GLARE AND THE FOUR FUNDAMENTAL FACTORS IN VISION*

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SYNOPSIS: This paper reopens the subject of "glare." Experimental data, consisting of measurements of visibility, are presented, showing the effect of a range of glare conditions upon a wide variety of test-objects. These confirm earlier work upon the subject, and in addition show that the result of the measurement depends in a noteworthy way upon the test-object selected. Suggestions as to the improvement of present-day lighting-for-work are made, with a view to the reduction of glare to a negligible minimum.

The phenomenon called "glare" has been a matter of great interest in lighting for many years. It is the familiar discomfort and handicap to seeing, which occurs when there are one or more very bright spots in the visual field, at an angle from the object of vision. When at all great in degree, there is not the least doubt in the mind of the observer that something is wrong and that vision is less easy in its presence. Many attempts have been made to measure its effect accurately, with results that are not altogether satisfactory. In general, there have been two modes of attack.

In one of these, the subject of the experiment is placed either in the situation to be investigated or in an experimentally devised situation, and asked for an estimate of the unpleasantness, discomfort, shock, dazzle, etc., resulting from the presence of the supposed glaring light; or possibly he is asked to compare two lights in this respect. This method leaves much to be desired, chiefly from the lack of adequate definition of the exact thing which the subject is to appraise.

The second method consists in measuring, under the supposed glaring conditions, the sensitivity of vision with reference to some standardized test-object, selected for the purpose, which itself has nothing to do with the glare conditions. This method also involves, first or last, a comparison with a similar measurement

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made with the suspected glare removed. This method has the advantage of definiteness, and hence relative precision. However, in the minds of many, it leaves something to be desired, because it fails to show a definite result under conditions which almost any judge would find uncomfortable. That is, such conditions would still have to be considered "glaring" when tried by the first-mentioned method. In short, glare measured by discomfort, and glare measured by visibility, do not always go hand-in-hand.

It has not been attempted in this paper, to settle the moot question implied. On the contrary, the method chosen out-and-out is the measurement of visibility, simply because this method yields results which are definite and leave no room for difference of opinion. This does not imply that we have any quarrel with anyone who wishes to oppose to these results conclusions based on the judgment of discomfort, etc., for it is realized, as just said, that such results may well lead to a divergent conclusion. It is, however, to be insisted upon, that a condition, glaring or otherwise, which shows unfavorable results when appraised by the actual measurement of visibility is, beyond a shadow of a doubt, an adverse condition as far as the eyes are concerned, and hence also adverse economically, from the standpoint of production, and physically, in the matter of the well-being of the one who is personally making use of the lighting.

Much work has already been done on glare, by the measurement of visibility. The conclusions reached are comparable with those of this work, and consequently, it might be well to review here some of the facts that have been elicited:

1. Provided the glaring light emanates from a circumscribed area in the visual field (as a bare lamp, or diffusing glassware), the degree of impairment of vision is dependent neither upon the brightness nor upon the area of the source alone, but is almost exactly dependent upon the normal intensity of illumination from the source measured at the eye.

2. For a given light-source, at a given distance from the eye; that is, for equal normal illuminations at the eye, the impairment of visibility is greater as the source approaches the line of vision.

3. For equal conditions as to the glaring source, the impairment of visibility is greater, the lower the brightness of the (test) object by which the effect of the glare is appraised.

In the earlier work from which the above conclusions are drawn, the methods used to measure visibility have not always been the same, although the conclusions have in general agreed very well. One method has been to use letters or characters in black upon a white surface, not essentially different from printed letters, and to estimate visibility in terms of the size of the smallest character correctly reported. Another method has been to select a test-object of somewhat larger size than is necessary for clear vision under the conditions chosen, and then to appraise visibility by the intensity of illumination necessary to reveal the object to the vision of the observer. The attempt at intercomparison of the results obtained by these two methods has always met with failure from the lack of the necessary data, although the results have been concordant insofar as definite trends were shown. The present work was planned for the purpose of obviating this difficulty. Instead of using only one sort of test-object, test-objects of nine different descriptions were used; and the variables of the experiment were extended over a wider range than has heretofore been done. All of the work was done with the help of the same group of subjects, and by an identical method all the way through, so that the results are intercomparable. Every result is a careful measurement of visibility.

