SHIP
CARBON MANUAL

THE
SHIP CARBON
MANUAL

Issued in the interests

of Better Projection

CONTENTS

PRICE FIVE SHILLINGS

History of The Ship Carbon Company

THE Ship Carbon Company of Great Britain, Ltd., was established in 1927 for the purpose of producing highly specialized Lighting Carbons in this country. The site chosen for the works was at Chadwell Heath, Essex, where some of the buildings had been used for many years previously by another Company engaged in carbon production.

As with many other great industrial enterprises, the Company owes much of its world-wide success to the vision of one man, Charles H. Champion, the Founder. He was unique in many respects and one of the very few men who anticipated the enormous potentialities of the arc lamp in the cinema industry.

After the 1914-18 War, when the cinematograph theatre really began to establish itself as the major contribution to international entertainment, it became necessary to specialise in the various types of arc lamp carbons required for cinematograph film projection.

The close matching of carbon production technique to the particular apparatus used for film projection was, therefore, one of the first essentials in the long term plan of the Company.

It was also realised at the outset that the results of an expert appreciation of screen brightness could be applied only through a scientifically accurate standard of measurement. Thus it happened that one of the early services of the Company to the cinema owner was the provision of a screen illumination service. It was put into operation through the subsidiary Company of Charles H. Champion & Co., Ltd., and the service was carried out by a chain of highly trained Service Engineers based on different areas of

the country. The vital importance of this service was eventually officially recognised by the cinema owner.

In the early days of the Company the principal requirements of the projection field were largely centred round the Low intensity type of carbon used in the, then, straight arc or the recently introduced mirror reflector type of arc lamp. The current factors were low and, in many instances, carbon diameters were large.

The High Intensity type of arc was not in extensive use for film projection.

The Company's research chemists, however, were acutely conscious of the trend of development and devoted a great deal of effort in the early stages of production to this class of carbon. The Company speedily expanded its range of lighting carbons to cover the fields of cinematograph film projection, industrial production, photographic studios, therapeutic clinics, hospitals, and other markets where powerful light sources were required. Although, at this stage, High Intensity Carbons were in use to some extent, the bulk of the demands were still for plain Low Intensity Pure Carbons.

By 1931, the Ship Carbon Company were ready to release an entirely new technique by providing small diameter High Intensity Carbons for use with Low Intensity Equipment. This type of carbon was known as the Ship " HILO " Carbon and was actually the forerunner of all the Modern High Intensity Copper Coated Carbons. And it is interesting to record that even the current ratings of the first Ship " HILO " Carbons, released in 1931, are still practically identical with the more modern Cerex and Cerelite and other complementary brands.

At this stage in the Company's history, which deals only with the first few years of the establishment of the present carbon manufacturing plant at Chadwell Heath, it will be seen that the factory had already produced a full range of arc lamp carbons, and, further, had pioneered the introduction of what was to prove the most successful and, to-day, the most widely used type of carbon in the field of cinematograph film projection.

In addition, many new grades and improvements on old ones, were introduced. The Ship Carbon Company, as a result, established a reputation of supplying quality products. Patient and intensive research work was—and it still is—continuous, and " Ship " Carbons developed from the " HILO " types are now in active demand from the four quarters of the globe.

The unswerving policy of the Company has always been the same — to place the interests of its customers first and foremost by providing a first-class product— and an efficient service after sales.

In the comparatively short space of a few years over a quarter of a century, the Company's lighting products have experienced a dramatic rise in popularity, if not fame, and this position has been won by honest, painstaking craftsmanship and skill and a rich experience of the needs of the industries and services supplied.

The Company to-day produces improved grades of Low Intensity Carbons of all types, in addition to the popular grades of High Intensity copper coated carbons, plain High Intensity Carbons for use in the searchlight pattern lamps and film studio apparatus, and improved types of White Flame Carbons for photographic purposes ; cored and solid enclosed carbons for Plan reproduction and special carbons for hospitals and clinical services ; and, last, but by no means, least, the highly specialised spectro-graphically pure carbons.

In fact, any grade of carbon required for lighting purposes can be produced by the Company. The production of lighting carbons, even in the " Ship " plant, is a day-to-day problem, calling for concentrated effort on the part of all concerned—all of whom are justly proud of the high prestige of " Ship " Carbons.

The position as the second-half of the Twentieth Century unfolds is that lighting carbons produced by the Ship Carbon Company of Great Britain Ltd., are to be found in almost every corner of the earth. The Company's products are regularly exported to some 92 countries and at home they are supplied to most lighting carbon users. From a comparatively small beginning, the production unit now occupies some fifteen acres and the policy remains the same—the Company specialises only in lighting carbon products.

The Manufacture of Lighting Carbons

THE chief raw materials used for the manufacture of the shells of arc lamp carbons are lampblack, cokes and graphites of various types, and binding materials such as pitch, tar and oils which are produced by the fractional distillation of coaltar. The properties of the raw materials used in the shell determine to a large extent the burning characteristics of the finished arc lamp carbon. Thus, any raw material which has, in the past, appeared to be at all suitable as a shell constituent has been subjected to most careful analytical examination and detailed production tests.

In a similar manner all promising materials, either manufactured or natural, which arise from time to time, undergo the same comprehensive study. This policy, applied over many years, ensures that Ship Carbons contain only the most suitable ingredients currently available and that no delay will be experienced in the future in exploiting any superior materials which may appear.

Comprehensive routine analytical examination of all deliveries of raw materials ensures that any inferior material is rejected. and is thus the first safeguard in maintaining an end-product which is reliable, consistent and trouble-free.

Lampblack

Lampblack is obtained by burning tar oils in a limited supply of air, and in order that the process shall yield a uniform high grade black, the rate of oil feed, conditions of draught, temperature gradient through the settling chambers, etc., are carefully controlled. The oil is fed into shallow pans which

are located beneath collecting hoods leading into large settling chambers. The oil is ignited in the pans and the restricted amount of air causes lampblack to separate in the flame. The gaseous products of combustion and the liberated black follow a tortuous path through the settling chambers which permits the suspended black to separate and settle out from the gas. The settled black is transferred by suction pipe lines to storage silos and from there to compacting, packing and weighing machines.

Lampblack, which is an ingredient of many shell compositions, must pass tests for purity, density, electrical conductivity, absorption value, etc., before it is approved for blending with the other raw materials.

Grinding Process

Lampblack produced as described above is in the form of an extremely fine powder and the cokes and graphites which are the other main shell constituents must also be finely ground before use. The reduction in size of these materials is effected in the grinding department which houses an assortment of tube mills, ball mills, jaw crushers, sieving machines, etc. Consistency in the final product cannot be obtained unless the powdered materials used in the primary mix exhibit a particle size distribution which always remains within closely defined limits. Thus the grinding and sieving processes always follow pre-determined cycles of rate of feed, weight of grinding balls, size of grinding balls, speed of rotation, total grinding time, etc. Furthermore, samples taken at frequent intervals are submitted to the laboratory for examination for mesh, purity, etc. In those machines where the comminution of the carbon is effected by the impact of steel balls or steel plates, some wear of the metal is inevitable. The small particles of metal which thereby become mixed with the powder are removed by passing the ground material under powerful electro-magnetic separators.

Mixing Process

The powdered materials are mixed with one or more of the binders on a specified weight basis. The temperature of the machine, method of introducing the ingredients, time of mixing, etc., are all carefully controlled. The first mixing process is carried out in large, heated mixers containing intermeshing paddle arms and the resulting mix is then subjected to further treatment in a variety of machines, all of which contribute to the production of a thoroughly homogeneous, extremely dense end-product.

Shell Extrusion

After this treatment the plastic mass is obtained in the form of billets suitable for insertion into large steam heated horizontal presses. Pressures of several thousands of pounds per square inch are used to force the plastic material through dies and mandrills, the sizes of which are constantly being checked in order to ensure that the external and internal diameters of the extruded shell shall be absolutely correct. The carbons which emerge from the heated presses are fairly soft and fragile and the operators who handle them at this stage do so with the utmost care in order to avoid bending them or blemishing the surface. All extruded carbons are carefully examined for size and for minute surface faults such as cracks or blisters.

Kilning of Shells

The extruded carbons are tied in bundles which are inserted in refractory pots, called saggers. The saggers are carefully stacked in chambers made of refractory bricks. The chambers can be heated by gas flames burning in the chamber, or by hot gases from other chambers. As the temperature slowly rises, the binding materials undergo partial distillation and partial carbonisation. The carbon thus produced from the binder is at first soft and electrically non-conducting, but as the temperature increases

the carbon becomes hard, dense, and highly conducting, and thus binds or welds the carbon powders into a strong rod or tube of low electrical resistance.

The kilning process is a most important and critical stage in the production of first class carbons. Hence, the rate of rise of temperature, the final temperature attained, the conditions of draught, the rate of cooling, the uniformity of temperature throughout the kiln, etc., are all under strict and unceasing supervision, and every care is taken to see that a cycle of operations, based on many years of experience, is rigidly followed.

Samples from every batch of carbons coming from the kilns are submitted to the laboratory for tests for electrical conductivity, density, porosity, mechanical strength, size, purity, etc.

Coring

The batches of shells which successfully pass the above tests are now cut to the required length and are then inspected. This means that every piece of shell is examined by trained operators for straightness, size, cracks, blisters, or any other surface blemish. Any inferior carbon having been rejected, the remainder now pass to the coring department. The main core ingredients are carbon powders, cokes or graphites, light-producing materials such as rare earth compounds, other special chemicals, and binding materials. As with the shell ingredients, all deliveries of these materials are subjected to laboratory examination before acceptance.

Various combinations of the above materials are used in different cores. For example, the Low Intensity core contains no rare earth compound and is designed to keep the arc positioned and stable, while the High Intensity core, which is designed to enhance the light output, contains a percentage of rare earth compounds. Other compounds which confer special properties or burning characteristics to the arc may be included in the cores. Years of experience and a vast amount of research have combined to formulate the core com-

positions and samples taken from every batch of cored shells are submitted to the laboratories for confirmation that no deviation from the formula has occurred and that core mixing and extrusion have been satisfactory.

In the coring process the various powders are introduced into the appropriate binding material and after a prolonged mixing period designed to effect thorough incorporation of the solid material with the liquid binder, the paste is charged into horizontal hydraulic presses. These operate at high pressure and squirt the pasty mass into the shell. The highly trained personnel, who do the coring, are extremely expert in completely filling the core hole with a compact dense core free from cracks or air pockets. Nevertheless, every core is subjected to X-ray examination.

After coring, the carbons undergo another stoving operation, during which all traces of volatile matter or moisture are expelled from the core and any organic binder is carbonised. Whatever type of binder is used the result of the stoving process is a hard dense core tightly adhering to the shell.

Copper Plating

Not all types of carbon have to be plated with copper. Carbons which are so treated are made the cathode, while plates of extremely pure copper form the anode in an electrolyte in which the most important ingredients are copper compounds of high purity. The temperature of the solution, time of deposition, current density, spacing of anode and cathode, and the agitation of the solution, are so arranged and balanced that the deposited copper is smooth, dense and highly conductible. Careful control tests ensure that the correct thickness of copper has been deposited, while the stoving treatment, which follows the plating process, removes all trace of plating solution from the carbon.

Final Operations

The final operations for both plated and unplated

carbons consist of pointing, burnishing or polishing, inspection and X-ray examination, printing and packing. The sealed bag in which the carbons are packed consists of a moisture-impervious plastic film, which is a guarantee that carbons which have been subjected to intense heat treatments at various stages in their manufacture to render them completely free from moisture shall not be able to absorb atmospheric moisture between the time of manufacture and the time of use.

Laboratory Burning Tests

Samples are taken from every batch of carbons at this stage for burning tests in the Physical Laboratory, using lamps and burning conditions identical with those existing throughout the cinema industry. These tests are conducted by physicists and laboratory assistants who have had many years experience in this work and are keenly alert to the behaviour and burning characteristics to be fulfilled by a perfect carbon. They are equipped with a comprehensive array of scientific instruments, many of which have been specifically adapted or designed for this particular work. These factors unite to make it virtually impossible for any inferior material to reach the consumer.

Conclusion

From the time that a raw material is delivered to the factory, until the moment that a projectionist opens a packet to select a carbon for insertion in his lamp, no effort is spared to make that carbon as perfect as possible. Trained expert personnel are employed at every stage of manufacture. Each process and operation is fully equipped with instruments and recorders. A staff of scientists are constantly reviewing and exploring any development likely to benefit the consumer, either economically or operationally. Trained service engineers in contact with the operators who use the carbons, send any criticisms or suggestions from the user back to the maker without delay. Each carbon that bears the name " Ship," is painstakingly prepared for the task it will perform.

The Low Intensity Arc

THE discovery of the carbon arc by Sir Humphry Davy in 1810 is, of course, the basis of those developments which have finally led to the production of the modern arc systems of illumination. On its introduction, Davy's discovery clearly showed that electrodes of carbon were much superior to those of any other substance, because, at extremely high temperatures, carbon vaporized directly from the solid state without any intermediate liquefaction.

It was appreciated, also, that Davy's electric arc was potentially the brightest " manufactured " light known to science.

The principle of this far-reaching invention was simple—the passage of direct electric current over the gap (the arc gap) between two carbon electrodes which caused a concentrated bombardment of one electrode, creating a considerable rise in local temperature to vaporization point, approximately 3,800K. The result of this action produced a heated, glowing-white face on the bombarded electrode, which set up an intense light of great brilliance—or, as we say to-day, an intense candlepower per unit area of carbon face.

By convention, the bombarded electrode was called the " positive " carbon and the one transmitting the current was called the " negative " carbon, both being connected respectively to the positive and negative terminals of the electricity supply.

To utilize effectively the light source of the carbon arc was the first obvious step in the development of the invention, two things being necessary—a means to secure the maximum emission of light at the arc and the construction of special optical systems to transmit the light for practical use.

The approach to the first problem led to many experiments in increasing the area of the positive face by using larger electrodes of solid carbon. But this required a higher arc current for heating the increased carbon diameter. This, in turn, required an increase in the size of the negative electrodes of solid carbon to support the strain of increased current loadings.

