

METHODS OF MEASURING UNDERGROUND ILLUMINATION, AND IMPROVEMENTS
IN THE DESIGN AND CONSTRUCTION OF MINERS' PORTABLE LAMPS TO
INCREASE LIGHTING EFFICIENCY.

by

S. Holmes, B.Sc.

S. Holmes

Edinburgh, October 1930.

Thesis submitted for the Degree of Ph.D. of the University of
Edinburgh.



P R E F A C E.

This Thesis records the result of part of a programme of research on Mine Illumination carried out under the direction of Professor W.H. McMillan, Hood Professor of Mining, University of Edinburgh. The research was conducted under the auspices of the Safety in Mines Research Board who very kindly made a grant for the purpose. The work described is therefore of a practical nature, and the theoretical side of the problem has only been introduced where necessary to amplify practical details.

The thanks of the author are due to the Royal Society, for the award of a Tyndall Mining Research Studentship for the three years 1936 - 1939, to several lamp manufacturers for the provision of lamps and equipment, and to the management of collieries in the Nottinghamshire Coalfield for facilities provided in the carrying out of underground observations.

Edinburgh, October 1939.

An account of most of the work herein described has already been published in collaboration with Professor W.H. McMillan, as follows:-

1. "Illumination Contours for Miners' Lamps and Underground Illumination Surveys."

Trans. Inst. Min. Eng., Vol. XCII.

2. "Improvements in Illumination from Miners' Electric Hand-Lamps."

Trans. Inst. Min. Eng., Vol. XCIV.

3. "Improvements in Light Distribution from Miners' Electric Cap-Lamps."

Trans. Inst. Min. Eng., Vol. XCVI.

4. "Glare in Underground Lighting; A Preliminary Study."

Trans. Inst. Min. Eng., Vol. XCVII.

C O N T E N T S .

	Page.
CHAPTER I. Introduction.	1.
CHAPTER II. The Illumination Laboratory.	6.
CHAPTER III. The Illumination Meter.	13.
CHAPTER IV. Illumination Contour Diagrams for Individual Lamps.	19.
CHAPTER V. Underground Illumination Surveys.	28.
CHAPTER VI. Improvements in Illumination from Miners' Electric Hand-Lamps.	39.
CHAPTER VII. Improvements in Light Distribution from Miners' Electric Cap-Lamps.	52.
CHAPTER VIII. Glare in Underground Lighting.	76.
CHAPTER IX. Conclusions.	91.

CHAPTER I - Introduction

During recent years, a great deal of attention has been directed towards the improvement of lighting conditions in industry, and as a result of careful deliberation by committees of experts, certain minimum standards of illumination have been recommended for factories and other industrial works on the continent. The adoption of these minimum standards has resulted in a higher grade of workmanship, increased output, and a reduction in the accident rate, while the psychological effect of better lighting on the workers in these industries has led to marked improvements in health and general well-being.

CHAPTER I.

INTRODUCTION.

Improved illumination still remains the worst lighted industry in the world. Several sound reasons can, however, be advanced to explain this state of affairs. Constantly changing conditions, the presence of obstacles of various kinds such as pipes and conveyors, the occurrence of inflammable and explosive gases, and the necessity for natural reflecting surfaces, all present difficulties which are by no means easy to overcome. These difficulties have in consequence hampered development in this particular sphere very considerably, and yet, as already stated, there is no industry which stands to gain more from better lighting conditions. This point has already been amply demonstrated where lighting from the mains has been introduced in roadways, junctions, and public-houses, i.e. in those parts of the underground workings where the working conditions are more or less permanent, where

CHAPTER I. Introduction.

During recent years, a great deal of attention has been directed towards the improvement of lighting conditions in industry, and as a result of careful deliberation by committees of experts, certain minimum standards of illumination have been recommended for factories and other industrial works on the surface. The adoption of these minimum standards has resulted in a higher grade of workmanship, increased output, and a reduction in the accident rate, while the psychological effect of better lighting on the workers in these industries has led to marked improvements in health and general well-being.

The benefits which accrue from better industrial lighting having been amply recognised, it might at first seem strange that coal-mining, which should be expected to gain most from improved illumination, still remains the worst lighted industry in the world. Several sound reasons can, however, be advanced to explain this state of affairs. Constantly changing conditions, the presence of obstacles of various kinds such as props and conveyors, the occurrence of inflammable gas, the necessity for using explosives in many cases, and the almost complete absence of natural reflecting surfaces, all present difficulties which are by no means easy of solution. These difficulties have in consequence hampered developments in this particular sphere very considerably, and yet, as already stated, there is no industry which stands to gain more from better lighting conditions. This indeed has already been amply demonstrated where lighting from the mains has been introduced in roadways, junctions, and engine-houses, i.e. in those parts of the underground workings where the strata conditions are more or less permanent, where methane /

methane is absent, where there is little likelihood of damage to fittings, and where reflection has been greatly improved by the compulsory whitewashing of the roof and sides.

A large proportion of the workers underground are, however, employed at the coal face, which is continually advancing. Here the strata conditions are not permanent, numerous obstacles are present in the form of roof supports, conveyors, etc., and the space is frequently so limited, particularly in height, that the types of fitting usually employed, together with their safety accessories are, at least in the present stage of development, inferior to the more modern types of portable hand lamps and still more inferior to the more modern types of cap lamps. In a few cases, admittedly, lighting from the mains has been introduced at the coal face with the greatest advantages, but in all these instances the seams have been over four feet in thickness, and it has been therefore possible to arrange the positions of the lamps so that there is little likelihood of damage. Even in these instances, however, unless provision is made for moving the lamps forward as work proceeds, particularly during the stripping shift, the illumination is very variable owing to the gradually increasing distance from the lamps at which the men are working. From the standpoint of general illumination, its superiority cannot be disputed, but it has yet to be proved that the illumination given on the working place of each individual worker is better than that obtained from modern portable lamps, which, because of their general handiness, will hold their own for some time to come, especially in the thinner seams. A similar conclusion has been reached with regard to coal face mains lighting in other countries besides Great Britain where such equipment has been installed.

The /

The illumination afforded to the underground worker by portable lamps has in the past been deplorably low, and although progress has certainly been made, this progress has been retarded by two conditions:- (1) All lamps used underground must conform to the safety regulations, and for this purpose must be sufficiently robust to withstand the often unnecessarily rough treatment which they receive. (2) The weight of the lamp must be kept down to reasonable proportions to ensure portability, a condition which is by no means easy to reconcile with the other requirement just mentioned.

In the Third Report of the Medical Research Council on Miners' Nystagmus, published in 1932, it was stated that insufficient illumination was the chief contributory cause of the disease, and after a study of the state of underground lighting at that time, the Council recommended that a minimum illumination of 0.1 foot-candle on the coal face would go far towards a reduction in the incidence rate of the disease, giving 0.25 foot-candle as the value to be aimed at. It is interesting to compare these illumination values with the recommendations of the Fourth Report of the Departmental Committee on Lighting in Factories (Home Office, 1938), from which the following extract is taken:- "Over the interior working areas of any factory the illumination at floor level, or at three feet below the level at which work is carried on, shall not fall below 1.0 foot-candle, without prejudice to the illumination required for the work itself." This evidently ensures that the illumination available at the actual place of working will be considerably higher than the 1.0 foot-candle minimum, and this disparity between factory lighting and mine lighting is rendered still more marked by the fact that the average reflection ratio of the materials met with in factories is considerably /

considerably higher than that prevailing underground at the coal face, resulting in great differences of surface brightness. It will thus be realised that a great deal must be done before lighting conditions underground can be brought within reach of surface standards, and the present work is therefore devoted to a study of this problem, an account being given of various investigations carried out in an attempt to improve the lighting performance of miners' electric hand- and cap-lamps, which, as already mentioned, will be the chief sources of coal face illumination for some time to come.

CHAPTER III

THE ILLUMINATION LABORATORY

CHAPTER II. The Illumination Laboratory.

To carry out the programs of work contemplated, it was necessary to have a fully-equipped photometric laboratory. Furthermore, as the light sources to be dealt with were of low intensities, it was essential that the photometric equipment should be of the highest possible accuracy, to ensure that error factors were reduced to a minimum. The apparatus was housed in a dark-room, the walls and ceiling of which were painted flat black to avoid stray reflections while lamps were undergoing test.

For accurate intensity (i.e. candle-power) measurements, a photometer of the Lummer-Brodhun contrast pattern type was employed. The standard CHAPTER II. (an electric bulb) was suspended in a sliding support from a rigid horizontal beam which also carried the photometer head, and the movement of the bulb support could be controlled by means of a racking arrangement situated near the photometer head. The lamp under test was placed on a rigid platform, the distance between platform and photometer being adjustable to suit widely-differing intensity measurements. Two sub-standard bulbs were used, one of 4 volt, 0.75 ampere rating, and the other of 4 volt, 1 ampere rating, these two bulbs being periodically checked against two standard bulbs which had been standardized by the National Physical Laboratory. Voltage control was carried out by means of carbon voltage-taps and finely-adjustable rheostats, but in cases where extreme accuracy was required, the voltmeter was replaced by a Tinsley self-contained potentiometer, in which a Weston-Cell, Standard Cell, galvanometer, lamp and scale were all component parts of the instrument. By means of this potentiometer, of

CHAPTER II. The Illumination Laboratory.

To carry out the programme of work contemplated, it was necessary to have a fully-equipped photometric laboratory. Furthermore, as the light sources to be dealt with were of low intensities, it was essential that the photometric equipment should be of the highest possible accuracy, to ensure that error factors were reduced to a minimum. The apparatus was housed in a dark-room, the walls and ceiling of which were painted flat black to avoid stray reflections while lamps were undergoing test.

For accurate intensity (i.e. candle-power) measurements, a photometer of the Lummer-Brodhun contrast pattern was employed. The standard of intensity (an electric bulb) was suspended in a sliding support from a rigid horizontal beam which also carried the photometer head, and the movement of the bulb support could be controlled by means of a racking arrangement situated near the photometer head. The lamp under test was placed on a rigid platform, the distance between platform and photometer being adjustable to suit widely-differing intensity measurements. Two sub-standard bulbs were used, one of 4 volt, 0.75 ampere rating, and the other of 4 volt, 1 ampere rating, these two bulbs being periodically checked against two similar bulbs which had been standardised by the National Physical Laboratory. Voltage control was carried out by means of Weston voltmeters and finely-adjustable rheostats, but in cases where extreme accuracy was required, the voltmeter was replaced by a Tinsley self-contained potentiometer, in which a Weston-Cadmium Standard Cell, galvanometer, lamp and scale were all component parts of the instrument. By means of this potentiometer, it was/

was possible to maintain the potential difference across the terminals of the standard bulb at 4 volts with an error of only ± 0.0004 volts. The voltmeters and ammeters used in the laboratory were themselves checked at intervals against the potentiometer. When carrying out intensity measurements on a light source, it was customary to record two sets of observations, the second set being made after reversing the plaster screen in the photometer head, thus eliminating any error which might arise due to differences in the diffusing properties of the two surfaces of this screen.

To obtain polar curve data for miners' lamps, a photovoltaic cell photometer was employed. This photometer was of the Davis "Standard" Mines Department pattern, the lamp being placed on a circular platform capable of rotation about a vertical axis and carrying an angular scale. The Weston Photocell was fixed in a suitable holder on a metal bar which was pivoted about a horizontal axis, a pointer on the bar at the centre of rotation moving over a vertical angular scale for the plotting of vertical polar curves. The photocell readings were recorded by means of a Tinsley Reflecting Galvanometer carrying a ten-inch scale, and this instrument could be set to give direct intensity readings by suitable adjustment of a variable shunt, assuming as a standard the intensity reading obtained on the Lummer-Brodhun photometer for a fixed position of the lamp under test. This photocell method of plotting polar curves, while quite adequate for rough comparisons, breaks down when greater accuracy is required. The errors which arise are due to the fact that the low intensities of miners' lamps make it necessary for the distance between the lamp and the cell to be comparatively small to ensure a reasonable cell response, and hence the cell subtends a considerable solid angle at the lamp. Because of this, the illumination may /

may vary over the surface of the cell, especially in the case of a modern cap lamp, where the angular variation in intensity is large. The inverse square law (illumination at cell = $\frac{\text{Intensity}}{(\text{distance})^2}$) on which the method is based, and which requires that the illumination shall be uniform over the surface of the cell for any one position of the cell, therefore no longer strictly applies. The two methods of overcoming this, namely, greater separation of lamp and cell, or reduction in the surface area of the cell itself will result in loss of sensitivity, and therefore lead to further inaccuracies.

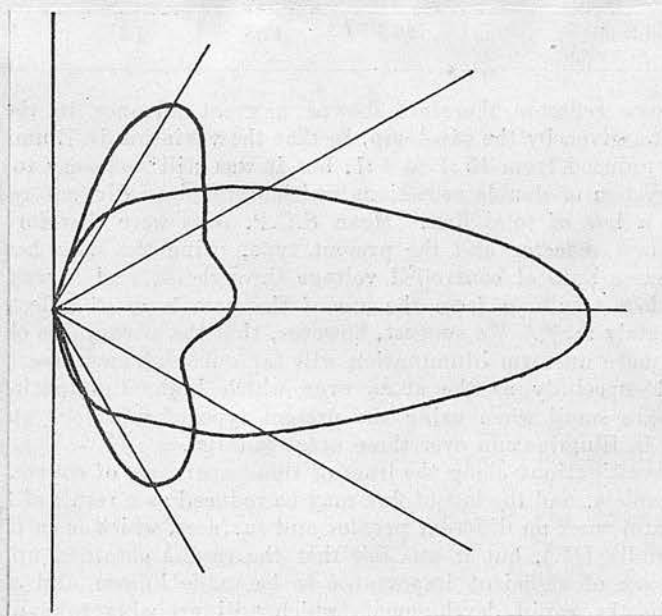


Fig. 1. - Polar Curves showing Different Distributions of the same Total Flux.

It should be mentioned here that while polar curves are a convenient means of showing the intensity distribution of a light source, they are of little value in comparing the total light flux output of two sources by comparing the areas of their respective curves, even when the curves are identical in all axial planes in both cases. This is clearly shown in the diagram (Fig. 1). The two polar curves represent the distributions from two cap-lamp sources having approximately the same total /

total light output, but it will be seen that the areas of the two curves are by no means equal, although the distribution in each case is the same in all planes through the axis.

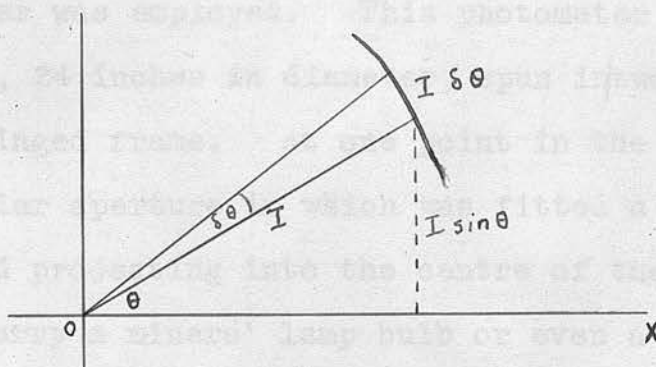


Fig. 2. - Sector of Polar Curve.

A study of Fig. 2, which represents a portion of a polar curve, will serve to explain this result. The area of the curve between the angles θ and $\theta + \delta\theta$ has the value $\frac{1}{2}I^2\delta\theta$, where I is the intensity. Hence the area A of the whole curve is given by

$$A = \frac{1}{2} \int I^2 d\theta \quad (1).$$

Suppose the curve is now rotated about the axis OX to form the polar solid, and let $\delta\omega$ be the solid angle subtended at the pole O by that portion of the curve between angles θ and $\theta + \delta\theta$. We at once have

$$\delta\omega = \frac{2\pi I \sin \theta \cdot I \delta\theta}{I^2} = 2\pi \sin \theta \delta\theta.$$

By the definition of intensity (flux per unit solid angle), the flux emitted in the solid angle $\delta\omega$ becomes $I \delta\omega$ or $2\pi I \sin \theta \delta\theta$.

Hence the total flux F emitted by the source becomes

$$F = 2\pi \int I \sin \theta d\theta \quad (2).$$

Hence the area of any sector of a polar curve is proportional to the square of the intensity (Equation 1), while the flux emitted in that sector is proportional to the first power of the intensity, and also to the sine of the angle between the sector and the axis (Equation 2). Hence total light outputs cannot be compared directly from polar curves, and if such curves are /

are to be used for this purpose, special constructions such as those due to Rousseau and Gerhardt must be used.

For all total flux measurements in the laboratory a spherical photometer was employed. This photometer consisted of a copper sphere, 24 inches in diameter, spun into two halves and mounted on a hinged frame. At one point in the wall of the sphere was a circular aperture in which was fitted a Weston Photronic Cell, and projecting into the centre of the sphere was a support to carry a miners' lamp bulb or even a complete lamp if necessary. This support was in the form of a hollow tube, through which were passed electrical leads to enable voltage and current control to be carried out from the exterior of the sphere. Fixed between the centre of the sphere and the photocell was a circular metal screen of such a size as to prevent direct light from the bulb or lamp at the centre reaching the cell. The whole of the interior of the sphere, including the bulb support and screen, was painted with white photometric paint (a matt white paint of high reflection ratio). The use of such a sphere for measuring the total light output of a source placed at the centre was first proposed by Ulbricht, and the method is based on the fact that, due to multiple reflections, the walls of the sphere become uniformly illuminated, the standard of illumination being directly proportional to the total output of the light source.

The illumination falling on the walls of the sphere was recorded by means of a Cambridge Wall Pattern Unipivot Microammeter of 0 - 15 micro-amps. range, connected to the Weston Cell already mentioned. Having obtained the microammeter reading for a bulb of known total output in lumens (a National Physical Laboratory Sub-standard), the total output of any other bulbs /

bulbs could be calculated from their respective microammeter readings. As voltage and current control was carried out from the exterior of the sphere, it was at once possible to obtain the efficiency of any bulb in lumens per watt, bulb efficiency being of the utmost importance in mine illumination work. The sphere also proved of great value in determining the proportion of the light given by a bulb which was usefully employed, i.e. that proportion of the total flux which was not absorbed by the lantern part of the lamp. This light loss could be evaluated by placing first, the bulb alone, and second, the bulb together with its well-glass and the lantern part of the lamp (the latter being painted with photometric paint), in the sphere, and noting the difference in the microammeter readings. A similar method could be used to determine the amount of light absorbed by different types of well-glass.

CHAPTER III
THE ILLUMINATION METER

CHAPTER III. The Illumination Meter.

Numerous data are now available on the intensities of miners' lamps, on the distribution of the light which they give, and on the illumination at any distance given by such lamps as calculated from polar diagrams of intensity. The application of surface methods, however, to the making of illumination surveys underground has not been seriously approached, except to a very limited extent where lighting from the mains is adopted.

The New Regulations governing the approval of portable lamps require that the lamps shall comply with certain definite standards of intensity, and it is interesting to note that the regulations for approval have probably been framed to attain the minimum illumination standard of 0.1 ft.c set down by the Medical Research Council on Nystagmus, as a lamp which complies with the minimum requirements of the regulations does approximately give 0.1 ft.c over a small area of surface, if the lamp is at a distance of from $3\frac{1}{2}$ to $3\frac{3}{4}$ ft. from the surface. Since, however, the distance from his work at which the underground worker places his lamp varies considerably, it is evident that if some ready means were available of measuring the actual illumination he obtains on his work, such means would prove of great practical value in providing a direct comparison of the light available to individual workers when using the various types of portable lamp. Such an instrument would, of course, be available also for making underground illumination surveys.

It will be agreed that if an illumination meter is to be of any value in underground conditions it must fulfil three essential requirements. The readings must be independent of the personal element, the instrument must be sufficiently delicate to /

to register illuminations down to, say, 0.005 ft.c, and it must be sufficiently portable and robust to be taken into the inside workings of the mine. The first of these at once rules out any meter of the comparison type, and limits the choice to some form of photo-electric cell, while the second and third requirements compel the use of a cell or suitable combination of cells with a larger output than that commonly used for illumination surveys on the surface, and also of an instrument for measuring the cell output for illuminations from 0.005 up to, say, 5 ft.c.

Experiments were first carried out with a Weston Photronic Cell, which had a sensitive surface of 1.7 sq. in., and an output of about 1.4 micro-amps. per ft.c. To use a single cell of this type for measuring illuminations down to 0.005 ft.c, as suggested, a galvanometer reading to 0.007 micro-amps. would be necessary, and such an instrument would obviously be much too delicate for underground use. Tests were next made with groups of six and nine of these cells in parallel, but the recording instrument was found to be still too delicate for underground use. This arrangement had the further disadvantage of the total area of the cells and their housing being too large for use at the small distances at which the lamps had to be placed from the illuminated surface to correspond with the distance from light source to surface in underground work. There was thus, in some cases, considerable variation of illumination over the surface of the cells, and the results obtained were far from accurate when compared with the illumination values obtained by calculation from polar curves.

Successful tests were then carried out with a larger type of light-sensitive cell of foreign manufacture. This cell, which had a sensitive area of approximately 5 sq. in., and an output /

output of about 8 micro-amps. per ft.c., permitted the use of a portable microammeter in which a deflection of nearly $\frac{1}{2}$ in. was obtained for an illumination of 0.1 ft.c. or $\frac{1}{40}$ in. for an illumination of 0.005 ft.c. The microammeter used was of the Cambridge Unipivot pattern.

Having thus obtained an illumination meter which fulfilled the requirements set out above, it was next necessary to graduate the instrument for the various types of illumination to be considered, as photoelectric cells are not equally sensitive to the different colours of light given by the various types of lamp. There is a marked difference in the response of the cell to a flame source and to an electric source of the same intensity, and the response also varies for bulbs of different efficiencies in the same lamp, although the voltage may be kept constant. The electric lamps to be used were accordingly fitted with external leads, and the bulb voltage was kept constant so as to ensure measurements at standard rating by using an external battery, rheostat, and standard voltmeter. The maximum horizontal candle-power was then measured for each lamp by means of a Lummer-Brodhun photometer. The photocell of the meter was then held at a fixed distance d from the lamp, normal to the direction in which the candle-power had been measured, and the microammeter reading θ was noted.

We then have

$$\begin{aligned} \text{Illumination on the cell} &= \frac{\text{Candle-power} - L}{d^2} \text{ (say)} \\ \text{and Standardization Factor} &= \frac{L}{\theta} \end{aligned}$$

All microammeter readings for the lamp under test could then be converted into illumination values by simply multiplying by the factor $\frac{L}{\theta}$.

