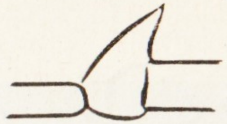
National
TRADE-MARK
PROJECTOR CARBONS



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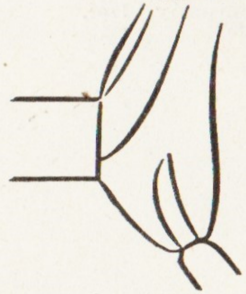


FOURTH EDITION

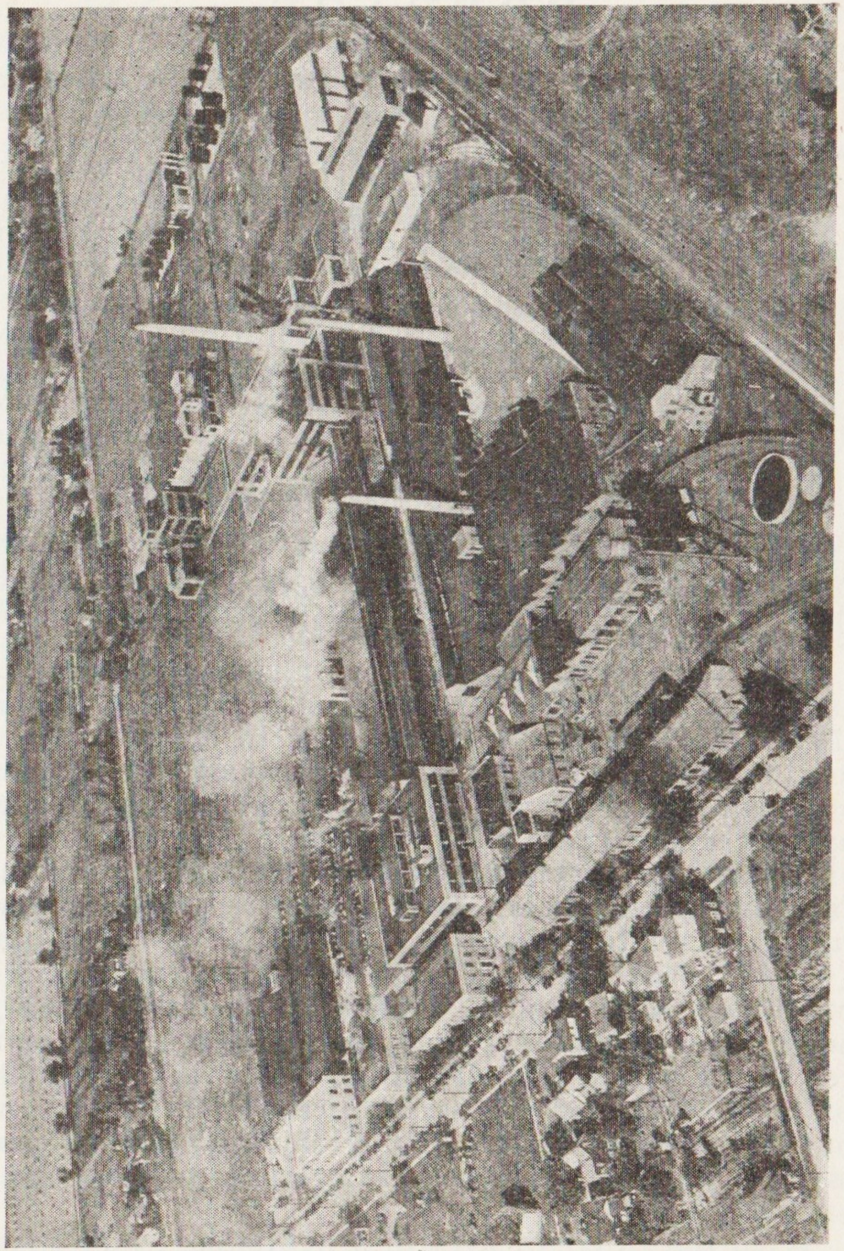
NATIONAL CARBON COMPANY, INC.
FOREIGN DEPARTMENT
Unit of Union Carbide and Carbon Corporation

UCC

30 East Forty-second Street
NEW YORK 17
N. Y., U. S. A.

CABLE ADDRESS
EVEREADY, NEW YORK

The terms "National", "Suprex", "Orotip", "Pearlex" and "Karbate" are trade-marks of National Carbon Company, Inc.



Fostoria Works of National Carbon Company, Inc.

Contents

CHAPTER I

Carbon

CARBON plays a most important role as a basic raw material in the modern industrial world. It ranks in importance with rubber, glass, steel, copper, magnesium, plastics and the other more familiar basic materials and is just as essential to our present mode of life. Without carbon, the wheels of many industries would cease turning; the manufacture of aluminum, steel, and many important alloys would be very seriously handicapped; the generation of electric power on the present huge scale would be impossible; and our greatest agency for education and entertainment, the motion picture, would be seriously handicapped through dependence on weak light sources of poor color quality.

Carbon is an element which is found in abundance in all parts of the world since it is a constituent of all organic materials. The most perfect crystalline form of carbon is the diamond and even the diamond is excelled in purity by special carbon and graphite electrodes manufactured for use in spectroscopic analysis. Other well-known forms of essentially pure carbon are graphite, lampblack, charcoal and coke. The latter forms, however, usually contain some mineral or volatile impurities. Coal contains a very high percentage of carbon as well as a variety of tarry hydrocarbons from which the numerous coal-tar products are derived.

The peculiar physical and chemical characteristics of carbon adapt it to many uses for which no other material is suitable and it has supplanted many materials formerly used.

From a chemical standpoint carbon is very inactive, resisting the effects of most acids, alkalies and solvents. It does not melt at any incandescent temperature, remaining a solid up to about 3670°C

(6640°F), and then going directly to a vapor without an intervening liquid phase.

It may readily be formed in a variety of shapes, either in the initial plastic condition or later by machining in solid form. In graphitic form carbon is valuable as a lubricant. The thermal conductivity of carbon in non-graphitic form is low as compared with that of most metals, but in graphitic form it is higher than that of most metals. Although higher in electrical resistance than the metals, carbon is nevertheless a good conductor of electricity, a characteristic adapting it to many uses in the electrical field.

