hundred of its seedlings. The differences are easily seen even in young plants and are mostly large enough to constitute new races. The more common ones of these races are produced repeatedly, from the seed from the wild plants as well as in the pure lines of my cultures. It is obviously a constant and inheritable condition which is the cause of these numerous and repeated jumps.

These jumps at once constitute constant and ordinarily uniform races, which differ from the original type either by regressive characters or in a progressive way. By means of isolation and artificial fecundation these races are easily kept pure during their succeeding generations.

I shall not insist here upon their special characters. The most frequent form is that of the dwarfs, *Œnothera nanella,* and the rarest is the giant, or *O. gigas,* which has a double number of chromosomes in its nuclei (28 instead of 14) and by this mark and its behavior in crossing proves to be a progressive mutation. Other new types which are produced yearly are *O. rubrinervis, O. oblonga* and *O. albida. O. lata* is a female form, producing only sterile pollen in its anthers and *O. scintillans* is in a splitting condition, returning every year in a greater or less number of individuals to the original type from which it started. Besides these there are a large number of mutations of minor importance, many of which have not even been described up to the present time.

Thus we see that the experiments provide us with a direct proof for the theory of evolution. They constitute an essential support of the views of Darwin, and moreover they relieve them of the many objections we have quoted and bring them into harmony with the results of the other natural sciences.

But, besides this, they show us the way into a vast new domain of investigation and afford the material for a study of the internal and external causes which determine the production of new species, at least in those cases in which, as in the primroses, mutations are relatively abundant. From these we may confidently hope to come some day to the study of those rarer mutations on which the differentiation of the main lines of organic evolution seem to have depended.

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THE PROBLEM OF LIGHTING IN ITS RELATION TO THE EFFICIENCY OF THE EYE[1]

Up to the present time the work on the problem of lighting has been confined almost entirely to the source of light. The goal of the lighting engineer has been to get the maximum output of light for a given expenditure of energy. Until recent years little attention has been given to the problem in its relation to the eye. It is the purpose of this paper to outline in a general way some of the more important features of this phase of the subject, and to give some of the results of work that is now being done on the problems that these features present.

Confronting the problem of the effect of lighting systems on the eye, it is obvious that the first step towards systematic work is to obtain some means of making a definite estimate of this effect. The prominent effects of bad lighting systems are loss of efficiency, temporary and progressive, and eye discomfort. Three classes of effect may, however, be investigated: (1) the effect on the general level or scale of efficiency for the fresh eye; (2) loss of efficiency as the result of a period of work; and (3) the tendency to produce discomfort. Of these three classes of effect the last two are obviously the more important, for the best lighting system is not the one that gives us the maximum acuity of vision

[1] This paper, with some changes, was read before the American Philosophical Society of Philadelphia, April 4, 1913.

for the momentary judgment or the highest level of efficiency for the fresh eye. It is rather the one that gives us the least loss of efficiency for a period of work, and the maximum of comfort.

In 1911 the American Medical Association appointed a committee to study the effect of different lighting systems on the eye. The writer was asked to share in the work of this committee. The problem presented to him was to furnish tests that would show the effect of different lighting systems on the eye, and more especially to devise, if possible, a test that would show loss of efficiency as a result of three or four hours of work under an unfavorable lighting system. In his work directed along these lines he has succeeded in getting methods of estimating effect which after eighteen months of trial seem sufficiently sensitive to differentiate between good and bad lighting systems with regard to these points. He has undertaken, therefore, to determine (1) the lighting conditions that give in general the highest level or scale of visual efficiency; (2) the conditions that give the least loss of efficiency for continued work; and (3) the conditions that cause the least discomfort. This plan of work, it is scarcely needful to remark, will involve a wide range of experimentation. The crux of the problem is, however, to secure reliable methods of estimating effect. Having these methods, the factors, whatever they may be, distribution, intensity, quality, position of the light relative to the eye, etc., can be varied one at a time and the effects be determined. From these effects it should not be difficult to ascertain what lighting conditions are best for the eye, and what is the relative importance of the factors that go to make up these conditions. Further, it should be possible on the practical side to test out and perfect a lighting system before it is put on the market; also to determine the best conditions of installation for a given lighting system; to investigate the effect of different kinds of type and paper on the eye; to study the effect of different kinds of desk lighting, etc. In short, it is obvious that the usefulness of such tests is limited along these lines only by their sensitivity.