Problems of light stability then arose. The larger solid carbon arcs spluttered, cracked and behaved erratically under the impact of higher loadings. The arc flame wandered violently around the crater face and the light emitted varied considerably in consistency.
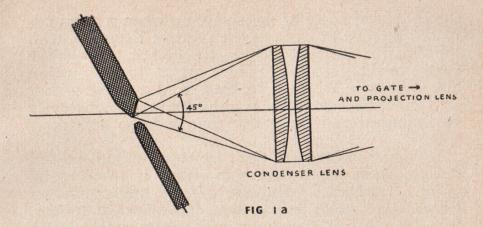
To stabilize the arc, the positive carbon was manufactured as a thick rod and holed centrally, the hole being filled with soft carbon material to form a core to the rod. The object of this was to enable the core to burn more rapidly than the surrounding shell, the burning action forming a shallow crater on the positive face. This crater encouraged the arc stream to remain in the area of the core, thus eliminating the greater part of the spasmodic disturbance in the solid positive electrode.

The remaining limitation to further light output was now the availability and the expense of higher currents necessary to raise the large positive face to the required temperature.
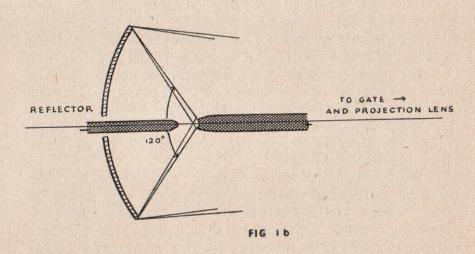
Development of Optical Systems

The construction of optical systems for collecting the emitted light and effectively presenting it for practical use, particularly in the growing Kinema industry, was developing alongside the carbon arc. The early methods of collecting emitted light were through the use of condenser lenses which were placed as near as possible to the arc. To collect the rays at their widest angle, the lenses had also to be made as large as possible. Even the most skilled optical inventors, however, could not produce a condenser system that could, on the one hand, withstand the

FIG 1a

effect of the heat, and on the other, overcome the limitation of increased lens dimensions.

The system indicated in Fig. 1a was the ultimate design in the condenser systems, but it was shown to be theoretically inefficient as compared with the system shown in Fig. 1b.

But it was a matter of time only before all condenser systems were superseded by the new, revolutionary designs embodying the optical mirror. Fig. 1b shows

FIG 1b

CONDENSER & MIRROR TYPE OPTICAL SYSTEMS

the increased angle of light pick-up when a mirror is placed directly in front of the positive electrode, with the negative electrode feeding, if required, through the centre of the mirror. To some extent this innovation also overcame the heat problem, and a larger mirror set further back from the positive face could obviously be manufactured far easier than a large condenser lens.

Having collected the light by this method, several devices were employed to transmit it to a useful point. Sometimes parabolic mirrors and condenser lenses were used, but it was the elliptical mirror, focusing the collected light in the manner which will be fully described in a later Chapter of this book, which was generally accepted.

With the improved optical methods for collecting the emitted light from the improved carbon arcs, the system was thought to be reasonably perfected at this stage of its development. But it was soon found to be not fully efficient.

It was at this point that the Low Intensity arc carbons came into existence.

This new-type arc was so named because it was produced by positive carbons of much smaller diameter than those used previously. For it was discovered that the mirror systems operated at their greatest efficiency when utilizing a small light source of maximum brilliance. The new positive carbons which achieved this result were of from 9 to 14 mm. diameter. Operating at saturation currents, they produced maximum light output. In course of time, therefore, they replaced the large positives of from 15 to 30 mm. diameter.

(Trims involving these "new" positives are frequently employed to-day for cinema projection in cases where requirements do not exceed the Low Intensity level, although, of course, the modern carbons of this type incorporate the many refinements and modifications that have been evolved in the meantime.)

At this juncture it might be well to discuss briefly the general characteristics of a Low Intensity arc between electrodes of nominal size burning in typical conditions, and also consider some of the possibilities and limitations of this class of arc.

First, light output. When a Low Intensity arc is "struck," the arc-current bombards the positive electrode face in the way described earlier in this Chapter. As the arc-current is increased, the area of face at vaporizing temperature is also increased and more light is emitted, though the temperature of the face does not rise. When the crater area on the positive face enlarges and ultimately envelopes the whole of the diameter, even more light is emitted and, naturally, the rate of carbon consumption increases in proportion.

This is the condition known as maximum light output and it coincides with the recommended maximum current rating. But if the arc-current is further increased, instability occurs. This is due to the crater attempting to "overlap" the positive size and creating malformations and air disturbances. Actually curves show (Fig. 2) that projector output per current rating for various-sized positives all tail off to a similar value at maximum rating. This is explained by comparing the effect at the gate of using a small and a large positive carbon. (A later Chapter explains how the magnification of an elliptical mirror is calculated and how, due to the magnification, the size of the positive crater face is enlarged around a projector gate of fixed dimensions.) The large positive will emit a zone of light, after magnification, that considerably overlaps the gate aperture, while the small positive's zone will just cover it. (See Fig. 3.)

This experiment will demonstrate that, although a larger diameter positive will yield greater light output, more light is wasted at the gate, and that a Low Intensity crater face, which is always at the same
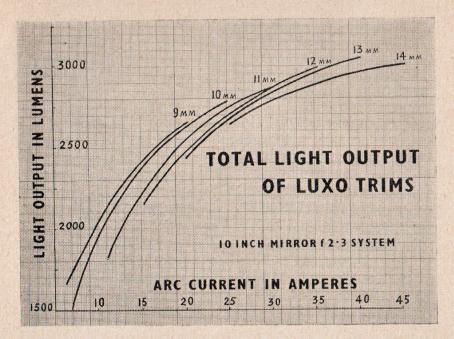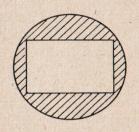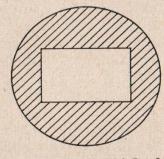
TOTAL LIGHT OUTPUT OF LUXO TRIMS

LIGHT OUTPUT IN LUMENS

3000 — 2500 — 2000 — 1500

9mm, 10mm, 11mm, 12mm, 13mm, 14mm

10 INCH MIRROR f 2·3 SYSTEM

ARC CURRENT IN AMPERES

10 15 20 25 30 35 40 45

Fig. 2

MAGNIFIED IMAGE OF POSITIVE FACE
AROUND GATE APERTURE

USING 10 MM POSITIVE   USING 14 MM POSITIVE

Fig. 3

20

brightness, will pass through the gate an amount of light equivalent to that of the larger positive.

The slight increase in light output from the larger positive is due to the fact that the ratio of core area to shell area at the crater decreases with an increase in the diameter, and also that the core area of the crater face is slightly less bright than the shell area in the Low Intensity positive.

To illustrate this point further, if an exploration were made across the diameter of a glowing positive, the record of the brightness of specific area in candles/sq. mm., would reveal that the overall distribution was level. A maximum brightness of 180 candles/mm., is located in the shell area and a zone of lower intrinsic brilliancy is coincident with the core area. (See Fig. 4.)
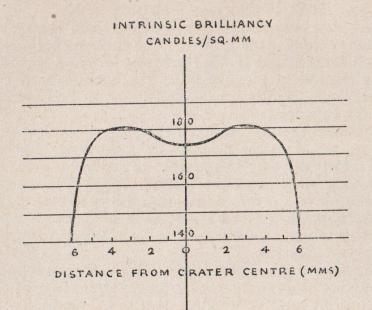
(The advantage of the larger trims is that, owing to the overlap at the gate, less strict manipulation of the arc controls and a greater degree of flexibility in operation, is afforded without unduly affecting the screen light.)

Optically, the Low Intensity positive face acts as a small, glowing disc of almost uniform brightness, and the polar curve of horizontal distribution of candle-power approximates to the shape of a simple circle based on the crater. That is to say that the candle-power of the arc when viewed from a particluar angle, is proportionate to the cosine of the angle that the line of view makes with a normal line through the axis of the positive. It should be understood that no auxiliary source of light emission is appreciable other than the glowing disc of the crater face in the Low Intensity arc. (See Fig. 5.)

Low Intensity Trims

The latest universal Low Intensity Positive has recently been introduced in a range of sizes of between 9 and 14 mm. These can be operated with a choice of negatives according to individual requirements. This

21

INTRINSIC BRILLIANCY
CANDLES/SQ.MM

DISTANCE FROM CRATER CENTRE (MMS)

VARIATION IN INTRINSIC BRILLIANCY ACROSS POSITIVE FACE

CRATER

SHELL   CORE   SHELL

12 MMS POSITIVE

Fig. 4

THEORETICAL CURVE
FOR GLOWING DISC

ACTUAL CURVE FOR
TYPICAL L.I. TRIM

**HORIZONTAL DISTRIBUTION
OF CANDLEPOWER OF L.I. ARC**
12mm POS/8mm NEG 30 AMPERES
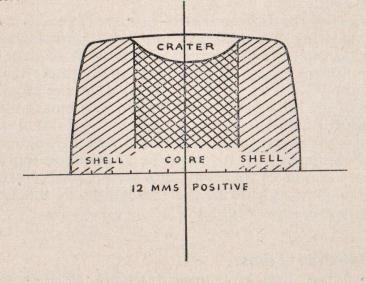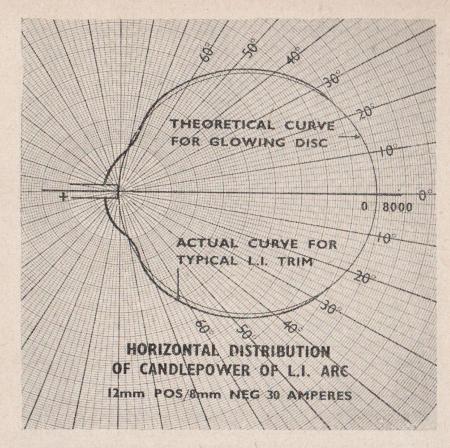
Fig. 5

positive gives a maximum light output and a minimum consumption rate at a wide range of current ratings for each size in any Low Intensity Projection System. It has a specially designed pure carbon shell of lampblack, designed both in composition and diameter to produce the correct symmetrical crater shape for the recommended current ratings.

A choice of negatives is available. For low current ratings in the recommended range a Low Intensity No. 27 solid negative of from 6 to 10 mm. diameter, pairs with the universal positive to give a clean burning performance. A Low Intensity No. 25 negative is

available in 6 to 10 mm. sizes for higher current ratings. This negative has a pure carbon shell and a copper-plated, hard core, inserted centrally in the shell to encourage correct point formations when burning. As a trim with the universal positive, this type of negative provides for stable operation and great flexibility at maximum current loadings. A further range of Low Intensity No. 28 negatives of pure lampblack carbon, with an external copper-plated sheath, can be utilized for high current ratings. These negatives have a greater current carrying capacity and, therefore, a smaller diameter negative than usual can be employed—the slight gain in light from some systems, due to less obscuration, is partly offset by the uneven burning rate ratio for this trim, whereas the former trims operate with a specially maintained 1 : 1 feed ratio.

It should be noted that each size of Low Intensity Positive, with an appropriate negative as a trim, has a recommended current range in which the best performances can be assured. If the maximum rating is exceeded, it is possible for instability and excessive burning rates to arise, with negligible gain in light. It will be seen from the curves shown here displaying light emission in lumens against arc current (Fig. 2) that the values approach a maximum at the limit of the recommended range. The complete table of recommended ratings and the data of performance is appended at the end of this book.

Colour Distribution

The colour quality of the Low Intensity arc is generally a poor match by comparison with the colour balance of the noon-day sun, and thus the projection of colour film from this arc suffers accordingly. The characteristic Low Intensity light is predominantly yellow and, on analysis, the emission is found to contain a higher proportion of red light than balanced sunlight. In the ensuing diagram (Fig. 6), a dotted curve showing the Spectral Energy Distribution of a
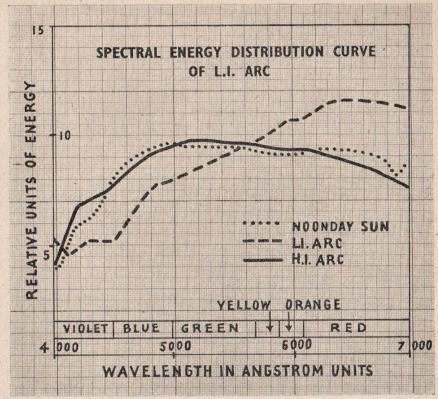
Fig. 6

typical High Intensity trim is given for the purposes of comparison. It will be seen that this curve follows closely that of the noon-day sun and is ideal for use in colour reproduction.

Burning Rates of Low Intensity Carbons

The charts of Positive and Negative Burning Rates for every size carbon and its operating current range, are shown on pages 93/4 and, naturally, an increase in the rate of consumption is apparent with increased current loadings. The actual value of Burning Rate in inches per hour is very low ($1\frac{1}{2}$-3) in all cases, and the Luxo Positive/Low Intensity Negative No. 25 and the Luxo Positive/Low Intensity Negative No. 27 trims are designed to give balanced 1 : 1 Burning Ratios over this operating range. Because of the

usual practice of arc lamp manufacture to feed positive and negative carriages together at the same speed through a common screw thread, this factor is most important. The effect of the controlled ratio is to ensure that the positive crater remains in the focal plane of the mirror for considerable periods without attention other than the maintenance of a suitable arc gap by periodic hand feeding, or continuous motor drive.

General Features of Burning

A trim of Low Intensity carbons burning at recommended conditions should require only the minimum of attention and operate with very steady screen light. The distance between the positive and negative electrodes, while burning, is termed the arc-gap and affects arc-voltage and screen light; too wide an arc-gap will be accompanied by a high arc-voltage, low arc current, and consequently a fall in light output. It is characteristic of a low intensity trim, when burning at the most satisfactory conditions, to produce about 50 volts at the arc—varying from 48 to 52, depending on the size of the selected trim. This corresponds to approximately a 6 mm. arc-gap for the higher ratings in each range when a Low Intensity Negative No. 25 is employed; and a somewhat closer arc-gap at the lower current ratings in each range when a solid Low Intensity Negative No. 27 is used.

The final point lengths of burnt carbons should be reasonably short, approximately $1\frac{1}{2} \times$ diameter of the electrode, if the carbon trim is of the correct size and burnt in the correct range. If the negative, for instance, is smaller than the size recommended, or if it is employed at arc currents above the maximum quoted, the point length increases, becomes quite sharp and affects the positive performance even though this itself is burning at the correct conditions. Great care should be taken to select a trim of carbons for burning, as advised in the data table, and to burn this trim within the suggested limits of arc current and at the recommended arc-gap.