The various industrial applications of carbon include carbon brushes for motors and generators; welding carbon products; carbon and graphite anodes and electrodes used in electrochemical and electrometallurgical industries; carbon Raschig rings, carbon and graphite tubes and carbon linings, "Karbate" impervious carbon and graphite for heat exchangers and other applications for handling and processing acids and other corrosive materials; dry cells, and numerous special applications among which may be mentioned switch and circuit breaker contacts, resistance discs, steam turbine packing, piston rings, stuffing box packing, thrust rings for automobile clutches, ingot mold plugs and stools, back plates, diaphragms and granular carbon for telephones, electronic tube anodes and grids and, in the form of pure graphite powder, as a lubricant and a constituent of lubricating greases.

The first commercial application of carbon on an extensive scale was in the electric arc lamp. Here the singular characteristics of this element make possible a quality and intensity of illumination which cannot be obtained in any other way. Possessing good electrical conductivity and low thermal conductivity, non-melting and slow burning at the extreme temperature of the arc, remaining a firm solid

at a temperature higher than that attainable by any other substance of suitable electrical conductivity, carbon has proved to be the ideal electrode material for this purpose.

Although the carbon arc lamp is no longer used for general illumination its importance has not diminished. The development of new types of carbons for special applications has greatly extended its use into fields where it has shown marked superiority over other sources of illumination. In the home —as well as in hospitals and sanatoria—the carbon arc is used to produce artificial sunlight and radiation of specialized character which physicians practicing light therapy have found valuable in the prevention and cure of certain physical disorders. The carbon arc has become an important tool of industry for processing materials by means of photochemical reactions and for accelerated tests of materials which tend to deteriorate under the action of sunlight. The most powerful searchlights utilize highly developed types of carbon arc lamps with carbons designed for this specific purpose. Thousands of carbon arcs are in daily use in photography, photo-engraving, blue printing, and allied industrial processes. The motion picture industry would never have reached and could not maintain its present high plane without the aid of the carbon arc which is used both for studio illumination as well as for the projection of motion pictures. The large screen, long throw, and high level of screen illumination in the modern theatre require an intensity in the light source that only the carbon arc can supply. The brightness of the crater may be as much as seven million times the brilliancy of the screen.

The demands made upon projector carbons are extremely severe and the present high quality of "National" Projector Carbons has only been attained by painstaking research and years of manufacturing experience. Great care is necessary in selecting raw materials of unusually high purity and in maintaining close control over every step in the six to eight weeks period of production.

Projector carbons must conduct electricity at very high current densities ranging from 140 to over 1500 amperes per square inch. They must permit the attainment of a very high concentration of energy in the gas ball confined within the positive crater, at the same time supplying material through volatilization to maintain this gas ball as an efficient radiator of light. No material other than carbon can satisfy these requirements—with the cup-shaped crater surrounding a ball of fire at a temperature in excess of 10,000°F and with the carbons gripped only a few inches away by metal jaws, the temperature of which cannot safely exceed 2,000°F.

Constant research is necessary to produce new types of projector carbons and means of utilizing them which will meet or anticipate the demands created by the steady development of the motion picture industry.

CHAPTER II

Manufacture of Projector Carbons

FROM a thoroughly modern plant, devoted exclusively to the manufacture of carbon products, "National" Projector Carbons go out to all parts of the world. Accuracy and precision mark every step in production, from raw material to finished product.

The raw materials used in the production of projector carbons are the purest commercial forms of carbon, such as petroleum coke and lampblack, and the bonding agents, tar and pitch. The tar and pitch are refined and distilled to the required viscosity under conditions which permit very close control. A view of the pitch plant is presented in Figure 1. The

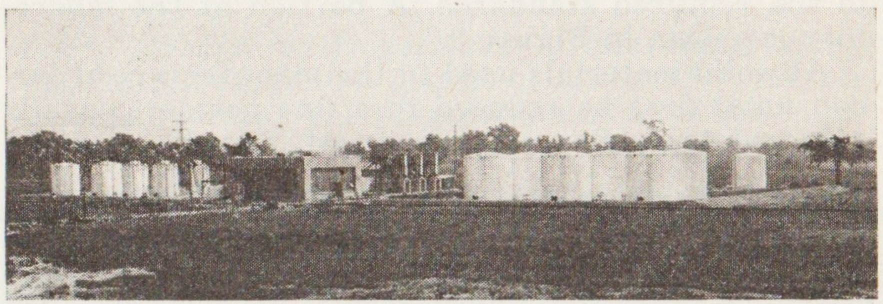


Figure 1
General View of Pitch Plant

lampblack is produced by burning oil or other suitable hydrocarbons in a special furnace, Figure 2, under carefully controlled conditions of temperature and restricted draft. Conditions are chosen which leave unconsumed a large part of the carbon in the fuel and this settles out in the form of soot or lampblack in the large settling chambers through which the products of combustion pass. Careful laboratory tests at this, as at every subsequent stage of production, check the purity and essential physical characteristics of the product to make sure that it is held

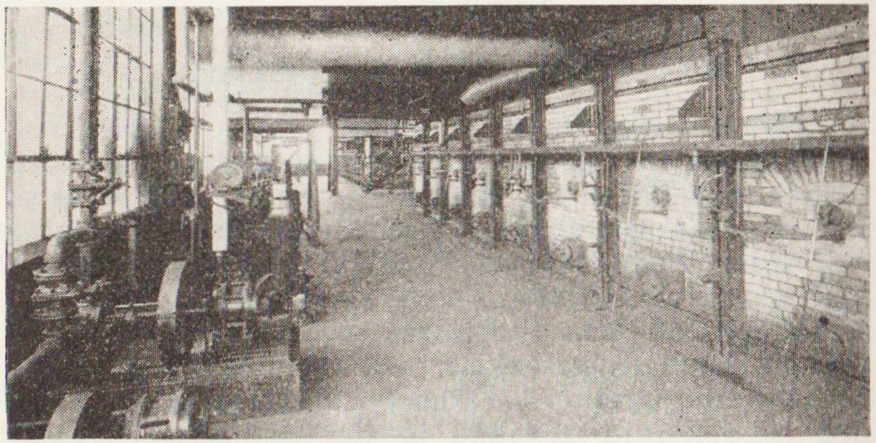


Figure 2
Section of Lampblack Furnace Room

to the required standards. A portion of the laboratory is shown in Figure 3.