A detailed description of the tests we are using has already appeared in print.[2] Time can not be given to them here. A brief report only of some of the results of the work in which they have been employed is possible in the time placed at my disposal.

In the study of the problems presented to us in this field it has been thought best to conduct the investigation at first along broad lines in order to determine in a general way the conditions that affect the efficiency and comfort of the eye. Later a more detailed examination will be made of the ways in which these conditions have been worked out in the various types of lighting systems in use at the present time. The following aspects of lighting sustain an important relation to the eye: the evenness of the illumination, the diffuseness of light, the angle at which the light falls on the object viewed, the evenness of surface brightness, intensity and quality. The first four of these aspects are very closely interrelated, and are apt to vary together in a concrete lighting situation, although not in a 1:1 ratio. For the purposes of this paper these aspects will be grouped together and referred to as the distribution of light and surface brightness in the field of vision, or still more generally as distribution. The ideal condition with regard to distribution is to have the field of vision uniformly illuminated with light well diffused and no extremes of surface brightness. When this condition is attained, the illumination of the retina will shade off more or less gradually from center to periphery, which gradation is necessary for accurate and comfortable fixation and accommodation.

The factors we have grouped under the heading distribution can be most conveniently discussed perhaps with reference to four types of lighting systems in common use

[2] "Tests for the Efficiency of the Eye Under Different Systems of Illumination and a Preliminary Study of the Causes of Discomfort," *Transactions of the Illuminating Engineering Society*, 1913, VIII., pp. 40–60.

to-day: illumination by daylight, direct lighting systems, indirect lighting systems and semi-direct systems. In the proper illumination of a room by daylight, we have been able thus far to get the best conditions of distribution. Before it reaches our windows or skylights daylight has been rendered widely diffuse by innumerable reflections; and the windows and skylights themselves, acting as sources, have a broad area and low intrinsic brilliancy, all of which features contribute towards giving the ideal condition of distribution stated above, namely, that the field of vision shall be uniformly illuminated with light well diffused and that there shall be no extremes of surface brightness. Of the systems of artificial lighting the best distribution effects, speaking in general terms, are given by the indirect systems. In this type of system the source is concealed from the eye and the light is thrown against the ceiling or some other diffusely reflecting surface, in such a way that it suffers one or more reflections before it reaches the eye. In some of the respects most important to the eye, this system gives the best approximation of the distribution effects characteristic of daylight of any that has yet been devised. The direct lighting systems are designed to send the light directly to the plane of work. There is in general in the use of these systems a tendency to concentrate the light on the working plane or object viewed rather than to diffuse it, and, therefore, a tendency to emphasize brightness extremes rather than to level them down. Too often, too, the eye is not properly shielded from the light source and frequently no attempt at all is made to do this. The semi-indirect systems are intended to represent a compromise between the direct and indirect systems. A part of the light is transmitted directly to the eye through the translucent reflector placed beneath the source of light, and a part is reflected to the ceiling. Thus, depending upon the density of the reflector, this type of system may vary between the totally direct and the totally indirect as extremes and share in the relative merits and demerits of each in proportion to its place in the scale. By giving better distribution this type of system is supposed also to be a concession to the welfare of the eye, but our tests show that the concession, at least for the type of reflector we have used,[3] is not so great as it is supposed to be. In fact, installed at the intensity of illumination ordinarily used or at an intensity great enough for all kinds of work, little advantage is gained for the eye in this type of lighting with reflectors of low or medium densities; for with these intensities of light and densities of reflector, the brightness of the source has not been sufficiently reduced to give much relief to the suffering eye.[4] Until this is done in home, office and

[3] The reflectors we used were supplied to us by a prominent lighting corporation, interested neither in the manufacture nor the sale of lighting fixtures, in response to a request for a representative semi-indirect lighting system. Obviously, however, final conclusions should be reserved until the tests are extended to other types of reflectors.