To show that this method is reasonably accurate, a horizontal polar curve of a lamp was plotted, the bulb voltage being /

being controlled as already described. The lamp was then placed 4 ft. from a vertical surface, and run at the same voltage. Readings of the meter were then taken with the cell on the surface opposite the centre of the lamp, and at distances of 1, 2, 3, and 4 ft. on each side of the centre in a horizontal plane. The standardization factor of the meter was calculated from the centre reading, and the values found for the other positions using this factor were compared with the values obtained by calculation from the polar curve. For the positions of the cell on either side of the central position it must be noted that the illumination is given by

$$\frac{\text{Candle-power} \times \cos \alpha}{d^2}$$

where d is the distance from the lamp to the point at which the cell is placed, and α is the angle between the line joining the lamp to this point, and the line from the lamp to the central cell position. It is at once seen that $d = \frac{4}{\cos \alpha}$ and hence the above expression reduces to

$$\frac{\text{Candle-power} \times \cos^3 \alpha}{16}$$

The results obtained are shown in Table I, and it is seen that the maximum error is less than 4%.

TABLE I. - Accuracy of Illumination Meter.

Angle α .	Candle-power from polar curve.	Illumination = $\frac{\text{c.p.} \cos \alpha}{16}$ ft.c.	Illumination from meter reading. ft.c.	% Error.
45	2.71	0.060	0.059	1.67
36.8	2.47	0.079	0.076	3.80
26.5	3.57	0.160	0.156	2.50
14	4.04	0.230	0.236	2.61
0	3.84	0.240	0.240	0
14	4.36	0.248	0.242	2.42
26.5	3.93	0.176	0.181	2.84
36.8	2.69	0.086	0.088	2.32
45	2.67	0.059	0.061	3.38

This method of standardization was carried out for each type of electric lamp. To calibrate the meter for flame-lamps, a standard candle was used. This last standardization was checked by means of standardized tungsten-filament bulbs which had been under-run to match flame sources.

TABLE II.

ILLUMINATION METERS READINGS FOR INDIVIDUAL LAMPS.

This investigation deals with (a) the illumination given on a flat black vertical surface by various types of lamps when placed at a distance from that surface corresponding to the average distance at which the lamp would be used in such cases, and with (b) a determination of the areas of surfaces illuminated to the minimum of 0.1 ft.c., as recommended in the Third Report of the Nystagmus Committee.

A vertical surface 5 ft. high and 5 ft. 3 in. long was painted black and divided into 9-in. squares. A later mark a 5 ft. by 5 ft. surface, divided into 1-ft. squares, was used. The lamps to be used were placed in turn opposite the center of this surface, at a distance of 4 ft. in the case of

CHAPTER IV.

ILLUMINATION CONTOUR DIAGRAMS FOR INDIVIDUAL LAMPS.

hand-lamps and 2 ft. in the case of pen-lamps. The height of the electric lamps was 2 ft. 6 in. and the voltage, as recommended by the committee, and this voltage was fixed so that the results obtained could be taken as approximately half-shift values. The lamps were adjusted so as to be on the point of flicker. For each lamp the coil of the illumination meter was held in the center of each of the squares on the illuminated surface, and the photometer reading for each position of the coil was recorded. By using the standardization factor obtained (as explained in the previous chapter) for the lamp under test, these photometer readings were converted into illumination values in foot-candles. From these values it was then possible to plot on scale an illumination contour map of a flat surface 5 ft. by 5 ft. when illuminated by the lamp under test situated at a fixed distance from the surface.

CHAPTER IV. Illumination Contour Diagrams for Individual Lamps.

This investigation deals with (a) the illumination given on a flat black vertical surface by the various types of lamp when placed at a distance from that surface corresponding to the average distance at which the lamp would be used in practice, and with (b) a determination of the areas of surface illuminated to the minimum of 0.1 ft.c., as recommended in the Third Report of the Nystagmus Committee.

A vertical surface 6 ft. high and 8 ft.3 in. long was painted dead black and divided into 9-in. squares. (In later work a 6 ft. by 8 ft. surface, divided into 1 ft. squares, was used.) The lamps to be used were placed in turn opposite the centre of this surface, at a distance of 4 ft. in the case of hand-lamps, and $2\frac{1}{2}$ ft. in the case of cap-lamps. The bulbs of the electric lamps were run at a controlled voltage, as previously described, and this voltage was fixed so that the results obtained could be taken as approximately half-shift values. Flame-lamps were adjusted so as to be on the point of smoking. For each lamp the cell of the illumination meter was held in the centre of each of the squares on the illuminated surface, and the microammeter reading for each position of the cell was recorded. By using the standardization factor obtained (as explained in the previous chapter) for the lamp under test, these microammeter readings were converted into illumination values in foot-candles. From these values it was at once possible to plot to scale an illumination contour map of a flat surface $5\frac{1}{4}$ by $7\frac{1}{2}$ ft. when illuminated by the lamp under test situated at a fixed distance from the surface.

The /

The method of plotting the illumination contour diagrams from the meter readings is illustrated by the following example:-

Suppose the diagram (Fig. 3) represents, to scale, an illuminated surface. Readings have been taken with the illumination meter at the points 1, 2, 3, etc., and the illumination values in foot-candles, as calculated from the meter readings and standardization factor, are shown.

Let us suppose that it is required to plot the illumination lines for 0.025 ft.c. It is seen that one point on this line lies between (1) (0.007 ft.c.) and (2) (0.028 ft.c.). Therefore suppose that the distance between (1) and (2) is divided into 21 equal parts ($0.028 - 0.007$), then the 0.025 line passes through a point distant three of these divisions from (2). (It is assumed that for all practical purposes the change in

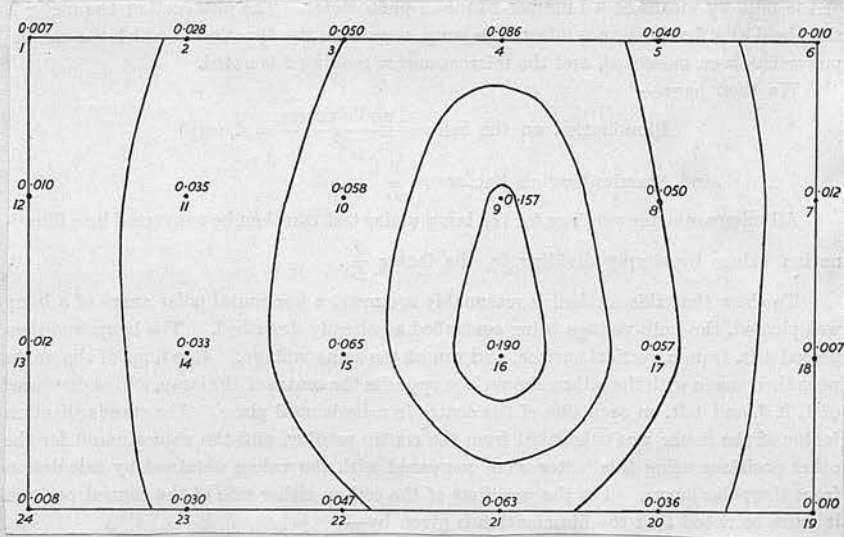


Fig. 3. - Diagram Explaining Method of Plotting Illumination Contours.

illumination over the surface is uniform between any two points at which readings have been taken.) Another point on the 0.025 ft.c. line lies between (11) (0.035 ft.c.) and (12) (0.010 ft.c.) and it is seen at once that this point is $\frac{2}{5}$ ths [15 divisions from (12) and 10 divisions from (11)] of the total distance between /

tween (11) and (12) from point (11)]. Similarly, points are found between (13) and (14), and between (23) and (24), and a line is drawn to pass through the four points obtained. This line is the illumination contour for 0.025 ft.c.

The contours for 0.05, 0.10, 0.15 ft.c. are similarly plotted, as shown.

It is thus seen that the method of plotting the illumination diagrams is exactly similar to that used for ordinary geographical contour maps.

Contour diagrams were plotted by this method for the various sources of light which are in general underground use, and some of the diagrams are shown in Figs. 4 - 15. The closely hatched portions represent areas over which the illumination is less than 0.025 ft.c., the wider hatchings represent areas illuminated between 0.025 and 0.05 ft.c., and the open hatchings represent areas whose illumination lies between 0.05 and 0.1 ft.c. The unhatched portions represent areas illuminated above the suggested minimum of 0.1 ft.c.

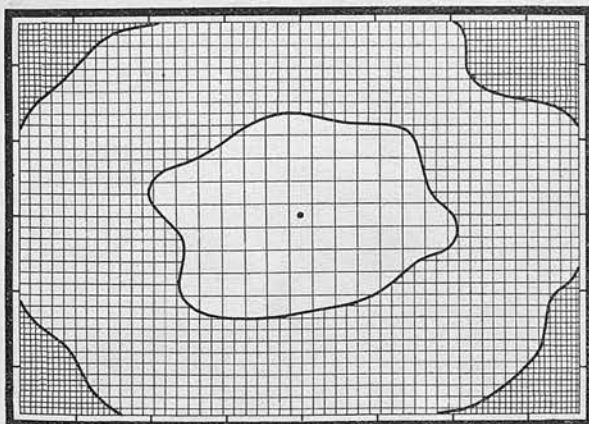


Fig. 4. - Standard Candle.

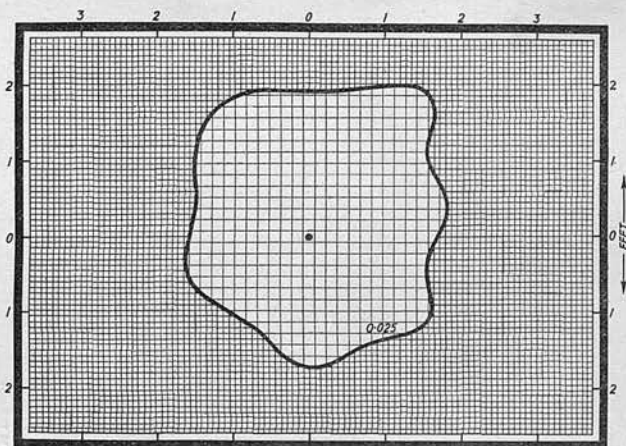


Fig. 5. - Old Oil Safety Lamp.

Figs. 5 and 6 show the great advance made in the illumination given by flame safety-lamps. Fig. 4, which is the illumination contour diagram for a standard candle, is given for comparison /

comparison purposes, and it is seen that there is no illumination of 0.1 ft.c. whatever. Fig. 5 is drawn for an old type oil safety-lamp, and here there is no area illuminated even to 0.05 ft.c.

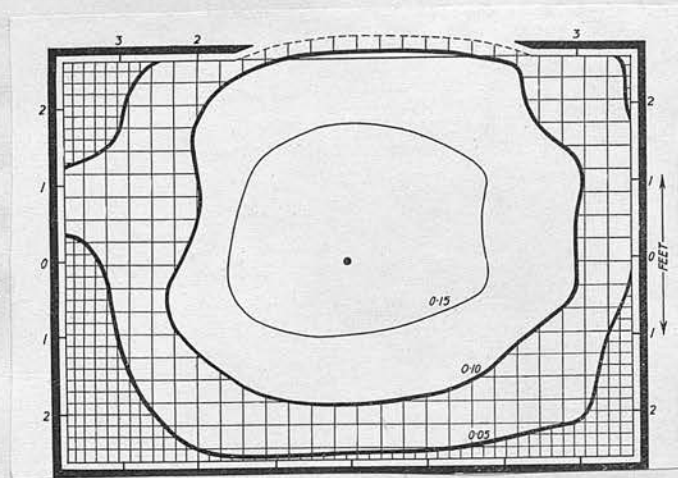


Fig. 6. - Modern High Candle-power Flame Safety-lamp.

Fig. 6 is the diagram for a modern high candle-power safety-lamp, and it is seen that there is a considerable area over which the illumination is above 0.1 ft.c. Part of this area, indeed, is illuminated over 0.15 ft.c.

Figs. 7, 8, and 9 similarly represent the advance in hand electric lamps. Fig. 7, drawn for a 2-volt lamp, shows that such a lamp placed 4 ft. from the surface to be illuminated gives

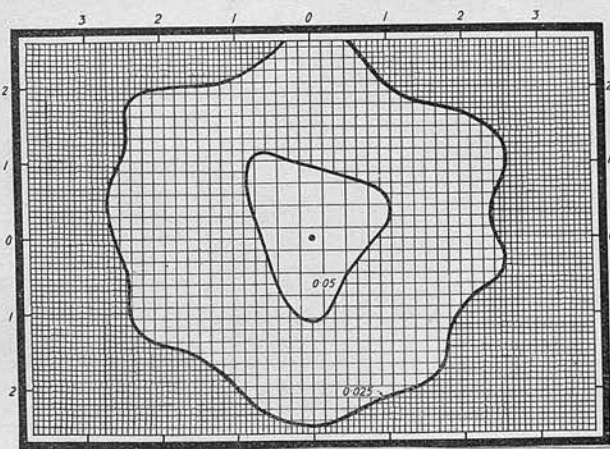


Fig. 7. - 2-volt Electric Lamp.

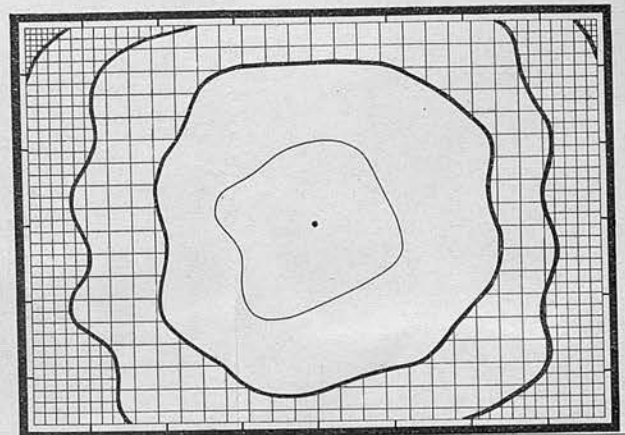


Fig. 8. - Small 4-volt Electric Lamp. (Cylindrical Prismatic Glass.)

no illumination of the 0.1 ft.c. standard. A small 4-volt lamp (bulb, 8 lumens per watt) as shown in Fig. 8, illuminates a considerable area above the 0.1 ft.c. standard, the centre portion being above 0.15 ft.c., while a large electric lamp (4-volt lead-acid, bulb, 8 lumens per watt; or 2.6-volt alkaline, bulb 7 lumens per watt) as shown in Fig. 9, increases the area illuminated to the required minimum, and illuminates a small area in the centre above 0.2 ft.c. The lamps used for Figs. 8 and 9 were both fitted with cylindrical prismatic well-glasses.

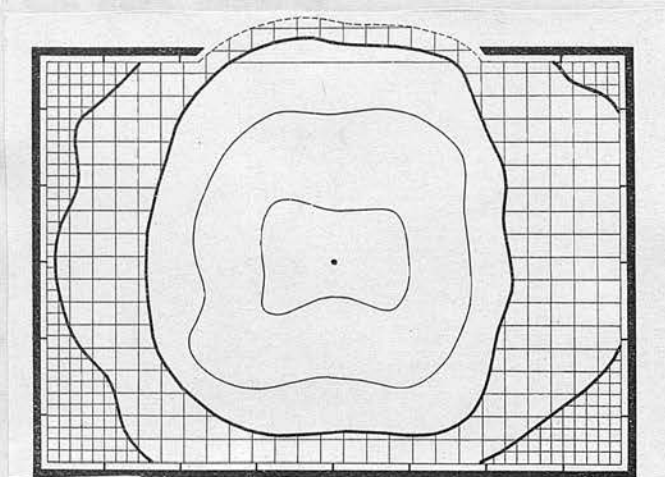


Fig. 9. - Large Electric Lamp. (Cylindrical Prismatic Glass.)

Figs. 10 and 11 represent the illumination contours of small and large electric hand-lamps, respectively, when fitted with spherical prismatic well-glasses. It is seen that for

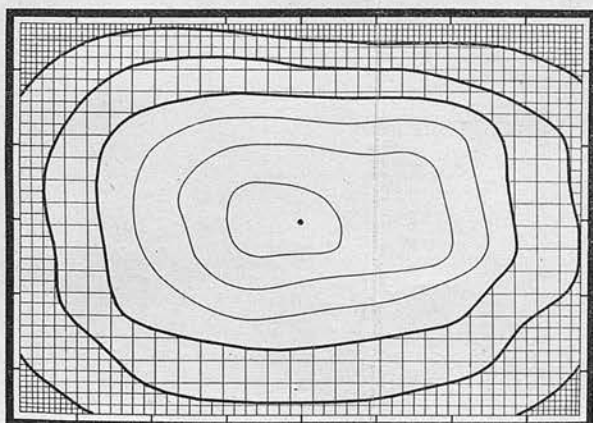


Fig. 10. - Small Electric Lamp. (Spherical Prismatic Glass).

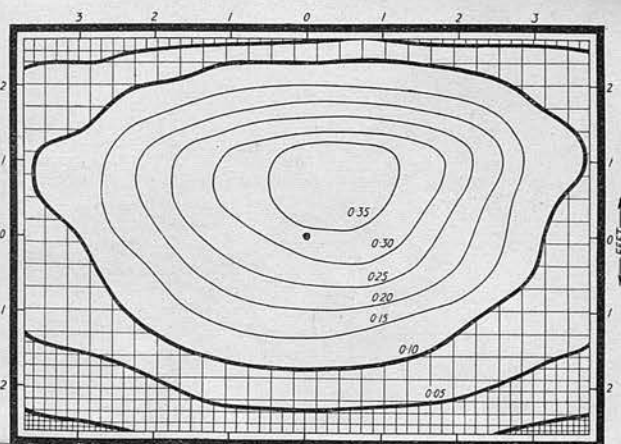


Fig. 11. - Large Electric Lamp. (Spherical Prismatic Glass)

the small lamp, a maximum illumination of over 0.25 ft.c. is reached, while for the large lamp this maximum lies above 0.35 ft.c. By comparing these two diagrams with Figs. 8 and 9 it will be seen that the spherical glass not only distributes the light in a horizontal direction, but also illuminates a small area of surface to a higher standard. It may thus be concluded that for narrow coal-seams (below 4 ft. in thickness, approximately) the spherical prismatic well-glass is more suitable than the cylindrical form. This conclusion receives a striking confirmation in the next chapter.

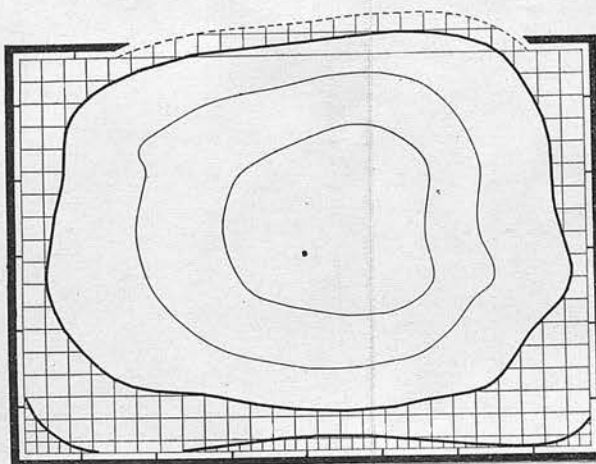


Fig. 12. - 4-volt Pillarless Electric Lamp.

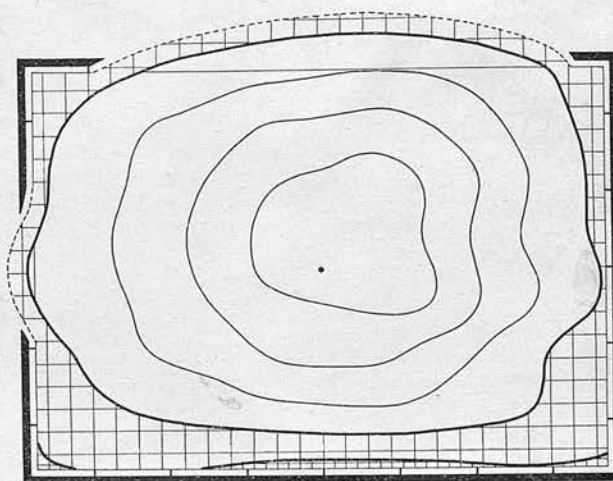


Fig. 13. - 4-volt Pillarless Electric Lamp with Reflector.

Figs. 12 and 13 are the illumination diagrams for a 4-volt pillarless electric lamp, Fig. 13 being the diagram for the same lamp as used for Fig. 12 but with the addition of a cylindrical reflector fitted outside the well-glass. The well-glass in both cases was dome-shaped and prismatic. It is seen by comparing Fig. 9 with Fig. 12 that the absence of pillars has effected a considerable increase in the area illuminated above 0.1 ft.c., as the same bulb was used in both cases. Table II gives the actual area illuminated above 0.1 ft.c. for each of the lamps /

Table II. - Areas Illuminated above 0.1 Foot-candle Standard by Modern Types of Safety-lamp.

Diagram.	Type of lamp	Type of well-glass.	Distance from surface, ft.	Area illuminated above 0.1 ft.-c., sq. ft.
Fig. 8	Small 4 v. electric	Cylindrical prismatic	4	16.0
" 10	" " "	Spherical	4	16.0
" 9	Large electric	Cylindrical prismatic	4	22.0
" 11	" " "	Spherical	4	22.0
" 12	4. v. pillarless	Dome	4	30.0
" 13	" " (reflector)	"	4	33.5
" 14	Electric cap-lamp	Clear	2.5	9.25
" 15	" " "	"	2.5	11.75
" 6	High c.p. Oil	"	4	22.0

N.B. - (1) The Contours shown on the diagrams for hand-lamps are at 0.05 foot candle intervals.

(2) The Scales on some of the contour diagrams apply to all diagrams and give an approximate idea of the areas referred to in the last column.

lamps discussed in this chapter under the conditions stated previously, viz., lamp placed 4 ft. from illuminated surface.

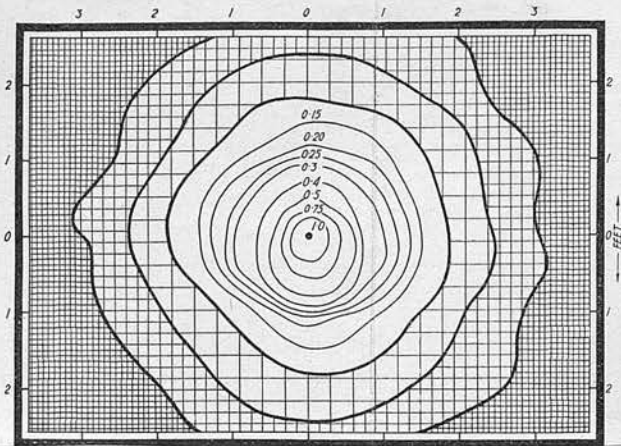


Fig. 14.
Diagrams for two Types of Modern Cap-lamp.