All solid materials used in the manufacture of carbon must first be reduced to a fine powder, usually referred to as flour. In Figure 4, may be seen the

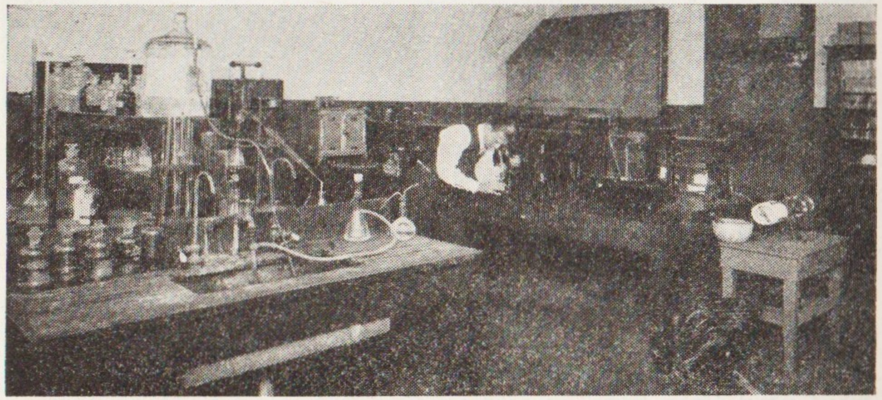


Figure 3
A View of the Laboratory

crushing and milling equipment by means of which this pulverizing of carbon is effected. The crude raw materials pass through these mills and the resulting

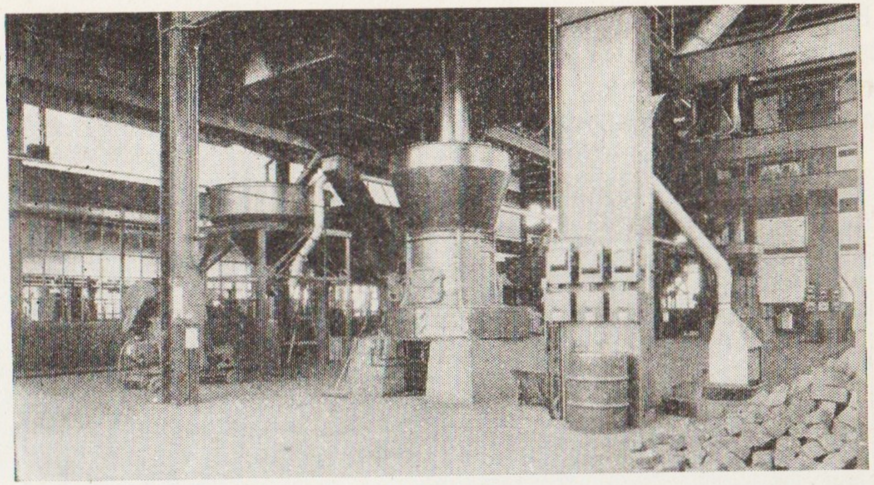


Figure 4
Section of Crushing and Milling Equipment

flour, blended with portions of preceding lots to maintain a maximum degree of uniformity, is stored in bins awaiting the preparation of a carbon mix.

In preparing a carbon mix the necessary ingredients are accurately weighed and thoroughly mixed with the required proportion of pitch bonding material in heated mixers, such as those illustrated in

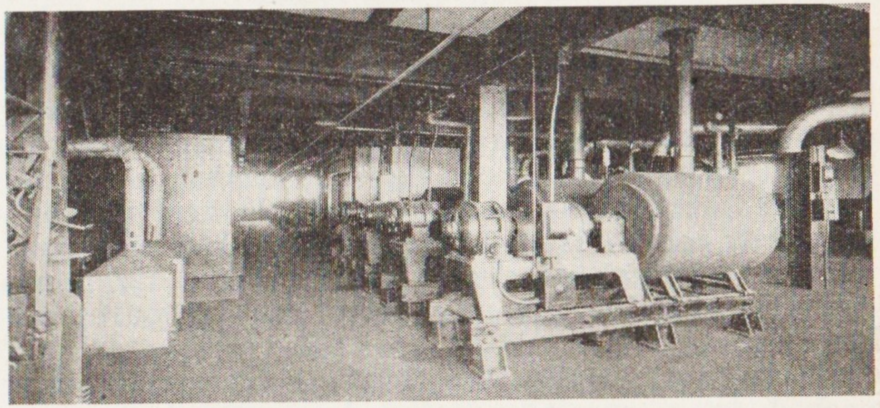


Figure 5
View of Mixing Department

Figure 5. The resulting mix is a plastic, dough-like material which is next placed in powerful hydraulic extrusion presses, Figure 6, and forced through accurately calibrated dies in the form of rods of the

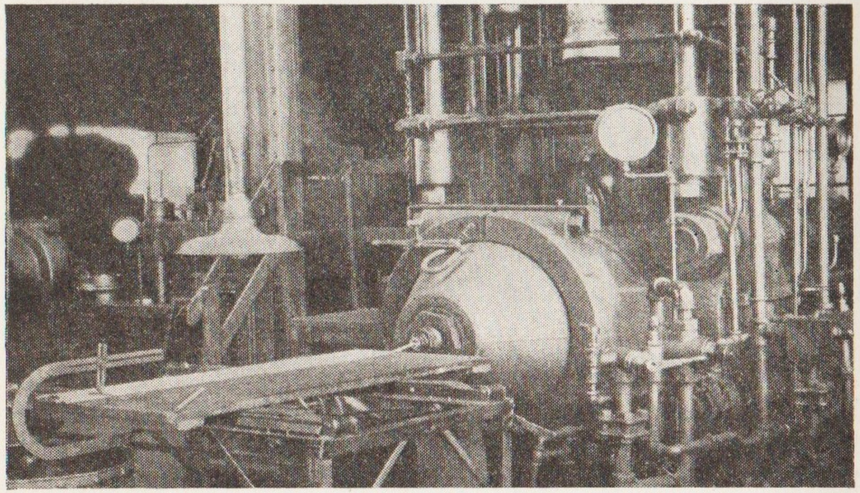


Figure 6
Hydraulic Extrusion Presses

required diameter. For carbons that are to be cored these rods are formed with a central opening into which the core material is inserted at a later stage of production. The extruded product is then allowed to cool. When cool, these "green" carbon rods, although fairly rigid, are still in the plastic form. Before they can be used, they must be baked at a high temperature which converts the pitch bonding agent into coke, leaving a homogeneous solid of pure carbon.