The procedure will be clearer if reference is made to work reported a year ago.[1] It was then pointed out that a visual object, and particularly one which represented the border between visibility and invisibility, could be defined in terms of not less than four variables. These are:

(a) The size of its critical detail, conveniently expressed as "minutes visual angle" subtended at the eye by the detail.

(b) The contrast between the object and its background, which may be defined as the ratio of the brightness-difference to the brightness of the background, and for simplicity computed and designated as "per cent contrast."

(c) The brightness-level to which the object is illuminated.

(d) The time during which the image of the object is allowed to rest upon the retina of the eye.

[1] Four Fundamental Factors in Vision, Cobb and Moss; TRANSACTIONS, I. E. S., Vol. 23, 1928, pp. 496-504. The Four Variables of the Visual Threshold, Cobb and Moss; *Jour. Frank. Inst.*, Vol., 205, 1928, pp. 831-847.

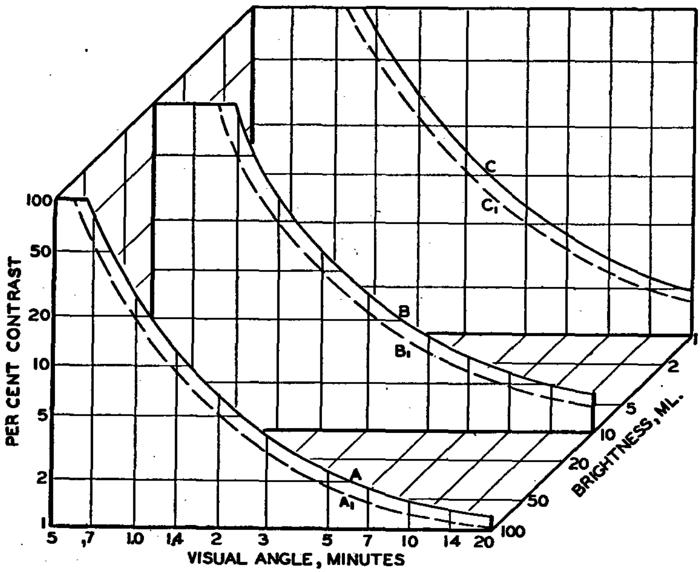

FIG. 1.—The relation between Size, Contrast and Brightness of an object at the limit of visibility. The curves A, B and C define a surface expressing the relation of these factors for an exposure-time of 0.075 sec. A_1, B_1, and C_1 give a similar relation for an exposure-time of 0.300 sec.

These variables were found to be closely interrelated, for all objects at the border of visibility, and a study of these relations yielded the results embodied in Fig. 1.

In the work about to be described, a number of variously sized test-objects were used, correspondingly different in the contrast distinguishing them from their respective backgrounds, and differing also in the brightness-level to which they were illuminated. These were nine in number: one of small size and high contrast, one of large size (16′ visual angle) and of correspondingly low contrast, and one intermediate between these; and each one of these was further varied by being illuminated to each of the three brightness-levels used: 1, 10 and 100 millilamberts.

The technique of experimentation here used is the same as before.[2] For each of these test-objects the exact grade of con-

[2] The Relation Between Extent and Contrast in the Liminal Stimulus for Vision, Cobb and Moss; *Jour. Exper. Psychol.*, Vol. 10, 1927, pp. 350-364.

trast was found, at which the object was at the border of visibility under each of four glare conditions, and without glare. Exceptions to this were, as noted later, the three cases in which the test-object was of 100 ml. brightness. It was found that here, even with the glare-lamp as close as 5° to the line of vision, the effect was small. In these cases, therefore, some of the glare-conditions were omitted. The glare-lamp was a 100-watt gas-filled inside-frosted tungsten lamp, located in the vertical meridian of the visual field at a uniform distance of 55 inches from the eyes to the light-center. Four standard positions of the lamp were used, at 40°, 20°, 10° and 5° above the visual line. The normal illumination at the eyes due to the glaring lamp was in all cases 5 foot-candles.

A uniform time of exposure of the test-object, 0.17 second, was used throughout. Each result in the body of Table I is the mean of the results of 5 series, taken by the method of serial groups, from each of 9 subjects. The total number of series represented is therefore 1755, which involve a total of some 80,000 to 90,000 separate observations.