Use of Low Intensity Arcs

If these instructions are followed, and all ancillary equipment is in working order, i.e., lead contacts, meter readings, mirror adjustments, etc., a trim of Low Intensity carbons can be employed with every confidence to give adequate illumination for small screens. An indication of practical usage is obtained by considering that the light output from a nominal trim burning at the top current rating is sufficient to illuminate a 15-foot screen width to the minimum brightness of viewing, as laid down by the British Standard. (See page 68). Such a level of brightness is provided by a 12 mm. Luxo Positive and 8 mm. Low Intensity Negative No. 25, burning at 30 amperes 50 arc volts, when the screen surface has an apparent reflectivity of approximately 0.7. This is the value of a reasonably new matt screen. If, however, the latest selectivity reflective metal screens are illuminated from such a Low Intensity source, screens of greater width can be projected at adequate levels of brightness.

It should, lastly, be remembered that numerous " Low Intensity " arcs of the earlier type, i.e., large diameter electrodes in condenser type lamps, are employed for general illumination, for spot or flood lighting, as in the theatre industry, etc. This type electrode, however, is now referred to as the " Stage Arc " Carbon and details of its performance and practical operation are discussed in a later Chapter.

High Intensity Arcs
Non-Rotating Copper-Coated

THE non-rotating copper-coated carbon provides the most popular arc lamp trim in general use to-day, as the size and types of carbons available cover a current range of 30-85 amperes and produce at an economic price, levels of light output, from conventional lamps, suitable for most sizes of screens.

For this class of arc, it is possible to introduce properties into the carbons that enhance their performance without producing adverse effects in other directions. (For example, carbons can be made to give slow rates of consumption, but this advantage can be offset by lowering their standard of luminosity or restricting their flexibility. Again, high light output is usually accompanied by a faster burning rate—and so on.)

The Ship Cerex and Cerelite series of positives, with their corresponding negatives, have been developed with the sole object of meeting the limiting factors present in any installation. Providing the correct trim is chosen, a satisfactory performance is assured.

Positives

All Cerex and Cerelite positive carbons have copper-coated shells with specially designed star section cores containing carbon and rare earths. The Cerex positive shell and core are designed to produce the maximum light for a given arc wattage, and are intended for use where the electrical power supply is limited.

The Cerelite positive, on the other hand, is designed to produce an economical burning rate together with adequate light output. They are, in consequence, at

their best when burned towards their maximum current and, due to their composition, the carbon consumption is still kept within the speed of feed of the lamp mechanism.

Negatives

The Cere-neg negative is an all-purpose carbon designed to be used with either Cerex or Cerelite positives. It is made in $\frac{1}{2}$ mm. sizes from 5 mm. to 8 mm. diameter, all of which are copper-coated to enable them to carry the required currents. Each negative has a round core to give stable burning, at the same time reducing carbide formations on the point to the minimum. This in itself greatly assists the stable burning of any trim, which is essential if reliable and steady screen light is to be maintained.

Properties of the Arc

Carbons of the types described are generally burned with the positive and negative directly opposed to each other, although they can also be operated satisfactorily in lamps in which the negative is slightly inclined to the positive axis. The appearance of the arc when burning normally is shown in Fig. 7.

It can be seen that the arc is a complex source of light with a fairly deep crater from which emerges a tongue of white flame referred to as the core flame. Surrounding this and extending upwards is the main tail flame which is tinged with red and yellow. Between the positive and negative electrodes the flame is bluish white, and not as intense as that near the crater.

The core flame is produced by the vaporisation of the rare earth content of the core due to the high temperature developed within the crater. This is known as the Beck effect, after the name of its discoverer. This typical phenomenon of High Intensity arcs was observed in 1910, and from it was created the high crater brilliances in common use to-day.

The strength of the core flame is influenced by the current passing through the carbons and also by their
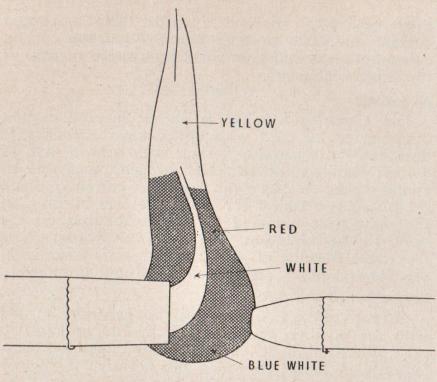
YELLOW

RED

WHITE

BLUE WHITE

Fig. 7

design, and it will be appreciated that this flame becomes more intense as the current is increased. The core flame fills the glowing crater and also extends into the arc stream. It is highly luminous and partly transparent, so that the glowing crater containing the flame can be seen through it and contributes to the total light emitted.

Magnetic Flame Control

With this type of arc it is essential that some form of magnetic flame control should be added to enable the arc to burn efficiently. If the arc is allowed to burn naturally without any external magnetic influence the formation of the flame is rather indefinite. It tends to lie well round the crater edge and on to the shell behind it. Consequently, the density of current

through the crater face is reduced at the expense of what passes through the shell behind the crater, so that the Beck effect is relatively poor and the crater brightness also suffers.

The arc flame which is carrying the current is subject to magnetic influence just as is any conductor carrying current. The flame can be moved or deflected by a magnetic field produced by permanent or electro-magnets. A suitably arranged magnetic field will force the arc flame upwards and, at the same time, the flame surrounding the shell behind the crater will be brought forward towards the crater edge, thus concentrating the flow of current through the crater and producing a well formed core flame.

In the case of arcs having an angular presentation of negative, the magnetic field surrounding the positive and negative carrying current is bent at the arc, so that the magnetic flux is denser just beneath the arc than above it. This in itself produces an upward force on the flame which helps the correct formation of the core flame so that any additional magnetic control need not be as strong as in the conventional straight arc presentation.

Most modern arc lamps are fitted with a properly designed and correctly positioned magnetic control, either electro-magnetic or permanent magnetic, or even " blower " type which maintains and positions the arc flame to give a satisfactory performance. Any serious weakening of this auxiliary field can influence the behaviour of the arc, particularly when the current is low enough to run the carbons below their minimum rating. Under certain conditions where the magnetic control is weak the behaviour of the arc is such that the core flame tends to surge, so that the light rises and falls over a wide range of intensity.

Total Light Output of the Arc

The light emitted from the arc varies in intensity as different angles to the axis of the carbons. This is best illustrated by a polar curve of candle-power at

HORIZONTAL DISTRIBUTION OF CANDLEPOWER

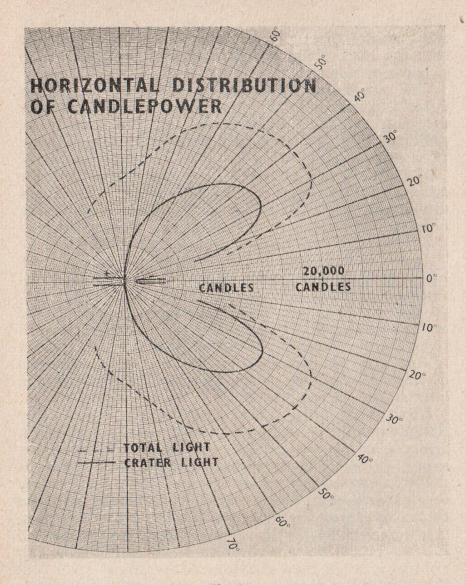20,000 CANDLES

CANDLES

- - - - TOTAL LIGHT
—— CRATER LIGHT

Fig. 8

in Fig. 8. It shows the variation in candle-power, the obscuration produced by the negative electrode, and the wide solid angle over which light is produced. On the same diagram is shown also the variation in candle-power of the crater alone. It will be seen that the shape of the curve of total light, although symmetrical, has a complex, somewhat pear-shaped form. The emission of the crater only is, however, practically a circular polar curve, if the obscuration of the negative is ignored. This shows that the radiation from the crater follows the well-known cosine law and supports the theory that the crater is behaving similarly to a glowing disc in respect of light output. It is, of course, the crater that is used as the light source for cinema projection, the light arising from the other components of the arc being lost before reaching the screen. The size and brightness of this crater are the governing factors of the light projected on to the screen. Under normal operating conditions the brightness of the crater is nearly three times that of the Low Intensity arc, and enables screens up to 50 feet wide to be adequately illuminated when the arc is used in conjunction with a large fast mirror system and projection lens.

Because the crater diameter does not change much with the arc current, the increase in crater brightness is very noticeable as the arc current is raised. This is quite different from the Low Intensity arc where increase of current produces a larger crater, the brightness of which is not greatly increased.

Lamp Optics

Fig. 9 shows a typical mirror type arc lamp using copper-coated carbons. The mirror has an elliptical section and has the property that an object placed at the minor focus f is imaged at the major focus F.1 Due to the fact that different zones of the mirror have different views of the crater, the image at F.1 consists of a large number of images superimposed on each other, giving a somewhat diffused spot on the film aperture.
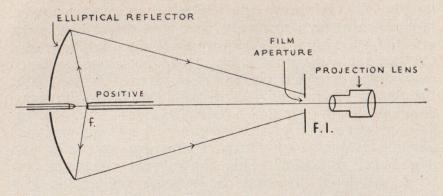
ELLIPTICAL REFLECTOR

FILM APERTURE

PROJECTION LENS

POSITIVE

f.

F.1.

Fig. 9

The relationship between major and minor focus of the mirror governs the size of this spot in regard to the crater diameter, and in the design of a lamp it is essential that this spot has a size sufficient to cover the film aperture. For a fixed magnification of the crater it is obvious that the larger the positive crater the more light is wasted at the aperture, but, at the same time, greater flexibility of control exists without producing bad corner illumination of the screen.

The amount of light collected by the mirror is a function of the solid angle of collection. It does not follow that a larger mirror must collect more light, as it is possible to have the same solid angle of collection with a smaller mirror having a shorter minor focus. This principle when applied reduces the initial cost of the mirror, but this is offset by the mirror, being closer to the arc, deteriorating quicker, due to its higher working temperature.

Little or no increase in screen light is observed if the optical speed of the mirror is increased beyond that of the projection lens, the extra light collected by the mirror being incapable of projection on the screen owing to the extreme rays from the edges of the mirror not being transmitted by the projection lens to the screen.

With this type of arc and optical system, precise setting of the focus of the crater and alignment of the lamp and mirror are essential if the maximum results are to be obtained on the screen. A reddish screen light and loss of total light occurs if the positive carbon is too near to the mirror, which will be imaging part of the glowing shell behind the crater on to the aperture. Conversely, if the positive crater is too far from the mirror, a bluish screen will be obtained as the blue column of flame instead of the crater will be in focus at the film.

PRACTICAL DATA

Screen Light

The total screen light is conveniently measured in lumens, which is the product of the screen area and mean light intensity in foot-candles. This is tabulated for all the trims of Cerex and Cerelite carbons over a current range of 30 to 85 amperes, and serves as a guide to the trim required for the conditions applying in any cinema.

The ultimate luminosity of the screen to the audience is a combination of illumination and reflectivity of the screen surface in the direction of viewing. It is now possible to obtain adequate screen luminosity with special types of metallised screens with lower crater brightness than required with matt screens. This subject is discussed in more detail in Chapter 10.

Carbon Consumption

The burning rates of Cerex, Cerelite and Cere-neg carbons, are conveniently expressed in inches per hour, and depend not only on the arc current, but also on the arc wattage. The carbon consumption figures quoted are average values, as it is known that the results vary from lamp to lamp, but are sufficient to serve as a useful guide to the burning rates of the electrodes.

As the positive carbon reaches its maximum current the increase of burning rate with current usually begins to rise more rapidly than at the lower end of the current range. On the other hand, the negative carbons have a burning rate increase with current rise which is more gradual. This point must be considered for lamps having a fixed feed ratio of positive and negative, as the burning rate ratio of positive to negative does not remain constant over the whole current range, and a suitable choice of trim must be made to enable the positive crater to remain in focus on this type of arc lamp.

Colour

The question of the colour of the light emission of the carbon arc in its many forms has been the object of much research and measurement by many workers in the field. There are several ways of interpreting these results, either as colour temperature, trichromatic co-ordinates, or in the form of a curve of spectral energy distribution. The latter method shows the colour of a light source in a readily understood manner and is of practical use to the carbon designer, enabling him to see where the light is deficient in certain radiations, which may be compensated ultimately to match another source.

A curve is obtained by allowing light from the arc to fall on the slit of a spectrometer through which it passes to a prism which separates the white light into its different wave-lengths in the form of a spectrum. The spectrum is explored by a thermopile mounted behind a second slit, both of which are moved along the spectrum, thus receiving a small portion of light of different wave-lengths, depending on their position. As the thermopile converts the light energy to electrical energy it can be connected to a sensitive meter whose deflection will indicate the energy at different wave-lengths. Applying certain corrections, a graph can be drawn of light energy against wave-length and this is termed the spectral energy curve of the light examined.

A typical curve of High Intensity light is shown in Fig. 6. It is seen to have a continuous radiation with certain peaks, the highest lying in the green region at 5,000 A.U. Beyond the red, at 7,000 A.U., the energy falls off gradually, and it is obvious that this light, having its main energy in the visible region between 4,000 and 7,000 A.U., is more efficient from the projection standpoint since any energy beyond the limits of the visible region does not produce screen light but only heats the film at the aperture.

Heating the Film

Visible light being a form of energy will itself heat the film at the gate. This heating exists as well as that of the non-visible infra-red portion of the spectrum. In consequence where high screen light values are required, the larger sizes of carbons, at their maximum operating conditions, produce enough radiation at the film to cause damage through embossing or buckling.

By suitably filtering the infra-red portion of the radiation in the beam before it reaches the film, substantial reductions in film heating can be made without serious loss of visible light. The filters used, because they are absorbing radiation, get hot and have to be fitted with a cooling system, usually an air blast.

High Intensity Rotating Positives

THE first practical application of the Beck Effect, by which high current densities were used with carbons containing mineral loaded cores, achieving high crater brilliancies, was in the field of uncoppered carbons with front electrical contacts. The first War gave the incentive to the development of searchlight lamps based on this principle. In these lamps the current was led into the carbons near the burning end, the negative carbon was orientated at a steep angle to the positive, and, to maintain a straight crater, the positive carbon was continuously rotated.

It was some years, however, before this type of lamp was employed for cinema projection, but in the early days of H.I. cinema lamps it was very popular, employing positive carbons between 9 and 16 mm. diameter, operating at a current from 60 to 150 amperes and usually employing a condenser lens optical system.

With the introduction of the trims of small copper-coated carbons operating with elliptical mirrors of high optical efficiency, the rotating arcs have declined in popularity in the cinema, although some projectionists have preferred to retain the condenser lamps by reason of their greater latitude of operation.

The more recent demands of film presentation which require more and more luminous output from a lamp, have revived practical interest in this field where higher crater brilliancies are potentially available.