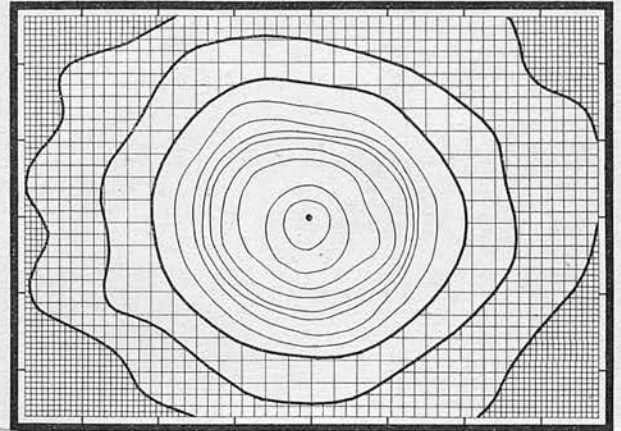


Fig. 15.

Figs. 14 and 15 are drawn for two types of cap-lamp, the lamps being placed at a distance of $2\frac{1}{2}$ ft. from the illuminated surface. It is seen that the area illuminated above 0.1 ft.c. is not so large as for some of the hand electric lamps, but the illumination opposite the centre of the lamp rises over a small area to a much higher standard. In both cases this standard actually exceeds 1.0 ft.c., i.e., ten times the suggested minimum, and by virtue of the position of the lamp, the wearer, of course, always has the advantage of this high illumination standard on his work. The question of light distribution from cap-lamps is, however, fully discussed in Chapter VII of this thesis.

CHAPTER IV. Underground Illumination Surveys.

Having obtained a series of illumination diagrams for the individual lamps in the laboratory, it was now necessary to carry out an illumination survey underground at the coal-face, where the various types of lighting are in use. By kind permission of the management, a number of galleries in the Nottinghamshire Coalfield were visited. As comparative results were required, and it was therefore necessary to ensure, as far as possible, that the reflection factors of surrounding surfaces did not vary, the seam chosen for the test was in every case the Nottinghamshire Top Hard, which varies in thickness between 4 and 6 ft. All lamps used in this investigation were ordinary service lamps taken from the lamp-room of the colliery visited.

CHAPTER V.

UNDERGROUND ILLUMINATION SURVEYS.

A straight piece of coal-face 20 yds. in length was selected, and 2 lamps were arranged along this face, 4 yds. apart, and at a distance of 4 ft. from the face. These lamps were in most cases hung near the roof, as it was found that this method of hanging the lamp was in most general use. It is, of course, difficult to find a better procedure, from the point of view of face illumination, would have been to hang the lamp on a prop along between the roof and floor. In this position, however, the lamp casts a shadow of the worker on the face, and also a very distinct shadow across the floor due to the presence of conveyors. In the roof position, the tendency is to cast the shadow downwards towards the floor, and past the conveyor. Having set the five lamps as described, a point on the face opposite the middle lamp was taken, and the face was marked off in 2-ft. steps for a distance of 8 yds. on each side of this point. The 16-ft. length of face thus marked was then ready for the illumination survey.

CHAPTER V. Underground Illumination Surveys.

Having obtained a series of illumination diagrams for the individual lamps in the laboratory, it was now necessary to carry out an illumination survey underground at the coal-face, where the various types of lighting are in use. By kind permission of the management, a number of collieries in the Nottinghamshire Coalfield were visited. As comparative results were required, and it was therefore necessary to ensure, as far as possible, that the reflection factors of surrounding surfaces did not vary, the seam chosen for the test was in every case the Nottinghamshire Top Hard, which varies in thickness between 4 and 5 ft. All lamps used in this investigation were ordinary service lamps taken from the lamp-room of the colliery visited.

A straight piece of coal-face 20 yds. in length was selected, and, in order to reproduce working conditions as nearly as possible, 5 lamps were arranged along this face, 4 yds. apart, and at a distance of 4 ft. from the face. These lamps were in most cases hung near the roof, as it was found that this method of hanging the lamp was in most general use. It is, of course, obvious that a better procedure, from the point of view of face illumination, would have been to hang the lamp on a prop midway between the roof and floor. In this position, however, the lamp casts a shadow of the worker on the face, and also a very considerable shadow across the floor due to the presence of conveyors, while in the roof position, the tendency is to cast the shadow downwards towards the floor, and past the conveyor. Having set the five lamps as described, a point on the face opposite the centre lamp was taken, and the face was marked off in 2-ft. steps for a distance of 6 yds. on each side of this point. The 12-yd. length of face thus marked was then ready for the illumination survey /

survey.

The cell of the illumination meter previously described was moved across this length of face in 2-ft. steps. For each step the microammeter readings were recorded for three positions of the cell, viz., near the roof, centre of face, and near the floor. Thus nineteen sets of three readings each (or 57 readings in all) were obtained for the 12 yds. of face. Knowing from Chapter III the meter standardization factor for the particular type of lamp used, each of these microammeter readings could be at once converted into illumination values. By the same method as that used in the previous chapter for individual lamps, an illumination contour map of the length of the face was then plotted to scale, illumination lines of 0.025, 0.05, 0.10, 0.15, 0.20, etc., ft.-c. being drawn, and areas illuminated below 0.1 ft.-c. were hatched, as in the diagrams of Chapter IV. Lower illuminations than these were recorded, but as such low illuminations are of little practical value, they were omitted to avoid confusion in the diagrams.

The diagrams obtained in this manner are shown in Figs. 16 - 27. The points on the coal-face directly opposite the lamp positions are marked by black spots. Figs. 16 - 18 refer to a 12-yd. length of face, 5 ft. in height. Fig. 16 shows such a face illuminated by candles (18 to the lb.) opposite the centre of the face, at a distance of 3 ft. In Fig. 17 the lamps are of the old combustion-tube type hanging near the roof at a distance of 4 ft., while Fig. 18 shows the result obtained with modern high candle-power flame safety-lamps, also at a distance of 4 ft. from the face. It is seen that the candles when at a distance of 3 ft. give an illumination above 0.1 ft.-c. over a small area, while the old oil-lamps at 4 ft. give no illumination of that standard. The modern oil-lamps show a considerable improvement /

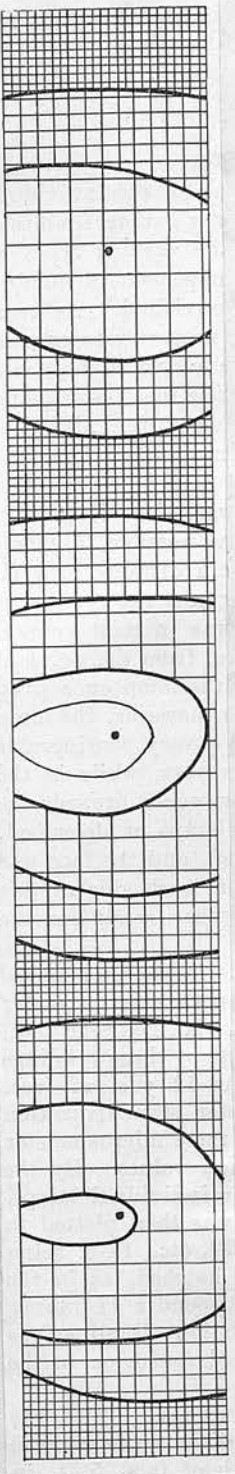


Fig. 16.

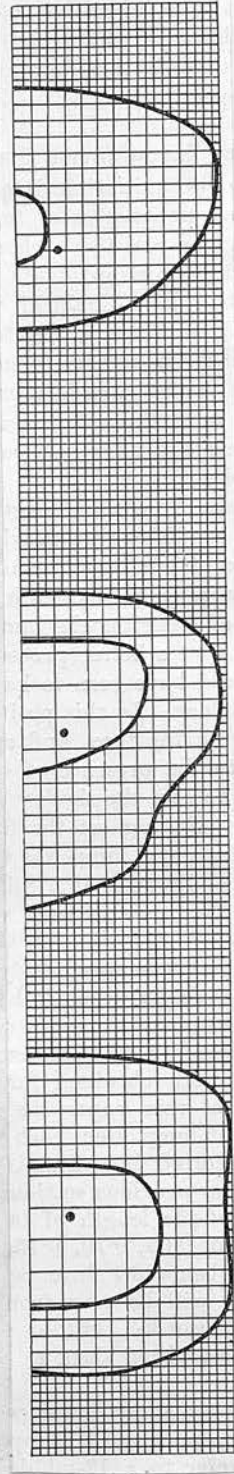


Fig. 17.

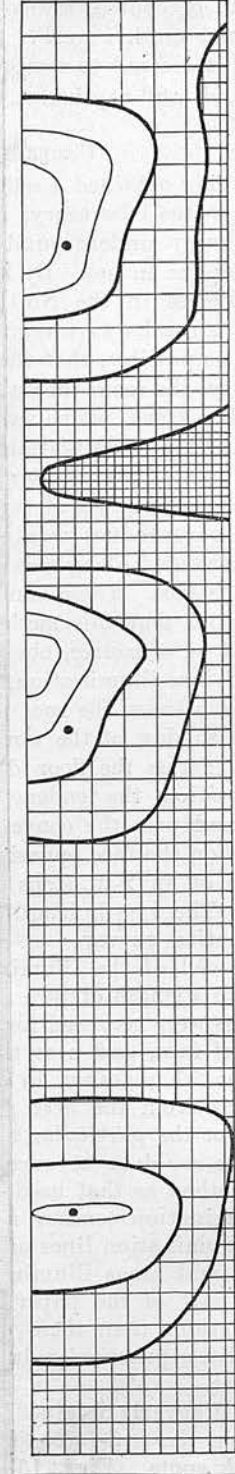


Fig. 18.

Fig. 17 - 18. - Coal-Face Illumination Surveys - Candle and Flame Safety-Lamps.

improvement, large areas being illuminated above 0.1 ft.-c. and small areas opposite two of the lamps being illuminated above 0.2 ft.c. The closely-hatched strip in Fig. 18 (below 0.025 ft.-c.) is due to a shadow cast by a prop.

Figs. 19 and 20 show the illumination diagrams for lamps of the same type (small 4-volt electric; frosted bulb, clear glass) when hung (Fig.19) midway between roof and floor, and (Fig. 20) near the roof, in seams $4\frac{1}{2}$ and 5 ft. thick, respectively. It can be seen that the area illuminated above 0.1 ft.-c. is considerably greater in Fig. 19 than in Fig. 20. Referring to Table III., the percentage areas are respectively 26.5 and 14.

Figs. 21 - 23 show three examples of a 12-yd. by 5-ft. coal-face lighted by means of electric hand-lamps. Fig. 21 shows the illumination due to 2-volt electric lamps. There is no illumination of the 0.1 ft.-c. standard, and over a considerable area /

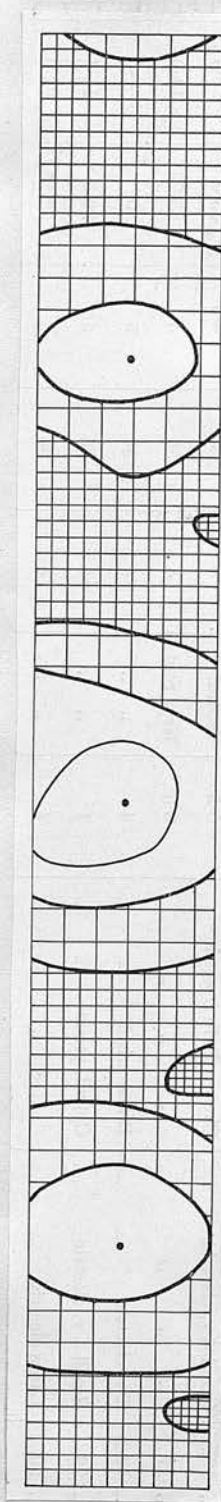


Fig. 19.

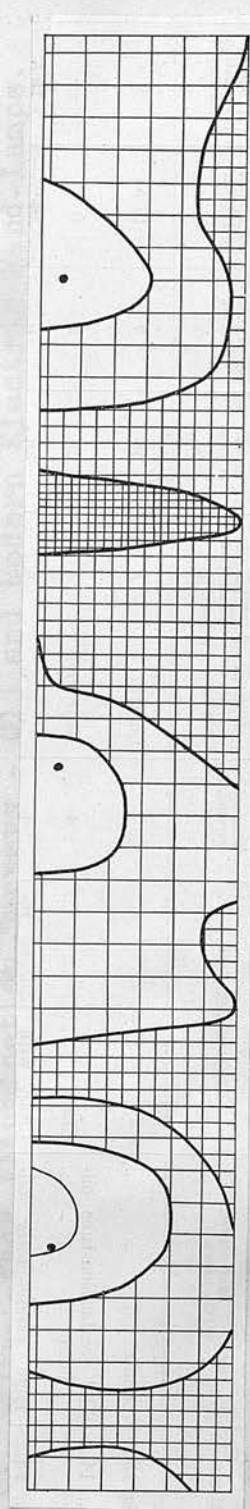


Fig. 20.

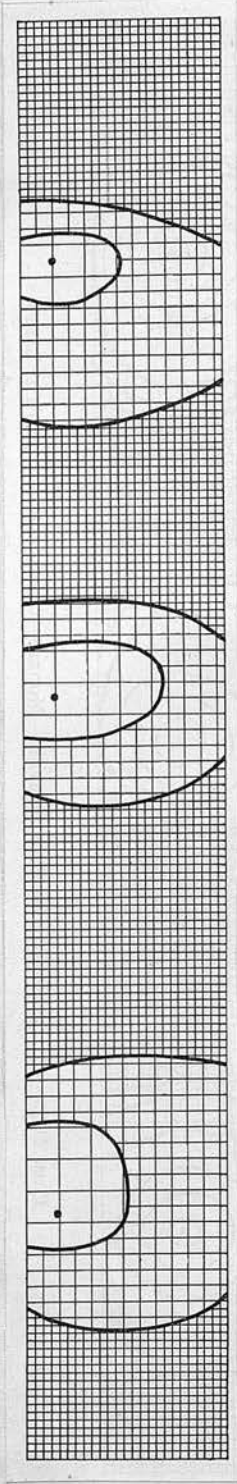


Fig. 21.

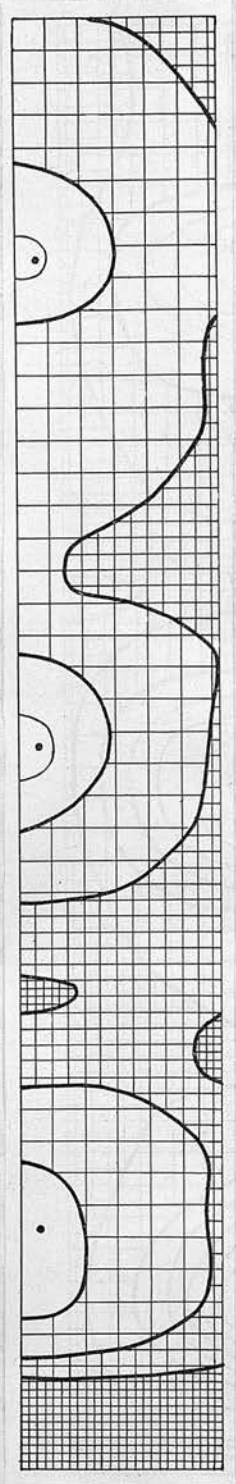


Fig. 22.

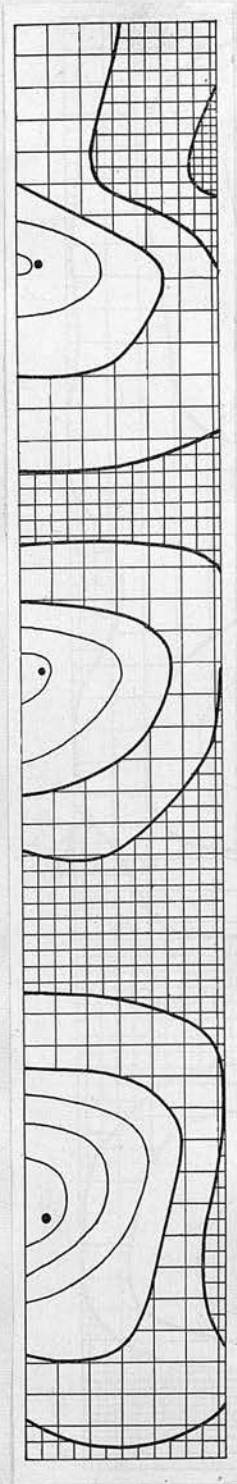


Fig. 23.

Figs. 21 - 23. - Coal-Face Illumination Surveys - Old and Modern Electric Hand-Lamps.

area the illumination is less than 0.025 ft.-c. For Fig. 22, small 4-volt lamps were used, with cylindrical prismatic well-glasses. These lamps show a definite improvement over those used for Fig. 21, but the area above 0.1 ft.-c. is still comparatively small. In Fig. 23, which is drawn for large electric hand-lamps also fitted with cylindrical well-glasses, there is a large increase in the portion illuminated above 0.1 ft.c. while over small areas opposite the lamps the illumination rises above 0.2 ft.-c. It will also be noticed that there are practically no deep shadows (i.e., areas illuminated below 0.025 ft.-c.)

Fig. 24 was obtained on the same face and using the same lamps as Fig. 22 (small 4-volt), but in this case spherical prismatic well-glasses were used. By comparing these two diagrams it is seen that the spherical well-glass improves considerably the illumination distribution over the face. This affords a good illustration of the conclusion reached in Chapter IV., viz., for seams /

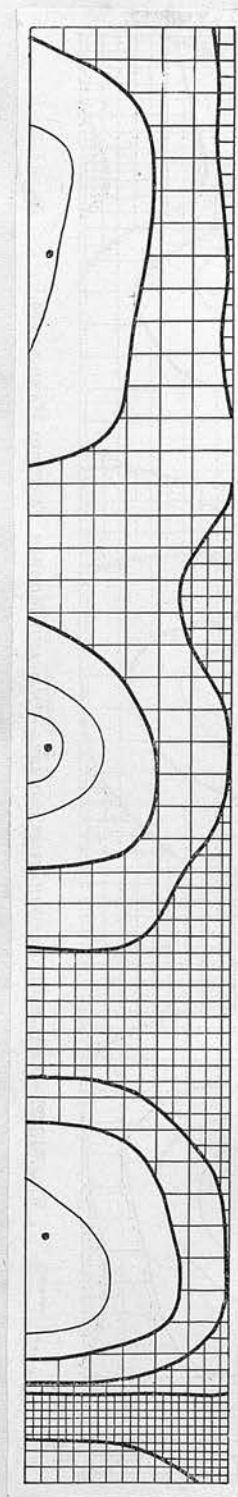


Fig. 24.

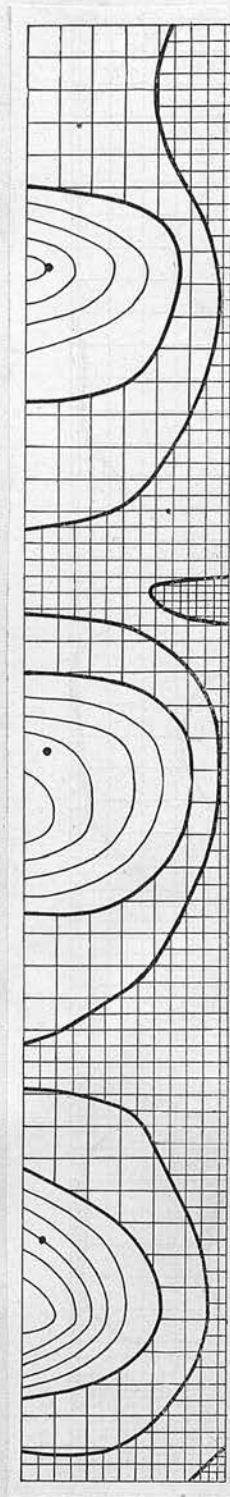


Fig. 25.

Figs. 24 - 25. - Coal-Face Illumination Surveys - Modern Electric Hand-Lamps.

Table III. - Percentage of Face Illuminated above 0.1 Foot-candle Standard by Different Systems of Lighting.

Diagram.	Type of light source, 4 yds. apart. 4 ft. from face.	Type of well-glass.	Time of burning, hours.	Position of lamps.	Distance from face. ft.	Length of face. ft.	Thick- ness of seam. ft.	Area illu- mination above 0.1 ft.c. sq. ft.	% Area illumin- ation a- bove 0.1 ft.c.
Fig. 16	Candle	-	-	Central	3	36	5	17.5	9.5
"	Old combustion tube oil-lamp	Clear	4	Near roof	4	36	5	0	-
"	High candle-power oil-lamp	Clear, with polished reflector.	4	"	4	36	5	33.25	18.5
"	Small 4 v. electric	Clear. Bulb frosted	0.5	Central	4	36	4.5	43.0	26.5
"	" " "	" " "	0.5	Near roof	4	36	5	25.25	14.0
"	2 v. electric	Dome prism	4	"	4	36	5	0	-
"	Small 4 v. electric	Cylind. prism	1	"	4	36	5	20.5	11.4
"	Large electric	" " "	4	"	4	36	5	50.25	28.0
"	Small 4 v. electric	Spher. " "	1	"	4	36	5	59.5	32.0
"	Large electric	" " "	4	"	4	36	5	51	28.5
"	Electric cap-lamp	Clear	0.5	Central	2.5	36	4	58.5	40.5
"		(1) Before stripping		Near Roof	5	11	4	44	100
"	Mains lighting (Lamps 8 yds. apart)	(2) During		"	7	12	4	29	60.5
"		(3) After		"	9 - 10	37	4	0	-

seams whose thickness is 4 ft. or less, the spherical prismatic glass is more suitable than the cylindrical type. Fig. 25 shows the effect of the spherical glass fitted to the large electric lamp. Comparing this with Fig. 23, the horizontal spread is not so noticeable (due to the fact that the glass is taller, without increase of diameter, and therefore the "lens effect" is not so marked), but the illumination is improved, reaching a value above 0.3 ft.-c. over small areas.

In Fig. 26 a length of face, 4 ft. in height, was illuminated by means of modern electric cap-lamps fixed midway between floor and roof at a distance of $2\frac{1}{2}$ ft. from the face. It is seen that there are deep shadows between the lamps, but directly opposite the lamps the illumination reaches very high values, the contour lines on the diagram representing 0.1, 0.5, 1.0, 1.5, 2.0, 2.5, etc., ft.-c. Thus, over very small areas, the illumination reaches a standard which is 25 times the suggested minimum. Of course, as already mentioned, it is difficult to make comparisons between hand-lamps and cap-lamps, because the worker using a cap-lamp can always maintain the high illumination on his work, although the disadvantage exists that his surroundings are in deep shadow.