TABLE I

Glare	1 ml.			10 ml.			100 ml.		
	1.76′	3.95′	16.0′	1.17′	3.20′	16.0′	0.88′	2.40′	16.0′
Off	37.9	9.23	2.78	48.1	6.01	1.57	58.6	5.68	1.31
40°	44.7	11.3	3.62	49.0	6.57	1.75			
20°	52.2	13.7	4.31	51.6	6.90	1.83			
10°	61.4	18.2	5.51	54.7	7.11	2.02	58.9	5.91	1.40
5°	88.4	30.4	9.81	59.0	8.12	2.41	61.8	6.11	1.49

The effect of glare from a 100-watt inside-frosted tungsten-filament lamp, at 55 inches distance from the eyes, situated in the vertical meridian and making various angles with the line of vision. The results are stated as per cent contrast (brightness-difference to brightness-level as the base) required in the test-object at the border-line between visibility and invisibility.

The results in the table for 1, 10 and 100 ml. brightness are represented graphically in Figs. 2, 3, and 4 respectively. The lower curve in each figure is the size-contrast relation for the condition of no glare. In Figs. 2 and 3 the curves above, in order, are the results obtained with the glare light placed at 40°, 20°, 10° and 5° from the visual line in the vertical plane. Since the extreme results came close together in the case of 100 ml. brightness of test-object, not all of these conditions were used in this part of the work, measurements being made under the no

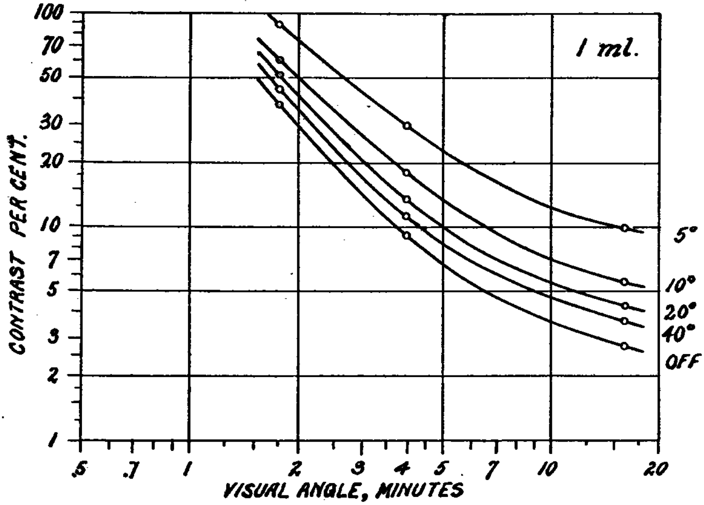

FIG. 2.—The effect on the size-contrast relation of a glare-source in the vertical meridian giving 5 foot-candles illumination at the eye, and making various angles with the line of vision. Brightness of test-object, 1 millilambert. Compare with Figs. 3 and 4.

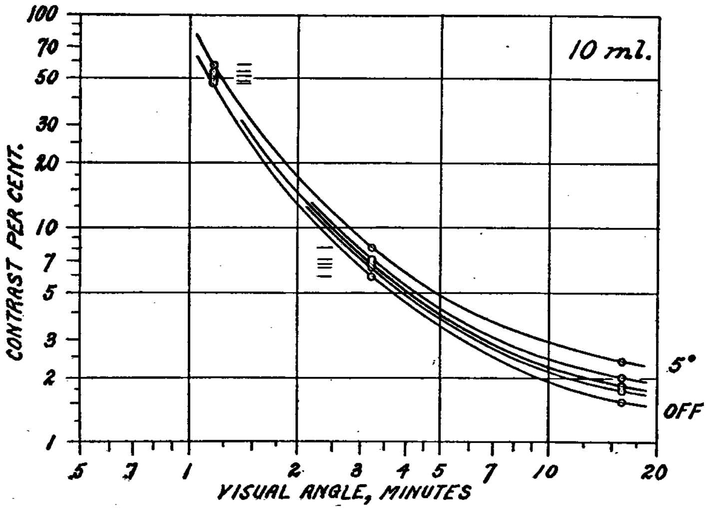

FIG. 3.—The same as Figs. 2 and 4. Brightness of test-object, 10 millilamberts.