Preparatory to baking, the "green" carbons are packed in a specially-designed, gas-fired furnace where they are subjected to a very high temperature. The time-temperature cycle of the baking operation is of great importance and is carefully controlled within close limits through the baking period. A typical furnace room is shown in Figure 7.

Figure 7
View of Furnace Room

When the carbons come from the furnace, they are cleaned, cut to the required length, and inspected for straightness and visible faults, after which the core material is inserted into those carbons manufactured in hollow form. This core consists of compounds of the cerium group of rare earths for high intensity positives and of neutral arc supporters (potassium compounds) for low intensity positive and negative carbons. These carbons are again baked to solidify the core material. Next, the carbons are pointed and those that are oversize are ground to exact diameter. All "National" Projector Carbons are polished with the exception of High Intensity positive carbons. Since these must be rotated by the feeding mechanism of the high intensity lamp, they are thoroughly cleaned but not polished. "Suprex" "Orotip" and A.C. High Intensity carbons are copper coated. After being stamped with the "National" trade-mark and grade designation each carbon passes through a final thorough inspection which includes an X-ray examination to de-

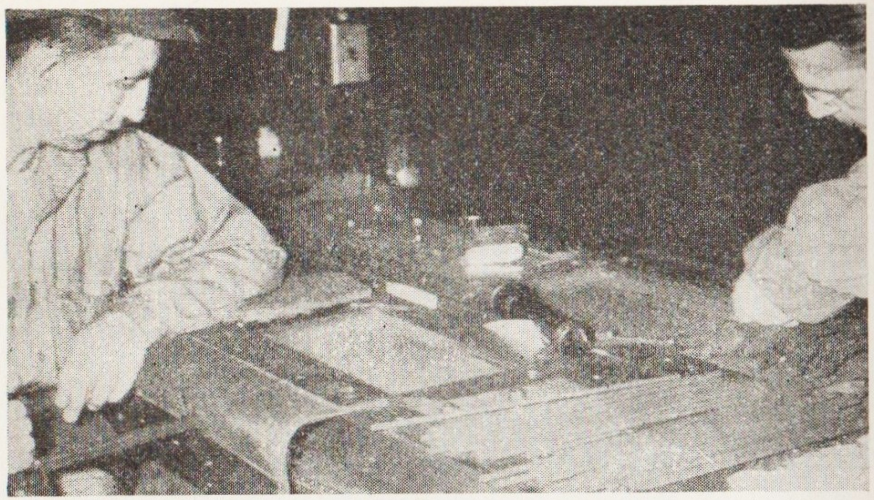


Figure 8
X-Ray Apparatus Used in This Stage of Inspection

tect any imperfection in the cores of the high intensity carbons.

Highly specialized equipment is required for the manufacture of projector carbons. At each stage of production, the greatest care is exercised to maintain the conditions which experience has proved essential to uniformity of product. Samples from every lot are tested by burning in the type of lamp for which they are intended. As a result of this extreme care and close technical control, the carbons reaching the user can be depended upon to give uniform quality and intensity of light as well as satisfactory performance in all other respects.

CHAPTER III

The Physics of Light

A BETTER understanding of the following discussion of the brightness and color of light will be afforded by a brief explanation of the terms in general use.

All forms of radiant energy may be considered as wave phenomena. These phenomena may be compared to the ripples produced when a stone is dropped into a pool of still water, causing concentric waves to radiate in all directions. Light waves travel at a speed of three hundred million meters (186,000 miles) per second. Their frequency of vibration is so high, however, that even at this tremendous speed, the wave length (or distance between wave crests) is submicroscopic. The longest wave length of visible radiation is 0.00003 inch long, and the shortest about half that length. To use our shortest familiar unit of length, the millimeter, in defining wave lengths would be equivalent to giving the size of this page in miles rather than inches. For this reason physicists have adopted a very short unit of length known as the Angstrom unit (Å), which is equal to 0.0000001 millimeter. Defined in density the longest wave length of visible radiation is about 7,000 Å and the shortest is about 4,000 Å. Another unit frequently used is the millimicron, which is equal to 10 Angstrom units, or 0.000001 millimeter.

A beam of light is usually composed of a mixture of radiations of many wave lengths which can easily be separated by simple optical means. Raindrops scatter the colors of sunlight to form a rainbow, and a prism or a diffraction grating spreads a ray of light to form what is called a spectrum. In such a separation, the violet or short wave lengths are displaced from their original direction more than the red or longer wave lengths.

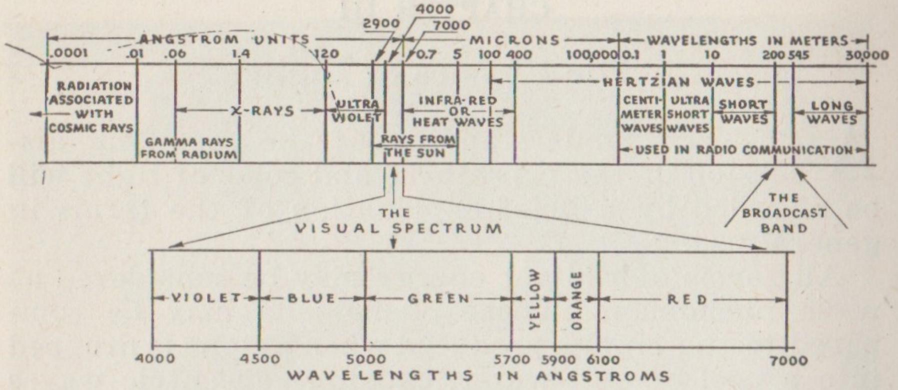


Figure 9

The Radiation Spectrum

Light waves are part of the same family which includes radio waves, infra-red waves, ultra-violet waves, X-rays, etc. Figure 9, is a chart illustrating the relation of the visual spectrum to the rest of the waves which are included in this important series. All the waves in this series are physically identical in nature as respects their speed of travel and their composition. They differ only in respect to their frequency of vibration and wave length. By frequency, is meant the number of complete waves or cycles passing a given point in one second; and by wave length, the distance between successive wave crests.

Intensity of radiation at various portions of this spectrum can be accurately measured. Plotting the values so obtained on a suitable vertical scale, at horizontal positions corresponding to their wave lengths, gives a curve which accurately describes the character of the radiation studied. This is called a spectral energy distribution curve. Such curves provide one of the best means for comparing the radiant energy from different sources. Fig. 10 shows spectral energy distribution curves within the visual spectrum with which the discussion in this book is primarily concerned.