Fig. 27 illustrates a survey carried out on a 60-ft. length of conveyor face illuminated by mains lighting. Stripping of the face was in progress at the time of the survey. This same face, with the same equipment, had already been surveyed, using an entirely different method, by H.J. Atkinson and Dr. G. Allsop.^x The lamps, 110-volt, 60-watt, gas-filled, were slung along the gob side of the conveyor, and were approximately 8 yds. apart. A plan of the face is shown above the illumination diagram, and the scale at the side represents the distance in feet between /

^x See "An Experiment in Coal-face Lighting", Trans. Inst. Min. E., 1935-6, Vol. xc., p. 270.

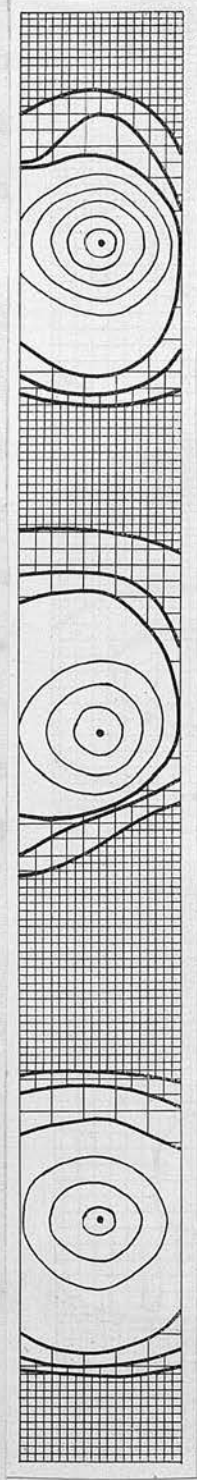


Fig. 26. - Coal-Face Illumination Survey - Modern Electric Cap-Lamps.

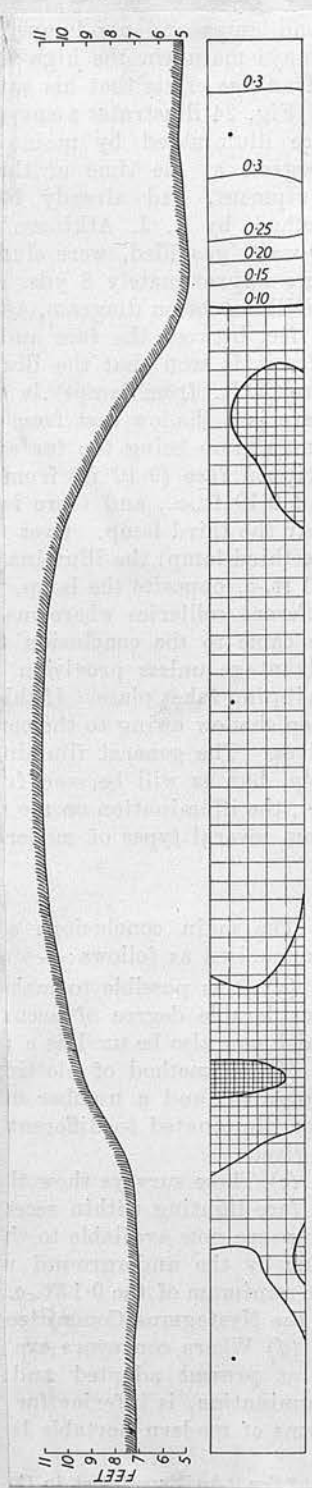


Fig. 27. - Coal-Face Illumination Survey - Lighting from the Mains.

between the face and the line of lamps. Commencing from the left, it is seen that the illumination over the piece of partly-stripped face (7 ft. from lamps) is above 0.1 ft.-c. Moving towards the right there is a shadow cast from the first lamp by the bend at the face, the centre lamp being too far away to compensate this. Over the piece of stripped face (9 - 10 ft. from lamps), the illumination lies between 0.05 and 0.10 ft.-c., and there is another shadow from the bend at the face near the third lamp. Over the last piece of unstripped face (5 ft. from the third lamp) the illumination is everywhere above 0.1 ft.-c., rising to 0.3 ft.-c. opposite the lamp. The result of this survey bears out the statement made in Chapter I., viz., that this system of lighting is of doubtful advantage unless provision is made for moving the lamps forward as stripping takes place. If this is not done, there are considerable areas in deep shadow owing to the conveyor-pans, props, and the workmen themselves. The general illumination is without doubt improved considerably, but as will be seen from Table III., the individual illumination, i.e., the illumination on the work being done, is inferior to that obtained from several types of modern portable lamp.

Professor W. H. Millikan has already made a brief reference¹ to the use of reflectors as a means of improving the directional intensity and intensity distribution of miners' electric hand-lamps and also to the effect of mechanical construction on the total useful flux from such lamps.

Since these papers were written, however, considerable improvements have been made in several types of hand-lamp. Larger and heavier lamps, with batteries of greater capacity and bulbs of higher current rating, have been accepted by the industry, contrary to the fairly general objection which was then raised against the heavier lamp. In some instances bulbs of 25% higher efficiency have been introduced. A few cases of the construction of the lamp have been altered to improve the distribution of

CHAPTER VI.

IMPROVEMENTS IN ILLUMINATION FROM MINERS' ELECTRIC HAND-LAMPS.

become fairly extensive, a general opinion prevails in the industry that the limit of weight, and therefore of capacity, has been definitely reached, and consequently further advance in the light given by the portable hand-lamp must come either from a still further improvement in bulb efficiency, or by the adoption of methods whereby a larger proportion of the available luminous flux of the bulb can be employed to advantage from the miners' standpoint.

This chapter deals with some several aspects of the problem in relation to the more recent advances which have been made in the methods of measurement of light flux from

¹ Comparative Photometric Tests of Miners' Electric Hand-Lamps. Trans. Inst. Min. E., 1931-2, vol. LXXII, p. 45 - 57.
² Miners' Electric Hand-Lamps - Intensity Conversion Factors. Proc. Inst. Min. E., 1933, vol. LXXIII, p. 310 - 311.

a detailed study of the use of various methods of improving directional intensity and intensity distribution.

The results of the investigation, therefore, fall under two heads:-

I. - The effect on intensity and intensity distribution of using various shapes of reflector and various reflecting surfaces either inside or outside the well-glass.

II. - The improvement effected by using higher intensity bulbs, and a combination of this with the best reflecting surface found in (I).

I. - The Use of Reflectors.

In several of the most modern types of flame safety-lamp a metallic reflector outside or inside the clear well-glass, or a mirrored reflector forming a portion of the well-glass itself, is employed to improve the light intensity in one direction. In an attempt to eliminate the casting of heavy pillar shadows, however, hand electric lamps are fitted with some form of diffusing glass (e.g., opal, frosted, or prismatic). In such cases, therefore, it may reasonably be assumed that a reflector fitted inside the well-glass has definite advantages over one fitted outside, as a light beam emerging in the forward direction after reflection from an external reflector has been transmitted through three thicknesses of well-glass, while a similar light beam from an internal reflector has only suffered one such transmission. As considerable absorption occurs due to the nature of the diffusing glass, the actual light loss is hence smaller when an internal reflector is used. Also, as the lamp-head is comparatively dustproof, the reflecting surface does not require frequent cleaning or renewing if it is fitted inside the well-glass. This investigation /

investigation, therefore, deals chiefly with internal reflectors although a few cases of the use of external reflectors are given.

An investigation was first carried out to determine which shape of reflector would prove most useful in improving the directional intensity of the lamp, without sacrificing to too great an extent the light distribution. A series of four reflectors of different shapes was made, the reflecting surface being in each case matt aluminium. These reflectors are shown in Fig. 28. No. 1 fitted closely over the bulb, restricting the emergent light to an angle of 180° . No. 2, being circular and slightly concave, was clipped close behind the bulb, and the cowl-shaped reflector No. 3 rested on the bulb-holder and fitted over the bulb. No. 4, of cylindrical shape, fitted inside the well-glass over an angle of about 180° .

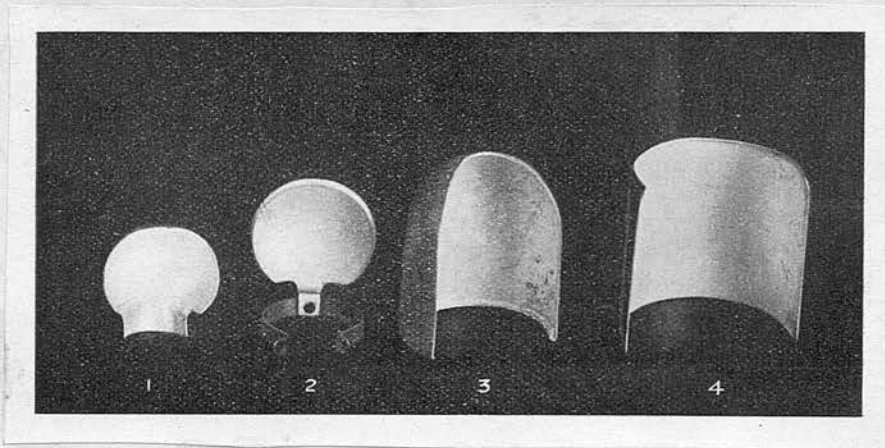


Fig. 28. - Matt Aluminium Reflectors.

Using each of these reflectors in a lamp fitted with a cylindrical prismatic well-glass, illumination contours were plotted, the bulb voltage being controlled externally. The same bulb was used in each case (4 volt, 0.75 amp.), and the lamp was placed 4 ft. from the illuminated surface. The contour diagrams are shown in Figs. 29 - 33. Each contour represents an illuminated area of 7 by 5 ft.; the close hatchings represent illumination below 0.05 ft.-c., the open hatchings represent illumination between 0.05 and 0.1 ft.-c. The unshaded portions are /

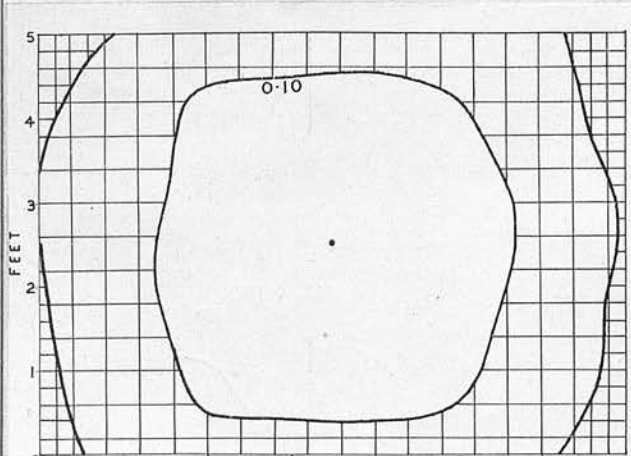


Fig. 29.

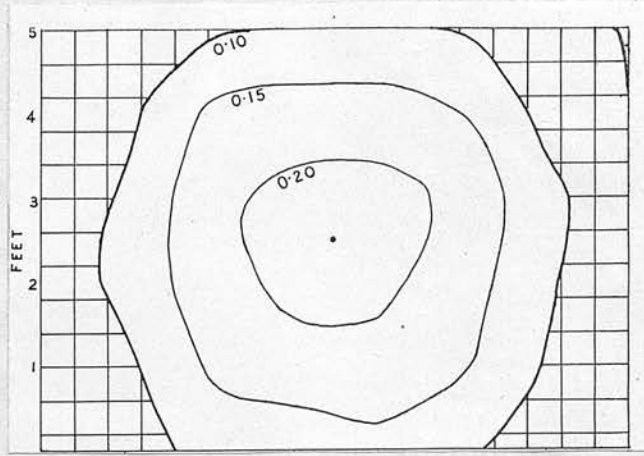


Fig. 30.

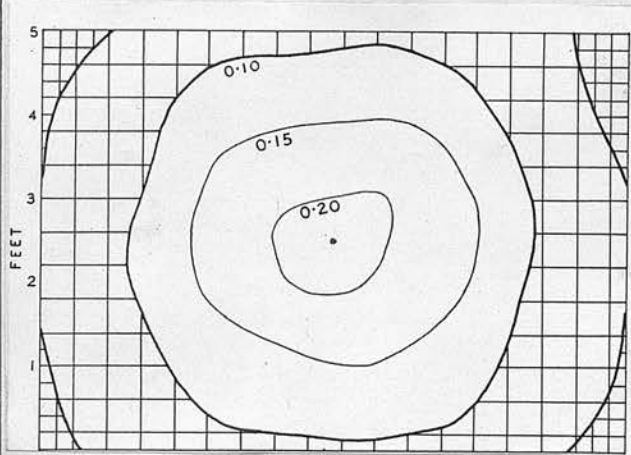


Fig. 31.

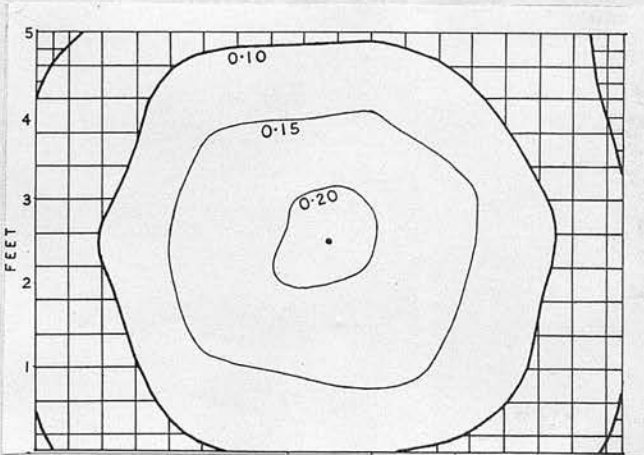


Fig. 32.

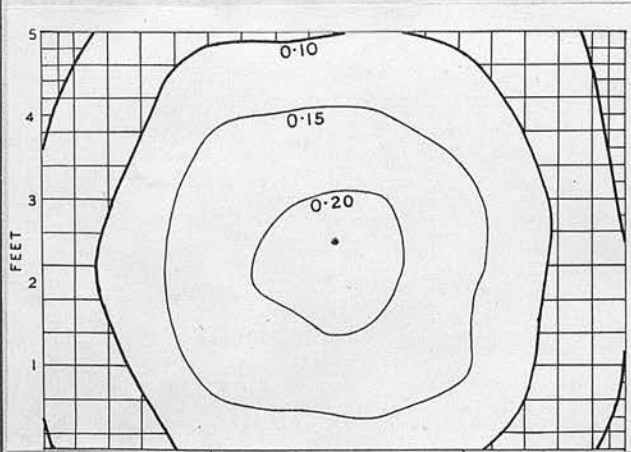


Fig. 33.

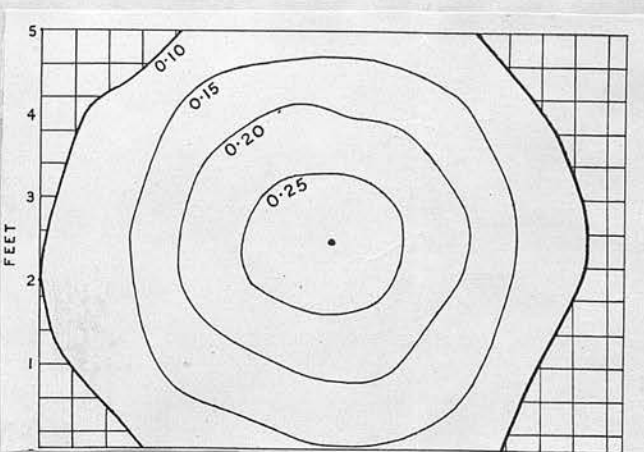


Fig. 34.

Figs. 29 - 34. - Illumination Contours for Electric Hand-Lamp Fitted with Various Reflectors.

are illuminated above 0.1 ft.-c. The contour lines in these areas represent 0.15, 0.2, 0.25, etc., ft.-c. Fig. 29 is the illumination due to the lamp alone. It is seen that considerable improvement in the standard of illumination on the working-area can be effected by using reflectors Nos. 1 - 4 (Figs. 30-33). A close examination of these diagrams shows that the best results are obtained by means of reflectors Nos. 1 and 4. Reflector No. 1, however, which fitted closely over the bulb, was found to restrict the over-all distribution of the light to too great an extent, and it was therefore decided to continue the investigation with reflectors of type No. 4, i.e., cylindrical in shape, and fitting inside the well-glass. To improve on the matt aluminium reflector No. 4 it was necessary to obtain a better reflecting surface, but specular reflection had to be avoided as far as possible. It was realized, however, that if a polished surface could be made to conform to the shape of the prisms inside the well-glass, the numerous reflecting surfaces so formed would give the effect of diffuse reflection.

The first of these reflectors was made by painting the inside of the well-glass over 150° with aluminium paint, and by this means the maximum horizontal candle-power (Max. H.C.P.) of the lamp was increased from 2.42 to 2.95. Thin polished tinfoil was next tried, and, as before, was fitted inside the glass and shaped to the prisms over an angle of 150° . The Max. H.C.P. was in this case 3.8. Finally, it was decided to paint the inside of the glass over 150° with photometric white paint, which has a reflection coefficient of about 0.95. The whole of the top of the well-glass and the bulb-holder were similarly painted, and the Max. H.C.P. reached the value of 4.61, representing an increase of about 90% over the original value of /

of 2.42. The horizontal and vertical polar curves for these three reflecting surfaces are shown in Fig. 35. It will be noticed from the horizontal polar curve for the photometric paint reflector that the reflecting surface is not entirely opaque, but transmits a small proportion of the light incident on it. In this case, there is an intensity of about 0.5 c.p. behind the reflector. By reducing the thickness of the paint surface, this intensity may be increased to 1 c.p., while the increase in intensity in the forward direction is still over 60%. It may be noted that this intensity of 1 c.p. is above the standard given by the old oil or 2-volt electric lamps, many of which were in daily use up to the end of the year 1936.

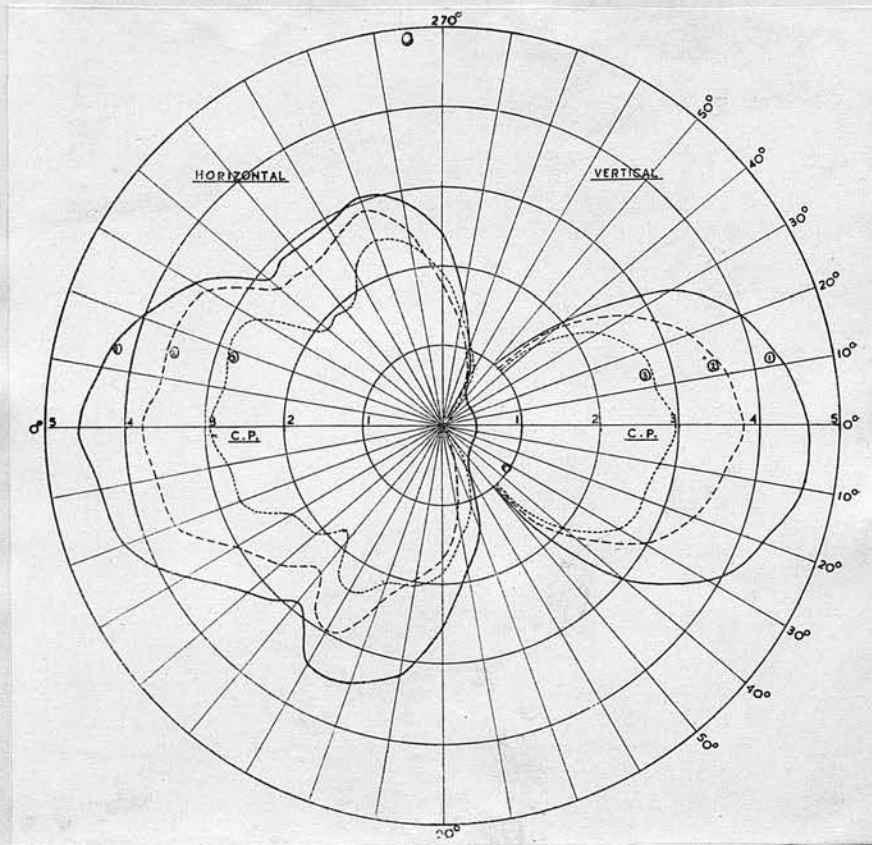


Fig. 35. - Polar Curves for Different Reflecting Surfaces:
 (1) Photometric Paint; (2) Tinfoil;
 (3) Aluminium Paint.

Having decided from the above investigations that the best reflecting surface was that obtained by painting the well-glass /

glass with photometric paint, it was next necessary to ascertain the extent of the improvement effected by such a reflector in the various types of electric portable hand-lamp. This can best be done by plotting illumination contours. To make comparison possible, all the lamps used were placed at a distance of 4 ft. from the illuminated surface, and run at normal voltage.

The first of these contour diagrams is shown in Fig. 34. The same lamp and bulb were used as for Figs. 29 - 33. By comparing Fig. 34 with Fig. 29 (no reflector), the great improvement in illumination due to the photometric paint is obvious. It is seen that the area illuminated above 0.1 ft.-c. has been greatly increased, while the illumination over a portion of this area rises above 0.25 ft.-c.

Figs. 36 and 37 are drawn for a 2.6-volt alkaline lamp, Fig. 36 being the lamp alone, and Fig. 37 the diagram obtained when photometric paint is used as a reflector. The maximum illumination in Fig. 37 lies above 0.25 ft.-c., and the area illuminated above 0.15 ft.-c. is as large as that illuminated above 0.1 ft.-c. in Fig. 36. Figs. 38 and 39 show the improvement effected by using the photometric paint reflector with a large 4-volt lamp (bulb, 9 lumens per watt). Only a very small proportion of the 7 by 5 ft. surface in Fig. 39 is illuminated below the 0.1 ft.-c. minimum, and the maximum illumination opposite the lamp is above 0.4 ft.-c. Figs. 40 and 41 are obtained by using the pillarless type of large 4-volt lamp, with the same bulb as for Figs. 38 and 39. It is seen from Fig. 41 that by using the photometric paint as a reflector in this type of lamp the whole of the illuminated area (35 sq. ft.) is illuminated above the 0.1 ft.-c. minimum, while, as in Fig. 39 the maximum illumination lies above 0.4 ft.-c.