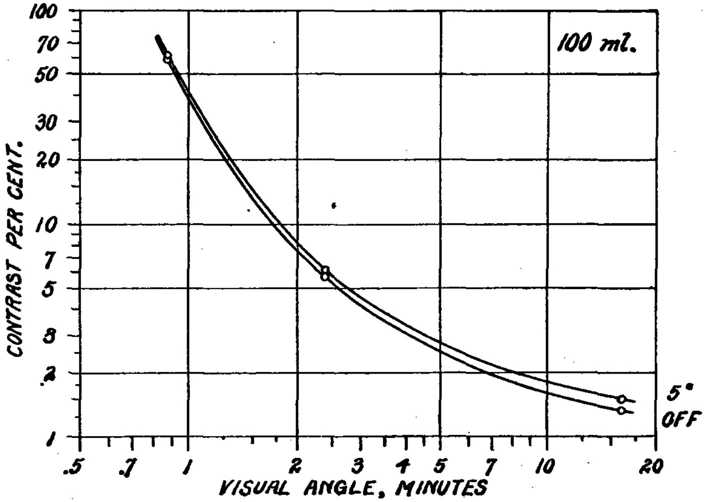

FIG. 4.—The same as Figs. 2 and 3. Brightness of test-object, 100 millilamberts.

glare, 10° and 5° conditions only. Since these results came close together, the results at 5° only are shown in Fig. 4.

The striking thing to be noted from these plots is the fact that the effect of a constant glare condition becomes less and less significant as the brightness of the critical visual object is raised. The wide differences seen at 1 ml. have become relatively small at 10 ml. brightness of test-object, and have become very small at 100. Although not new, this fact is one which perhaps has a very practical bearing on the problems of lighting, which will be discussed later.

A new fact, which appears clearly from these results, is the dependence of the degree of impairment of visibility upon characteristics, other than brightness, of the test-object which is selected to elicit this effect of the glare. From Figs. 2, 3, and 4 it appears clearly that the effect is proportionately greater for a large test-object seen in low-contrast with its background, than for a small, high-contrast object such as a printed letter, which is the type of "visual acuity" object that has mostly been used in past experimental work upon this subject. Whether the glare effect is measured in percentage increase in contrast, or percentage increase in size, necessary to offset the effect of the glare,

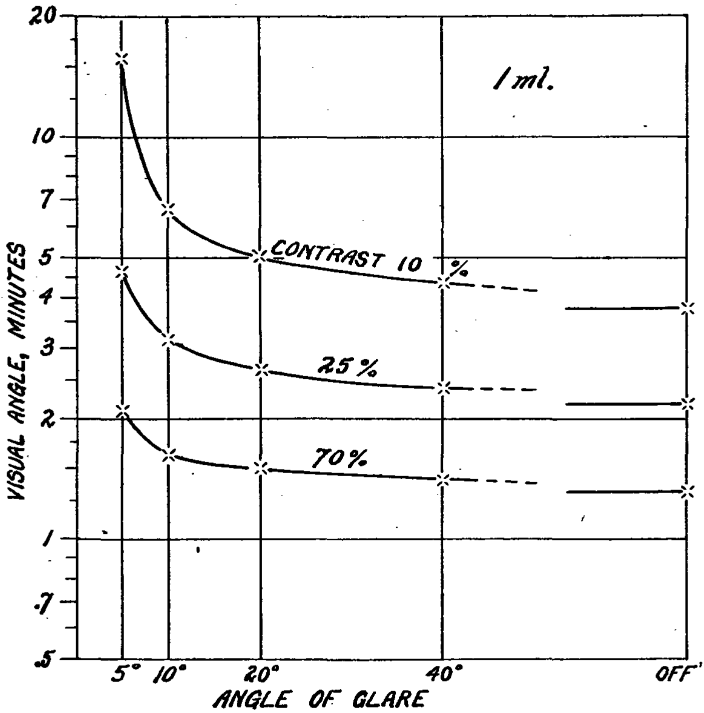

FIG. 5.—The relation between size of object (visual angle) and angle of glare, for objects making different grades of contrast with their backgrounds. Brightness of test-object, 1 millilambert. Compare with Figs. 6 and 7.

this increase is uniformly greater for the "dim shadow" type, than it is for the "printed letter" type of test-object. It is therefore quite possible in the factory or in the street, that the untoward effect is considerably greater than could be determined, even by extremely careful work, with the test-letter type of object.