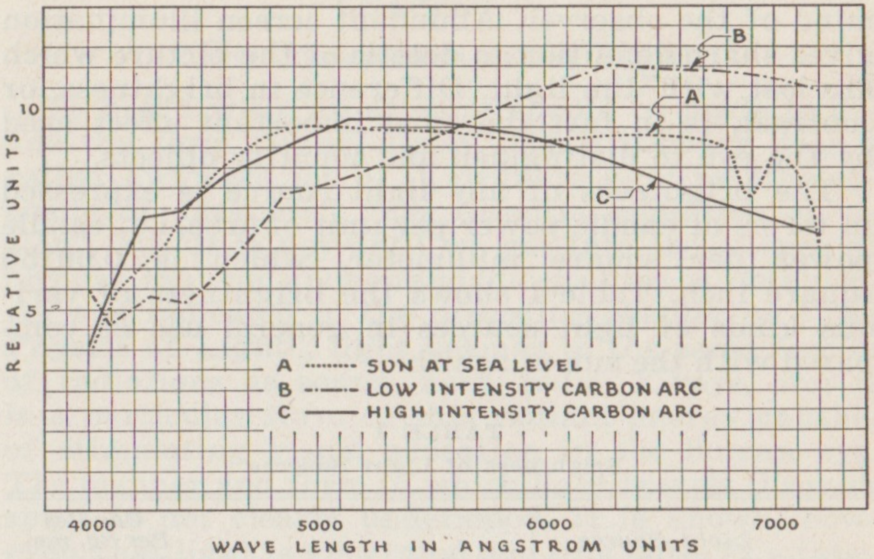


Figure 10

Since most objects are normally viewed by daylight, a motion picture is most realistic when projected by light of daylight quality. This reaction is noticeable with pictures presented in black and white and resulted in a preference on the part of theatregoers for snow-white projection light before color features were known. The advent of colored motion pictures, however, greatly increased the importance of color quality in projection light.

Daylight consists of an essentially even balance of all spectral colors. Therefore to obtain the greatest realism, color pictures not photographed in daylight are made under carbon arc lighting of daylight quality. The best effect will be obtained when they are projected with light of the same type. The popularity of color features today makes color quality of light practically equal in importance to quantity of light.

The brightness of the screen image is an important factor in creating the feeling of realism in the mind of the observer. Abundant screen illumination gives sharp definition to details of the picture which are lost with dim light. Difference in brightness, or contrast, is in fact the most important effect used by the eye to distinguish and identify objects.

The brightness of any light source is expressed in terms of candle power per unit of area, i.e., candle power per square millimeter, which is 0.00155 square inch. Table I shows the brightness of various kinds of light sources in general use as compared with the sun at zenith.

TABLE I

Brightness of Light Sources

Light Source	*Candles Per Sq. mm.*
Fluorescent Lamp	0.0011-0.0147
Sodium Vapor Lamp	0.07
60-Watt Coiled Tungsten Filament Lamp	
Bulb Brightness	0.17
Filament Brightness	7.9
750 Watt, 25 Hr. Tungsten Lamp (Used in 16mm Film Projectors)	
Average Brightness Perpendicular to Filament	32
Same—Reinforced with Spherical Mirror Back of Lamp	36
Carbon Arcs—Positive Crater Center Brightness	
D.C. Low Intensity Arc	175
"Pearlex" H.I. Arc (Used in 16mm Film Projection)	350
70-Ampere "Suprex" Type D.C. Arc	700
150-Ampere D.C. High Intensity Arc	860
170-Ampere D.C. Super High Intensity Arc	940
D.C. High Intensity Carbon Arc (Experimental)	2000+
Sun at Zenith	1650

The very high brightness of the high intensity carbon arc makes it an ideal light source for the projection of motion pictures because the small area of very high brilliancy permits the optical system of the lamp and projector to project large quantities of light effciently through the film aperture and onto the screen.

CHAPTER IV

The Measurement of Light

To begin with, an attempt should be made to define the term "light" itself. The dictionary does a rather awkward job of it, defining light as "the opposite of darkness", "the essential condition of vision", etc. It is not until we get into the science of physics that an understandable picture is obtained. As was indicated in the preceding chapter on "The Physics of Light", light belongs to the same family of radiations as sound, heat, radio, X-rays, etc; it is a particular form of this radiant energy capable of stimulating visual sensation in the human eye. The manner and form in which light travels through space is not clearly understood. It is known, however, that light is generated one tiny pulse at a time, each pulse the result of an energy change within a single atom. An astronomical number of these tiny light pulses is required to illuminate an object to an easily visible level. Something more than ten million billion (10×10^{15}) such pulses of white light per second, for instance, are required to provide the same illumination per square foot as a single candle at one foot distance would provide.

The measurement of light in motion picture projection applications is concerned with the specification not only of the characteristics of a source of light but also the illumination of an object by light directed upon it from such a source. With respect to the source, interest is centered not alone in the total light produced, but in the "brightness" of the source as well. With an illuminated object, interest is in the light per unit area, in the total quantity of light falling on the object, and, particularly in the case of the motion picture screen, in the intensity of the reflected light. The terms "candle", "candlepower", "lumen", "foot-candle", and "foot-lambert" are conventionally employed as units of measurement of light in such cases. The following explanations of these terms are based on their application to motion picture projection.

The *"candle"* is the fundamental unit of light intensity and is a measure of the ability of a source to radiate light. A source is said to have an intensity of one candle if it is capable of illuminating an object at a particular distance to the same degree as would a standard candle. The standard candle was originally defined in terms of the open flame of a ⅞ inch sperm candle burning at a specified rate. A group of carbon filament lamps preserved at the National Bureau of Standards is now used in place of the sperm candle as the standard units of comparison.

The *"candlepower"* of a source is the light intensity expressed in "candles". Thus it is proper to state that a particular carbon arc has a *"candlepower of 80,000 candles"*.

Particularly with carbon arcs, which emit light in one hemisphere ahead of the crater, the light intensity (or "candlepower") varies with the direction of view toward the source. It is therefore common to further specify the candlepower with respect to the direction, such as *"horizontal candlepower"*, *"axial candlepower"*, *"forward candlepower"*, etc. Candlepower values can be specified for any direction or angle from which the light source is viewed.