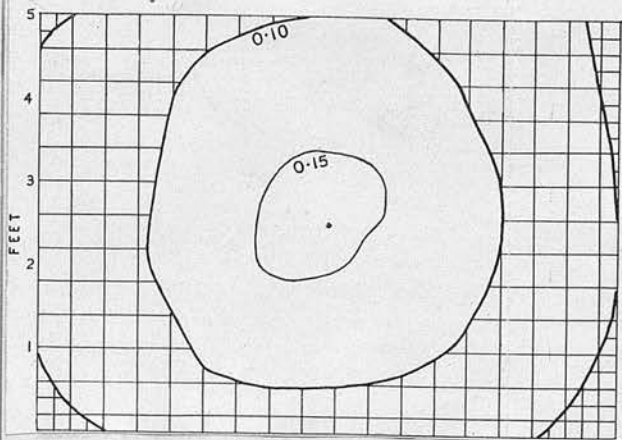


Fig. 36.

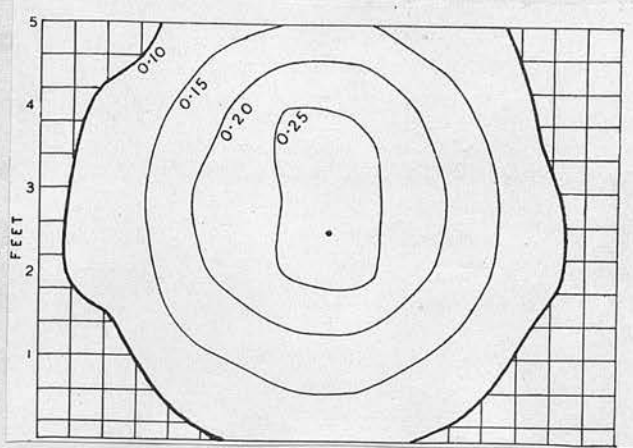


Fig. 37.

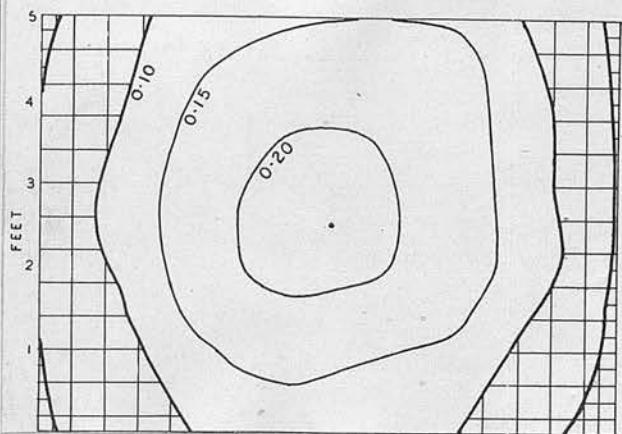


Fig. 38.

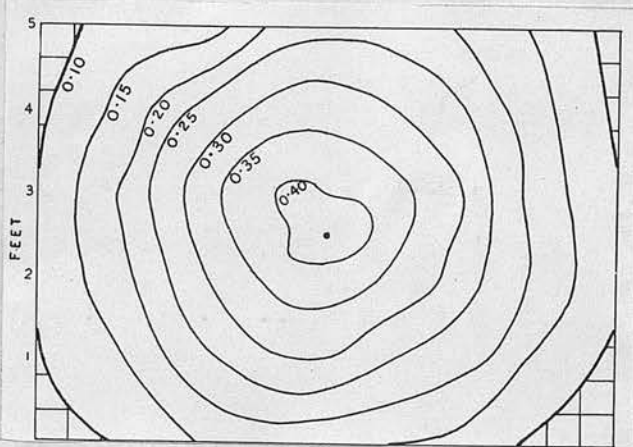


Fig. 39.

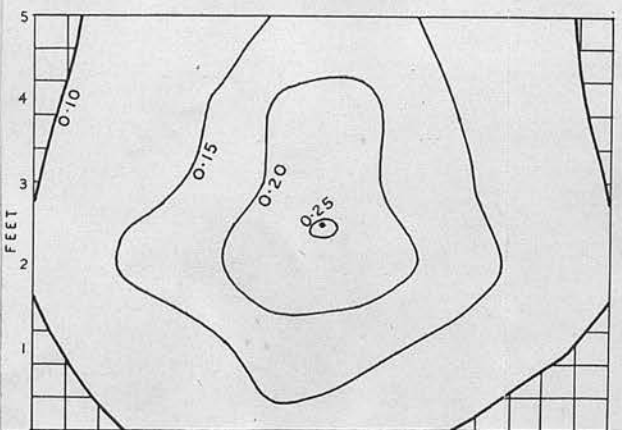


Fig. 40.

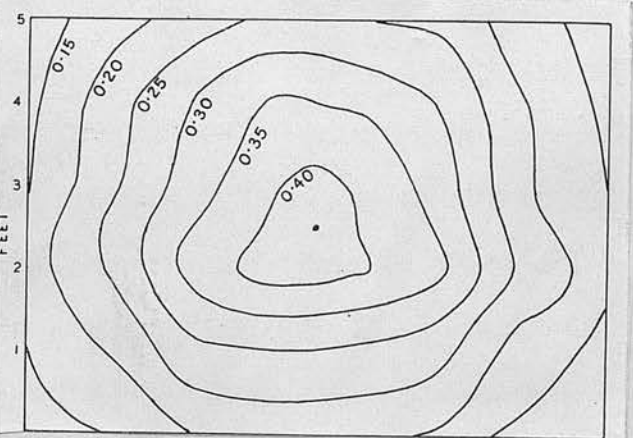


Fig. 41.

Figs. 36 - 41. - Illumination Contours for Photometric Paint Reflector in Various Electric Hand-Lamps.

It may be mentioned that a number of tests have also been carried out with reflectors fitted outside the well-glass of the lamp. Matt aluminium, white enamel, flat white, and polished metal surfaces have been used, but in no case has the result been comparable with that obtained for the internal reflector described in detail above. It appears, however, that if an external reflector is required, the best surface for the purpose is polished metal, and the reflector should be designed to fit between the well-glass and two adjacent pillars of the lamp, leaving projecting "wings" about 1 in. in width on both sides.

Attempts have also been made to increase the illumination given by a lamp by hanging the lamp in front of a flat board painted white, and also by hanging the lamp in the flange of a steel prop which has been similarly painted, but in each case only a slight improvement has been effected.

II. - The Use of Bulbs of High Efficiency.

To increase the amount of light given by a bulb without increasing the electrical energy dissipated, it is necessary to increase the efficiency of the bulb. This is done by raising the filament temperature, and if this procedure is not to shorten the life of the bulb, improvements in the material of the filament are necessary. Recently, such improvements have resulted in the production of bulbs of higher efficiencies than those of a short time ago. The use of these high-efficiency bulbs produces a considerable increase in the light given by portable electric hand-lamps.

This is clearly illustrated in Figs. 42 - 45. Fig. 42 is /

is the illumination contour diagram for a large 4-volt lamp fitted with a bulb of efficiency 8 l/w, while Fig. 43 is drawn for the same lamp using a 10-l/w bulb. It is seen that the high - efficiency bulb has effected a considerable increase in the area illuminated above the 0.1 ft.-c. standard, while the maximum value has been increased from 0.18 to 0.3 ft.-c. Fig. 44 shows the result of employing the 10 l/w bulb in combination with the photometric paint re - flector. The illumination over the whole of the area is above the 0.1 ft-c. minimum, and over a small portion a value of 0.1ft.-c. is reached. These three diagrams can be readily compared by referring to Fig. 45, which shows horizontal sections taken through the centre of each diagram. It may be noted that the curve of Fig. 42 lies above the 0.1 ft.-c. /

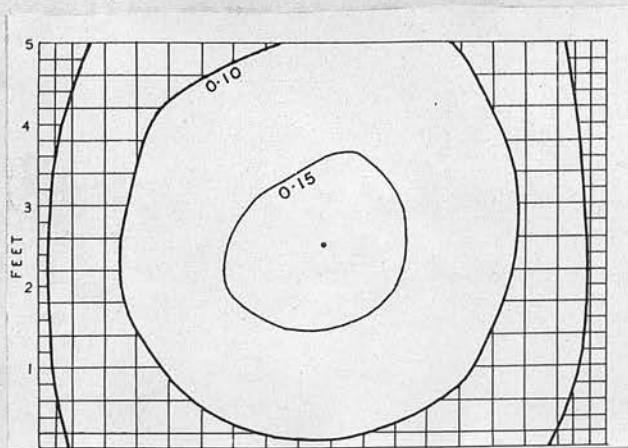


Fig. 42.

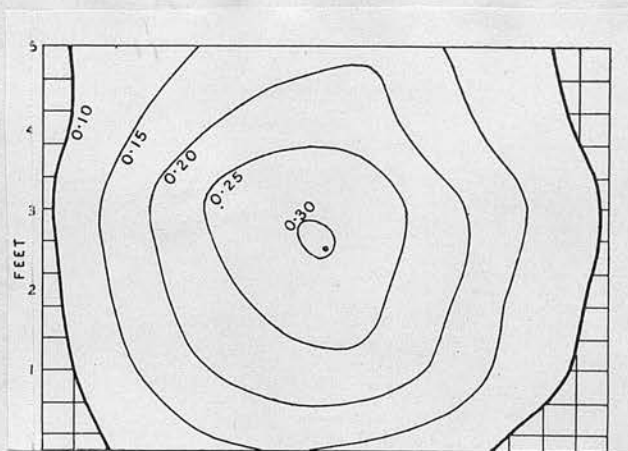


Fig. 43.

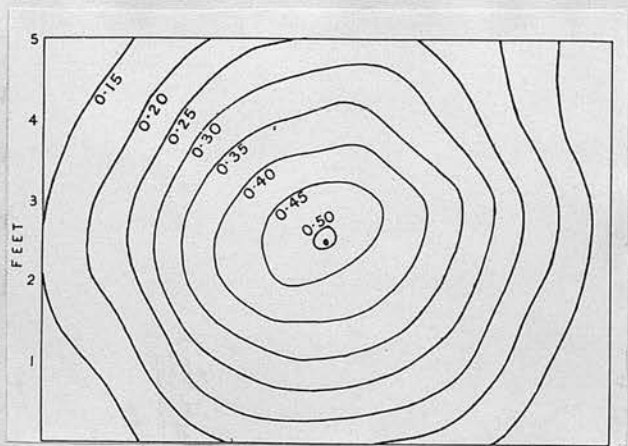


Fig. 44.

Figs. 42 - 44. - Diagrams illustrating the Use of High Efficiency Bulbs.

ft.-c. line for about 5 ft. of the 7 ft. length represented in the diagram, while that of Fig. 44 lies above the 0.25 ft.-c. line (shown dotted), for the same length. This is an important point in view of the fact that, while the Nystagmus Committee recommend that the minimum coal-face illumination should be 0.1 ft.-c., they suggest 0.25 ft.-c. as the value to be aimed at.

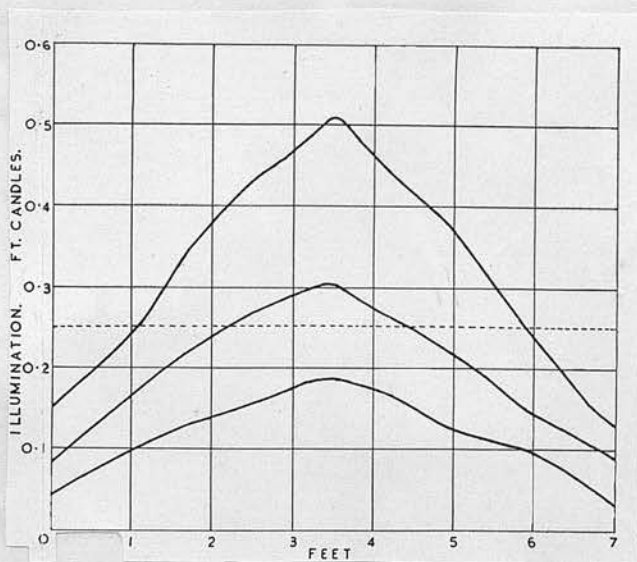


Fig. 45. - Diagram illustrating the use of High-Efficiency Bulbs.

In a modern high candle-power lamp, even when fitted with a prismatic glass, a considerable degree of glare is experienced underground. This complex problem of underground glare is discussed more fully in Chapter VIII, but it may be mentioned here that the discomfort is considerably reduced by using an opal well-glass to lower the intrinsic brightness of the source. The objection hitherto raised against the opal glass has been that, due to its dense nature, it reduces the light intensity to too great an extent. This objection may now be removed by the use of the high-efficiency bulbs described above. Using such a bulb with the opal glass (Fig.46), the light intensity available to the worker compares favourably with that obtained from a lamp fitted with an ordinary prismatic glass /

glass and one of the bulbs of lower efficiency, as shown in Fig. 38. If a higher standard of illumination is required this can be best obtained with the minimum of discomfort by using a combination of opal glass, high-efficiency bulb, and photometric paint reflector, the result being shown in Fig. 47.

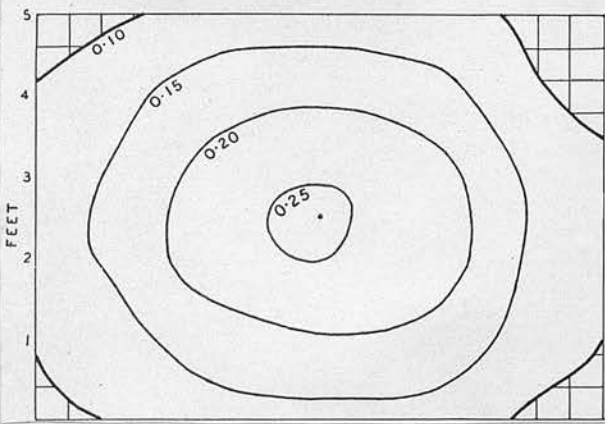


Fig. 46.

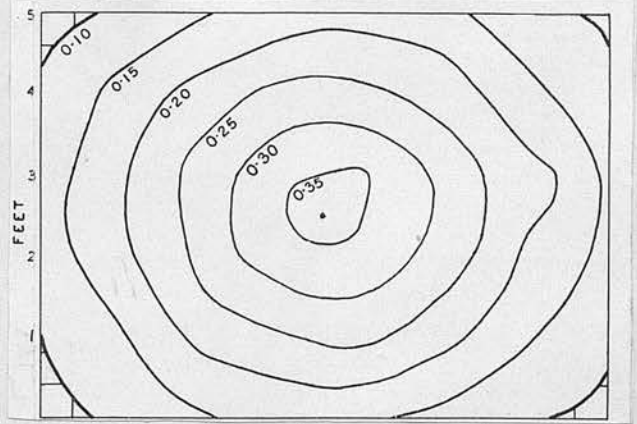


Fig. 47.

Illumination Contours for Opal Glass.

Since the above investigations were carried out, gas-filled bulbs using krypton instead of argon as the inert gas have been produced for miners' lamps. These bulbs have efficiencies of 11 and 12 l./w., and will obviously effect a still further improvement in the standard of illumination available to the underground worker.



CHAPTER VII. Improvements in Light Distribution from Miners' Electric Cap-Lamps.

For many years, Dr. F. Lister Llewellyn, the late Dr. J.S. Haldane and others stressed the advantages of the cap-lamp as the best portable source of illumination at the coal-face, and it is now worthy of note that in a recent Report of a Departmental Committee on Industrial Diseases Involving Miners' Nystagmus,¹ the definite recommendation is made that an extension of the use of this form of lighting should be encouraged.

It is not intended to discuss here the relative merits of hand- and cap-lamps from the standpoint of utility and maintenance. This question has been discussed on many occasions within recent years, and it is unlikely, in any case, that uniformity of opinion can be reached, but it is certainly interesting to find that

CHAPTER VII.

IMPROVEMENTS IN LIGHT DISTRIBUTION FROM MINERS'

ELECTRIC CAP-LAMPS.

An examination of the Chief Inspector of Mines shows that there has been a decided increase in the use of electric cap-lamps within recent years. It is difficult to deduce what the future position will be, but it may be predicted that if even the present rate of increase continues, hand-lamps will have been replaced very largely by cap-lamps within ten years from now. Over 50% of the electric lamps used in Scotland are cap-lamps, and the figure for England and Wales has risen from 15 to over 50% in the last six years. Numerous deductions may be made by comparing these figures with Haldane's statistics, but only one point needs mention here, viz., the incidence of Nystagmus is much greater in other countries than in

¹ Home Office Report, 1935, para. 5657.

CHAPTER VII. Improvements in Light Distribution from Miners' Electric Cap-Lamps.

For many years, Dr. T. Lister Llewellyn, the late Dr. J.S. Haldane and others stressed the advantages of the cap-lamp as the best portable source of illumination at the coal-face, and it is now worthy of note that in a recent Report of a Departmental Committee on Industrial Diseases including Miners' Nystagmus,^x the definite recommendation is made that an extension of the use of this form of lighting should be encouraged.

It is not intended to discuss here the relative merits of hand- and cap-lamps from the standpoints of utility and handiness. This question has been discussed on many occasions within recent years, and it is unlikely, in any case, that uniformity of opinion can be reached, but it is certainly interesting to find that the electric cap-lamp is growing rapidly in popularity. An examination of the Annual Reports of H.M. Chief Inspector of Mines shows that there has been a decided increase in the use of electric cap-lamps within recent years. It is difficult to deduce what the future position will be, but it may be predicted that if even the present rate of increase continues, hand-lamps will have been replaced very largely by cap-lamps within ten years from now. Over 90% of the electric safety lamps used in Scotland are cap-lamps, and the figure for England and Wales has risen from 2% to over 20% in the last six years. Numerous deductions may be made by comparing these figures with Nystagmus statistics, but only one point needs mention here, viz., the incidence of Nystagmus is much greater in other coalfields than in /

^x Home Office Report, 1938, Cmd. 5657.

in Scotland, and in the United States of America, where cap-lamps are almost universally employed, Miners' Nystagmus is unknown.

I. - Light Flux Distribution from the Cap-Lamp.

While the superiority of the intensity of the light from the cap-lamp and the greater illumination thereby obtained on the work being done must be admitted, it is realized generally that the distribution of the light which it gives leaves room for much improvement. It is with this latter problem that the present chapter is concerned.

In one Midland colliery all cap-lamps were at one time fitted with lens (bull's eye) glasses to give a beam effect, but on making individual enquiries at the colliery it was found that the workmen on the face would have preferred a more evenly distributed light, and that only the shot-firers favoured the beam, because, as they claimed, they found it much better for making up the shots and for examining the shot-holes before charging and stemming. The general conclusion drawn from these and other enquiries is that for special purposes, such as examination of the waste and high places in roadways, some haulage operations, etc., the beam, such as is also given by several types of inspection lamp, has definite advantages. For general work at the coal-face, however, an evenly distributed light is considered to be preferable. R.L. Lythgoe ^x has shown experimentally that visual sensitivity is at its highest when the brightness of the surrounding field is approximately equal to the brightness of the object being viewed. This has been confirmed by J.W. Howell, ⁺ using /

^x Trans. Illum. Eng. Soc. 1936, Vol. I., p. 3.

⁺ Trans. Illum. Eng. Soc. 1937, Vol. II., p. 39.

using illumination standards such as may be encountered at the coal-face. It appears, therefore, that light distribution which gives a relatively high standard of illumination over only a small portion of the area of vision, and leaves the remainder of this area illuminated to a comparatively low standard, should be avoided, especially in mining, where it is particularly necessary that the worker should see the immediate surroundings clearly as well as the object of his direct vision.

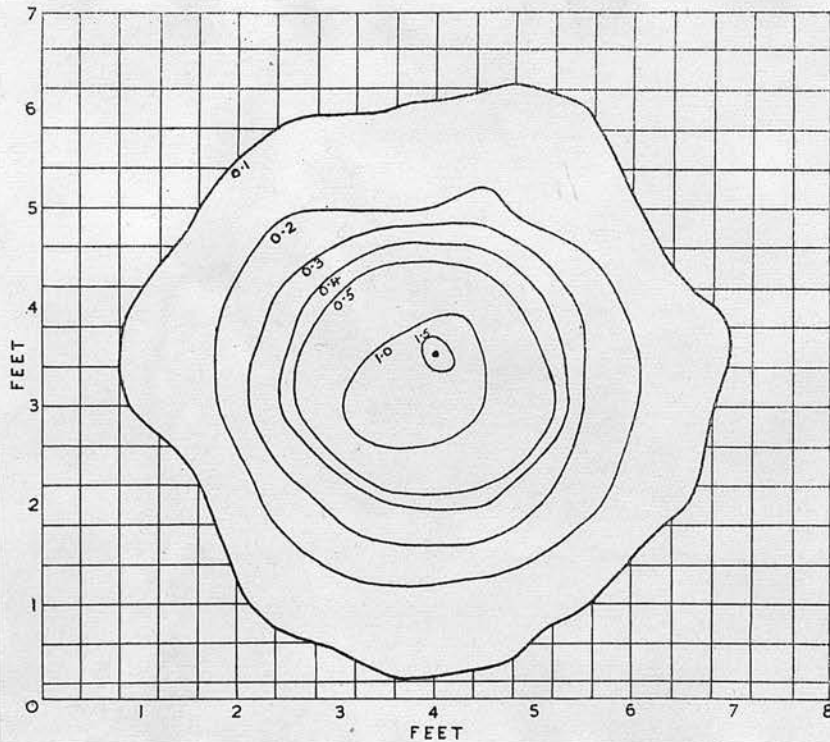


Fig. 48. - Typical Cap-Lamp Illumination Diagram.
Hemispherical Matt Aluminium Reflector.

Examination of a representative illumination contour diagram for the present type of cap-lamp, showing illuminations of 0.1 ft.-c. upwards, when placed at a distance of $2\frac{1}{2}$ ft. from the illuminated surface (Fig. 48) shows that over an area of 26.5 sq. ft. the illumination varies from 0.1 to 1.5 ft.-c., the average illumination over this area being 0.28 ft.-c. As a result of this great variation the workman is in many cases unconsciously directing the maximum illumination or beam (in the above /

above case an area 12 to 15 in. in diam.) on the work being done, and the problems which required to be solved, therefore, were (a) to redistribute the luminous flux in such a way that there would be much less variation over the working-area and (b) to do this with the smallest possible loss of original flux.

II. - The U.S.A. and British Requirements for Electric Cap-Lamps.

In the United States, a definite standard of distribution for cap-lamps is laid down by the Bureau of Mines. The regulations relating to this are -

- (1) Total angle of light flux from the headpiece to be not less than 130° .
- (2) Average minimum c.p. delivered at any point in the illuminated area (taken at design voltage of bulb) shall not be less than 1 c.p.
- (3) The maximum c.p. at any point in the light stream must not be greater than five times the average over the light stream.
- (4) There shall be no sharp contrasts over the light stream.