This fact shows plainly in Figs. 8 and 9. The lower curves in the figures bend more sharply in every case, and represent, of course, the lower-contrast, larger test-objects. In Figs. 5, 6 and 7, interpolated values of the size of test-object have been scaled off from Figs. 2, 3 and 4 respectively, for the purpose of showing the relation between size of object and glare-angle. The fact just discussed appears again here. The upper curves represent the greater visual angles, and hence the lower-contrast test-

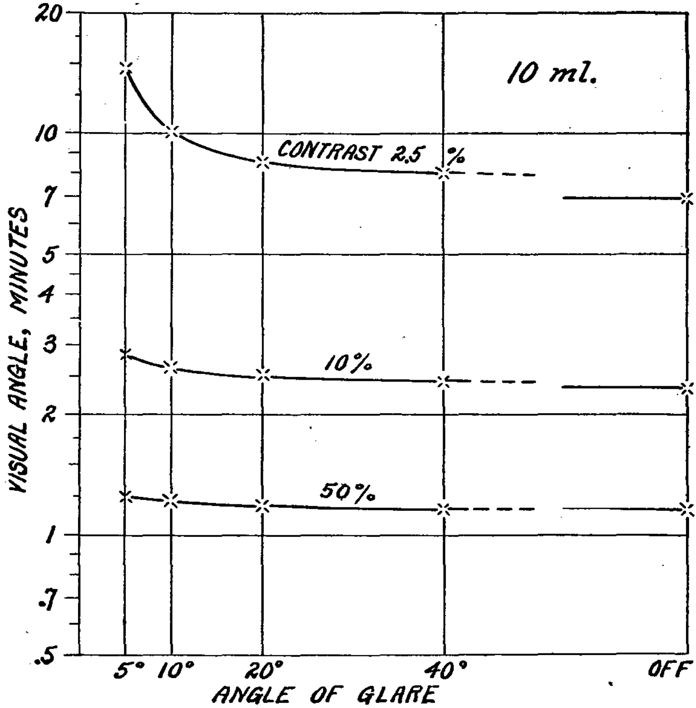

FIG. 6.—The same as Figs. 5 and 7. Brightness of test-object, 10 millilamberts.

objects, and here again these are seen to bend upward more sharply than the others as the glare-angle is diminished.

The following are a few concrete illustrations which may be deduced from the data so far presented:

If the brightness-level of the test-object is 1 millilambert, the presence of a glare-source at an angle of 5 degrees with the line of vision and producing an intensity of illumination at the eyes of 5 foot-candles will require that the size of an object seen in 20 per cent contrast be increased from 2.51 to 5.70 minutes in visual angle to be recognized. The significance of this change in the limiting size of the test-object may be better realized if we state that the object seen under the glare at 20 feet distance would, if the glare were removed, be just visible at 45 feet.

The effect of glare on vision may also be shown in terms of illumination. If the same glare-source be placed at 5° and with

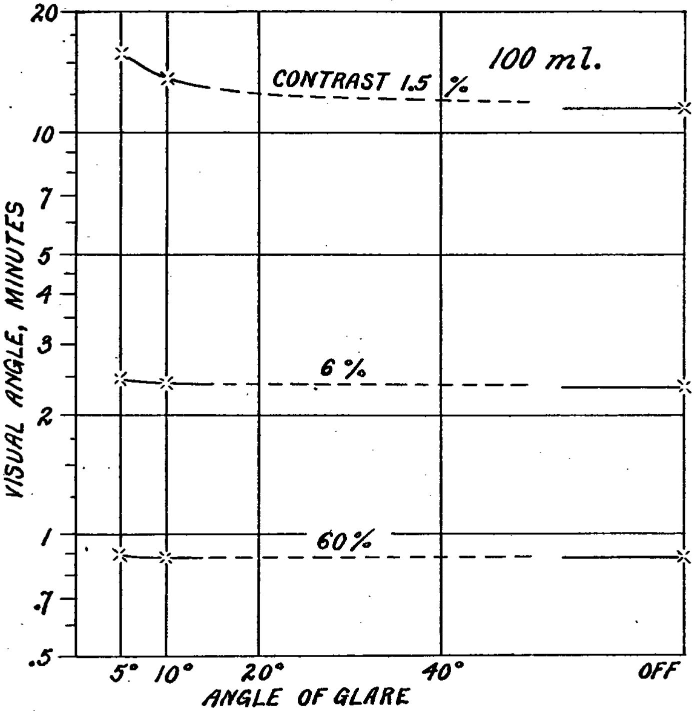

FIG. 7.—The same as Figs. 5 and 6. Brightness of test-object, 100 millilamberts.

a test-object at a brightness-level of 1 millilambert, visibility is reduced somewhat more than it would be if the 100 foot-candle lighting system were replaced by a 1 foot-candle system.

