantle in 1885. This was timely for gas-lighting, because it prolonged its period of formidable competition with electric lighting for about twenty-five years.

Practicable electric light sources had already appeared—the carbon arc in 1877 and the carbon-filament lamp in 1879. They would have appeared much sooner but they had to await the arrival of practicable sources of electrical energy. Going back we find Davy the first formidable investigator of the carbon arc. He also heated wires to incandescence by passing an electric current through them. But his investigations would not have been made if Volta had not supplied the Volta pile—a source of electric energy. In 1801 Davy noted that the carbon terminals of a voltaic cell produced an electric arc when touched together and separated. In 1808 the Royal Institution supplied him with a voltaic battery of 2,000 cells—the first notable subsidization of scientific research. He exhibited and studied the electric arc on a large scale. Faraday, his assistant and pupil, was then developing a scientific foundation which in his later studies of induction was to lay the cornerstone of the great electrical development of the future.

Thus the germ of the enormous electrical industry came into being, but the actual birth of this industry must be credited to electric lighting. Forty-four years ago Edison sent all the electric filament lamps in existence in this country to the famous Pearl Street Station in New York in a market basket. In 1925 nearly a half billion electric filament lamps were manufactured in the United States. In that year in this country the total investment in electric light and power companies was nearly eight billion dollars; sixty billion kilowatt-hours of electrical energy were generated and sold for one and one half billion dollars. Of this gross revenue two thirds came from electric lighting. Add to this the investment in the manufacture of electrical apparatus and supplies and in electrical equipment and wiring and we see business, the tax-assessor, the individual and others deeply indebted to science through electric lighting.

There were many workers on electric light sources before they actually came into use and, of course, this knowledge was available to those whose names are commonly coupled with the first really practicable ones. Brush, with the arc lamp, and Edison, with the carbon filament lamp, are the most familiar in this country. Edison discovered that a current passed between the terminals of the filament through the near-vacuum. This is an example of the by-product of fundamental knowledge contributed by the inventor. This "Edison effect" has found many applications, for example, in the radio-tube.

Chemistry, spectroscopy and other branches of physical science contributed much to the development of a number of arcs. Jandus and also Marks enclosed the arc, greatly reducing the rate of consumption of carbon. At the present time, the arc has been largely relegated to special uses, although the magnetite arc, particularly, is still used to some extent in street lighting.

The carbon-filament lamp was steadily improved, but the first radical improvement was made by Whitney in 1906. The filament was treated by heating in an atmosphere of hydrocarbons, and it was so altered that it could be operated at a higher temperature with a satisfactory life. Higher temperature, in the case of filament lamps, means greater luminous efficiency. Therefore, refractoriness—high melting point—is desired. Inasmuch as carbon has a higher melting point than any of the metals now in use for filaments, one may look to it as still a possibility. The evaporation of carbon has been a limiting feature and Whitney's improvement achieved a reduction in this.

Since Mendeleeff in 1870 enunciated the periodic law of elements, scientists in the field of light-production have studied the gaps in the periodic table with much interest. One by one these gaps have been filled until the two remaining have little interest for them. They must turn more hopefully to metallurgy and to the chemistry of compounds and perhaps look toward the day when the secret of atomic structure may make it possible to make elements or compounds of the desired characteristics. This applies particularly to the production of light from incandescent solids.

In this hurried review we may pause for only a word of praise for the ingenuity exhibited by Nernst in devising the lamp which bore his name. More efficient than the carbon filament lamp which was in the field when it appeared, its cost and complex character militated against a general use of it. Tantalum and osmium were used for filaments; however, they were soon crowded out by tungsten, but experience with them was a valuable heritage. Scheele and Bergman discovered tungsten in 1781 in scheelite. It was not used for filament material until 1906—125 years later. Then it could not be drawn into wire, so the filament was made by mixing powdered tungsten with organic matter and heating this to remove the binding material. The increased luminous efficiency and intensity of these light-sources gave a great impetus to the lighting art. The Illuminating Engineering Society was born the same year that the tungsten lamp came into use. Improvements were rapidly made and this lamp, simple though it may appear, is at the focus of various branches of science, all of which have contributed and are still contributing to its improvement.