The Lighting Regulations in this country read as follows:-

- (a) Intensity of Light. The lamp after burning continuously for nine hours under the appropriate standard conditions must give light such that the mean spherical candle-power (M.S.C.P.) is not less than 0.4, and the mean intensity over the horizontal angle of distribution (M.H.C.P.) must not be less than 1.5 candle-power.
- (b) Distribution of Light. The lamp must be so designed as to yield throughout a continuous burning period of nine hours, a sufficient and suitable distribution of light, without giving rise to glare and as far as practicable without marked contrast of light and shade within the area of distribution. The lamp will normally not be regarded as having a suitable distribution of light unless the intensity of light is not less than one candle-power anywhere within a solid angle of 100° .

Thus the regulations in force in the U.S.A. (see (3) above) appear to make more definite provision against high lights /

lights on the working-area than the Mines Department Regulations, although clause (b) given above covers this point to some extent but leaves the decision to the Testing Officer. The angle of the light stream is also greater - 130° as against 100° - but it may be noted that the much larger area thereby illuminated is not of great practical importance, as it was pointed out in a paper written some years ago by Professor W.H. McMillan^x that the maximum solid angle over which clear vision is possible with one position of the head is between 90° and 100° , and in the discussion on that paper, these figures were endorsed by Dr. T. Lister Llewellyn.

III. - The Nature of the Light Streams.

Before proceeding with the problem of the redistribution of the light flux, it was necessary to make a careful examination both of the total light output and the intensity distribution from the shape of cap-lamp reflector in common use at the present day with various combinations of reflecting surface and bulb. Photographs were accordingly taken of (a) cap-lamp beams in a smoke-filled chamber and (b) the illuminated areas on a dead-white screen due to various combinations of surfaces and bulbs. It should be noted that these photographs demonstrate distribution only and must not be compared for intensity, as no attempt was made to regulate exposures.

The beam photographs, Figs. 49 and 50 are for a chromium-plated and a matt aluminium reflector, respectively. The photographs of the illuminated surfaces are shown in Figs. 51, 52, and 53, the area shown being in each case 4 ft. square, with /

^x "The Practical Interpretation of Mine-lighting Intensity Standards", Trans. Inst. Min. E., 1932 - 3, Vol. lxxxiv., p. 256.



Fig. 49. - Cap-Lamp Beam. Chromium-Plated Hemispherical Reflector, Clear Bulb.



Fig. 50. - Cap-Lamp Beam. Matt Aluminium Hemispherical Reflector, Clear Bulb.

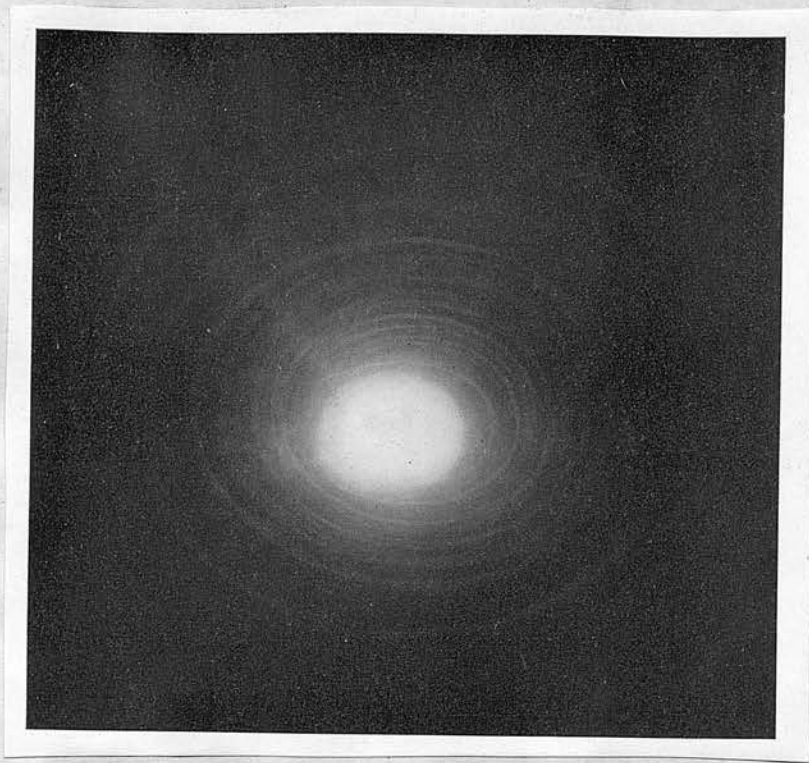


Fig. 51. - Illuminated Area. Chromium-Plated Hemispherical Reflector, Clear Bulb.



Fig. 52. - Illuminated Area. Chromium-Plated Hemispherical Reflector, Frosted Bulb.

with the lamp at a distance of $2\frac{1}{2}$ ft. from the surface.

Fig. 51, which is the illumination due to a lamp fitted with a chromium-plated hemispherical reflector and clear bulb, the bulb projecting through the centre of the back of the reflector, needs little comment. The central bright spot and the uneven system of alternate bright and dark rings show clearly the unsuitability of such a lamp for underground work, although it was

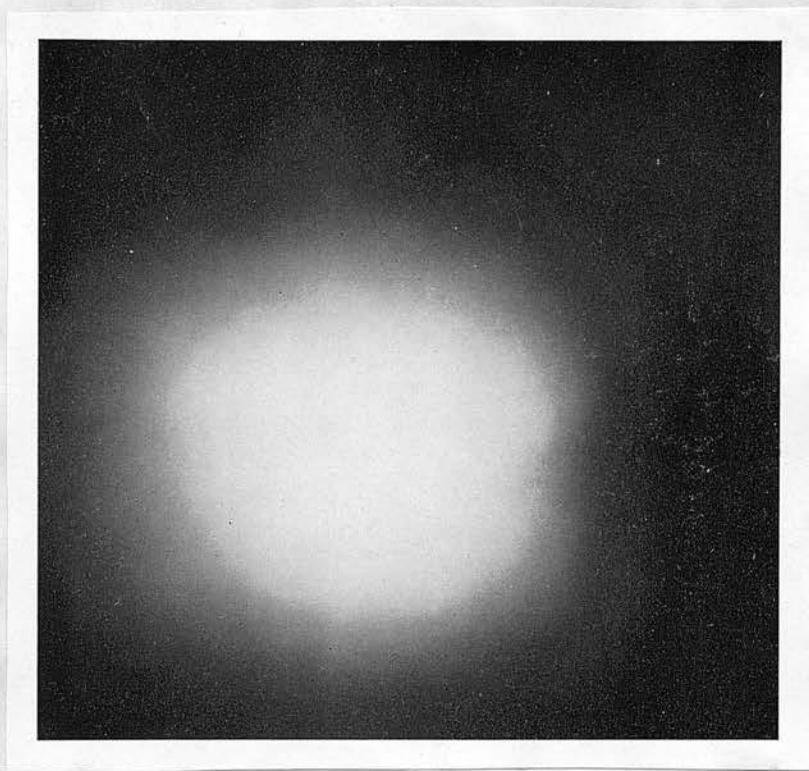


Fig. 53. - Illuminated Area. Matt Aluminium Hemispherical Reflector, Clear Bulb.

commonly used at one time. By using the same reflector with a frosted bulb, the ring system disappears (Fig. 52), but the centre spot remains. This spot is only about 6 - 9 in. in diam., however, when the distance between lamp and surface is $2\frac{1}{2}$ ft. and this combination is therefore by no means suitable in practice.

In Fig. 53, which was taken for a clear bulb and matt aluminium hemispherical reflector, the bulb projecting from the side /

side, the distribution has been improved, but there is still a definite highlight in the centre. In connexion with these photographs, particularly Fig. 49, it will be seen that there is a well-defined pencil of light, which is only $\frac{1}{2}$ in. in diam. at a distance of 5 ft., and it will also be noticed that the prominent rays cross on the axis at a short distance (about 3 in.) in

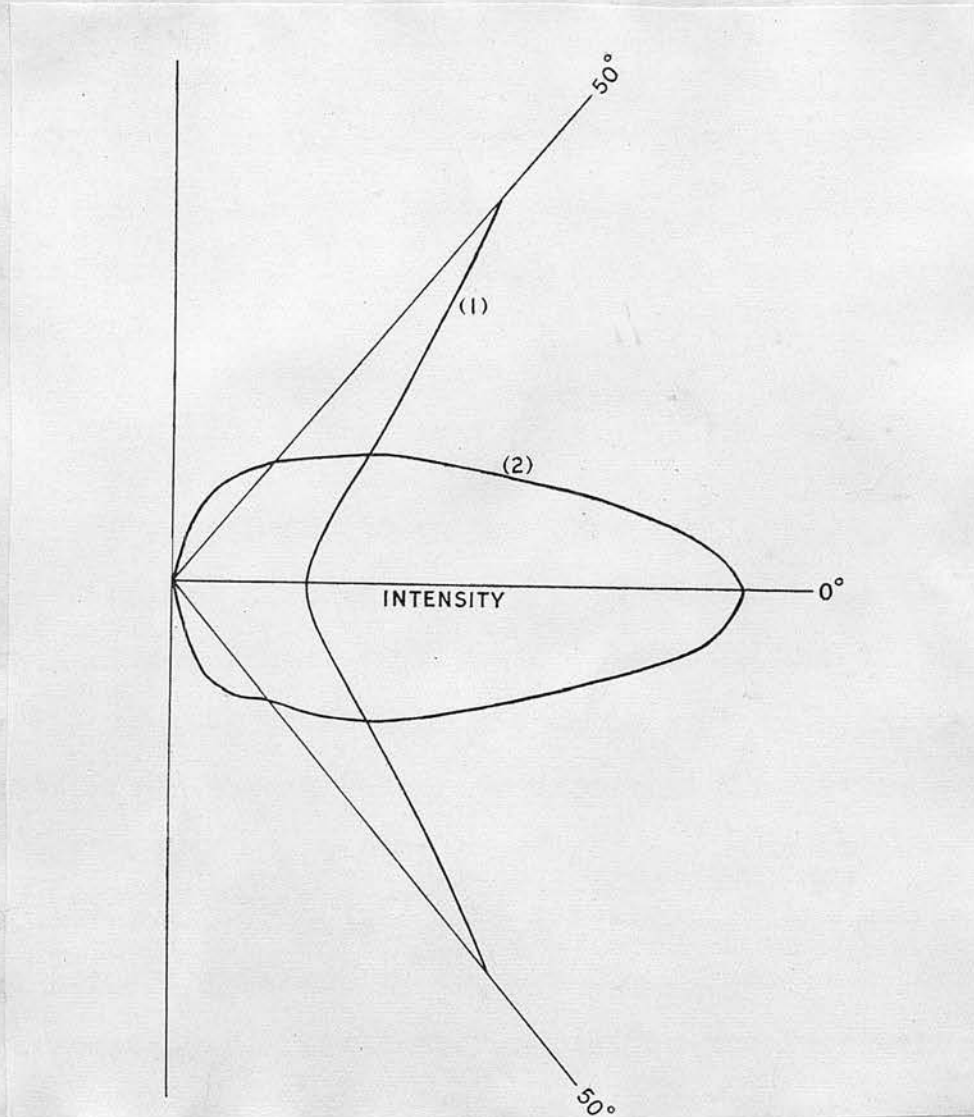


Fig. 54. - Cap-Lamp Polar Curves, Theoretical and Actual.

front of the lamp. This is worthy of note in a consideration of the flux distribution, especially as an opaque disc of about $\frac{1}{4}$ in. in diam. can be held in the centre of the lamp-glass without appreciably affecting the emergent light. This also applies to /

to a considerable extent to the distributions shown in Figs. 52 and 53, although the focal point is at a slightly greater distance.

A careful examination of these photographs, together with visual tests, proved valuable in indicating the lines along which progress might be made. The theoretical polar curve to give uniform illumination over a solid angle of 100° was first plotted. This curve is shown in Fig. 54 (1), and on comparing it with curve (2), which is the common form of light-distribution curve for the types of cap-lamp in use to-day, it was obvious that drastic alteration in the shape or size of the reflector, or of both, was necessary.

III. - Redistribution of Light Flux.

An appeal to the methods used in large-scale illumination work on the surface did not help to solve the problem to any great extent for several reasons, but for two in particular, namely (1) loss in total flux had to be kept to a minimum - a condition which is not nearly so important in surface problems where much larger sources of flux are used, and (2) the size of the reflector fitting (i.e., the headpiece) could not be increased without introducing serious disadvantages from the practical standpoint. This last restriction precluded the design of a reflector from theoretical considerations, because such a reflector designed for the type of bulb in use at this time would require a larger and heavier headpiece to house it.

Because of these limitations of size and weight, it was felt that it would be inadvisable to depart from the present size of headpiece, and accordingly it was decided to endeavour to obtain the desired result by re-designing the profile of the existing reflector. It was also decided to adhere to the matt aluminium/

inium surface which in a previous investigation ^x by Professor W.H. McMillan proved the best diffuser, and which also possesses the great advantage that it can be cleaned easily and quickly when it becomes tarnished.

Reference to the photographs already described, visual analysis, tests with opaque discs, and an examination of the theoretical polar curve of Fig. 54, all indicated that the well-defined light rays coming from somewhere near the rim of the present type of reflector should be made to cross the axis at a point much nearer the front of the lamp so as to just clear the opposite edge of the reflector.

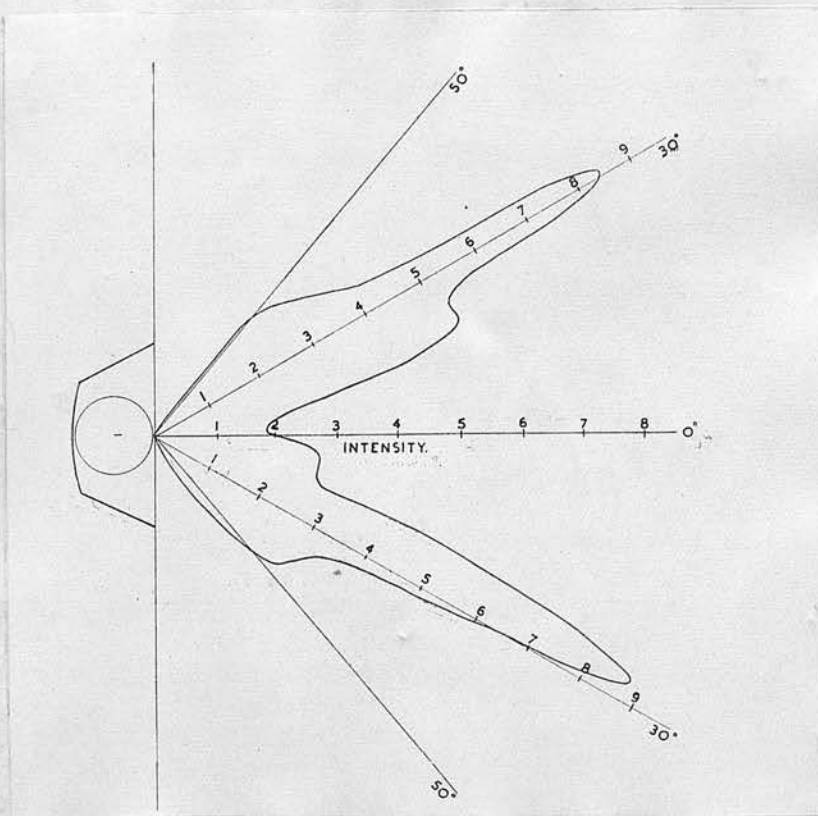


Fig. 55. - Reflector Profile and Corresponding Polar Curve.

A preliminary experiment was accordingly carried out with a reflector of the profile shown in Fig. 55, but a central beam was still found to be present. This beam appeared to be due to light reflected from a portion of the concave back of the reflector /

^x Proc. Nat. Assoc. Coll. Man., 1932, Vol. xxix., p.145.

reflector suffering a second reflection near the rim, and emerging in the forward direction. This was confirmed by painting out the rim with matt white paint, the polar curve then obtained being shown alongside the reflector in Fig. 55. Two pronounced intensity maxima are seen, separated by an angle of about 60° . This separation of the two maxima was, however, still far short of the requirements shown in the theoretical curve in Fig. 54.

The experiment, nevertheless, indicated that, with the size limit imposed by practical conditions and by bulb dimensions and construction, the development of the profile nearest to the ideal could only be reached by a process of gradual alteration. It was obvious that a large number of profiles would have to be tried, and as it was found impossible to get any firm to make these except at prohibitive cost, it was felt that a definite comparison of the various distributions, neglecting actual intensities, might be obtained, in the first instance, in some simple way. Profiles of the desired shape were accordingly turned from a circular beam of hard wood, and the surfaces of these were completely covered with strips of semi-matt tinfoil. In this way, information as to variations in distribution was obtained which made it possible to effect the necessary alterations in profile readily and quickly as the investigation proceeded. The same bulb was employed throughout, being supported from the side of the reflector as in most types of present-day cap-lamp. This bulb had a line filament lying along the axis of the reflector. It should be noted that this position of the filament with respect to the reflector seems necessary in order to ensure that the majority of the light flux falls on the sides of the reflector surface and is therefore reflected and distributed over the wider angles of the cone of distribution or light stream.

IV. - A New Reflector.

It was realized from the experiment of Fig. 55 that the slope had only to be made still steeper in order to obtain the 100° separation of the intensity maxima aimed at, but the double reflections mentioned above had at the same time to be avoided as far as possible. A reflector of the shape shown in Fig. 56 was therefore tried, and the polar curve obtained is shown alongside. It is seen that the 100° separation has been achieved in this case, and that the central beam is no longer present.

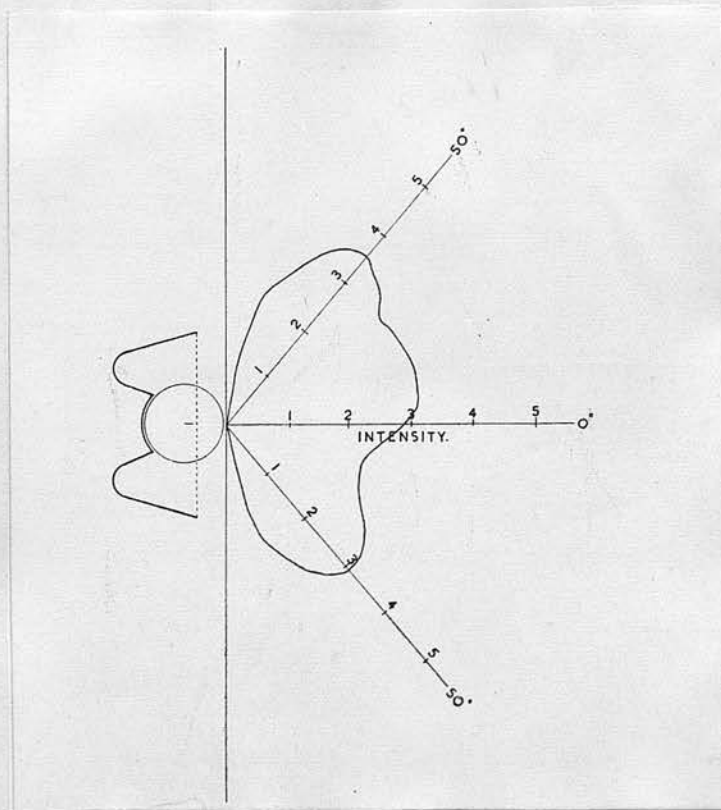


Fig. 56. - Reflector Profile and Corresponding Polar Curve.

For a reflector of this shape, however, it was found necessary to have the bulb-filament placed well forward in order to attain the desired distribution. Indeed, in obtaining the curve shown in Fig. 56, the bulb projected beyond the front of the reflector, resulting in a combination which would be difficult to house. Fig. 57 shows the next step, in which the reflector was /

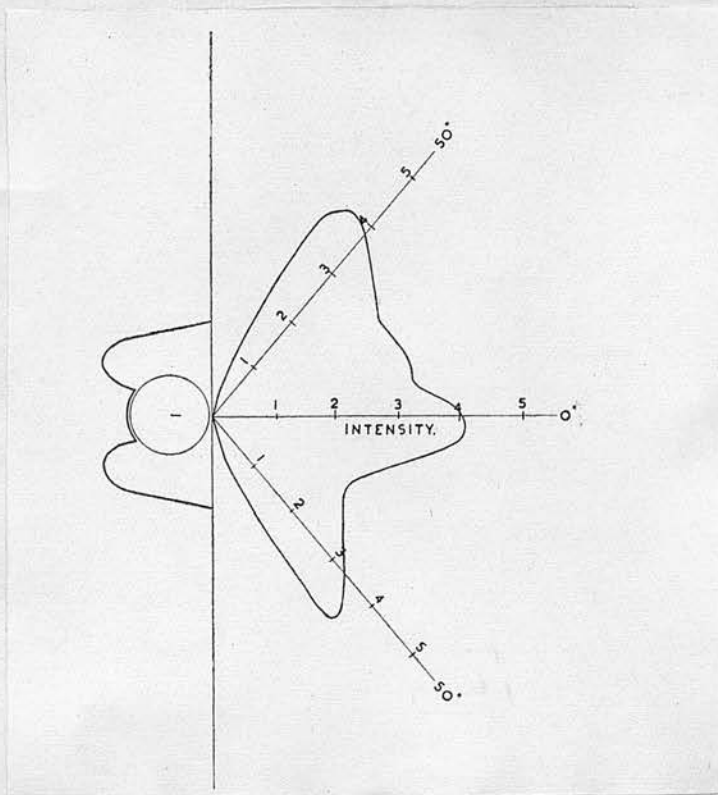


Fig. 57.

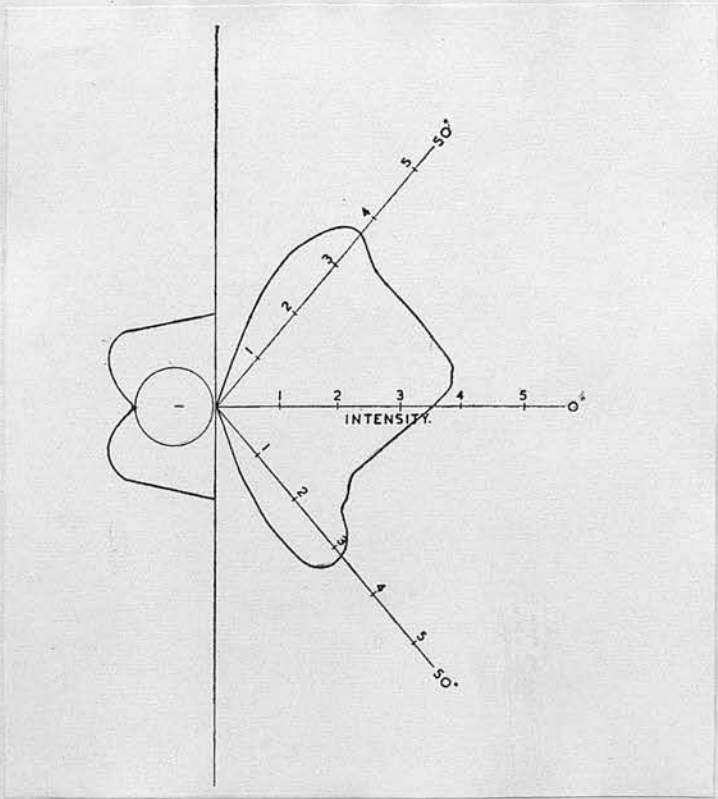


Fig. 58.