[4] The semi-indirect system used by us was but little better for the eye than the direct system. The direct system we employed was the one in general use throughout the building in which our tests were made. It was installed about six years ago and is, therefore, not of the most modern type. It seems to the writer safe to say, however, that it gives effects fully as good as most direct lighting in actual use in the country to-day. Furthermore, it is difficult to believe that any great injustice has been done to direct lighting, so far as this principle of lighting has been commercialized up to this time, by the selection of this system, because of the fact that very little less loss of efficiency was obtained from the semi-indirect lighting system, which on account of its similarity to indirect lighting represents, we have good reason to believe from our results, a greater modification of direct lighting for the welfare of the eye than any that is found within the class of direct systems. However, a final conclusion will be reserved until a more extensive investigation of the direct systems has been made. The writer further does not wish to be understood as contending that direct lighting can not be accomplished in a way that is not excessively damaging to the eye. Doubtless great improvement can be made in this type of lighting if proper attention is given to the fundamental principles governing the effect of light on the eye. It does not seem to the writer, however, that the prin-

public lighting we can not hope to get rid of eye-strain with its complex train of physical and mental disturbances.

It is not our purpose, however, at this time to attempt a final rating of the merits of lighting systems. For that our work is still too young. Moreover, there are relatively good and bad systems of each type, and good and bad installations may be made of any system. What we hope to do is by making an appropriate selection and variation of conditions to find out what the factors are that are of importance to the eye, and from this knowledge as a starting point to work towards reconstruction.

With regard to the effect of the distribution of light and surface lightness on the eye a brief statement will be given here only of its effect on efficiency; and in the consideration of efficiency loss of efficiency will receive the major part of our attention. No attempt will be made, for example, to present the results of the study of the factors producing discomfort. The study of these factors has constituted for us an entirely separate and independent piece of work investigated by separate and independent methods.

Our tests for loss of efficiency[5] show that when the intensity and quality of the light are equalized at the point of work, the eye

ciple of direct lighting offers as great possibilities in this direction as the indirect; still he permits this also to remain an open question in his mind. It is obvious that much can be accomplished for the welfare of the eye in cases both of the direct and semi-indirect systems by using sources of large area and of low intrinsic brilliancy, by removing them as much as possible from the field of vision, by employing better means of diffusing the light, etc.

[5] The tests were made in a room 30.5 feet long, 22.3 feet wide, and 9 feet high. The artificial lighting was accomplished by means of two rows of fixtures of four fixtures each. Each row was 6 feet from the side wall and the fixtures were 6 feet apart. The reflectors were in the different cases 19–26 inches from the ceiling. Clear tungsten lamps were used as source. The voltage was kept constant by means of a voltmeter and a finely graduated wall rheostat placed in series with the lighting circuit. In case of the direct system two bulbs making an angle of 180° were used for each fixture and the distribution was obtained by means of white slightly concaved porcelain reflectors 16 inches in diameter fastened directly above. In case of the indirect system corrugated mirror reflectors, enclosed in brass bowls, were used. For the semi-indirect system the distribution was obtained by means of inverted alba reflectors 11 inches in diameter which threw a part of the light against the ceiling and transmitted the rest directly to the room, minus a rather large absorption quantity. The daylight illumination came from three windows all on one side of the room and situated in a line parallel with the line of sight used when making the tests. These windows were so sheltered that it was never possible for them to receive light directly from the sun or from a brightly illuminated sky. Moreover, the light from one of them, the one nearest the observer, was further diffused by passing through a diffusion sash made of double thick glass ground on one side. The intensity in foot-candles was made equal at the point of work for all the systems employed. In making this equalization the light was photometered in five directions at the point of work: with the receiving surface of the photometer in the horizontal plane, at angles of 45° and 90° pointing towards the observer, and at angles of 45° and 90° pointing in the opposite direction. In installing the lights in the different systems it was impossible to make the intensity equal in all of these directions. Care was taken to make it equal in the plane of the test card, *i. e.*, the vertical plane, and as nearly as possible equal in the other planes. The Sharpe-Millar portable photometer was used to make these measurements, also another method mentioned in a former paper (*op. cit.*, p. 49) which is more sensitive to daylight illumination than is the Sharpe-Millar method. The effect of varying distribution of light was thus tested under conditions in which quality and intensity were reduced as nearly to a constant as was possible with the systems employed. The intensity in the vertical plane was made in each case 1.4 foot-candles or approximately so. Space can not be taken here for an engineering specification of the installations used and the lighting effects produced. A full report of the work including detailed brightness and illumination measurements, photographs showing the illumination effects obtained, descriptions of installations, etc., will be published in the *Transactions* of the Illuminating Engineering Society.