"Candlepower", then, is the measure of the light-emitting power of the source, without regard to the area of the source. Obviously two sources can be of the same candlepower even though one is much larger in area than the other, in which case the source with the smaller area is said to be the brighter of the two. The *"brightness"* of a light source is therefore expressed in terms of *"candles per unit area"*. The square millimeter (0.00155 sq. in.) has been chosen as the unit area for expressing the brightness values of the carbon arcs described in

this book. *"Candlepower"* and *"brightness"* therefore are measures of the power of a source to radiate light, and if such measurements are taken in all directions the source is completely specified.

The *"lumen"* is a measure of the rate at which light pulses are emitted or received. Since a light pulse is so very small, it would be altogether impractical to relate a workable unit directly to a single pulse. To do so would be like attempting to buy a steak from the butcher by the atom. A more practical unit (like the pound, for steak,) is needed. The *"lumen"* has been so chosen after the following fashion: if a source having a candlepower of one candle in all directions be completely enclosed at the center of a sphere of one foot radius, and if a door of one square foot area on the spherical surface be then opened, light pluses will emerge at the rate of one *"lumen"*. The lumen is thus a measure of light flow, just as in electrical units the ampere is a measure of the rate of current flow.

The *"foot-candle"* is a measure of the rate at which light pulses fall per unit area on a surface. A surface of any area, all points of which are located a distance of one foot from a source having an intensity of one candle, is said to have an illumination of one *"foot-candle"*.

The illumination in *"foot-candles"* multiplied by the area in square feet of the object illuminated gives the total *"lumens"* over that area.

"Foot-candles" and *"lumens"* are the units commonly used to express values of the projected or incident light on motion picture screens. Screen light is frequently expressed in *"incident lumens"* which is a measure of the total useful light output of the carbon arc lamp and projector mechanism. To measure the screen lumens in any particular case, the screen may be divided into small areas of substantially uniform illumination, and the magnitude of the illumination in foot-candles measured

in each such area. The foot-candle values thus obtained, multiplied by the associated area in square feet gives the total lumens for that area; and the summation of these lumen values for all the areas gives the total screen lumens. Light measuring devices calibrated to read directly in foot-candles are available for making such measurements.

If the total lumen output is given for a particular projection system the average illumination in foot-candles for any given size screen may be obtained by dividing the total available lumens by the area of the screen in square feet. For example, if a projection system delivers 3,600 lumens to a screen 300 square feet in area the average light intensity on the screen will be 3,600 divided by 300 or 12 foot-candles which is equivalent to 12 lumens per square foot. In all practical cases, however, the light is not distributed uniformly over the screen area in this fashion; the light intensity at the sides of the screen is usually 60% to 80% of that at the center. The term *"screen light distribution"* is used to express the degree of uniformity of screen illumination. Ordinarily this term is simply the ratio of the illumination near the edge of the screen, on a horizontal center line, to the illumination at the center. A *"screen light distribution of 80%"*, frequently more precisely expressed as *"the side to center distribution ratio"*, simply means that the side illumination is 80% of that in the center. If such measurements are to be reliable, care must be taken to align the lamp optical system properly and to hold the arc crater precisely on the desired operating point so that the screen will be symmetrically illuminated at optimum value.

The next important factor to consider is the amount of light reflected from the screen to the observer. The amount of reflected light depends upon the initial character of the screen surface as well as its age and condition of cleanliness. In the case of

the motion picture screen the term *"brightness"* refers to the light per unit area reflected from the screen. The *"foot-lambert"* is the unit of *"brightness"* ordinarily used to define the amount of light per unit area reflected from the screen. A perfectly diffusing surface reflecting light at the rate of *one lumen per square foot* is said to have a *brightness of one foot-lambert* and it appears equally bright from all angles of view. The *brightness* of a screen which is not perfectly diffusing will generally vary with different angles of view. Some screens with directional properties (such as silver screens and beaded screens) concentrate the reflected light in one direction and may, therefore, appear much brighter in this direction than a perfectly diffusing surface reflecting the same total amount of light. The *apparent reflectivity* of a screen in any given direction is defined as the ratio of the brightness in foot-lamberts to the incident intensity in foot-candles. For diffusing type (flat white) screens the apparent reflectivity is approximately constant over a wide angle of view and generally does not exceed 75% to 90%. Dirt and age may, in extreme cases, reduce these values by as much as one half. A directional screen may have an apparent reflectivity of 200% or 300% in a selected direction and fall much below 100% in other directions. This *apparent reflectivity* must not be confused with the total or *overall reflectivity* of the screen which measures the ratio of the total light reflected in all directions to that incident on the screen and which will always be less than 100%. Information on the reflecting power of any given screen in its original condition can be obtained from the screen manufacturer.

In the example cited previously the method of calculating the average intensity of the light delivered to the screen was shown and an average value of 12 foot-candles, or 12 lumens per square foot was obtained. Let us assume that this is a perfectly diffusing screen with a reflecting power of 75%. This means that 75% of the light delivered to the screen is reflected and that 25% of this incident light is absorbed by the screen. Therefore the quantity of light reflected by this screen or its "brightness" will be 75% of the incident light (75% of 12 lumens per square foot) or 9 lumens per square foot which by definition is equivalent to 9 foot-lamberts. In other words, if the light intensity in foot-candles and the reflecting power of the screen are known, the "brightness" of the screen in *"foot-lamberts"* can be determined by multiplying the foot-candle values by the reflecting power of the screen. For a screen of known reflecting power the light intensity in foot-candles necessary to obtain a given brightness in foot-lamberts is determined by dividing the foot-lambert value desired by the reflecting power of the screen. Since a motion picture screen is ordinarily brightest at the center the specification of brightness of a particular screen should include values not only for the center but for the sides and perhaps the corners as well.

In order to ensure a sufficient screen brightness for proper viewing conditions the American Standards Association (Standard Z22.39-1944) has specified that "The brightness in the center of the screen for viewing 35mm motion pictures shall be $10\,{}^{+4}_{-1}$ foot-lamberts when the projector is running with no film in the gate". In other words, the brightness in the center of the screen should be within the range of 9 to 14 foot-lamberts. For a perfectly diffusing screen of 75% reflecting power, the incident light to meet these conditions should be within the range of from 12 to 18.7 foot-candles.