Figs. 57 - 58. - Reflector Profiles and Corresponding Polar Curves.

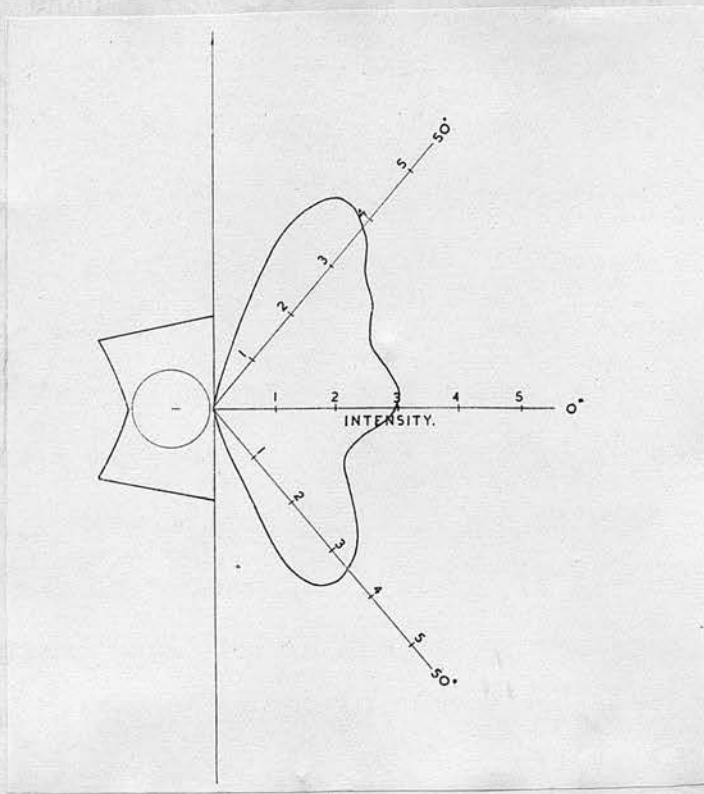


Fig. 59.

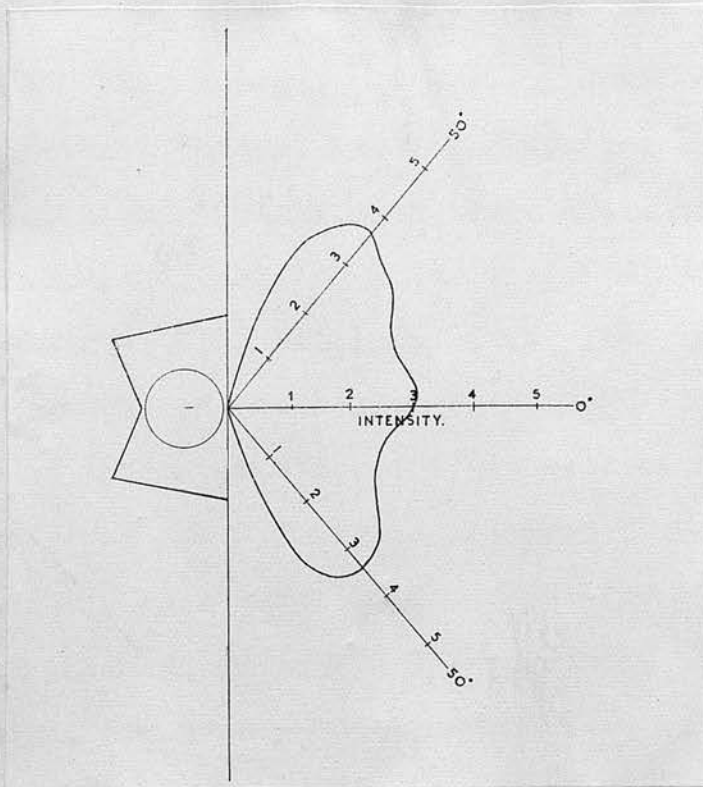


Fig. 60.

Figs. 59 - 60. - Reflector Profiles and Corresponding Polar Curves.

was made deep enough to house the bulb properly, and it will be seen that, although the two maxima are still present at the high angles, the central beam has in some measure reappeared. In an attempt to remove this, the curvature at the back was further altered, as shown in Fig. 58. The accompanying polar curve, when compared with that of Fig. 57, shows that, apart from a slight smoothing-out of the curve, no improvement had been effected by this alteration. The profile of the back of the reflector was, therefore, still further changed to that shown in Fig. 59, and the advance made is shown in the diagram. This polar curve shows that the intensity in the centre is less than that at an angle of 50° on either side, which is a very decided step towards the attainment of the theoretical curve. A further modification in profile, in which the back portion was made conical, as in Fig. 60, is seen to have little or no effect on the distribution.

Having thus reached a stage approaching practical application, several reflectors of the desired shape, with slightly varied aluminium surfaces, were obtained from a firm of lamp manufacturers, and the illumination diagram for the best of these is shown in Fig. 61 (lamp $2\frac{1}{2}$ ft. from the illuminated surface). On comparing this diagram with that given by the present type of reflector (Fig. 48), it will be found that the area illuminated to the 0.1 ft.-c. standard is 35.5 sq. ft. for the new reflector, as against 26.5 sq. ft. for the present type, and the areas illuminated to 0.2 ft.-c. (twice the minimum standard recommended) are approximately equal (see Table IV.). The light distribution given on a white screen by the new reflector is shown in the photograph of Fig. 62, which was taken under the same conditions as Figs. 51 - 53. The illumination contour diagram /

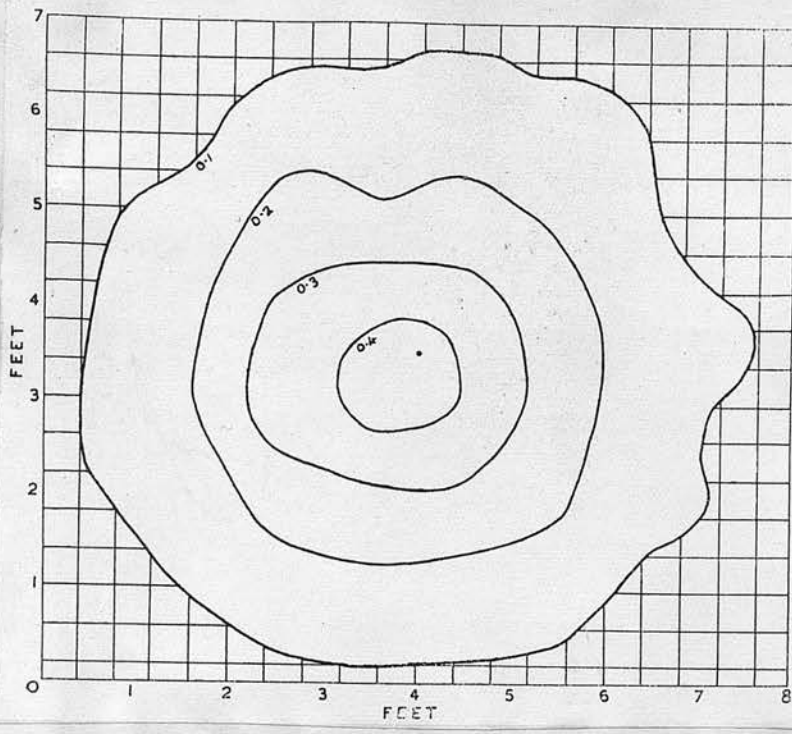


Fig. 61. - Illumination Diagram. Cap-Lamp with New Reflector.

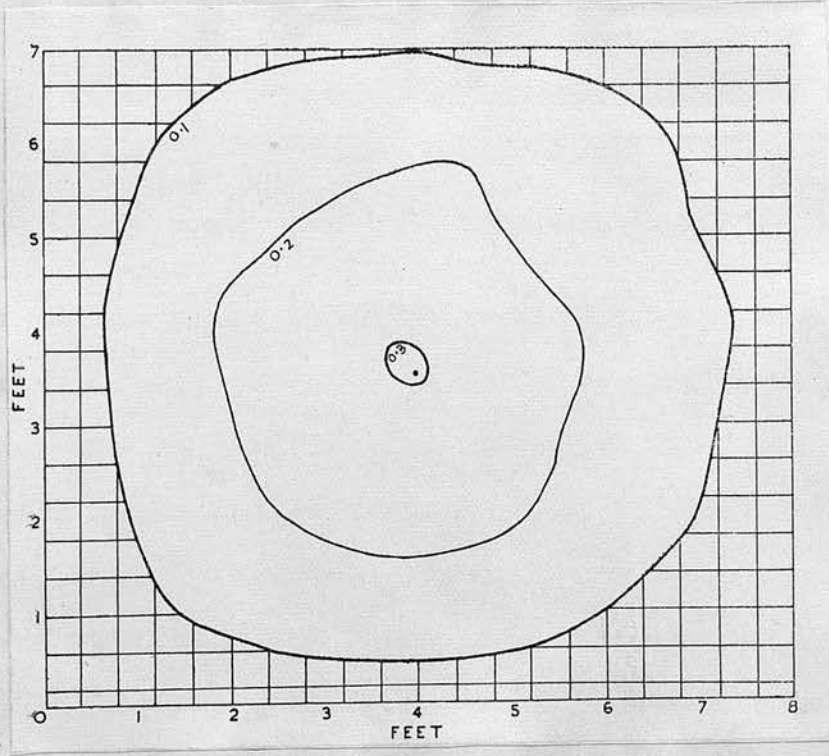


Fig. 63. - Illumination Diagram. Large Electric Hand-Lamp.

diagram (Fig. 61) shows that absolute uniformity of illumination has not yet been attained, but it is worthy of note that the area illuminated to the 0.1 ft.-c. standard is approximately equal to that for one of the larger electric hand-lamps (at a distance of 4 ft.), of which Fig. 63 is a typical diagram. A

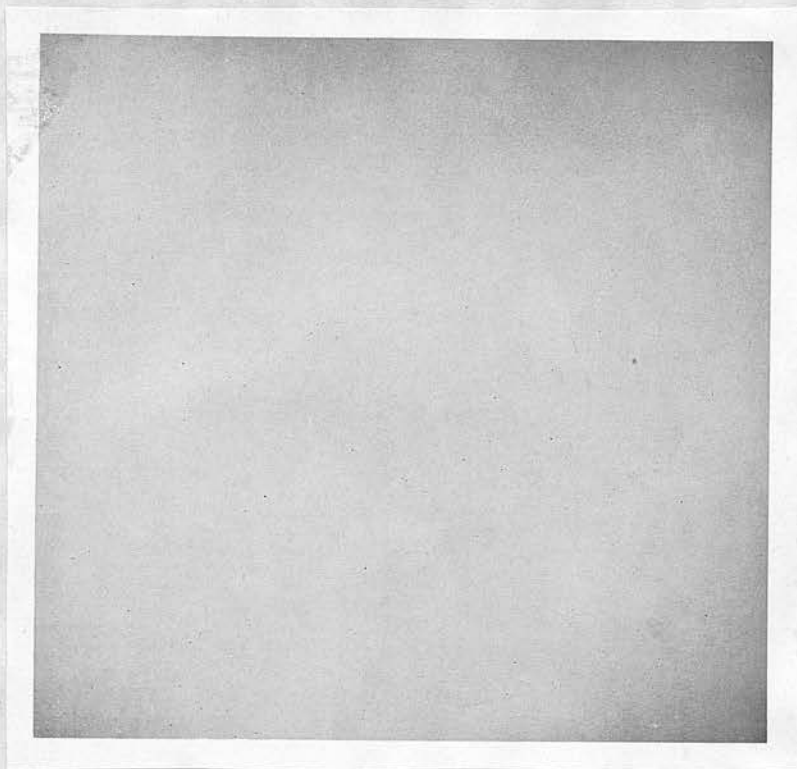


Fig. 62. - Illuminated Area. New Reflector, (Matt Aluminium), Clear Bulb.

comparison of the areas illuminated to different standards by these two cap-lamps is given in Table IV., from which it will be seen that in the case of the cap-lamp with this new profile of reflector, at least the same standard of illumination over the same area of surface has been obtained and with a lamp of little more, and in several cases less, than half the weight.

This new reflector therefore showed a great advance in the light distribution given by the cap-lamp, in that the variation in useful illumination had been reduced from 15:1 to 4:1, but it was still necessary to ensure that the system of double reflections which it involved did not result in too great a loss of /

of total flux. Mean S.C.P. tests were therefore made with the new reflector and the present type, using the same headpiece and the same bulb at controlled voltage throughout, and it was found that the loss resulting from the use of the new form of reflector was approximately 9.5%. It is suggested, however, that the advantages obtained from the more uniform illumination will far outweigh such loss in total flux, and especially as the areas over which high illuminations are obtained are small when using the present type of reflector, while the variation in illumination over those areas is large.

TABLE IV. - Areas Illuminated to Different Standards.

Lamp.	Areas Illuminated (sq. ft.).			
	Above 0.1 ft.-c.	Above 0.2 ft.-c.	Above 0.3 ft.-c.	Above 0.4 ft.-c.
Cap-lamp (present type)	26.4	13.6	8.9	6.2
Cap-lamp (new reflector)	35.6	14.6	5.9	1.3
10 lb. Hand-lamp	36.3	12.3	0.2	Nil

The dimensions of the reflector described are:

	Cm.
Diameter at front.. ..	6.0
" " back	4.6
Maximum depth	3.7
Depth in centre	2.7

Throughout the investigations described in this chapter, an attempt has been made to provide uniform illumination over the whole of the illuminated surface, but it must be realised that the value of this illumination, if attained, will be strictly limited. The total output of a cap-lamp bulb is, on the average, in the region of 20 lumens, and allowing a headpiece efficiency of 60%. the "useful flux" is approximately 12 lumens. Such /

Such a cap-lamp, having an angle of distribution of 120° "cut-off" (i.e., the whole of the flux being concentrated within this angle), will illuminate an area of 59 sq. ft. from a distance of $2\frac{1}{2}$ ft., and if the illumination is to be uniform over the whole of this area, it is clear that its value cannot be greater than $\frac{12}{59} = 0.2$ lumens per sq. ft. (or ft.-c.), approximately. If, therefore, a greater uniform illumination than 0.2 ft.-c. over the whole of the area illuminated is to be obtained from the present available flux, it is obvious that this can only be done by restricting the light distribution to a smaller angle than 120° . Restriction to 100° cut-off, for example, would give an illuminated area of 28 sq. ft., and a uniform illumination over this area of $\frac{12}{28} = 0.43$ ft.-c., while restriction to 90° would result in a uniform illumination of $\frac{12}{19.6} = 0.6$ ft.-c. over an area of 19.6 sq.ft., again assuming that the whole of the flux is concentrated within those angles.

It will be realised, therefore, that in designing reflectors for cap-lamps, the angle of cut-off should be kept as small as is compatible with practical considerations. 100° is suggested as the most practical value for this angle.

V. - The Design of a Reflector from Theoretical Considerations.

It has been stated that, at the time of the investigation just described, the size of bulb then available precluded the design from theoretical considerations of a reflector to give a more uniform illumination. Since that time, however, krypton-filled bulbs have been produced, and these new bulbs have a considerably smaller envelope than the older argon-filled type. An attempt was therefore made to design a cap-lamp reflector /

reflector for use in conjunction with one of these smaller bulbs and having a 100° cut-off. The reflector finally obtained is shown with its dimensions in Fig. 64, together with the illumination diagram obtained from it. From the latter it will be seen

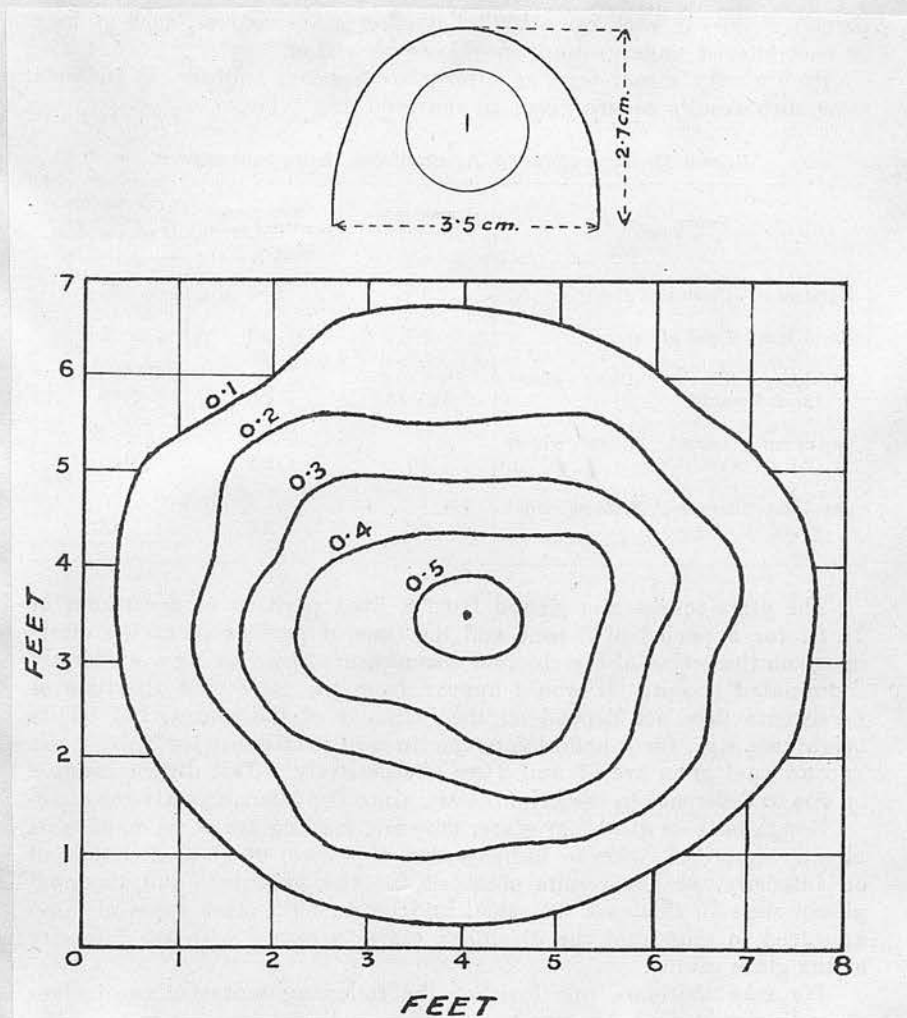


Fig. 64. - Illumination Diagram for New Small Matt Aluminium Reflector and Small Envelope Bulb (2.2 watts.). Reflector Profile, with Dimensions, shown above.

that the variation in illumination over the illuminated area has been reduced to about 5:1 as against 15 or more to 1 obtained with the majority of reflectors in use in cap-lamps at the present time, and this has been done without any loss in total flux. Also, the new reflector can be housed in a smaller and therefore lighter headpiece than that at present in use.

The method used in the design of the reflector is fully /

fully described by Jolley, Waldram, and Wilson,^x and may be briefly indicated as follows:-

In the discussion on polar curves given in Chapter II., it was shown that the solid angle $\delta\omega$ subtended by that portion of the curve between the angles θ and $\theta + \delta\theta$ was given by

$$\delta\omega = 2\pi \sin \theta \delta\theta$$

Hence the solid angle subtended by a zone of the curve between angles θ and ϕ becomes

$$\begin{aligned}\omega &= 2\pi \int_{\theta}^{\phi} \sin \theta d\theta \\ &= 2\pi(\cos \theta - \cos \phi).\end{aligned}$$

If the value of ω is calculated from this equation, and then multiplied by the average intensity in the zone considered, the flux emitted in that zone will be obtained.

The polar curve of the bulb alone was therefore plotted and the average intensity over each zone of 10° was obtained. Making use of the corresponding "zone factor" for each of the 10° zones, the total flux emitted by the bulb was calculated. Remembering that the cut-off of the reflector is to be 100° , all the flux emitted at angles higher than 50° on either side of the central 0° line will suffer loss by reflection and a portion of it will suffer further loss by passing through the bulb after reflection. Assuming an absorption of 20% by reflection, and a further 20% by transmission through the bulb, the total flux to be emitted by the combination of reflector and bulb was estimated. By an application of the zone factor method to the theoretical polar curve for uniform distribution, the proportion of this total flux required by the zones $0^\circ - 10^\circ$, $10^\circ - 20^\circ$, $40^\circ - 50^\circ$ was calculated.

The /

^x "The Theory and Design of Illuminating Engineering Equipment", (Chapman & Hall) p. 237 - 246.

The reflector profile was then built up in the form of a large number of small elements, each element being orientated so as to reflect the flux falling on it into the appropriate zone.

Several profiles were designed before the reflector of Fig. 64 was obtained, considerable difficulty being experienced due to the small size of the reflector and bulb. Again, the theory is based on specular reflection, while the reflecting surface used was matt aluminium. The ideal of uniform illumination has not yet been attained, but it will be seen that some progress has been made in this direction.

CHAPTER VIII.

GLASS IN ORDINARY LIGHTING.

CHAPTER VII.

The first of these is the fact that the work has been carried out with-
out the aid of any special apparatus, particularly in con-
nection with the use of the various devices, and in some special
cases of special interest, but as the present is devoted
entirely to the study of the relation of glare to work,
it is not possible to say anything more when it is realized
that the other side of the question has been
entirely neglected. It is not possible to make the workers
in any way more comfortable by the use of this degree of efficiency
and so on.

CHAPTER VIII.

GLARE IN UNDERGROUND LIGHTING.

The first of these is the fact that the work has been carried out with-
out the aid of any special apparatus, particularly in con-
nection with the use of the various devices, and in some special
cases of special interest, but as the present is devoted
entirely to the study of the relation of glare to work,
it is not possible to say anything more when it is realized
that the other side of the question has been
entirely neglected. It is not possible to make the workers
in any way more comfortable by the use of this degree of efficiency
and so on.