loses practically nothing in efficiency as the result of three to four hours of work under daylight. It loses enormously for the same period of work under the system of direct lighting selected for our work and almost as much under the system of semi-indirect lighting. Under the system of indirect lighting, however, the eye loses but little more than it loses in daylight. The results of these tests show also that acuity of vision as determined by the momentary judgment is higher for the same foot-candles of illumination for the daylight system than for the systems of artificial lighting, and that for the latter systems, it is highest for the indirect system, next highest for the semi-indirect system, and lowest for the direct. It will thus be seen that for all purposes of clear seeing, whether the criterion be maximum acuity or the ability of the eye to hold its efficiency for a period of work, the best results are given in order by the systems that give the best distribution of light and surface brightness. The effect of distribution is not so great, however, on the ability of the fresh eye to see clearly as it is on its power to hold its efficiency.

The loss of efficiency found in the above work seems to be predominantly, if not entirely muscular, for the tests for the sensitivity of the retina show practically no loss of sensitivity as the result of work under any of the lighting systems employed. The following reasons are suggested why the muscles of the eye giving both fixation and accommodation should have been subjected to a greater strain by the systems of direct or semi-direct lighting, than by the system of indirect lighting or daylight. (1) The bright images of the sources falling on the peripheral retina which is in a perpetual state of darkness-adaptation, as compared with the central retina, and is, therefore, extremely sensitive in its reaction to such intensive stimuli, set up a reflex tendency for the eye to fixate them instead of, for example, the letters which the observer is required to read. (2) Likewise, a strong reflex tendency to accommodate for these brilliant sources of light, all at different distances from each other and the lettered page, is set up. (3) These brilliant images falling on a part of the retina that is not adapted to them, causing as they do acute discomfort in a very short period of time, doubtless induce spasmodic contractions of the muscles which both disturb the clearness of vision and greatly accentuate the fatiguing of the muscles. The net result of all these causes is excessive strain, which shows itself in a loss of power to do work. In the illumination of a room by daylight, however, with a proper distribution of windows, the situation is quite different. The field of vision contains no bright sources of light to disturb fixation and accommodation and to cause spasmodic muscular disturbances due to the action of the intensive light sources on the dark-adapted and sensitive peripheral retina. As has already been pointed out, the light waves have suffered innumerable reflections and the light has become diffuse. The field of vision is comparatively speaking uniformly illuminated and there are no extremes of surface brightness. The illumination of the retina, therefore, falls off more or less gradually from center to periphery, as it should to permit of fixation and accommodation for a given object with a minimum amount of strain.

It is not our purpose, however, to contend that distribution is the only factor of importance in the illumination of a room. We have chosen to begin our work with types based on distribution, only because it has seemed to us, both from our own work and from a survey of the work done by others, that this is the most important factor with which we have yet to deal in our search for the conditions that give minimum loss of efficiency and maximum comfort in seeing. The quality of light and its intensity at the source are already pretty well taken care of, apparently better taken care of, at least in general practise relative to their importance to the eye, than is distribution. A systematic study of factors, however, can not stop with an investigation of the effect of distribution alone. The intensity and quality of light must also be taken into account. For example, one of the most persistent questions asked by the illuminating engineer is, "How much light should be used with a given lighting system to give the best results for seeing?" We have undertaken, therefore, to determine the most favorable range of intensity for the four types of distribution mentioned above. Curves have been obtained showing the effect on the efficiency of the eye of three or four hours of work under different intensities of light, for the direct and semi-indirect systems; and rough comparisons have been made for the indirect system and for daylight. Detailed tests will be made for these latter two systems early next year. Our tests show, in general, the following results. A very wide range of intensity is permissible for daylight and the indirect system. For the semi-indirect system the eye falls off heavily in efficiency for all intensities with the exception of a narrow range on either side of 2.2 foot-candles, measured at the level of the eye at the point of work with the receiving surface of the photometer in the horizontal plane. For the direct system no intensity can be found for which the eye does not lose a very great deal in efficiency as the result of work. Thus it seems that distribution is fundamental. That is, if the light is well distributed and there are no extremes of surface brightness as is the case for daylight and the indirect systems of artificial lighting, the ability of the eye to hold its efficiency is, within limits, independent of intensity. In short, the retina is itself highly accommodative or adaptive to intensity, and if the proper distribution effects are obtained, the conditions are not present which cause strain and consequent loss of efficiency in the adjustment of the eye.