CHAPTER V

Progress in Projection Lighting

WHEN Sir Humphrey Davy in his classic experiment early in the 19th century produced the first electric arc between carbon electrodes he could have had no thought of the importance his discovery was to have in the development of an industry to be founded almost a century later. Yet the phenomenal strides made by the motion picture industry in its relatively few years of existence were made possible by the adaptability of the carbon arc to its expanding needs.

Many other factors, including technical advances in other lines, have had important parts in the development of the motion picture industry over a relatively short span of years into one of the major industries of the country. The artistry of directors, cameramen, and actors have played a large part. The sagacity and courage of the industry's executives have contributed largely to its record of progress. These factors involving personalities have been given much publicity and have tended to overshadow the improvements in the carbon arc and its utilization, which have likewise had a vital part in making possible the tremendous growth that has been realized. Furthermore, the adaptability and skill of the motion picture projectionist have been an important but little publicized element in these developments.

The optics of motion picture projection are such that a light-source of small dimensions and very high brightness is essential. No light-source has been available throughout the history of the industry which satisfies these requirements so well as the carbon arc. The crater of the positive carbon offers an essentially flat field of light emission, sufficiently uniform in brightness over its entire area to provide a satisfactory uniformity of illumination on the largest screens. Due, however, to the enormous difference in area between the screen and the source of projection light, and to losses encountered in the optical system, the brightness of the light-source must be millions of times that of the light reflected from the screen. It is therefore but natural that, from the first commercial exploitation of motion pictures, the carbon arc should have been selected as the source of projection light. For the carbon arc, at that time to be seen on almost every street corner, was by far the most brilliant source of light man had then produced. Subsequent improvements, the product of constant laboratory research, have kept the arc abreast of the needs of this growing industry.

The first projection lamps burned the carbons in a position slightly inclined from the vertical, with the positive carbon in the upper position so that the brilliant positive crater was turned partially toward the condenser lens which focuses the light on the film aperture. To further direct exposure of the positive crater to the condenser lens in this type of lamp, the position of the negative carbon was adjusted so that the tip of the positive carbon more nearly faced the condenser.

From the first adaptation of the arc to projection there has been steady progress toward more and more efficient production and utilization of projection light. Developments in projector carbon manufacture have adapted the arc to more efficient optical systems and, combined with improvements in the lamps themselves, have successfully met the increasingly critical attitude of theatre patrons and kept the carbon arc in its position as the preferred source of projection light. The need for more light, first to increase the brightness of the screen image, and then to meet the needs of larger theatres, resulted in the use of larger carbons and higher arc currents. Steadiness of the light was improved, first

by making the positive carbon in the form of a thick-walled tube with a central core of softer, neutral carbon. Further improvement in steadiness of the arc was effected by using a metal-coated negative carbon, considerably smaller in diameter than the positive. Figure 11 is a drawing of this improved trim which indicates also the form of the positive crater. These improvements in the carbon trim, combined with improvements in optical systems, substantially increased the efficiency of the types of projection lamps then universally used.

By this time motion picture theatres were emerging from the limitations of capacity which the audible range of voices from the stage had previously imposed on the theatre. Houses seating 3,000 and 6,000 patrons were being built, screens were enlarged for the benefit of the patrons in the rear seats, and the need for still more screen light became urgent. Fortunately, a new development of the carbon arc was made at about this time. This has been aptly termed the "high intensity" arc and, for distinction, the term "low intensity" arc has been applied to the types of carbon arcs previously in use.

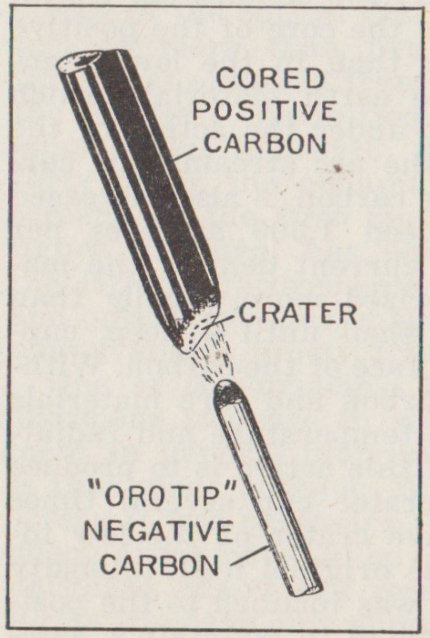


Figure 11

The low intensity, neutral cored carbon arc is seldom operated at a current density much over 200 amperes per square inch in the positive carbon. The light used in projection all comes from the incandescent crater face of the positive carbon, the brightness of which is determined by its temperature. Since carbon vaporizes at a temperature of about 3,670°C, further increase in current beyond the value which produces this temperature does not increase the crater temperature and brightness but increases only the area of the crater up to the full cross section of the carbon without spindle. If the current is increased the carbon consumption is increased proportionately. The phenomenon is the same as that of the three-minute egg. You can turn up the gas and boil the water away more rapidly, but the temperature remains the same in the pan and the three-minute egg is still a three-minute egg. In practical operation the upper limit of crater brilliancy in the low intensity D.C. arc is approximately 17,500 candles per sq.cm.

In the high intensity arc the core of the positive carbon is relatively larger than in the low intensity arc and contains rare earth materials which become highly luminescent under the action of the electron bombardment in the arc stream. The current density in the positive carbon is also increased to values which may exceed 1,500 amperes per square inch. At this high current density the material of the core is vaporized more rapidly than that of the outer carbon shell until a deep, cup-like crater is formed in the face of the carbon. Within this crater vapors of carbon and core materials are excited to a very high temperature and radiating efficiency. The effect of this action is to produce a brightness within the crater cup several times that possible at the positive crater of the low intensity carbon arc. In these original high intensity lamps the negative carbon was inclined to the positive and the latter was rotated to maintain a symmetrical crater form. This method of operation is still used on lamps of higher power. Figure 12 shows the appearance of this type of high intensity arc as viewed from the side.