Probably the most critical factor in such a high current density lamp is the design of the jaws whereby the current is led into the carbon at as short a distance from the burning tip as is practicable. The jaws must make good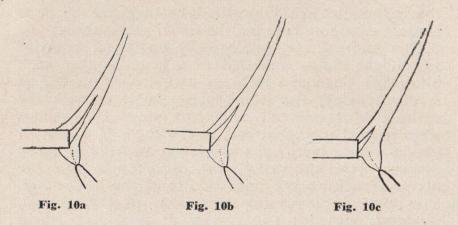 mechanical and electrical contact with the carbon to avoid localised heating due to poor contact or arcing between the metal and carbon.

One method very successfully employed in some searchlight lamps consisted of a gland packed with plumbago through which the carbon was pushed as it burnt away, the whole gland rotating with the carbon. More generally in cinema lamps, alloy metals were shaped to the carbon in the form of a pair of spring-loaded jaws. If these jaws are situated some distance from the carbon tip, the heating from the arc itself will be low and the life of the jaws good. The long, incandescent protrusion of the carbon, however, provides a large surface area from which carbon evaporation can take place, and the consumption rate suffers severely.

The trend, therefore, is to reduce the protrusion as much as possible without damaging the jaws. Developments of more recent years have been to utilise water-cooled, silver jaws with short protrusion and such developments have been made all the more necessary with the demand for higher current densities.

The angle at which the negative carbon is orientated with respect to the positive is of importance. The optimum angle is a matter of experimentation with each particular lamp design and trim of carbons, and is a compromise between various factors. A shallow angle would produce a certain amount of optical obscuration of the crater, but would give an upright tail flame to the arc. A steep angle would tend to throw the tail flame forward, possibly enough to impinge on the mirror or lens in use, which must obviously be avoided.

The explanation of the variation of the tail-flame angle lies in the influence on the arc-stream of the magnetic field created by the arc-current itself. With a horizontal arc the magnetic lines of force are distributed uniformly round it and therefore exert no force, but as the negative carbon is angled more and more steeply to the positive, the lines of force underneath the arc become more and more compressed

Fig. 10a   Fig. 10b   Fig. 10c

and those above it spread out, the resultant action being that the flame is thrown forward. It is for this reason that it is generally unnecessary to introduce a supplementary magnetic control as with horizontal H.I. arcs, although it may be employed in some instances. Arc stability and even light output are tied up with the magnetic influence and all these factors must be considered in determining the optimum angle at which to set the negative carbon.

The relative positioning of the positive and negative carbons is also of importance to obtain the optimum conditions of steadiness and light output, and it is illustrated clearly in the accompanying diagrams.

If the positive carbon is fed too far forward as in Fig. 10a so that the arc-flame well overlaps the shell of the carbon, the energy is not fully concentrated within the crater and some loss in light output can result. Instability may also be introduced by the overlapping arc-flame occasionally tending to jump further back along the positive shell. The opposite extreme is illustrated in Fig. 10c where the bowed arc-flame, introduced by the retarded positive, creates a fluttering and unstable arc. The correct positioning lies between these two and is illustrated in Fig. 10b where the arc-flame hooks nicely on to the shell without producing any of the above deficiencies.

In general, these lamps, whether for studio or cinema use, are operated with a condenser lens optical system, but with the small to medium diameter carbons, elliptical mirrors are frequently used.

With the older type cinema lamp, almost extinct, and the new types demanding much higher current densities to cope with current demands in film presentation, little is to be gained by listing types, sizes and performances of carbons available. Several new carbons have been developed for individual requirements and research continues both in carbon and lamp design, aimed at higher current densities and stable performances.

Negative carbons, both plain and coppered, are available to pair with the positives to suit any particular requirements.

Projection Carbons For Use With Alternating Current

THE burning of a carbon arc when operating from an alternating current supply demands special qualities in the carbons. Good arc stability must be achieved in spite of the fluctuating current and the craters must give as constant a light output as possible, even though each carbon of a trim spends half its life as a negative electrode. At the same time, provision must be made for the high current densities that are indicated in the Appendix. They must be accommodated without the pencilling of the carbon.

The range of carbons marketed under the name Alternalux, have been designed with these factors in mind. They offer the projectionist who does not require a high luminous output, an arc which is very simple to control with a simple electrical supply unit, yet giving a screen matching the colour of those provided by the High Intensity D.C. trims.

The carbons are made in diameters from 7 to 9 mm. and are basically similar to the Cerex and Cerelite positives, i.e., a copper-coated shell with cores loaded with rare earth salts, but with the necessary modifications to render them particularly suitable for A.C. operation when two identical carbons are opposed to one another. The arc itself is symmetrical about the centre plane, each carbon forming its own core and tail flames. The shape of the carbon tip after burning, as might be expected, is a cross between normal positive and negative formations. Thus a crater is formed, but this is much more shallow than with a Cerex or Cerelite positive, and the point is more tapered. The result is that the crater diameter is rather smaller than with the corresponding D.C. grade of carbon.

The rate of consumption of the carbons also lies between those of a positive and negative of the same size when burnt at their respective corresponding D.C. loadings. It is to be expected, therefore, that the crater brilliancy will also fall short of that of the High Intensity D.C. craters and, indeed, this mode of operation helps considerably to fill the gap in luminosity existing between screens of Low Intensity and High Intensity trims.

If it were possible to utilise effectively the light emitted by both craters, the alternating current arc would give a luminous output similar to the High Intensity D.C. arc. The optical complications are, however, insuperable, and it is customary to work with the established elliptical mirror system, although some attempts partially to collect the light from the opposing crater have been made.

The opposing crater, being larger than the pointed D.C. negative, must obscure a certain amount of available light from the mirror, but it is not suggested that a wider arc-gap than the recommended 6-7 mm. be used to reduce this obscuration. For any given electrical input this gap has been established as the optimum compromise between light-output and stability, and, in general, if a wider gap is used, the light output will fall.

It has been mentioned in Chapter 3, that small diameter craters with standard magnification within the optical system give less light spill around the film-gate, and require a little more care in mirror adjustment. This also applies to the smaller craters of the Alternalux carbons and, in practice, a little more precision is required than with the same size Cerex or Cerelite carbons used on D.C. The coverage of the gate is, however, quite adequate and it does not follow that the distribution of light across the screen must suffer. As stated previously, the major portion of the useful light from a crater arc emanates from the core-flame and the larger core utilised in

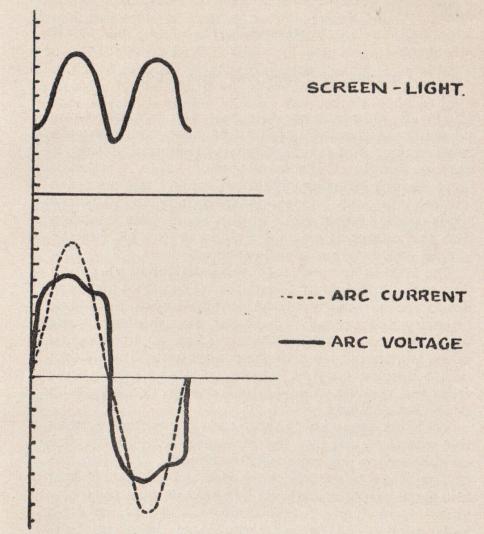Alternalux carbons results in a screen of very satisfactory flatness.

It will be appreciated that in consequence of the alternating potential of each electrode, the light output must vary through a regular cycle in harmony with the frequency of the supply. Ship Alternalux carbons have been designed to reduce this variation to a minimum and reference to Fig. 11, which illustrates a typical oscillogram of the light as received at the screen centre, shows that the light output reaches a peak not only when the carbon facing the mirror is positive, but also when it is negative, although the latter peak does not quite reach the same height as the former. It will also be observed that the minima, which coincide with zero current, drop lower when followed by the negative half of the current cycle.

The flicker shutter operates at a speed of 48 per second, i.e., the shutter is open for a little less than half the duration of the cycle illustrated in the oscillogram. The area under the curve is a measure of the quantity of light received by the screen and measurement shows that during the period of the shutter being open, i.e., 1/96th second, the total quantity of light reaching the screen cannot vary by more than 5 per cent. above or below the mean value. It needs a critical eye to be able to detect a " beat effect " of this magnitude on a plain screen and it should not be observable when a film is running.

The oscillograms of the arc-current and voltage show that these two remain in phase, but while the former is not greatly distorted, the arc-voltage wave form is markedly different from the sine-wave form of the supply. This distortion results in a power factor of approximately 0.96.

SCREEN - LIGHT.

----- ARC CURRENT

——— ARC VOLTAGE

TYPICAL OSCILLOGRAMS OF SCREEN-LIGHT, ARC CURRENT AND ARC VOLTAGE FROM AN H.I. A.C. ARC.

Fig. 11

Carbons for Stage and Spot Lighting

STAGE illumination does not call for the same degree of precision as the cinema screen, where the projectionist must maintain a brightness within a narrow margin of his standardised value, whichever lamp he may be using. He must achieve this standard without the light dropping materially towards the edges of the screen, while at the same time ensuring that the composition of the light is suitable for the correct presentation of colour films.

The spot-lamp operators' job calls for illumination that is the opposite of constancy. The art of his work lies is the variability of the illumination in spot-size, intensity and colour to suit the presentation of the particular scene on the stage. Thus, so long as his lamp is capable of providing adequate illumination of the largest spot he wishes to use, all variations from this may be achieved by focusing, diaphragming or by use of filters.

With his apparatus there is no permanent restrictive aperture, such as the film-gate, to limit the size of the carbon he can usefully employ, and for this reason the straight-arc lamp with its condenser lens and large diameter carbons has held its own for many years as a simple, economical, and yet effective instrument. The use of these large diameter, Low Intensity carbons provides very efficient trims for the lamps and to fill these requirements the range of Ship Stage Arc carbons has been developed. Positives are available in diameters from 10-25 mm., each size being paired with a negative carbon designed to give an equivalent burning rate to its respective anode over the recommended range of burning conditions.

A table listing the pairings of positive and negative carbons, the recommended current ranges, and the consumption rates, is given in the Appendix.

It will be observed that three grades of negative are listed, the copper-coated core type being matched with the smaller positives while, for the higher currents, externally plated negatives are employed. These two grades cover between them, the whole range of positive carbons and assure equality of burning rate to be achieved while presenting a sharp point to the positive carbon, thereby giving good stability of operation.

A more economical alternative is provided in the unplated solid negative which, by reason of its lower current-carrying capacity, burns with a little blunter point. The arc, in consequence, is a little less stable and to accommodate this, the positive has to be burnt at a rather lower current.

In practice, each of a pair of carbons is mounted in line with the other and at a small angle to the vertical, say, 20-30°, with the positive electrode uppermost. The negative is positioned to give a positive crater facing the condenser lens as accurately as can be achieved without the negative tip obscuring the collection of the light and so producing a patchy spot, or without the formation of undesirable lips to the crater. In general, it remains necessary for the crater to be facing slightly downwards but, even so, the major portion of the available light will be collected by the condenser lens. The negative position is, of course, very important but this can rapidly be established with experience.

Such lamps have altered very little from the day of their inception and, indeed, still give a very satisfactory performance for a large proportion of spot-light requirements. The trend of more recent years, however, has been to develop cinema-type projection lamps for spot-light use. Lamp-houses and mechanisms, in some cases identical to those used for film projection, utilising elliptical mirrors or some equivalent optical system and employing either Luxo, Cerex,

Cerelite or Alternalux carbons, are becoming more and more popular for the larger theatres and stadia.

In general, since the aperture to be filled with light is larger than the cinema aperture, it is the larger carbons of a grade that are used, the Low Intensity and alternating current trims being burnt at cinema ratings. In the case of the High Intensity, copper-coated grades of carbons, the light output attainable at their cinema ratings is largely unnecessary and the rate of consumption of the carbons is too high for continuous use over a lengthy period. It is therefore customary to burn these carbons at medium current densities only. Thus a 9 mm. Cerelite positive may be burnt at 50-70 amps., an 11 mms. at 75-95 amps. and so on. Under these conditions a major saving in burning rate is achieved and since smaller negatives than those for use at fuller loadings, would be employed, the consumption ratio of the carbons may fall to 3 : 2 or even less.

The craters formed at these current densities are much shallower than when the carbons are fully loaded, but High Intensity colour is still achieved. The carbons may be burnt in a horizontal position or with the negative at a steep angle. In the latter case, the negative is orientated to form the positive crater at an angle of about 60° to the carbon axis, which condition is the best compromise between the quantity of light projected towards the mirror, the avoidance of obscuration by the negative, and the stability of burning of the arc. Low Intensity carbons may also be burnt in this manner and, indeed, both high and low intensity trims of this nature are still in use in some cinemas for normal film projection.

Such lamps for spot-light use are provided with an adjustable iris to vary the illumination from a small spot to a flood. With small spots the crater does not require a high degree of magnification to give adequate coverage and in this instance the smaller High Intensity carbons with their higher crater brilliancy

have the advantage. On the other hand, to cover the iris when fully open, the carbons must be moved considerably closer to the mirror, to increase the crater magnification. The smaller degree of de-focusing required by the larger low-intensity craters often enables these to match the medium current density trim in large spot brightness. Indeed, under such conditions it is often only the large carbons that can fill the aperture adequately without de-focusing to such an extent as to render the light-spot patchy.

Between the types of lamps available and the ranges of carbons to suit them, all normal requirements of stage and spot-lighting have been met, and the variety offered by the Ship Carbons enables the customer to select his trim according to the size and brightness of the illumination required, while at the same time, considering running costs and the availability of current.

The Carbon Arc
A Source of Light for Special Purposes

THE carbon arc in its many forms is unique in the sphere of illumination. It is applied on a large scale in many processes where intense, readily reproducible and controlled radiation is required.

The wide field of cinema projection is covered in some detail elsewhere in this book, but there are other fields of application for the carbon arc which are also worth mentioning.

Film Studios

Because of its high light output and reproducible colour, the carbon arc is used for many processes in the film studio, both as a general illuminant for colour photography and for special application in rear projection.

For studio illumination the two principal types of arc used are, first, the rotating positive High Intensity type, uncoppered, with a forward contact just behind the positive crater. This is used with a copper coated negative inclined to the positive. These arcs are used in conjunction with a large Fresnel type condenser and suitable carbon trims have been developed to cover a current range of 70 to 200 amperes, depending on the type of lamp used.

The second type of lamp burns four carbons making two arcs in series, the light emission being used from the flame between the electrodes, which passes through a diffusing screen after reflection from a curved metal surface behind the arcs.