In 1910 the development of ductile tungsten increased the possibilities of lighting enormously. There is no better illustration of the complexity of the avenues of knowledge which were traveled in this development by Coolidge and Langmuir in the Research Laboratories of the General Electric Company. Specialized knowledge of physics, chemistry, metallurgy, crystallography and the like was focused upon the problem. The result demonstrates the value of organized industrial research with definite objectives, and the necessity for great resources of all kinds for prosecuting such an investigation. Ductile tungsten made it possible to provide light-sources of all shapes and sizes necessary. For the first time glass-enclosed light-sources of high luminous intensity and small volume were available. Now the laws of geometrical optics could be more fully utilized in the design of lighting equipment. The divisibility of the tungsten filament throughout a large range adds to the prestige of this method of light-production. Lamps varying from a fraction of a watt to 30,000 watts have been made, and there is no reasonable upper limit. The age of controllable light had arrived.

In 1914 Langmuir, by a study of the dependence of heat-losses upon the size and shape of the filaments and of the physics of conduction from a solid to a gas, established the foundation for the gas-filled lamp. Now inert gases were necessary, and we must thank science for having discovered them long before. However, much scientific work was still necessary to obtain them in required quantities and in a sufficiently pure state.

Lockyer in 1868 had found new spectral lines in the solar chromosphere, which were later identified as belonging to a new element. It was named helium. This gas was isolated by Ramsay shortly after the discovery of argon in 1894. For a century preceding, it had been supposed that the composition of the atmosphere was thoroughly known. With the exception of variable quantities of moisture and traces of carbonic acid, hydrogen and ammonia, the only constituents recognized were nitrogen and oxygen. Analysis of air consisted of determining the amount of oxygen and assuming the remainder to be nitrogen. A long series of scientific observations in the interest of Prout's law had been conducted to determine accurately the densities of hydrogen, oxygen and nitrogen. The density of nitrogen was found to differ when the gas was prepared from air than when obtained from another source. This led to the discovery of argon in the atmosphere by Lord Rayleigh and Sir William Ramsay. Thus pure science supplied what is now the best vacuum substitute in tungsten filament lamps.

With these outstanding points at which science has touched our light-sources, let us pass on to the measurement and utilization of light. We now deal with light as a sensation and with vision; hence, we enter the psycho-physiological realm. We have behind us the great storehouse of scientific knowledge inherited from Helmholtz and his colleagues and those who followed. However, a large amount of scientific work remains to be done along these lines from the new viewpoint of the lighting art. The measurement of light in all its aspects is by no means a settled problem. Only a few laboratories in this country are equipped with the knowledge and experience necessary, and perhaps only two are strictly up-to-date. Even these find many gaps still existing in the knowledge available. Color-photometry is by no means completely solved and standardized. At best it is a laborious process. Spectrophotometric equipment is rare and here again accuracy depends upon experience and knowledge and attention to many details. The variation of individuals makes it necessary to use many observers, which is laborious and costly, and means are sought to standardize an observer in terms of the average of a sufficiently large and representative group. The prosecution of work in the physical sciences where unvariable instruments are used requires only one or two observers, but work in the psycho-physiological realm is valueless unless a sufficient number of observers is used to establish an average result applicable to human beings as a whole. Investigators failing to do this are guilty of a lack of appreciation of the variations of individuals from the normal. Still many researches have been published based upon the observations of only one or two observers—and unfortunately the engineer accepts them in his lack of acquaintance with the many pitfalls.