Details of the conditions of installation and of the methods of working can not be given here. It will be sufficient to state that the work was done in the same room, with the same fixtures, and in general with the same conditions of installation and methods of working as were used in the tests for distribution. Nor can a full statement of results be made. Time will be taken, however, for a more detailed examination of the results obtained for the direct and semi-indirect systems. For the semi-indirect systems, our test showed that the intensity most favorable to the eye was secured when the photometric reading with the receiving surface in the horizontal plane showed 2.2 foot-candles of light at the point of work, 1.52 foot-candles in the 45° position, and .58 foot-candle in the vertical position. At this intensity of illumination, the semi-indirect system, so far as its effect on the eye's loss of efficiency is concerned, compares fairly well with the indirect system at such ranges of intensity as we have employed. At intensities appreciably higher than this most favorable value, or lower, the loss of efficiency is very great. At the intensity commonly recommended in lighting practise, the semi-indirect system is almost, if not quite, as damaging to the eye as the direct system. The intensity recommended by the Illuminating Engineering Society, for example, in its primer issued in 1912, ranges from 2–3 to 7–10 foot-candles, depending upon the kind of work. Five foot-candles is taken as a medium value. This medium value, it will be noted, is more than double the amount we have found to give the least loss of efficiency for the type and installation of semi-indirect system we have used. The intensity we have found to give the least loss of efficiency for this type of lighting, does not, however, give a maximum acuity of vision as determined by the momentary judgment. At an intensity that does give maximal acuity for the momentary judgment the eye runs down rapidly in efficiency. That is, in this type of lighting, one or the other of these features must be sacrificed. High acuity and little loss of efficiency can not be had at the same intensity. They could both be had only under the indirect system and daylight. However, the amount of light we find to give the least loss of efficiency seems to be sufficient for much of the work ordinarily done in the home or office. It is not enough, though, for drafting or work requiring great clearness of detail.

In case of the direct system, we were able to improve the conditions, so far as loss of efficiency is concerned, by reducing the intensity; but the system never proved so favorable in this regard as even the semi-indirect system. In the tests made under the direct system care was taken to have the fixtures in the same position in the room in every case as they were for the semi-indirect system. The most favorable intensity is secured by an installation that gave 1.16 foot-candles in the horizontal, .85 in the 45° position and .45 in the vertical. At this intensity, however, the loss in the efficiency of the eye for three hours of work was almost four and one half times as great as for a wide range of intensities for either the indirect system or daylight.

Two facts, then, may be emphasized at this point. (1) Of the lighting factors that influence the welfare of the eye, those we have grouped under the heading distribution apparently are fundamental. They seem to be the most important we have yet to deal with in our search for the conditions that give us the minimum loss of efficiency and the maximum comfort in seeing. If, for example, the light is well distributed in the field of vision and there are no extremes of surface brightness, our tests seem to indicate that the eye, so far as the problem of lighting is concerned, is when the proper distribution is present, intensities high enough to give the maximum discrimination of detail may be employed without causing appreciable damage or discomfort to the eye. (2) For the kind of distribution effects given by the majority of lighting systems in use at the present time, our results show that too much light is being employed for the welfare and comfort of the eye.