A recognition of the characteristic effects of glare on vision is of value to the lighting specialist, but in order to be most helpful in design of lighting systems, the magnitudes of the various effects should be known. It requires but a brief examination of the subject, however, to realize that the visual situations encountered in practice are diverse almost without number and an attempt to state what the effect of glare would be under actual working conditions is correspondingly difficult. In this research the difficulty of attempting to analyze a multitude of different visual situations has been avoided by selecting a group of test-objects of representative characteristics, so that one or another of

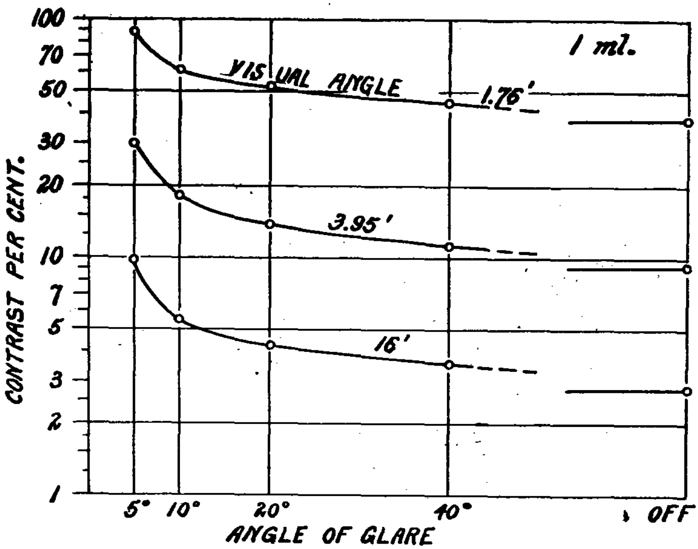

FIG. 8.—The relation between contrast made by visual object with its background and angle of glare, for visual objects of various sizes (visual angles). Brightness of test-object, 1 millilambert. Compare with Figs. 9 and 10.

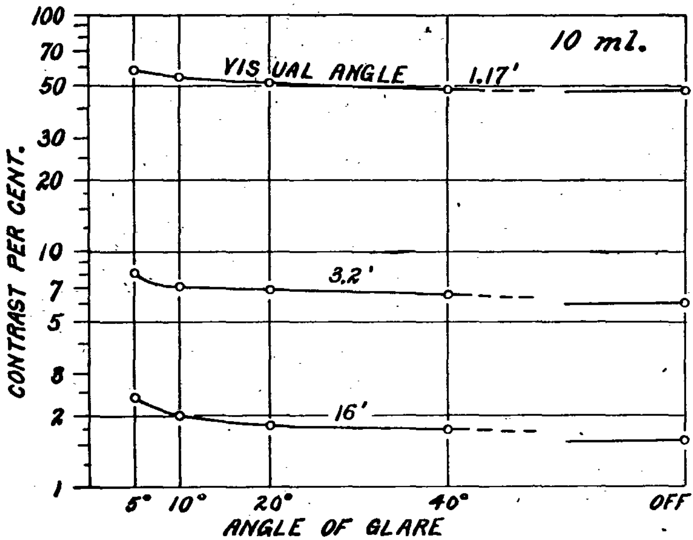

FIG. 9.—The same as Figs. 8 and 10. Brightness of test-object, 10 millilamberts.