CHAPTER VIII. Glare in Underground Lighting.

Much valuable investigation has been carried out within recent years on the problem of glare, particularly in connexion with night driving, street lighting, and in some special cases of indoor lighting, but up to the present no detailed study has been undertaken in its relation to underground work.

This, however, is not surprising when it is realized that the chief difficulty in this particular problem has been, and still is, to obtain sufficient light to enable the workers to carry out their duties with a reasonable degree of efficiency and safety, especially at the working-face.

Research has consequently had to be concentrated on the problem of quantity rather than quality and distribution, but although the former still falls lamentably short of requirements, the conditions are so vastly different from those which exist on the surface that every care must be taken to ensure that the methods adopted to meet the deficiency in quantity do not introduce other difficulties which may prove even more serious from other standpoints.

More, and still more, light is wanted underground, but the results which have been obtained in surface investigations have clearly demonstrated that under coal-mining conditions where, it must be remembered, reflection is practically nil, the distribution of this greater quantity must be such that the questions of health and safety are not directly affected.

In connexion with mains lighting at the working-face, for example, Professor W.H. McMillan has on many occasions expressed the opinion that apart altogether from the question of safety /

safety, an indiscriminate increase in the candle-power of lamps is not likely to provide a satisfactory solution, but that an increase in the number of lamps of smaller candle-power will prove a much better method in the dark background of the mine. It is appreciated that as a result of the development of the mercury-discharge lamp of much higher efficiency, which has been approved recently by the Mines Department, this opinion may have to be modified, at least in some underground situations.

Another reason why the problem of glare has not been approached seriously lies in the fact that the technique of the measurement of glare, or rather of its effects on vision, even under the more favourable surface conditions, still presents numerous difficulties. It is suggested, however, that the progress made has been such as should not any longer constitute a sufficient reason for neglecting the problem of enquiry in its relation to underground lighting conditions.

The object of this study, therefore, was to demonstrate that, as development in methods of the comparative measurement of glare take place, such methods should be applied to and proceed concurrently with any advances which take place in mine lighting, and to ascertain by laboratory tests, to what extent glare may affect the workers in the performance of their various tasks.

What is glare? It is that condition in lighting which causes visual discomfort, and is the sensation produced when we look at something which is very much brighter than its surroundings, such as the sun on a very bright day, the bare filament of an electric bulb under artificial lighting conditions, or at very bright or polished surfaces which reflect powerful rays /

rays towards the eyes. It is the uncomfortable feeling we experience if we look directly at the head-light of a motor car at night, if the eyes meet the beam of a cap-lamp underground, or if we light a cigarette out of doors at night. It not only reduces for a time the ability to "see" when the eyes are turned away from the glare source, but also our ability to see clearly objects which are in the neighbourhood of the line of vision either between the eye and the glare source or beyond the glare source.

I. - Glare in Daylight and Artificial Light.

There are two types of glare, namely, discomfort and disability glare.

Discomfort Glare. - This type is the most common. It may be due to a light source itself or to images of such a source reflected from polished surfaces. It is uncomfortable and distracting. It is well illustrated by street-lighting lamps on the surface, or by hand-lamps and mains lighting on the face in underground work, although in all such cases, and particularly in mining, the sources are usually bright enough in relation to their surroundings to cause also some degree of disability glare. This is shown by the fact that visibility is definitely improved if the eyes are shaded from the direct light of the sources.

Blinding or Disability Glare. - This type is due to an extreme brightness, which greatly reduces for a time the ability of the retina to respond to light. The vision is paralysed, and the effect frequently results in blind-spots, while powerful after-images of such dimensions as to blot out the object of vision entirely, remain for seconds, or even for a minute or two, depending on the brightness of the glare source. It occurs when we /

we pass into a level of illumination much higher than that to which the eyes have just been adapted. The motor car head-lamp at night or a cap-lamp with a beam of high intensity are excellent examples.

Both types of glare are present in underground lighting, but before discussing them in relation to coal-mining conditions it will be of value to recall some of the more important features of daylight and artificial light. At noon on a clear midsummer's day the total illumination is of the order of 10,000 ft.-c., of which roughly 2,000 ft.-c. is skylight, and 8,000 ft.-c. sunlight. If we shield the eyes from the sun we have no feeling of discomfort in looking at the sky, i.e., in looking at a source of much higher intensity than is usually found in any artificial lighting conditions. There is no sensation of glare. Or again, the variation in the illumination during daylight hours due to cloud or elevation of the sun may be enormous, but owing to the high illumination values, this variation is much less noticeable out of doors than are much smaller variations under ordinary artificial lighting conditions. In other words, a fall in illumination from 8,000 to 4,000 ft.-c. in daylight is of small moment, but a fall from 8 to 4 ft.-c. in artificial light might prove most annoying. It would be like replacing the most modern electric cap-lamp with the half-candle oil-lamp which was so common a few years ago.

It seems, therefore, that while we are unaffected in skylight which gives an illumination of, say, 2,000 ft.-c., the beam of a cap-lamp in the mine, giving an illumination of less than 5 ft.-c., may prove exceedingly disconcerting. This immediately raises the questions of visual adaptation of the retina.

The /

The retina of the eye is sensitive to an enormous range of brightnesses, but if the eye has been working for some time at fairly low brightnesses, and is suddenly exposed to a very bright source, the retina does not respond at once. It is commonly believed that the iris, or diaphragm of the eye, compensates for brightness changes by opening or closing to regulate the light falling on the retina. This is only part of the truth, however, as the iris only gives a brightness range of about 10:1. The whole process of adaptation includes changes which take place in the retina itself, and these changes may take a considerable time. When proceeding from high illuminations, such as daylight, it is estimated that the eye takes about an hour to become adapted to complete darkness. When the eye is dark adapted, even a comparatively low source of illumination will cause discomfort, and this is the condition which holds in underground work.

II. - Brightness-Difference Threshold and Background Brightness.

The glare from a light source cannot be evaluated directly, but it can be measured by the "reduction in ability to see" effect on the observer.

Suppose a flat surface S (see Fig. 65) is illuminated uniformly to a brightness of B candles per sq. ft. A spot of light is projected on to the surface S at point P , which lies in the direction of central (i.e., foveal) vision. Let δB be the additional brightness due to the light spot, the difference of brightness between the spot P and the surrounding field will be $B + \delta B - B = \delta B$.

Suppose the brightness of the spot is varied until it is (1) just detectable, (2) just not detectable, then the mean of these two values of δB will be the least detectable difference of /

of brightness, and this is called the brightness-difference threshold. By carrying out a series of tests for different values of the screen-background brightness B , it is found that the brightness-difference threshold varies with B , and a curve can be plotted to show the relation between them.

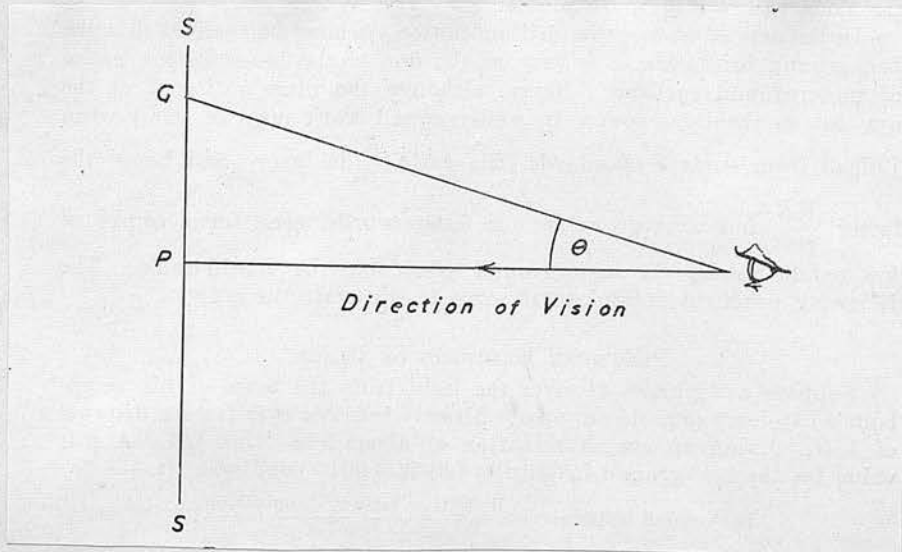


Fig. 65. - Diagram illustrating the Method of Glare Measurement.

Suppose a glare source is now placed at point G , separated from P by the angle θ . It is found by experiment that δB increases, i.e., the least detectable brightness difference is now greater, and hence vision is not so good. For any given glare condition, δB can be measured. By reference to the curve obtained for the variation of brightness-difference threshold with background brightness without the glare source, a background brightness β can be found for which δB has the value just measured. β is called the equivalent uniform-field brightness, and as a result of experiments which have been carried out by different observers in recent years, it appears that β can be expressed by the formula :-

$$\beta = B + \frac{KE}{\theta^n}$$

In other words, the effect of the glare source on the brightness-difference /

difference threshold is reproduced by superposing a uniform brightness equal to the factor $\frac{KE}{\theta^n}$ on the background brightness B. Hence the term "equivalent uniform-field brightness."

β and B are measured in candles per sq. ft., and θ in degrees. E is the vertical illumination produced at the eye by the glare source (in ft.-c.).

K and n are constants, $K = 10$, $n = 2$, being their approximate values.

The measure of the disability glare (D.G.) may then conveniently be taken as the ratio of the equivalent uniform-field brightness β to the true background brightness B,

$$\text{i.e., D.G.} = \frac{\beta}{B} = 1 + \frac{KE}{B\theta^n}$$

From an analysis of this result, we see at once that when no glare source is present, $E = 0$ and $D.G. = 1$, but the introduction of such a source increases D.G. by the factor $\frac{KE}{B\theta^n}$ and to avoid serious effects this must be kept small. The variable terms are (a) E, (b) B, and (c) θ :-

- (a) The illumination at the eye E increases with the candle-power of the glare source, but decreases when the distance between the source and the eye increases. Therefore the greater the candle-power of the source, and the nearer it is to the eyes, the greater will be the glare;
- (b) increase in the background brightness B will reduce the glare, e.g., mains lighting in roadways, engine-houses, road junctions, etc., which are whitewashed;
- (c) increase of the angle θ between the glare source and the direction of vision will also reduce the glare, even for the same distance of glare source.

In the case of underground illumination, it must be realised that the background brightness B is very small, due to the low-reflection ratios of underground surfaces. Hence, although the illumination E at the eye due to the light source in underground work may be small when judged from surface standards, the /

the ration $\frac{E}{B}$ is large, and hence the factor $\frac{KE}{B\theta^n}$ has a large value. In other words, even for a source of low candle-power, the underground glare may be considerable. The following practical examples will serve to illustrate the point.

III. - Practical Examples of Glare.

Suppose a workman receives the light from the beam of his neighbour's cap-lamp (c.p. 15, approx.) directly into his eyes from a distance of 4 ft., giving an eye illumination of about 0.94 ft.c. (E). A fair value for the background brightness (B) is 0.0016 candle/sq.ft. -

Background brightness = $\frac{\text{Reflection ratio} \times \text{illumination}}{\pi}$.

For underground conditions, if the average reflection ratio be taken as 5% and the illumination as 0.1 ft.c. then -

$$B = \frac{5 \times 0.1}{100 \times \pi} = .0016.$$

Hence we have, assuming for convenience that $\theta = 1^\circ$ (foveal vision),

$$\text{D.G.} = 1 + \frac{KE}{B\theta^n} = 1 + \frac{10 \times 0.94}{0.0016 \times 1} = 5876.$$

For a hand-lamp of 4 c.p. under the same conditions, i.e., if looked at from a distance of 4 ft., the value of D.G. becomes -

$$1 + \frac{10 \times 0.25}{0.0016 \times 1} = 1563.$$

If the cap-lamp or hand-lamp be looked at from a distance of 2 ft. under these conditions, the value for D.G. becomes approximately 23,000 and 6,000, respectively. This might at first sight appear to be to the disadvantage of the cap-lamp, but it must be remembered that the cap-lamp is seldom stationary, except /

except possible^y when it is shining on the working-face during hand-holing or stripping, whereas the hand-lamp is in one position over long periods, and the tendency towards exposure to glare source is therefore much greater in this case.

Now, by way of comparison, let us consider the artificial lighting conditions in an ordinary room (12 x 12 x 9 ft.) lit by a 60-watt lamp (c.p. 70, approx.). On looking at the lamp from a distance of 4 ft., the eye illumination (E) has the value 4.4 ft.-c. If we take the average reflection ratio of the walls, ceiling, and floor to be 40%, the brightness of the surroundings (B) becomes 0.182 candle/sq. ft. Assuming the average distance from lamp to walls to be 7 ft., the illumination = $70/49$ ft.-c.,

$$\text{and } B = \frac{40 \times 70}{100 \times 49 \times \pi} = 0.182.$$

Therefore ($\theta = 1^\circ$ as before) we have

$$\text{D.G.} = 1 + \frac{10 \times 4.4}{0.182 \times 1} = \underline{243.}$$

This means that the amount of glare experienced by the underground workman who looks at his neighbour's cap-lamp is much greater than that experienced when looking at a 60-watt lamp under typical surface-lighting conditions from a distance of 4 ft. in both cases, although the figures given probably exaggerate the differences in glare, and must not be compared directly.

It appears, therefore, that while intensity and illumination are important for seeing, their usefulness may be greatly diminished and even annulled for a time if due attention be not given to the very important factor of distribution. Safety may even be affected.

It /

It will be noted that the glare formula just discussed takes no account of the effect of the brightness of the source of glare experienced. Brightness is not identical with intensity (candle-power), but is defined as candle-power per unit area of source. Thus the brightness of a 3-c.p. flame source is much less than the brightness of a point electric filament of the same intensity due to the difference in size of the two sources (in the case of a krypton-filled bulb the filament is at least 500 times as bright as the flame source). Experiments carried out by various observers indicate that, within the range of sizes of source which they used, the size and brightness of different sources of the same intensity have no effect on the brightness-difference threshold.

IV. - The Investigation of Glare.

For the experimental investigation of disability glare, the background screen was painted dead black to approximate to underground conditions, and the test-spot occupied a fixed position in the field of view. The mounting for the different glare sources was situated directly above the spot position, the angular separation being of the order of 5° . The intensity of the test-spot could be varied by means of an Ilford Wedge, moving in a pair of vertical guides. This wedge was a neutral filter of variable density, giving practically 100% transmission of light at one end, with the transmission factor gradually decreasing along the length of the wedge, until, at the other end, only about 1/1000th of the incident light was transmitted. For accuracy of observation, a flashing test-spot was preferred to a continuous one, and a camera shutter was therefore set up in front of the wedge.

In /

In making observations for a given glare source, the position of the wedge was adjusted so as to render the test-spot invisible, and the wedge was then slowly moved by a racking mechanism until the spot was just visible, and the wedge position was noted on a scale. A second reading was obtained by making the spot fully visible, and then racking back the wedge until it was on the point of disappearing. This process was repeated a large number of times for each glare source. Throughout the investigation, the distance between the observer and the screen was kept constant, and the spot was viewed by foveal, i.e., central, vision. The results obtained indicated that disability glare depends on intensity only, a conclusion already reached in surface investigations carried out by W.S. Stiles and B.H. Crawford at the National Physical Laboratory.

Using three sources of the same intensity (1) a point source formed by a clear miners' lamp bulb (2) a ball source formed by a prismatic well-glass (3) an extended source formed by an opal well-glass, it was found that the disability glare factor was the same in each case as expected. Without doubt, however, the opal glass gave rise to much less discomfort than either the prismatic glass or the clear bulb, due to the much lower brightness. It was thought that this discomfort was connected in some measure with the tendency of the source to produce the sensation on the retina giving rise to an after-image. Different light sources were therefore viewed from a fixed position at a distance of $2\frac{1}{2}$ ft. for a period of 5 seconds, and the time of persistence of the after-image on the retina of the observer was measured roughly by viewing a uniformly-illuminated screen. The results of this test are shown in Table V., and it would appear that the time of persistence does not depend on the intensity of the source /

source, but on its brightness, e.g., for a hand-lamp, the times of persistence for a prismatic and an opal glass are 67 and 2 seconds respectively. This difference must be due to difference in brightness, since the intensities are the same.

TABLE V. - Measurements of After Image Persistence.

Source.	Candle-power (Maximum).	Brightness (Arbitrary units).	After-glare image persistence (sec.) (5 sec. exposure).
Hand-lamp (Prismatic glass)	3.7	10.2	67
Hand-lamp (Opal glass)	3.7	8.3	2
Cap-lamp (Small) (Clear glass) (2 - 2.5 watts.)	12 - 15	9.9	60
Cap-lamp (Large) (Clear glass) (2.5 - 4 watts.)	40	12.3	105
Cap-lamp (Large) ("Flashed" Opal glass)	5.5	8.6	15

The brightness measurements were carried out by means of an illuminometer, designed by B.H. Crawford. Using a Lummer-Brodhun cube, the light from a small electric lamp forming one arm of a balanced Wheatstone-bridge circuit is matched against the external brightness by varying the current through the bridge circuit. The change in temperature of the lamp is accompanied by a change in its resistance, and hence the Wheatstone bridge is thrown out of balance. The out-of-balance current is registered on a milliammeter which is placed across the bridge, and this current gives a measure of the external brightness. By the use of suitable filters in either the external or comparison fields, the instrument may be calibrated for several brightness ranges.

V. - The Reduction of Glare.

The first attempt made to reduce the effect of glare from head-lamps was the adoption of tinted bulbs and well-glasses. Cadmium-tinted bulbs were first compared with an ordinary clear bulb inside a frosted prismatic well-glass. A slight improvement in the discomfort seemed to have been effected, but this was probably due to the loss in candle-power resulting from the coloured glass of the bulb. When the tinted bulbs were slightly over-run to give the same intensity as the clear bulbs, there appeared to be no reduction in the discomfort. A number of tinted well-glasses, of various types, were next tried. As in the case of the coloured bulbs, however, any benefit derived from their use could be attributed to the loss of intensity due to increased absorption. When the intensity was made equal to that of a lamp fitted with an ordinary prismatic well-glass, a number of mining students expressed the opinion that the coloured glasses effected no reduction in the glare. In an investigation carried out by the Department of Scientific and Industrial Research,^x the same conclusion was reached in regard to the use of coloured glasses in motor-car headlights. It, therefore, appears that the best solution to the glare problem as far as hand-lamps are concerned is that stated in Chapter VI. viz., a combination of opal well-glass and photometric paint reflector.

The glare experienced where cap-lamps are in use is much more disconcerting than that from hand-lamps, owing to the high beam intensity. The best method of reducing the effect is the adoption of one of the reflectors described in Chapter VII., as the more uniform distribution of the light flux with a consequent /

^x Illumination Research Technical Paper No. 20, 1937.

90

sequent reduction in the maximum intensity has a most decided tendency to reduce the disability effect. A similar result can be obtained by using a glass of "flashed" opal, except that this method involves some loss in total flux. This method is particularly applicable to the most recent types of cap-lamp employing bulbs of 3 and 4 watts rating. The variation in illumination over the illuminated area for such lamps may be 60 or more to 1, but by substituting a "flashed" opal glass for the clear glass, this variation can be reduced to about 8:1. The total flux, however, is reduced by approximately 30%, but the available flux still exceeds by 50% that obtained from the majority of the smaller types of cap-lamp, the glare experienced is much less than it is in even these smaller types, and the lamp can be looked at with practically no feeling of discomfort.

At collieries where cap-lamps are just being introduced, it is occasionally the custom to provide certain "key men" with cap-lamps, while other workers are provided with hand-lamps. As a result of tests carried out during this investigation, the fact emerges that this form of "mixed lighting" should be avoided, as it is found that glare experienced by a worker due to his neighbour's cap-lamp may be greatly reduced if his own lamp is of a sufficiently high intensity to illuminate the background behind the glare source to a reasonable degree.

CHAPTER IX. Substitutions.

The main conclusions and findings of this investigation may be summarized as follows:-

- (1) It is possible to make illumination surveys underground with a considerable degree of accuracy, and an instrument for this purpose, which can also be used as a photometer, is described.
- (2) A method of plotting such surveys as illumination diagrams is explained, and a number of examples of surveys showing the effect of face illumination by different methods for different systems of lighting is given.
- (3) These surveys show the great improvement which has taken place in the

CHAPTER IX.

CONCLUSIONS.

- (4) Where enclosures are used at the face, lighting from the main, as at present adopted and arranged, while providing better general illumination, is inferior for individual work to that obtained by several forms of modern portable lamp.
- (5) For a portable electric hand-lamp, the best reflectors are those which may be fitted inside the well-glass. The best reflecting surface is the matt white surface of photographic paper.
- (6) The standard of illumination may be greatly improved by

The main conclusions and findings of this investigation may be summarized as follows:-

- (1) It is possible to make illumination surveys underground with a considerable degree of accuracy, and an instrument for this purpose, which can also be used as a photometer, is described.
- (2) A method of plotting such surveys as illumination contours is explained, and a number of examples of surveys showing the areas of face illuminated to different standards for different systems of lighting is given.
- (3) These surveys show the great improvement which has taken place in face lighting within recent years; also that several types of portable lamp are now available to the industry which illuminate the work being done by the underground worker to, and in some cases well beyond, the minimum of the 0.1 ft.-c. standard recommended in the Third Report of the Nystagmus Committee.
- (4) Where conveyors are used at the face, lighting from the mains, as at present adopted and arranged, while providing better general illumination, is inferior for individual work to that obtained by several forms of modern portable lamp.
- (5) For a portable electric hand-lamp, the best reflectors are those which may be fitted inside the well-glass. The best reflecting surface is the matt white surface of photometric paint.
- (6) The standard of illumination may be greatly improved by the /

the use of high-efficiency bulbs, especially in combination with the photometric paint reflector. Care, however, should be taken to ascertain that such bulbs have passed the life test (600 hours burning).

- (7) While the cap-lamp is rapidly growing in popularity, the distribution of the light which it gives leaves room for much improvement, especially for work at the coal-face. Two new reflectors, designed to give a more uniform light distribution, are described.
- (8) In underground illumination glare is to a certain extent inevitable, but suggestions are made for reducing its effect. For hand-lamps the best solution to the problem is the combination of opal well-glass and photometric paint reflector, with a high efficiency bulb to compensate for light losses due to absorption. Tinted bulbs and glasses seem to effect very little improvement.
- (9) For reducing the effect of glare from cap-lamps, two methods are suggested (a) the use of one of the new reflectors already described (b) the use of a "flashed" opal glass in one of the modern lamps of 3 or 4 watts rating.
- (10) Under all circumstances, "mixed lighting" should be avoided.