In the fields of production of light and design of lighting equipment the engineer is on safe ground because these involve the physical sciences. But the utilization of light finally involves the psycho-physiological aspects of vision and other sensations. The engineer inherited the lighting field, and although many others have entered it, the engineer still dominates it. The lighting art being so new is passing through the stage of evolution of the lighting specialist who, in order to be properly equipped, must not only possess a knowledge of applied physical sciences, economics and the like; eventually, if he is to make his work worthy of his opportunity, he must become familiar with the psycho-physiological aspects. For the artistic phase of lighting the lighting artist is evolving, but the lighting specialist should also develop himself in this direction.

Very little work is being done on the psycho-physiological aspects of the lighting art. Only a few individuals are interested as yet. Therefore, it may be permissible to refer to the Lighting Research Laboratory at Nela Park, where systematic work is being done on the relations of intensity of illumination, speed of vision, size of test-object and contrast of test-object. This is a work of years which has grown out of continuous work in the psycho-physiological realm begun seventeen years ago. Our goal is to establish eventually a complete relationship of these and other factors. Glare and visibility are also being studied year after year with the hope of eventually showing how improper lighting distorts the relationships already mentioned. Besides these we are studying such factors as eye-fatigue, visual acuity, accuracy, effect of contrast, color-vision and certain psychological effects of light and color as they influence the efficiency, the production, the welfare and the happiness of individuals. The large number of observers and the time required make such work laborious, but the results are supplying the foundation of knowledge for the development of lighting. Much more scientific work is needed relating light, lighting, color and vision. A few individuals are working elsewhere, but science has not generally awakened to the great importance and opportunities of work in the psycho-physiological realm of light and vision.

Illuminating engineers and others have applied scientific methods and knowledge to such developments as the coefficient of utilization method in the design of lighting installations, the visibility of electric signs, the design of lighting equipment utilizing the laws of geometrical optics and to the development of artificial daylight, colored accessories, special lamps and portable photometers.

Scientific methods are being employed in actual tests of street lighting, of automobile headlamps, of production in factories as influenced by lighting, of the relation of safety and lighting and other phases of lighting, but they are handicapped by the scanty knowledge and doubtful test-methods as yet available. The special applications of lighting in which scientific knowledge and research is entering already are vast in number.

I have dwelled longer upon light-production than upon light-utilization. But this has been done because the former has been well developed, and scientific work in the latter field only began relatively recently. The science of light-utilization, so far as it touches vision and the user of light, is in the early stages of evolution. It is getting its bearings; it is designing and trying out its tools—test-methods; but it is already involved in many fascinating problems, only a few of which have been mentioned in the foregoing. With space limited and with the work barely begun, it seems best to give only this glimpse to show what the field is like. However, I wish to emphasize that lighting, upon which vision is dependent, is important enough to demand not only the attention of the engineer and of every employer and user of light, but the assistance of many qualified scientific investigators in the psycho-physiological realm. The few of us associated with the work in this field find it difficult to avoid being overwhelmed with a view of the work to be done. The lighting specialist is waiting for more foundation upon which to build the utilization of light. There is nothing spectacular to attract workers to the field. On the contrary, the work is complex, tedious and time-consuming. However, there is the fascination of entering a field which explorers have just invaded and the satisfaction that one is dealing with an essential to our most important sense—vision. Furthermore, artificial lighting is still so far from the ideal in intensity and quality of the daylight under which our eyes evolved, that we may look forward into the misty future before seeing artificial light overtake natural light in these respects. And then, finally, we may have the satisfaction of improving upon natural light and lighting. Who knows? No one, for scientific investigation has still to supply the answer.

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BARRO COLORADO ISLAND BIOLOGICAL STATION

THE National Research Council has received the third annual report of the executive committee of the Institute for Research in Tropical America, prepared by Dr. Thomas Barbour, acting chairman of the committee. It is, in effect, a report on the conditions and activities of the Barro Colorado Island Biological Station for the period March 1, 1926 to February 28, 1927.

The station was closed to visiting scientists for a part of this year owing to the fact that extensive repairs were necessary to the launch, and that a great deal of new construction was undertaken which made it necessary to use the living accommodations for workmen. It was possible, however, to arrange