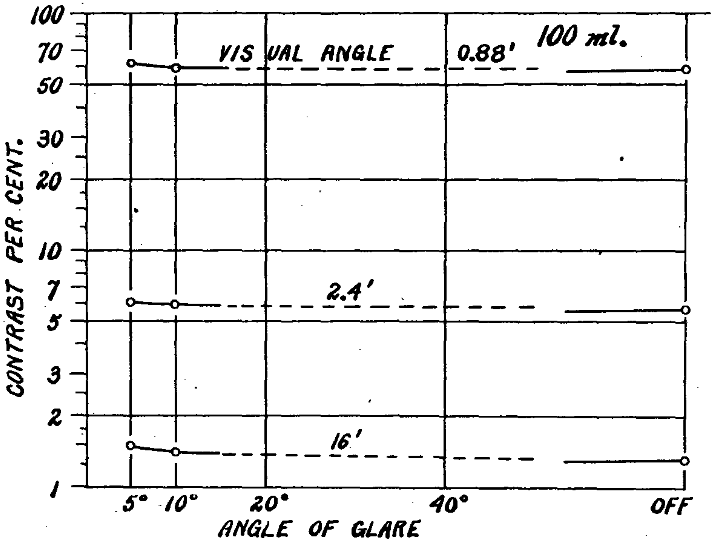

FIG. 10.—The same as Figs. 8 and 9. Brightness of test-object, 100 millilamberts.

them could be selected as approximating the known conditions of any practical visual situation. Furthermore, the factor of glare introduced into the experimental situations has, in some cases, been made more severe than any that would be tolerated in actual lighting practice. A detailed study was made with these few test-objects and wherever glare ceases to be a significant factor, it follows from the results that in other cases of larger glare-angle or brighter test-objects the effect of the glare will be still less significant. Thus, if the experimental situation selected is considered to be very trying to the eyes when compared with an actual or contemplated installation, then the results given here are conservative and imply a factor of safety.

The intensity of five foot-candles incident upon the eyes of the subject in the experiment was selected as the probable illumination on the vertical plane which would, in general, result with an installation yielding ten foot-candles on the horizontal plane. There was but one intensity of glare source used, owing to the very large number of observations necessary to measure the effect of glare on the several fundamental factors in vision. The effects of glare for angles of 5, 10, 20 and 40 degrees were considered as covering the range of interest in lighting, since the effect of a glaring light-source decreases rapidly as the angle between light-source and line of vision increases. The illumination upon the test-object, yielding brightnesses of 1 to 100 millilamberts, equivalent to 1.16 to 116 foot-candles on a white surface reflecting 80 per cent of the incident light, or 11.6 to 1160 foot-candles on a surface of 8 per cent reflection-factor, certainly extends over any range of intensity of illumination in use or contemplated.

Modern lighting with its relatively high intensities of illumination has brought about an appreciation of the results to be had from good lighting in the increase of production and in the improvement of working conditions in many and diverse ways. However, with the usual installation of high-intensity lighting, the entire beneficial effect of the lighting has not been realized, partly because of the handicap to vision due to glare which accompanies the use of powerful light-sources. The lighting installation may be partially described by: (a) the "specified" illumination or the intensity of illumination that the specifications state is delivered upon the work-plane. However, (b) the "effective-for-seeing" illumination at any work-point where vision is essential is never up to the specified illumination, even though the latter is realized by actual measurement on the unshadowed work-plane. It is necessarily less than this, and may be very much less, owing to shadows cast, the presence of the worker, and the disposition of the work in space. And this feature of the situation is one concerning which it has been mentioned as well as shown by the experimental results, that the unfavorable effects of glare are more especially to be realized. The identical glare situation brings about relatively more impairment of visibility in an object of low brightness than in one of high brightness. The loss of effectiveness is therefore out of proportion to the photometric loss suffered by the light in finding its way from the light-source to the shadowed work-point.

The foregoing would suggest that the increase of intensity of the general illumination is by no means always the most effective way of improving the lighting of work-places. In work-places where it is advantageous to have intensities of illumination of the order of 100 millilamberts, this intensity may better be obtained by supplementing the general lighting with local lighting. The creating of the high-intensity illumination by adding to the general illumination at critical places is not only an economic utilization of light, but has the additional and important characteristic of securing the high level of illumination without the disadvantage of increasing the glare present. The supplementary lighting, since it is designed for the individual work-place, can be installed so that the eyes are shielded from the direct light of the light-sources. By such a combination of good general lighting, plus well designed supplementary lighting, a total installation can be produced which is practically "glareless," since by virtue of the high level of illumination upon the visual object, the effect of the glare, already present, from the general overhead lighting may be reduced to a negligible value as measured in terms of visibility.