Generally, for rear projection applications, rotating positive arcs are employed with condenser systems. These enable uniformly illuminated screens to be projected at the very high levels of intensity required for this class of work.

Searchlights

It is well known that the carbon arc is used exclusively for military and naval high intensity searchlights. Generally, rotating positives are employed in conjunction with very large parabolic reflectors which throw an intense parallel beam of high candle-power. Smaller types, using Low Intensity carbons, are also used where slow burning rates of the carbons and lower light values are desirable. Long running searchlights are also used on ships passing through canals, such as at Suez, the beam guide illuminating the banks and water way during night passages.

Photographic Use

Flame arcs are used to a large extent in the photo-printing trade for illumination of the copy for reproduction in newspapers and magazines. These arcs fall into two main categories. The first, the open white flame arc, is used principally for colour reproduction, where its high light emission and suitable colour value make it ideal for this accurate photographic technique. This arc quickly establishes its light emission on striking. The arcs used are either run individually from a transformer on A.C. supply, or run in the form of up to four arcs in series from the mains supply. Direct current arcs are also used and electrodes are specially developed for this system. Other arc lamps burning three carbons on 3-phase A.C. supply find many uses.

Enclosed arc lamps burning plain carbons in a glass envelope, developing strong blue-violet emission, are used with materials which are principally blue sensitive. These lamps can be run for very long periods maintaining a constant emission with a very slow rate of consumption of the electrodes. The electrodes are manufactured specially to be very clean so that deposits on the lamp glasses are reduced to the minimum.

Spectroscopy

One very important application of the carbon arc is in the field of spectro-chemical analysis, where it is applied in conjunction with a spectrograph to analyse materials on the following principle:

When atoms or molecules [are disturbed, e.g., by heating them to a sufficiently high temperature, they begin to radiate energy in the form of light of various wave lengths. This can occur in both the visible and ultra-violet regions of the spectrum. Because the atoms of different elements have variously arranged constituents, the radiations from each element can differ from each other. Every element radiates with its own individual characteristic groups of wave-lengths, which serve as a means of identification, if the wave-lengths are measured and identified.

The spectrograph is the instrument which enables radiation to be analysed into its various wave-lengths, which appear on the photographic plate in the form of vertical lines in different positions. This collection of lines we refer to as a spectrum, and it is possible to measure the wave-length of each line from its position on the plate. It follows that if the wave-lengths of the lines obtained in a spectrum correspond to a certain element it can be assumed that this element has produced them.

To analyse a material it is placed into a hole drilled in the lower carbon of a vertical arc. As the arc burns the material radiates its characteristic wave-lengths as these, as explained, are identified on the photographic plate of the spectrograph. The carbons themselves are of course also heated and radiate wave-lengths corresponding to carbon, but fortunately, in a wide region of the ultra-violet, carbon only produces one line so that the spectrum is left practically clear for the observation of the wave-lengths produced by other elements. It is, naturally, essential that the carbon electrodes used in the examination are themselves free of any impurities which would appear as lines in the spectrum thus confusing those given by the material under examination. Special electrodes are therefore made for this purpose which are extremely pure.

This method of analysis has become of general use in the modern laboratory, where it is applied to many industrial problems requiring a rapid analysis of a given material. Due to the very high temperature produced in the arc, practically all elements are volatilised so that a complete analysis may be quickly established. Its applications are numerous and include rock and soil analysis as well as the control of many manufacturing processes in the chemical industries.

Use of Ultra-Violet

The carbon arc emits ultra-violet radiation, the quality and quantity of which may be controlled by the ingredients introduced into the cores of the electrodes. Ultra-violet is used as a source of curative radiations in hospitals and clinics where " sunlight " treatment is given. Because of its intense radiation of ultra-violet light, the open-type flame arc is a suitable source for rapid ageing and fade testing of coloured fabrics and paints. It is also used for the tropical testing of rubber coverings. Samples under test in this connection are placed close to an arc lamp which will subject the materials to an intense radiation similar to sunlight and thus give an accelerated test under controlled and reproducible conditions.

Photometry

THE purposes of this chapter is to explain the methods of measuring light in connection with cinematographic projection and its problems, and to explain why these measurements are necessary.

In recent years there have been many advances in projection technique. Colour, wide and very wide screens, stereoscopic and " stereo-audio " effects are some of the most important innovations—all of which have been developed to give the cinema audience a more entertaining presentation.

These advances, of course, are the fruit of years of expensive research by the cinematograph industry, but the benefits they bestow can be completely nullified if the level of screen brightness is incorrect.

To point this out should be unnecessary, as it is so obvious, but in spite of the fact that the projectionist regards the maintenance of a correct level of screen brightness as one of the fundamentals of his job, recent surveys have shown that the screen brightness of many cinemas falls far outside the recommended range.

In a few cases no improvement can be made with the equipment available. For example, even when the most appropriate equipment has been installed, the screen brightness as viewed from the best seats (say, the rear centre stalls, or the front centre circle) is too high, and at the same time from the worst seats (say, the extreme side front stalls) it is far too low. However, such cases are rare and only occur when the cinema is of an unconventional design. In most cases an improvement can be made by carefully choosing and installing the correct equipment.

The first need therefore is to be able to measure the screen brightness from various positions in a theatre, and then to decide whether the figures obtained indicate that the picture is satisfactory. That is, whether the screen brightness falls within the recommended limits (8 to 16 foot-lamberts).

The question immediately arises as to how these limits have been chosen and whether they are a correct choice. Before discussing this, it is necessary to explain the fundamentals of the measurement of light and the terminology used.

PHOTOMETRIC UNITS

The Candle. Light is radiant energy perceptible to the eye. It has been found possible to describe this radiant energy in terms of quantity and intensity, based upon its visibility to the eye.

It is convenient to define the units used in Photometry in such a way that they are dependent upon a standard source of light. This is called a Candle, since the first standard suggested was in fact a candle, made of a specified kind of wax, and of certain dimensions. It was eventually abandoned because it was found that the rate at which such a candle radiated light was not constant, and, moreover, varied from one candle to another. So a lamp burning pentane was adopted. This also varied slightly and in 1948 it was abandoned in favour of the present standard source. This is platinum, heated to its melting point (2042°K.) in a crucible of thorium oxide, under certain specific conditions. The Candle is defined as a point source emitting light uniformly in all directions, at the same rate as one-sixtieth of a square centimeter of platinum under the above conditions. In the latter case the light is measured in a direction perpendicular to the surface of the platinum.

Of course, in actual practice it is impossible to have a " point source emitting light uniformly in all directions," but it is an easily understood conception which may be used to define a unit of quantity of light.

The Lumen. Let us suppose that there is a point source of light equal to one Candle placed at the centre of a sphere of radius one foot. Now let a window be cut in the sphere of area one square foot. Thus some of the light, instead of falling on the inside surface of the sphere will pass out of the window. The amount of light thus escaping every second is defined as the Lumen. This is the unit of quantity of light.

Illumination. The point source, in the above case, is emitting light uniformly in all directions, hence one lumen every second is falling on each square foot of the inside surface of the sphere. Now the illumination of a surface is defined as the quantity of light falling on each square foot of the surface, each second. Thus the illumination of the inside of the sphere is one lumen per square foot.

The Inverse Square Law. If the first sphere in the above case, is replaced by another of radius two feet, then all the light which originally fell on the inside surface of the first sphere will now be spread out over the larger area of the larger sphere. Now the area of the second sphere is four times that of the first. Therefore its illumination is now one lumen for every four square feet, i.e., $\frac{1}{4}$ lumen per square foot. In the case of a third sphere of radius three feet, its area is nine times that of the first sphere, and hence the illumination is now one lumen for every nine square feet, i.e., 1/9th lumen per square foot. Examination of the reasoning above leads to a law which states the illumination at a surface facing a source at any given distance. This is the important inverse square law which states that the illumination at a surface is inversely proportional to the square of its distance from a point source of light. If, in the example given above, the point source had been fifty Candles, then such sphere in turn would have been receiving fifty times as much light, and the illuminations would have been 50, 50/4ths and 50/9ths lumens per square foot respectively. Thus the illumination of a surface is

56

proportional to the number of Candles of the source, or as it is usually written, proportional to the Candlepower of the source.

The two results can be incorporated in a single formula:—

$$\text{Illumination (Lumens per sq. ft.)} = \frac{\text{Candlepower of source}}{\text{Square of the distance from the source, in feet.}} \quad - \text{(A)}$$

For example, to find the illumination of a surface facing a 144 Candlepower source of light, four feet away:—

$$\text{Illumination (Lumens per sq. ft.)} = \frac{144}{4^2} = \frac{144}{16} = 9.$$

The term " lumens per square foot," has become changed by popular usage to " foot-candles." The latter term is completely illogical, but it is now used almost exclusively. The two terms have exactly the same meaning.

Measurement of Candlepower. Often it is necessary to find the candlepower of a source. This is achieved by measuring the illumination due to a source at a known distance away from it, by means of one of the many types of instruments which are available and which measure the illumination in foot-candles directly. For example, suppose the illumination is found to be $8\frac{1}{2}$ foot-candles (or $8\frac{1}{2}$ lumens per square foot) at a distance of twelve feet away from the source. Then the formula (A) states that:—

$$8\frac{1}{2} = \frac{\text{Candlepower of source}}{(12)^2}$$

or:—

$$\text{Candlepower of source} = 8\frac{1}{2} \times 12^2 = 8\frac{1}{2} \times 144 = 1224$$

57

POLAR DISTRIBUTION OF LIGHT FROM AN H.I. ARC

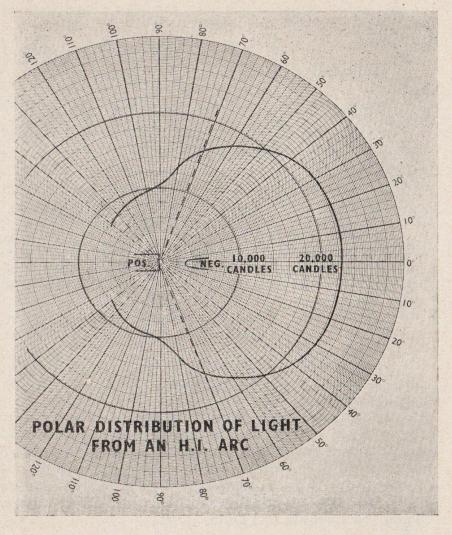POS   NEG   10,000   20,000
              CANDLES   CANDLES

Fig. 12

The Polar Distribution of Light from a Source. In the above case if the measurement of illumination is made from another direction, but still at a distance of twelve feet, it may be found to be quite different. Suppose it is found to be 4 foot-candles, then again using formula (A) the calculated candlepower will be 576. This happens in the case of almost all sources of light, and therefore it has become customary to speak of the candlepower in a specified direction, and such self-explanatory terms as " forward candlepower " or " horizontal candlepower," are often used. In order to describe completely the characteristics of a source of light it is evident that it is necessary to quote its candlepower for a large number of directions. This would involve a complex table of directions and corresponding candlepowers, and only after considerable study would it show the general behaviour of the light source. It has been found much more convenient to draw a special graph known as a polar curve. (See Fig. 12). This is drawn in such a manner that the distance of the curve from the origin of the light in any direction is proportional to the candlepower in that particular direction. From such a curve the general characteristics of the light source are at once obvious. For example, Fig. 12 represents the light output from a high intensity arc. It shows at a glance that most of the light is radiated within an angle of 70° either side of the axis of the trim, and explains why manufacturers incorporate mirrors i their arc lamps covering as much as possible of this angle.

Of course, the polar curve only indicates the characteristics in a single plane. For example, it does not show the candlepower in a direction out of the paper towards the reader's eye; or in the other direction on the far side of the arc. However, it is reasonable to suppose that, in the case of a horizontally opposed trim, the light emission is nearly symmetrical about the axis of the positive carbon. Hence, if the

polar curve is rotated about that axis it would sweep out a polar surface which would more completely represent the light output (i.e., the distance of any point on the surface from the origin of the light would represent the candlepower in that direction). It is evident that as any source emits light in three dimensions, the polar curve should always be in fact a polar surface. Obviously, except for the most simple cases, such a surface would be extremely difficult to illustrate on a sheet of paper, and polar curves therefore only are usually shown in technical literature, from which the reader can grasp the essentials of the form of the polar surface.

The Cosine Law. One particular case of interest arises when the source of light is a small flat surface. In almost every instance the resulting polar curve is a sphere, placed so that the small flat surface is tangential to it. If a section is taken through the flat surface perpendicular to it, the polar curve so found will be a circle, as shown in Fig. 13. A small plane source of light which gives a perfectly spherical polar surface, as described above, is said to obey the Cosine Law, since its candlepower in a given direction is proportional to the cosine of the angle between that direction and a line drawn through the centre of the surface and perpendicular to it.

The Calculation of Screen Light. To find the total amount of light falling on a surface it is necessary to explore the surface with a measuring instrument which indicates the illumination in foot-candles. Remembering that foot-candles are lumens per square foot, the method that immediately suggests itself, is to divide the surface into areas, one foot square, and then measure the illumination of the centre of each area. The instrument reading in foot-candles then shows the number of lumens falling on each area, and to find the total incident lumens, it is only necessary to add all the readings together. Unfortunately, in the case of a cinema screen such a method would

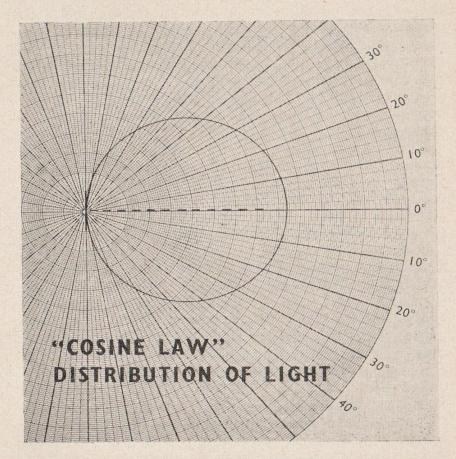"COSINE LAW" DISTRIBUTION OF LIGHT

Fig. 13

require as many readings as there are square feet of screen surface. Since the light on a screen does not vary much from point to point it should be possible, by taking fewer readings, to find the average foot-candles or lumens per square foot falling on the screen. Hence the total lumens may be found by multiplying the average by the screen area in square feet. To obtain reasonably accurate results it is important to choose the positions at which the measurements are taken, with care. The method usually employed is to measure the incident foot-candles, at the centre of the screen, at the centre of each of the four edges, and at each corner. The method used to calculate the average is then as follows:

The centre reading is multiplied by four, the readings for each of the four edges by two. These figures are then added together with the four corner readings and the total divided by sixteen. This method is known to give results which are as accurate as is possible when only a limited number of readings are taken.