The effect of quality of light on the eye has been the subject of much discussion and much misunderstanding. There seems to be a feeling even among lighting engineers and ophthalmologists that colored light gives better results for seeing than white light. Some, for example, hold that the kerosene flame furnishes the ideal source of light and that its virtues are due largely to the yellow quality of the light it gives off. While the writer has not as yet begun a systematic study of the effect of quality of light, and while he is, therefore, not as yet willing to commit himself on this point, he will say that when intensity and distribution are equalized, an installation of clear carbon lamps, which gives a light comparatively rich in yellow and red, causes the eye to fall off more in efficiency as the result of 3–4 hours of work than an installation of clear tungsten lamps, the light from which is more nearly white. In short, the question whether or not white or colored light is better for the eye can not be answered until definite tests are made of this point alone under conditions in which all other factors are rendered constant. The effects of the kerosene flame, for example, as compared with other sources of illumination, must be tested under a system of installation that gives the same intensity at the source, and, as nearly as possible, the same distribution in the field of vision as is given by other illuminants. This has not been done at all. Our judgment of the comparative merits of the color quality of the light given by it have been based on the roughest kinds of impression, obtained under conditions of installation in which there has been no attempt at control of the other factors that influence the effect of light on the eye. The work that has been done up to this time on the relation of quality of light to seeing has been confined to visual acuity as determined by the momentary judgment, and even this work which alone can give no safe grounds at all for drawing general conclusions as to the effect of light on the welfare of the eye, shows, whenever the comparison has been made, that white light gives a greater acuity of seeing than light with a dominant color tone. If, as has been maintained by some on the grounds of their working experience, the kerosene flame is easier on the eye than the more modern sources of illumination, the writer would be inclined, more especially in view of his results on the effect of differences in intensity on the efficiency of the eye, to ascribe the benefit, whatever there may be, to the low intrinsic brilliancy of the kerosene flame. For, as has already been stated, it may be safely said that for the kind of distribution effects we are getting from the large majority of our lighting systems, too much light is being used for the welfare and comfort of the eye. Added to this is the effect of the position of the light in the field of vision. The kerosene lamp may be placed at the back or side of the person using it, and, if in the field of vision, it is usually at or near the level of the eye. In the two former cases the effect of concealed lighting is given, and in the latter case the lamp occupies the most favorable position possible for an exposed source. That is, if the source of light is to be in the field of vision at all, it should be as nearly as possible at the level of the eye. This is because of the greater tendency of a light source to produce discomfort and loss of efficiency when its image falls on the upper and lower halves of the retina than when it falls in the horizontal meridian. These facts have been clearly brought out in our work on the effect of position of the light in the field of vision.

In addition to studying the conditions that give us maximum efficiency, it is important to determine the lighting conditions and eye factors that cause discomfort. In fact, it might well be said that our problem in lighting at present is not so much how to see better as it is how to see with more comfort and with less damage to the general health on account of eye-strain. Any comparative study of the conditions producing discomfort necessitates a method of estimating discomfort. As stated earlier in the paper, our method of estimating discomfort is entirely distinct and separate from our method of studying efficiency. Time can not be taken here to go into details of either the method or of the results of this study. It will be sufficient to say that the effect of distribution of light and surface brightness, intensity, and quality are also being studied in their relation in the comfort as well as to the efficiency of the eye.

In conclusion, the writer wishes to point out that no one of the factors he has mentioned can be safely omitted in the search for the most favorable conditions of lighting. Nor can one be investigated and a correlation between it and the others be taken for granted. We have been content, heretofore, to base our conclusions with regard to the relation of a lighting system to seeing on the conventional visual acuity test. While this test may tell us something about the general level or scale of efficiency of the fresh eye, it can tell us nothing of loss of efficiency, because the muscles of the eye, although they may have fallen off enormously in efficiency, can under the spur of the will be whipped up to their normal power long enough to make the judgment required by the test. Moreover, it tells us nothing of the conditions that produce discomfort. In short, the general level or scale of efficiency of the fresh eye, loss of efficiency as the result of work, and the tendency to produce discomfort constitute three separably determinable moments, no one of which should be neglected in installing a lighting system.

C. E. FERREE

BRYN MAWR COLLEGE

CARL FUCHS

MR. CARL FUCHS, the well-known entomologist, died on June 11, 1914, at his home in Alameda, California. He had attained the good age of 74 years, 6 months and 17 days, and was a native of Hanan, Frankfurt-am-Main, Germany, where he was born on November 25, 1839. His remains were cremated. He was always active, energetic and punctual in business, and was noted for his enthusiasm on all matters appertaining to his favorite study. His specialty was the Coleoptera, and up to the time of the earthquake and fire of 1906, he had the largest collection on the Pacific Coast. The loss of this—his life's work, with the exception of a few boxes which contained a genera collection—greatly depressed his spirit and ambition for a time. He rallied, however, and had by unceasing efforts up to the time of his death amassed another moderately large collection.

Mr. Fuchs was one of the most hospitable, kind and lovable of men, ever ready to aid amateurs or his younger colleagues, both as regards advice and material. The news of his death will be a shock to his numerous friends both in the United States and abroad.

His trade was that of a chaser and engraver,