SUMMARY

1. The subject of glare is briefly discussed, and it is pointed out that there are two distinct methods of its appraisal, the one consisting of the judgment as to the degree of dazzle, etc., the other in the actual measurement of visibility of one or more selected test-objects.

2. Previous work on the subject, by the method of visibility, has been conducted with different test-objects, and with different techniques, which make the intercomparison of the results difficult. However, the results have agreed qualitatively, and the conclusions are stated.

3. The present experimental work is conducted with a systematically selected variety of test-objects, involving three sizes, and three brightnesses, all widely separated.

4. In addition to confirming previous conclusions, it is shown that a test-object of large dimensions, and seen in relatively feeble contrast with its background, has a substantially greater susceptibility to the effect of glare than a small, high-contrast object, such as a printed letter.

5. Some illustrations of the meaning of the results are presented, and some possibilities in the way of improvement of present lighting conditions are suggested, having in view the minimization of the element of "glare."

DISCUSSION

C. S. WOODSIDE: I would like to have Dr. Cobb give the difference in glare where the lamp is above or below the line of vision.

P. W. COBB: We have investigated only the vertical meridian above the line of vision. I believe some differences have been found, but they are of a small order of magnitude.

J. T. MACGREGOR-MORRIS: Some of us had the privilege of seeing the apparatus used in this excellent work a few days ago. There is just one point I should like to ask Dr. Cobb, and that is whether he has had time to investigate the effect of doing these experiments with different colored lamps. The work described has, I understand, been done with a white source. I should like to know whether similar results would be obtained if red or green lights were used for the experiments.

P. W. COBB: We were not able to do any work with different colored lights on this subject. I think the gentleman will realize that getting results which are at all reliable in this sort of work involves a great amount of detail; a large number of observations have to be made and averaged before we have results of which we may really feel sure.

J. W. T. WALSH: I believe I may have a better appreciation of the painstaking and laborious character of work of this kind than others in this room because it so happens that some of my staff at the National Physical Laboratory have been carrying out work of this nature, and I am well aware of the thousands and thousands of observations that are required before one can get a curve of the character Dr. Cobb has given in this paper. I should like, therefore, to be allowed to say how much I feel we are all indebted to the authors for the painstaking work they have carried out.

There are just two questions I should like to ask Dr. Cobb. The first is how many observers were used for the curves obtained. Further, I should like to know whether he has any data as to the spread of the observations for a single observer on a single occasion, and also the difference he found between the average obtained by a single observer on different occasions, and also the difference there was between the different observers. If data of that kind can be given in reporting work of this nature it is always very valuable.

P. W. COBB: In reply to Dr. Walsh's questions, we had nine observers. We worked by a method of serial groups, which consists in showing the observer the test object ten times, five times in each of two different positions in shuffled order, at easily recognizable intensity, then stepping down one step and showing it ten times in a similar way, and so on until he breaks down; and then appraising the point of break-down from this series of results. There were five such results from each of the nine observers for each point represented in Figs. 2, 3 and 4.

The variation between individuals was rather large. On the other hand, in previous work by the same method (*Journal of the Franklin Institute,* Vol. 205, pp. 831-847, 1928) it was found that each individual was consistent with himself to the point that the mean result from the nine had a relative probable error of 1 or 2 per cent. This was computed in such a way that the individual differences did not tend to augment it. The individual differences appeared to be quite systematic, and were so regarded, that is, they were not held to detract from the reliability of the trend of the mean results of the nine subjects.

E. STEWART: These fundamental researches on glare are of great value to those interested in street lighting. There we get both those effects of discomfort and reduction of visibility and there is a suspicion, indeed, that under conditions where theoretically there should be no interference with visibility due to glare, one gets a feeling of discomfort which in turn impairs vision. This may be a psychological effect. I should like to know if the authors have any information on this point. In fact, we know of streets where there is no glare at all. Glare has been removed as you remove it in a factory. But in such a street the effect upon many observers is that because there is a lack of brightness there is apparent reduction of visibility. It is probably a psychological effect.

Another factor we get in street lighting is the distraction caused by various moving objects. I should like to know if any work has been done on this as to its effect on visibility, other conditions being the same.

P. W. COBB: I have to plead ignorance of the answers to both questions Mr. Stewart has asked. They are, I think in the domain of psychology, and that is a domain in which there are many variables and no constants.