True and Apparent Reflectivity—The Foot-Lambert. When light falls upon a surface some is reflected, some absorbed, and, depending upon the nature of the surface, some may be transmitted. Except in certain special cases, which can be ignored here, every surface reflects less light than it receives. The fraction of the incident light which is reflected, is called the " True Reflectivity " of the surface, and thus it is always less than one.

A perfect reflecting matt surface is defined as having a true reflectivity of one, and, moreover, it appears equally bright no matter from what angle it is observed. It is obvious from the above statements that such a surface is only theoretically possible, but in actual practice surfaces have been found which closely approximate to this ideal. When an illumination of one lumen per square foot falls on such a surface its brightness is defined as being one foot-lambert. In the case of a good commercial matt screen, when illuminated by one lumen per square foot, the brightness as viewed from a position roughly perpendicular to the screen is about 0.8 foot-lamberts. When viewed at a more oblique angle it usually falls away to say 0.5 foot-lamberts at extreme angles. If the illumination had been 10 lumens per square foot, then the brightness in each case would have been ten times as great, i.e., 8.0 foot-lamberts and 5.0 foot-lamberts respectively. In general, the ratio of the brightness to incident illumination is called the Apparent Reflectivity of the surface, and this varies with the direction from which the surface is examined. The relationship between brightness and incident illumination is easily understood from the following equation:—

Brightness (Foot-Lamberts)
= Incident Illumination (Lumens per square foot)
× Apparent Reflectivity. (B)

For example, if 20 foot-candles (or lumens per square foot) fall upon a surface whose brightness is found to be 14 foot-lamberts when viewed from a particular direction, then the apparent reflectivity for that direction is 0.7.

It is very important to distinguish between true reflectivity, which determines the total amount of light reflected and is always less than one, and apparent reflectivity which determines the brightness for a given intensity of incident light.

The latter may be greater than one. This is possible because some surfaces reflect little light at oblique angles, and thus are able to reflect more of the available light in a direction back towards the source. Thus the reading of brightness in foot-lamberts, using an appropriate measuring instrument, is found to be greater than the incident illumination measured in lumens per square foot. Hence from equation (B) the apparent reflectivity is greater than one. Such surfaces which give a high level of brightness when the incident illumination is low, are obviously of con-

siderable importance to the cinematograph industry.

Polar Distribution of Apparent Reflectivity. From the above remarks it is evident that to describe the behaviour of matt surfaces, it is sufficient to quote a single figure for apparent reflectivity, but for other surfaces, with directional properties, it is necessary to quote the apparent reflectivity for a large number of directions. As in the case of the candlepower distribution of a source of light, it has been found more convenient to draw polar curves of apparent reflectivity. Again it must be emphasized that a polar curve is really a section through a polar surface, which cannot be easily illustrated on a sheet of paper.

Unfortunately, when the angle between the incident beam of light and a directional surface changes, its polar curve of reflectivity also changes. However, in cinemas, the angle between the perpendicular to the screen and the incident projection light is seldom more than 15°, so that in the case of a cinema screen the polar curve of apparent reflectivity is usually shown for the case when the incident light is perpendicular to the screen. When interpreting the curve an allowance must be made for the existence of a small angle. This is described in more detail in the Chapter on Properties of Screens, which also contains illustrations of typical polar curves of apparent reflectivity.

The Colour of Light. So far the measurement of quantity of light has been described, but no reference has been made to the determination of its colour. When the light is nearly white, (e.g., light emitted by the sun, by low or high intensity arcs, or from tungsten electric light bulbs) it is usual to describe it as having a certain colour-temperature.

To explain how colour-temperature is defined is beyond the scope of this Chapter. It is sufficient to mention that yellow light has a low colour-temperature (about 1500°K.), "white" light has a medium colour-temperature (about 5500°K.), and bluish-white light has a high colour-temperature (8000°K. upwards).

Measurements have shown that the screen light from a Low Intensity arc has a colour-temperature of about 3800°K. and for a High Intensity arc it varies from about 5100°K. to 5600°K. Now colour films are printed in such a way that the balance of colours on the screen are most nearly correct when the projection light has a colour-temperature of about 5400°K. Thus all High Intensity arcs give suitable colour renderings, but a Low Intensity arc is unsatisfactory, giving prominence to the yellows and reds in the picture and leaving the blues too dark.

To avoid confusion it must be understood that the figures quoted above are for the colour-temperatures of the light falling on the centre of the screen after passing through the normal optical system of the projector, and apply for both mirror and condenser optical systems. The colour-temperature of light emitted by bare arcs is distinctly different, varying considerably with the region in the arc under investigation.

It is not possible to include here the methods of accurate measurement of colour-temperature, but small portable meters, which will detect fairly large differences in colour-temperature, are available. They are described below.

PHOTOMETRIC INSTRUMENTS

There are many different types of photometric instruments. In this section only the instruments used for measuring screen light will be described.

The Measurement of Illumination. There are certain photo-electric cells available which, when illuminated, generate a small electric current. This current may be measured by a sensitive ammeter or galvanometer, and it has been found that for a given cell and electrical circuit, the current generated is roughly proportional to the illumination falling on the cell. Thus a cell and ammeter can be used to measure illumination. Some

types of meters, instead of reading milliamperes, read foot-candles directly. Others are used in conjunction with calibration curves, which can be easily changed if the sensitivity of the instrument varies slightly.

The meters are calibrated by using a standard filament lamp of known candlepower. Equation (A) is used for the necessary calculations. If the instrument is to be used to measure high intensity screen light, then a small correction factor must be applied. This is because the cells employed respond differently to light from filament lamps, and high intensity screen light.

Such instruments are particularly suited to the exploration of the light falling on a cinema screen, since the cells may be mounted on a telescopic rod.

The Measurement of Brightness. The most portable instrument for measuring screen brightness is the visual type. This takes the form of a low power telescope, except that when the cinema screen is viewed through it a small patch of light is seen in the centre of the field. The brightness of this central patch can be adjusted until it appears equal to that part of the screen adjacent to it. The brightness in foot-lamberts is then read from a scale on the instrument. Using such an instrument, it is possible to measure the brightness of any point of the screen, from any seat in the cinema.

Such instruments depend upon the ability of the operator to decide when two fields of light are equally bright. However, the inaccuracy due to this uncertainty is reasonable.

Another instrument which has been developed to measure screen brightness does not depend upon the discrimination of the operator's eye. This takes the form of a camera, the lens of which forms an image of the screen which, instead of falling on a photographic film, falls upon a blackened plate. In the centre of this plate there is a small hole behind which is placed a photo-electric cell. To measure the brightness of a

position on the screen, the camera is so aligned that the image of the position falls on the hole, and passes through to impinge on the cell. It can be shown that the current generated is roughly proportional to the screen brightness at the position in question, and that it is independent of the distance between the camera and the screen. The instrument is accurately calibrated in the laboratory.

A very similar instrument is used to monitor the total screen light. This takes the same general form as the camera above except that the whole image of the screen falls on to the cell. This cannot be used to measure either the total lumens falling on the screen or to explore the screen brightness, but it will show the proportional difference in light between one lamp and another, or between different trims of carbon in the same lamp. It can also be used to examine the steadiness of the screen light, and also to detect any variation of total screen light while other photometric tests are being made.

Measurement of Colour-Temperature. Accurate determinations of colour-temperature can only be made using special apparatus under laboratory conditions. However, small portable instruments are available which are able to give a fairly good indication of colour-temperature. These incorporate a photo-electric cell which measures the reddish and the bluish content of the light, selected by the use of special colour filters.

Such meters are usually manufactured for photographic purposes only, and they admirably fulfil their functions. They are able to differentiate clearly between the yellow light emitted by a tungsten filament lamp and the High Intensity arc screen light, but are seldom accurate enough to distinguish between one High Intensity arc and another.

RECOMMENDED SCREEN BRIGHTNESS

It is now possible to deal with the problem of deciding upon the most desirable level of screen brightness.

The term " screen brightness " will be used so often that at this point it is necessary to state the conditions under which it is measured. They are as follows: First, the projector is running under normal operating conditions (i.e., with shutter rotating and the arc burning normally), except that there is no film at the gate. Second, the auditorium lighting is that normally used when a film is being projected.

To produce a satisfactory picture on the screen the density of the film print must be taken into consideration. Thus a very dense print will require a very strong projection light, and vice-versa. Now the quality of the print depends to a considerable extent upon its density. On a very transparent print details of the highlights of a scene are lost, whereas at the other extreme, on a very dense negative, shadow details are invisible.

Obviously, then, there exists an optimum density for a print. By research this optimum density has been found and " ideal " prints have been made. Unfortunately, a really good projected picture can only be obtained from them when the screen brightness is in the order of 100 foot-lamberts, which is unattainable in any commercial cinema.

Thus film makers have had to compromise. They have reduced the density of their prints to such a level that any further reduction would result in a serious loss of detail in the highlights. Thus print density has by necessity become standardised, and any increase of density would require greater screen light, and any reduction would seriously affect the picture quality. In actual practice, prints made for general release are adjusted for density within narrow limits.

During the years 1945-47, a Committee was formed under the auspices of the British Standards Institute, to investigate the screen brightness required for standard release prints. The method used consisted of viewing a wide variety of scenes, projected with a large range of screen brightnesses. Both black and white, and Technicolor films were included.

Every precaution was taken to ensure that any preconceived ideas about screen brightness had no effect upon their results. For example, the screen brightnesses were not disclosed until the whole of the test was complete. Moreover, the projections were made with screen brightnesses in a random order so that no member of the Committee could gauge the screen brightness of one projection by comparison with the previous one. Also, the observers were not allowed to compare notes.
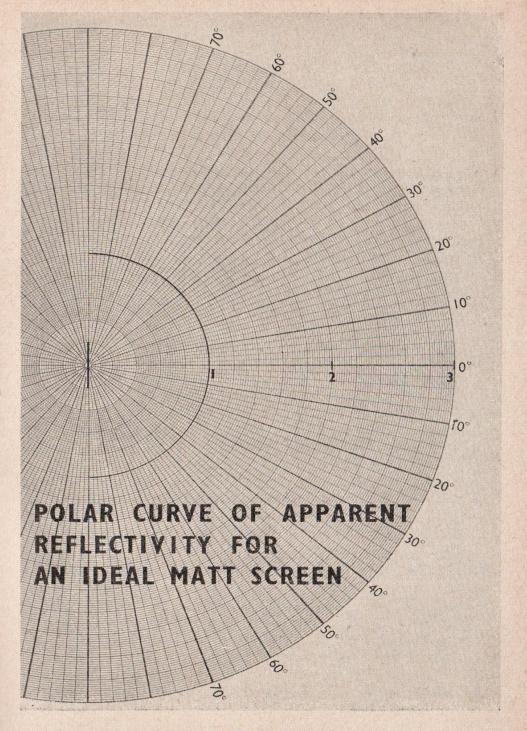
When the results were studied a remarkable measure of agreement was found between the observers, and thus it was possible to draw definite conclusions from the experiment.

These, rather unexpectedly, applied almost equally to both Technicolor and black and white film. Below 6 foot-lamberts the picture was too dull. Above 20 foot-lamberts, night scenes were spoilt, and in certain types of scene, grain and flicker became annoying. Recent printing techniques have reduced the problem of grain to a certain extent, but the other criticisms are still valid. After all possible factors had been taken into consideration, it was found that the picture in general was satisfactory if the screen brightness at the centre lay within the range 8 to 16 foot-lamberts. A more complete report on these results can be found in the British Standard Specification 1404 : 1953.

The above result agrees closely with those of independent investigations. The American standard (PH22.39-1953) is 9-14 foot-lamberts, and that of the French (NFS 27-003) is 7.3-14.6 foot-lamberts. German research has also lead to results agreeing with the above figures.

The British specification also states that the brightness at the sides of the picture should be about 0.7 times that at the centre. Any great divergence from this ratio reduces the artistic quality of the picture.

It should be emphasized that all the above figures apply when the screen is viewed from any seat in the cinema. With the directional screens the above requirement sometimes cannot be fulfilled, but often the position is further aggravated by the incorrect choice or installation of a screen. Some remarks on this subject are made in the Chapter on Properties of Screens.

POLAR CURVE OF APPARENT REFLECTIVITY FOR AN IDEAL MATT SCREEN
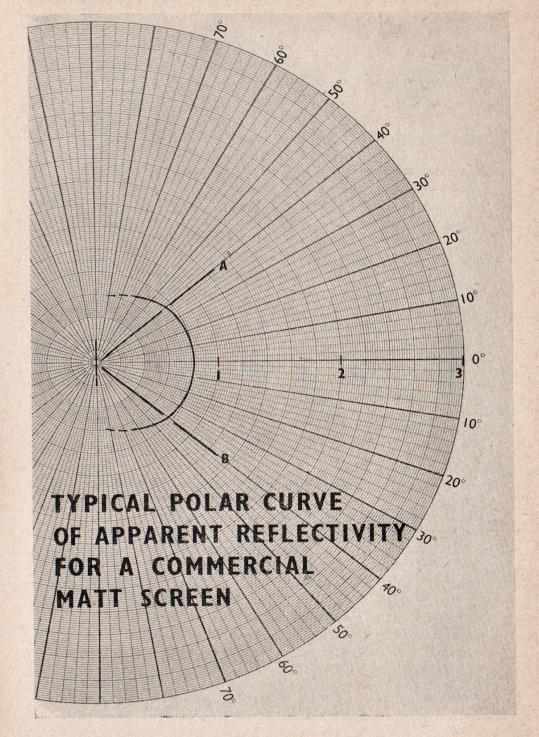
Fig. 14

CHAPTER X

Properties of Screens

OF the various forms of cinema screen those of the metallized type are of the greatest importance to-day. The beaded screen is now obsolete, and the matt screen is being replaced. However, as the latter has long served the cinematograph industry, its characteristics will be briefly described so that a comparison with the metallized screen can be made.

The Matt Screen

As explained elsewhere in the Chapter on Photometry, an ideal matt screen is such that from whatever angle it is observed its brightness remains the same. That is to say, its polar surface of apparent reflectivity is a hemisphere, and in the ideal case it has a radius of one unit corresponding to an apparent reflectivity of one. Moreover this polar surface remains exactly the same if the source of light is moved off-centre with respect to the screen, as is usually the case in a cinema where the projector is seldom perpendicular to the screen. The polar curve (cross-section of the polar surface) is shown in Fig. 14.

For various reasons a commercial matt screen is not quite the same as the one mentioned above. Its polar curve has an optimum radius when new of about 0.8 units, corresponding to an apparent reflectivity of 0.8. When viewed from extreme angles there is a fall-off in brightness; that is to say its apparent reflectivity falls below 0.8. Also the polar curve varies slightly with the angle at which the screen is illuminated. Its polar curve for perpendicular illumination is shown in Fig 15.

TYPICAL POLAR CURVE OF APPARENT REFLECTIVITY FOR A COMMERCIAL MATT SCREEN

Fig. 15

Since the projector is in actual fact almost perpendicular to the screen, and the audience is within the angle AB, the fall-off at extreme angles outside AB is of little importance as far as we are concerned.

The brightness of a screen depends upon the illumination and the apparent reflectivity, and is given by the formula:—

Brightness (Foot-Lamberts)
= Illumination (Foot-Candles)
× Apparent Reflectivity.

So if a matt screen is illuminated by 5 foot-candles, and its apparent reflectivity is 0.7, then the brightness will be 3.5 foot-lamberts. This is well below the recommended brightness range of 8-16 foot-lamberts. A typical case when such figures occur would be on a wide screen, where the available light may be reduced by masking at the film gate, and the remaining light spread over a greater screen area.

The Metallized Screen

One way of increasing screen brightness would be to increase the illumination, but this may not be possible unless new projection equipment is installed.

Another way is to increase the apparent reflectivity of the screen. This can be achieved by giving the screen directional properties. That is to say, more light is reflected in the direction of the audience and much less towards the roof, the sides, and the stage of the cinema, where it is wasted.

Metallized screens have this effect. They are produced by coating a surface with a very thin layer of metal. The metal surface tends to reflect light in exactly the same way as an ordinary mirror. This obviously would be useless as a cinema screen. To overcome this effect a rough surface is selected for coating, or better still, a surface which has been broken up by more or less scientifically designed ridges and hollows. In each case the result is that the light reflected by the screen is spread out to a degree which depends upon the form of the screen surface.
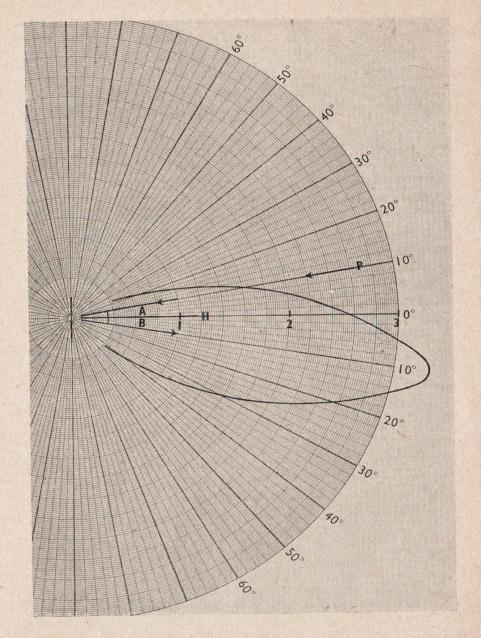
Fig. 16

If the surface is only slightly rough the spreading will be small, i.e., the polar curve of apparent reflectivity of such a screen will be long and narrow as shown in Fig. 16.

It should be noted that the direction of optimum reflectivity is such that the angle A is equal to the angle B, where H is a perpendicular to the screen.

Looking at the polar curve, it is seen that this type of screen would be suitable for a long narrow cinema, where none of the audience views the screen from oblique angles. A screen with a polar curve like this has been produced solely for this purpose.

In most cinemas a screen with a broader polar curve is required. This is achieved by using a screen with a rougher surface. Fig. 17 shows the broad polar curve of a screen which has been installed in several cinemas. It will be noticed that the apparent reflectivity in the optimum direction has fallen now that the light is less concentrated. Thus, for the screen whose polar curve is shown in Fig. 16, the maximum reflectivity is about 3.4, whereas for that shown in Fig. 17 it is about 2.4. Of course this fall-off in reflectivity as the polar curve becomes broader is inevitable.

On examination of the above polar curves, the immense advantage in brightness of the metallized screen over the matt screen is at once evident. From the Fig. 17 it is seen that the apparent reflectivity is approximately 2.0, or greater over a fairly wide field of view. Therefore if this screen is illuminated by 5 foot-candles, its brightness over a wide field of view will be about 10 or more foot-lamberts, giving a satisfactory picture. It will be remembered that the same illumination on a matt screen gave extremely poor results.

The choice or design of a surface, which after coating will form a satisfactory screen, is by no means a haphazard affair. Manufacturers of screens have done a considerable amount of research on this problem. That is why such unsatisfactory results
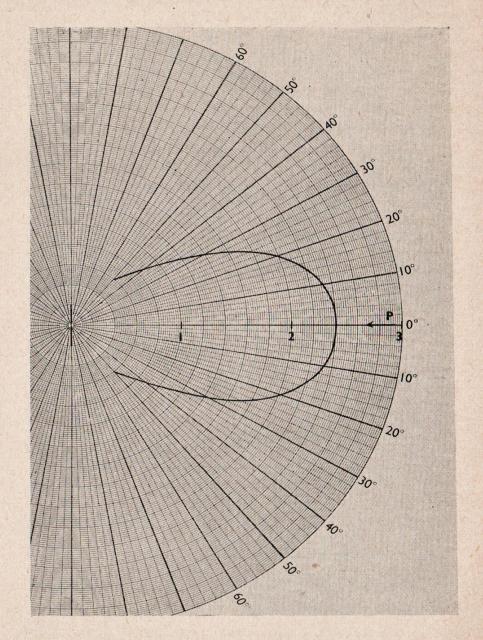
Fig. 17

were often obtained when an old matt screen was merely sprayed by aluminium paint.

Another advantage of the metallized screen is that when polarised light is projected on to it, the reflected light is also polarised. In other words, it can be used for the polaroid type of 3-D. Matt screens, on the other hand, tend to depolarise the incident light and thus are useless for 3-D presentation.

Even a poorly manufactured metallized screen has a slight tendency to depolarise the incident light. This is the main reason for the presence of ghost images. The polarisation defect of a screen may be determined by measuring the ratio of the brightness of the ghost to the brightness of the main image, using high quality polarised filters set at the correct angles. No formally established tolerance on polarisation defects exists, but unsatisfactory results occur if it is greater than 1 per cent.

From what has been said so far, it is evident that, to a certain extent, screens to suit each type of cinema can be obtained, by a screen with a broad polar curve for a broad cinema, etc. Now let us see what screen properties are required for an average cinema. Fig. 18 shows a side view of the supposed cinema. H is a horizontal drawn through the centre of the screen. Then the angle AB, drawn from 12° above the horizontal, to 18° below it, will embrace 90 per cent. of the audience. Thus it is evident that as far as this view is concerned, a screen whose polar curve of reflectivity covers an angle of 30° is required. Fig. 19 is a view of the same cinema from above, and now we see that the angle XY which embraces most of the audience is about 60°. A screen with a much broader polar curve which fully covers an angle of 60° is, therefore, required.

Some screens have been reproduced to satisfy these conditions. Their surfaces consist of a series of ridges and hollows. The ridges run both vertically
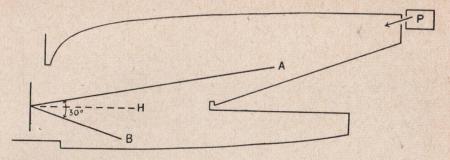
Fig. 18. *SIDE VIEW OF AN AVERAGE CINEMA, SHOWING THE REQUIRED DISTRIBUTION OF REFLECTED LIGHT*

and horizontally across the screen surface, but the vertical ridges are much more strongly defined. Hence, light falling on the screen is spread out vertically, and also horizontally, but in the latter case in a much broader beam, so meeting the conditions required in an average cinema.
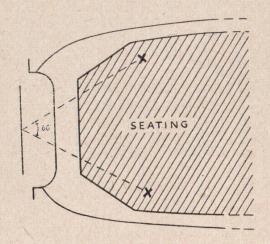

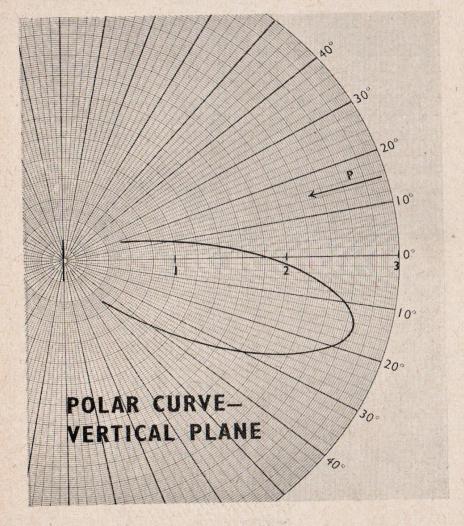Fig. 19. *PLAN VIEW OF AN AVERAGE CINEMA, SHOWING THE REQUIRED DISTRIBUTION OF REFLECTED LIGHT.*

POLAR CURVE—
VERTICAL PLANE

Fig. 20

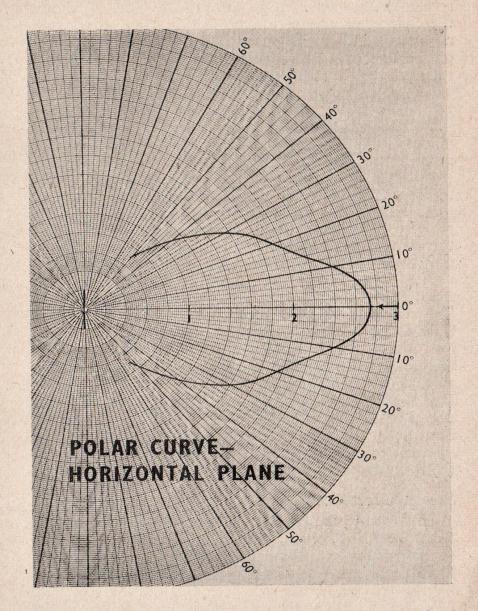POLAR CURVE—
HORIZONTAL PLANE

Fig. 21

The polar curves of reflectivity of this type of screen are shown in Figs. 20 and 21. Fig. 20 shows the case when we have a projection rake of 15° and no screen tilt. It will be noticed in this instance most of the light will be reflected into the front stalls and very little towards the circle. If we take a more practical example in which we have a projection rake of 18° and a screen tilt of 6° then the direction of optimum reflectivity for almost all metallized screens is 6° below the horizontal. Again the stalls will receive much more light than the circle.

This state of affairs could be corrected by tilting the screen back by more than 6°, but this may be impossible for two reasons. First, because of a "keystone" effect when the screen is viewed from the front stalls, and second, difficulties in erection may occur, especially when a curved screen is involved.

A screen which is a slight modification to that mentioned above solves this problem. Each hollow into which the screen is divided is individually tilted upwards, by a few degrees, without tilting the screen as a whole. The result is that the distribution of light is similar to that mentioned above (the screen whose polar curves are given in Figs. 20 and 21), except that the direction of optimum reflectivity is raised by about 11°. That is to say, it behaves as if the screen had been tilted back by another $5\frac{1}{2}$°, without of course, the disadvantage of keystoning as viewed from the front stalls.

Screen Curvature

So far only the centre of the screen has been dealt with, and the further problems which arise when screen height and width are taken into consideration have been ignored. Let us now look at the effect of having a wide screen which is not curved (see Fig. 22). A ray of light from the projector P falling at the screen centre will give a polar curve of reflectivity, as shown. Rays of light falling at the sides of the screen will result in polar curves tilted outwards in
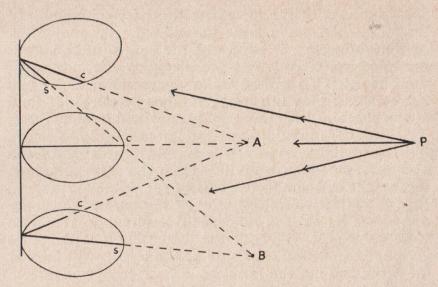
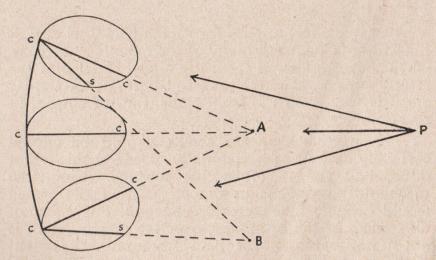Fig. 22. *SHOWING THE UNSATISFACTORY DISTRIBUTION OF LIGHT FROM A FLAT WIDE METALLISED SCREEN.*

Fig. 23. *SHOWING HOW THE USE OF A CURVED SCREEN RESULTS IN A MORE SATISFACTORY DISTRIBUTION OF LIGHT.*

accordance with the laws of reflectivity of metallized screens, which have been mentioned. To a member of the audience, A, sitting at the centre of the stalls the effective reflectivities are given by the lengths of the chords (CC) of the polar curves shown. It will be seen that they are much smaller at the sides than at the centre, hence the brightnesses will be much less. This fall-off is in addition to the normal side to centre fall-off of light. Again, for another member of the audience, B, the reflectivities from the sides are given by lengths of the chords (CS) of the polar curves and thus the effective reflectivities of the near edge of the screen (as far as B is concerned) is much greater than for the far side. Thus, if the light falling at the sides is about equal, the near side of the screen will appear far brighter than the far side.

In practice, these effects are partially overcome by curving the screen, so that the polar curves at the sides are tilted back towards the centre of the cinema. This is shown in Fig. 23. In this case it is seen that the chords CC which represent the reflectivities, as far as A is concerned, are much more equal. The same applies to the chords CS which represent reflectivities for B.

The same effect applies for screen height as well as for width. Thus, with many of the metallized screens, when they are viewed from the circle, the top of the screen appears brighter than the bottom. A similar effect is seen from the front stalls, but, of course, in reverse.

This suggests that the screen should be curved vertically as well as horizontally. Usually this is not done, and for the following reasons. First, the mechanical problems in the erection of the screen would become much greater. Second, this effect of differences of the brightness over the screen height is not so noticeable as over the width because the height of the screen is usually much less than the width, and, third, because the screen is not viewed from such

extreme angles in the vertical plane as it is in the horizontal plane.

It should be noted that these various problems of illumination are aggravated by the use of a screen with a narrow polar curve. Hardly any of the problems which arise in the use of a metallized screen arise when a matt screen is used with its very broad polar curve. On the other hand, a properly installed metallized screen has an immense advantage over the matt screen in its high reflection factor, quite apart from the fact that it is available for use with the polaroid type of 3-D.

CHAPTER XI

New Techniques of Film Presentation.

THE introduction of wide screen and three dimensional techniques to the cinema has called for a careful choice of carbon trims to satisfy the necessary requirements for these types of film presentation.

In the case of wide screen projection where the larger aspect ratio is achieved by masking the normal aperture and projecting with a lens of shorter focal length than usual to obtain a wider picture, the available screen light is reduced, depending on the amount of masking applied. The original luminous flux available is not redistributed over the new screen shape and the governing factor is the width of the screen projected. In consequence, if the original screen surface is used, the screen luminance can only be maintained by increasing the output of the carbon trim by an increase of current or by suitably loading a larger trim of carbons.

The installation of metallized screens with their higher reflection factor has to a large extent offset the need for more available light output from the arc lamp and in most cases, increase in screen width has been achieved with conventional arc lamps and carbons while maintaining satisfactory luminance of the screen.

With the Cinemascope system, where a slightly larger film aperture is used, the problem of light output from the projector is not serious. The available light flux is redistributed over the wider screen by the anamorphic lens attachment, and excepting the additional light losses in this attachment, more screen light is available for a given width of screen than with the masked aperture, wide screen system.

Of course, it will be realised from an earlier Chapter

that with the metallized screen the reflective properties vary with the type of screen used, the angle of projection and the angle of viewing from the auditorium. If wide viewing angles apply to some of the seats it will often be difficult to arrange that all seating positions have the centre screen luminance within the British Standard of 8 to 16 foot lamberts as this only permits the variation of reflectivity to have a factor of 2. In consequence, if a satisfactory level of luminance is maintained over the major seating position some of the extreme side seats will have conditions of viewing below the minimum recommended.

3-D Projection

The normal system of projection of three-dimensional films requires that two images corresponding to right-eye and left-eye views are projected simultaneously to the screen by plane polarised light, the planes of polarisation of the two pictures being at right angles. By viewing through suitable analysing spectacles the right eye can only accept the right-eye picture and the left eye the left-eye picture, so that the stereoscopic effect is obtained.

We need only consider the system for one projected image and eye as the two eyes viewing two separate pictures does not make the picture look twice as bright.

The light from the projector passes through a polarising filter from which approximately 38 per cent. of the light emerges as plane polarised light. The picture produced by this light is viewed through the appropriate spectacle filter which transmits about 80 per cent. of the polarised light. This means that as far as the viewer is concerned the light is reduced by some 70 per cent. Because a matt screen surface to some extent de-polarises the plane-polarised light so that a double image would be seen, only the metallized type of screen is suitable, and as it has the advantage of a higher reflection factor, it offsets some of the losses experienced with polarisation.

In spite of this, the problem of 3-D projection is greater than that of wide screen projection from the standpoint of adequate screen luminance and with conventional equipment the size of screen has to be limited to about 25 feet wide if adequate brightness is to be maintained.

The demand for more light for 3-D and wide screen means that the film itself is subjected to a greater intensity of heating with its attendant film buckle or embossing.

When using carbon trims designed for the higher light values it will be necessary to reduce film heating by using infra-red filters between the film and the arc lamp. These filters have the effect of reducing the infra-red rays more than the visible rays so that the film is kept cooler. There is some loss of visible light also, but this may be offset by a small increase in arc current. As the filter absorbs a large amount of heat energy it is essential to cool the filter by air blast to prevent fracture.

Running Time

In the case of wide screen projection using standard reels with running times of the order of 20 minutes, all the Ship carbon trims have burning rates which allow for adequate projection time in the average arc lamp. Where only two projectors are available for 3-D presentation and longer running time without re-trimming is required, some compromise must be made.

Running time is a function of carbon burning rate and the feed travel of the carbon holders. The latter varies considerably from lamp to lamp and it is necessary to consider each lamp and choose a trim to allow the time to be achieved.

For burning times of the order of 50 minutes, the burning rate of the positive carbon is usually the limiting feature. In this case the use of 9 mm. positives gives an advantage, as by a suitable choice of current a low burning rate may be obtained with an advantage in light output over that of the smaller sizes of carbons.

The sizes and types of carbons in the Ship range enable us to choose the best trim for all conditions of operation, but it should be realised that high light output and longer running times are diametrically opposed, and with conventional arc lamps some compromise has to be made which must influence the size of screen used.

CHAPTER XII

Direct Current Supply Systems

IT is well known that, because of the negative temperature coefficient of resistance of the carbon arc, all arcs have to be supplied with current by a system containing some form of ballasting effect in the circuit so that the tendency for the arc current to increase with arc temperature is prevented.

The conventional method of running the arc from a D.C. Generator or rectifier with a simple ballast resistance in series with the arc serves the purpose very satisfactorily. The electrical efficiency of this arrangement, however, depends on the line voltage of the supply, the arc voltage, and the amount of resistance which is necessary to maintain the arc current at its correct value. The electrical energy dissipated in the ballast resistance does not contribute to the light output from the arc, and for a number of years, specially designed rectifiers have been available in which the ballasting effect is introduced in other ways to increase the overall electrical efficiency from mains to arc, and at the same time enable arcs to be burned in a stable manner.

D.C. supply units can be designed so that the variation in arc current for small changes in arc resistance, caused by changes in arc gap, is large or small depending on the regulation of the supply, which is determined by the characteristics of the circuit. Supply units which have the characteristic of large variations of current with arc gap are analogous to a resistance ballasted generator with a low line voltage and small ballast resistances. This type of equipment is suitable for the operation of arcs of the high intensity type having low arc voltages of the order of 30 to 40 volts, provided that the automatic feed associated with

these arcs responds sufficiently quickly to prevent the arc being extinguished, due to the arc gap becoming too wide.

Further, supply systems with these characteristics reduce the tendency of the arc to surge or " pump " when underloaded and make it possible to burn a trim of carbons at lower currents than are possible with a higher line voltage and bigger ballast resistance.

The converse to the above also applies, that high line voltage characteristics encourage the pumping phenomenon at low loadings.

This low line voltage type of supply is not suitable for the operation of low intensity arcs, which require a higher arc voltage of the order of 50 volts, and are apt to become unstable and hiss if the arc gap is changed rapidly during feeding. Further, as low intensity arcs are generally fed by hand at intervals, on low line voltages, a much more regular feeding is required to prevent the arc being extinguished.

Smoothing of the supply

The ripple which can exist in rectified A.C. supply systems, can, if it is too great, have an adverse effect on the burning of the arc. The formation of the core flame is poor, and the light output is considerably reduced.

This defect is more likely to be observed with single phase rectifiers than with 3-phase, the latter generally requiring less smoothing of the full wave rectified current.

A ripple content in the D.C. supply up to 12 per cent. appears to be acceptable, and does not seriously influence the efficiency of the arc ; but A.C. ripple much above this value will produce a marked deficiency in light output and carbon performance which is not offset by a reduction in carbon consumption. In extreme cases, ripple can produce a variation in light output, which, in conjunction with the frequency of the flicker shutter, gives a visible light " beat " on the screen.

APPENDIX

Burning Data

THE following pages show typical burning data of Ship Carbons used for cinematograph projection.

Indications are given for different trims of carbons showing their rates of consumption and light output in conventional arc lamps.

These figures are intended as a practical guide to the performance of the carbons and show the recommended electrical conditions for satisfactory burning. The carbons, however, are sufficiently flexible in design to perform satisfactorily at conditions of burning slightly different from those illustrated. For example, they may be burned at shorter or longer arc gaps where necessary, in which case the arc voltages will be less or more than those stated, depending on the gap setting. In certain supply conditions, and with some arc lamps, lower currents may be used than the minima indicated, but in all cases the maximum currents shown should not be exceeded.

Light emission, where indicated, is quoted in all cases without flicker shutter. These figures have to be reduced depending on the cut-off of the shutter which is usually of the order of 50%. The ultimate screen illumination relies on the optical efficiency of the arc lamp mirror and projection lens, together with the losses through the port-hole glass, so that screen lumens could be more or less than the figures quoted depending on these variable factors.

Burning rates also vary from lamp to lamp and are influenced by ventilation as well as by arc current and voltage.

ALTERNALUX DATA

Carbons	Arc Amps	Arc Volts	Inches Consumed Per Hour	Screen Lumens
7 mm. Alternalux	65	23·5	4·4	4,650
,,	70	24·5	4·8	4,900
,,	75	25	5·3	5,150
8 mm. Alternalux	80	24	4·1	5,200
,,	85	24·5	4·3	5,450
,,	90	25·5	5·0	5,700
9 mm. Alternalux	95	25	3·6	5,550
,,	100	25·5	4·1	5,700
,,	105	26	4·5	5,850

LOW INTENSITY DATA

Carbons Positive	Carbons Negative	Arc Amps	Arc Volts	Inches Consumed Per Hour Pos.	Neg.	Screen Lumens
9 mm. LUXO	6 mm. LUXO No. 25	12 / 16	48-52	2·2 / 2·8	2·3 / 2·6	2,250 / 2,500
10 mm. LUXO "	7 mm. LUXO No. 25 "	15 / 20	"	2·1 / 2·5	2·1 / 2·3	2,000 / 2,650
11 mm. LUXO "	7 mm. LUXO No. 25 "	20 / 25	"	2·0 / 2·4	2·3 / 2·6	2,550 / 2,750
12 mm. LUXO "	8 mm. LUXO No. 25 "	25 / 30	"	2·0 / 2·4	2·1 / 2·4	2,700 / 2,900
13 mm. LUXO "	9 mm. LUXO No. 25 "	30 / 35	"	1·9 / 2·2	1·9 / 2·1	2,800 / 2,950
14 mm. LUXO "	9 mm. LUXO No. 25 "	35 / 40	"	1·8 / 2·0	2·1 / 2·3	2,900 / 3,000

Carbons Positive	Carbons Negative	Arc Amps	Arc Volts	Inches Consumed Per Hour Pos.	Neg.	Screen Lumens
9 mm. LUXO "	6 mm. LUXO No. 27 "	8 / 13	48-52	1·7 / 2·4	1·6 / 2·1	1,850 / 2,300
10 mm. LUXO "	7 mm. LUXO No. 27 "	10 / 16	"	1·6 / 2·2	1·5 / 1·9	1,950 / 2,450
11 mm. LUXO " "	7 mm. LUXO No. 27 " "	12 / 18 / 20	" "	1·5 / 1·9 / 2·0	1·6 / 2·0 / 2·1	1,900 / 2,200 / 2,550
12 mm. LUXO " "	8 mm. LUXO No. 27 " "	15 / 20 / 25	" "	1·4 / 1·7 / 2·0	1·5 / 1·8 / 2·0	2,150 / 2,450 / 2,700
13 mm. LUXO " "	9 mm. LUXO No. 27 " "	20 / 25 / 30	" "	1·3 / 1·6 / 1·9	1·5 / 1·7 / 1·9	2,400 / 2,650 / 2,800
14 mm. LUXO " "	10 mm. LUXO No. 27 " "	25 / 30 / 35	" "	1·3 / 1·6 / 1·8	1·5 / 1·7 / 1·9	2,650 / 2,800 / 2,900

HIGH INTENSITY (NON-ROTATING) DATA

Carbons Positive	Carbons Negative	Arc. Amps	Arc Volts	Inches Consumed Per Hour Pos.	Inches Consumed Per Hour Neg.	Screen Lumens
6 mm. CEREX	5 mm. CERENEG	30	28	5·1	3·9	6,050
"	"	35	30	8·5	4·2	8,940
"	"	40	33	13·0	4·6	11,290
6 mm. CERELITE	5 mm. CERENEG	35	28	7·0	4·2	8,070
"	"	40	32	10·0	4·6	10,890
"	"	45	35	14·6	5·0	12,690
7 mm. CEREX	6 mm. CERENEG	40	32	6·2	3·6	8,095
"	"	45	34	8·5	3·8	10,760
"	"	50	36	11·3	4·1	12,640
7 mm. CERELITE	6 mm. CERENEG	45	31	7·0	3·8	9,440
"	"	50	34	9·8	4·1	11,840
"	"	55	37	13·0	4·3	13,110
8 mm. CEREX	6·5 mm. CERENEG	50	36	6·7	3·4	10,890
"	7 mm. CERENEG	55	38	8·5	3·6	13,110
"	"	60	40	10·9	3·5	14,790
"	"	65	42	14·0	3·7	16,140
8 mm. CERELITE	6·5 mm. CERENEG	55	36	7·0	3·6	11,910
"	7 mm. CERENEG	60	38	9·3	3·5	13,920
"	"	65	41	12·3	3·7	15,330
"	"	70	43	15·5	3·9	16,540
9 mm. CEREX	7 mm. CERENEG	60	39	7·8	3·5	14,930
"	7·5 mm. CERENEG	65	41	10·7	3·7	16,740
"	"	70	43	14·8	3·9	18,150
"	"	75	45	18·5	3·6	18,690
9 mm. CERELITE	7·5 mm. CERENEG	75	39	9·8	3·6	15,060
"	"	80	42	13·0	3·8	16,740
"	"	85	48	17·0	4·0	18,290
"	"	90	50	23·0	4·2	19,710

STAGE ARC and SPOT LIGHT DATA

Type of Carbon	Current Range Amperes	Diam. Positive mm.	Diam. Negative mm.	At Normal Current of Amps.	Inches Consumed Per Hour		Arc Volts
					Positive	Negative	
Stage Arc Pos. Cored and Stage Arc Neg. Copper Cored	10–15	10	7	15	2·7	2·4	48–52
	15–20	11	7	20	2·6	2·7	
	20–25	12	8	25	2·7	2·3	
	25–35	14	9	30	2·3	2·2	
	35–45	16	10	40	2·2	2·2	
	45–55	18	12	50	2·1	1·9	
Stage Arc Pos. Cored and Stage Arc Neg. Copper Covered	55–65	20	10	60	2·1	2·1	
	65–75	22	11	70	1·9	1·9	
	75–85	25	12	80	1·9	2·2	

Type of Carbon	Max. Current Amperes	Diam. Positive mm.	Diam. Negative mm.	Inches Consumed Per Hour		Arc Volts
				Positive	Negative	
Stage Arc Pos. Cored and Stage Arc Neg. Solid	20	14	10	1·5	1·9	50–55
	25	15	11	1·7	1·7	
	30	16	12	1·7	1·8	
	40	18	13	1·8	1·7	
	50	20	15	1·7	1·8	
	60	22	18	1·6	1·5	
	70	25	20	1·4	1·3	

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