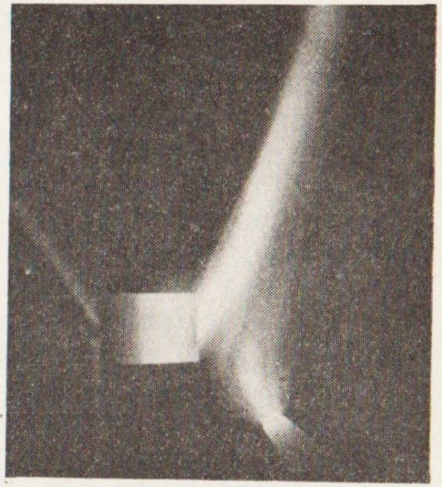


Figure 12
Photograph of D.C. High Intensity Arc in Condenser Type Lamp

Application of the high intensity arc to projection through the medium of a condenser lens optical system gave three to four times as much light on the screen as was then available from the low intensity arc and further improved the efficiency of light production. Subsequent improvements in the condenser lens system for high intensity lamps raised the efficiency of the optical system to more than five times that obtained from the earliest projection lamps. Thus improved, these lamps delivered about forty times the amount of light projected on the screens of the first motion picture theatres. This figure, in turn, has been more than doubled by the latest improvements in high intensity carbons and optical systems, making the screen illumination now available ninety times that originally used.

One of the principal benefits realized from this enormous increase in screen light is the improvement in general illumination of the theatre which is thus made possible. With only 200 lumens on the screen it was necessary for theatres, even of nickelodeon dimensions, to be operated in almost complete darkness. Many will recall the days when red exit lights were the only supplement to the dim illumination resulting from screen reflection. However, a ninety-fold increase in screen illumination, even on much larger screens, permits a clear picture to be shown in the presence of a comfortable level of general illumination, and the large theatres which adopted high intensity projection were prompt in capitalizing this advantage.

Small theatres could not afford these large high intensity lamps, however, nor did they have need for so great a volume of screen light. The development of the reflector type low intensity lamp had brought to the small theatre a considerable measure of improvement in screen light and permitted the installation of some general illumination. In the place of the condenser lens which, in the old type low intensity lamp, picked up a light cone of approximately 45 degrees, the reflector lamp uses an elliptical mirror to pick up more light from the positive crater and focus it on the aperture plate. Figure 13 shows a diagram of a typical reflector type low intensity arc. Both carbons are mounted in a horizontal position with the crater of the positive carbon facing the mirror.

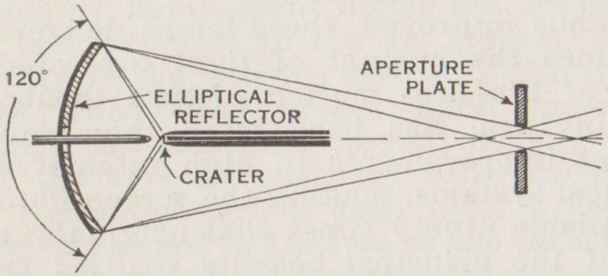


Figure 13
Low Intensity, D.C. Reflector Arc Lamp with Elliptical Mirror

By the adoption of this optical principle the cone of light picked up from the crater was increased from 45 to 120 degrees, and projection efficiency, greatly improved. The needs of theatres requiring more light than this, but not large enough to require the condenser type high intensity lamps, were met in a similar manner by using the mirror principle with the high intensity arc, in what is commonly termed the "Hi-Low" lamp.

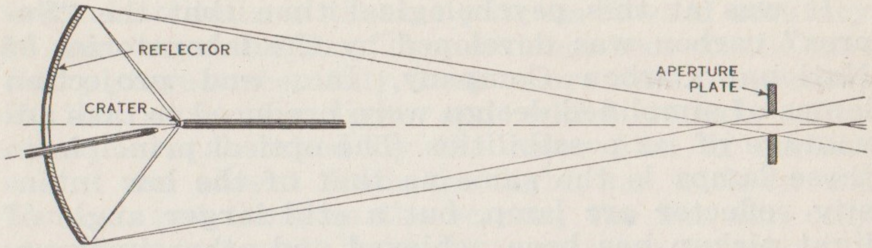


Figure 14
Diagram of High Intensity "Hi-Low" Reflector Arc Lamp

Figure 14 is a diagram of a "Hi-Low" or reflector high intensity lamp. In this lamp the negative carbon is inclined to the rotating positive, but at a much smaller angle than in the condenser type high intensity lamp. The positive carbon used is 9mm in diameter, and the arc is operated at a current of about 75 amperes, whereas the condenser type lamp uses a 13.6mm positive and an arc current of about 125 amperes or more.

In the early 30's the increasing attention being given by the public to the subject of adequate illumination was becoming a serious problem to a large number of motion picture theatres. Theatres using high intensity projection had demonstrated the feasibility of maintaining a level of general illumination which permitted comfortable vision on the part of patrons entering from the street or the brilliantly lighted lobby. Theatregoers were no longer willing to grope and stumble to their seats without complaint or to accept screen projection of inferior quality. A clear screen image requires a screen brightness conforming to the A.S.A. Standard Z22.39-1944 of 10 $^{+4}_{-1}$ foot-lamberts with the projector running and no film in the gate. Low intensity projection lamps will not provide this amount of light on the screens of many neighborhood houses.

It was at this psychological time that the "Suprex" carbon was developed by the laboratories of National Carbon Company, Inc., and projection lamps of simplified design were produced to take advantage of its possibilities. The optical principle in these lamps is the same as that of the low intensity reflector arc lamp, but a still larger angle of light pickup has been achieved and other improvements have been made which considerably increase the projection efficiency.

These lamps use small diameter, copper-coated, high intensity carbons operating without rotation in a horizontal position, as seen in Figure 15. Admirably meeting the needs of theatres of intermediate size, they have even reached into the fields formerly held by the earlier types of high intensity lamps. These simplified high intensity lamps occupy the wide gap between the maximum light output of the low intensity lamp and the very high light output of the present angular trim, rotating positive, condenser high intensity types. Furthermore, the cost of operation is so low on these simplified high intensity lamps that the advantages to be gained from increased screen light and better general illumination more than offset the slight increase over the operating cost of low intensity lamps.

Figure 15
Photograph of "Suprex" Type Arc

Another factor which gives further advantage to theatres using high intensity projection is the constantly growing popularity of color features and the

critical attitude of theatre patrons toward accuracy of color reproduction. The audience sees on the motion picture screen only those colors that are present in the projection light and which remain after others are absorbed by the color film. If certain colors are absent from the light, no trick in the film can put them on the screen; the film can only absorb or transmit light. It cannot create colors in any other way. On the other hand, excess of certain colors in the light source likewise distorts the natural hues of color features. High intensity carbon arc projection assures an evenly balanced light with all colors present in essentially equal intensity.

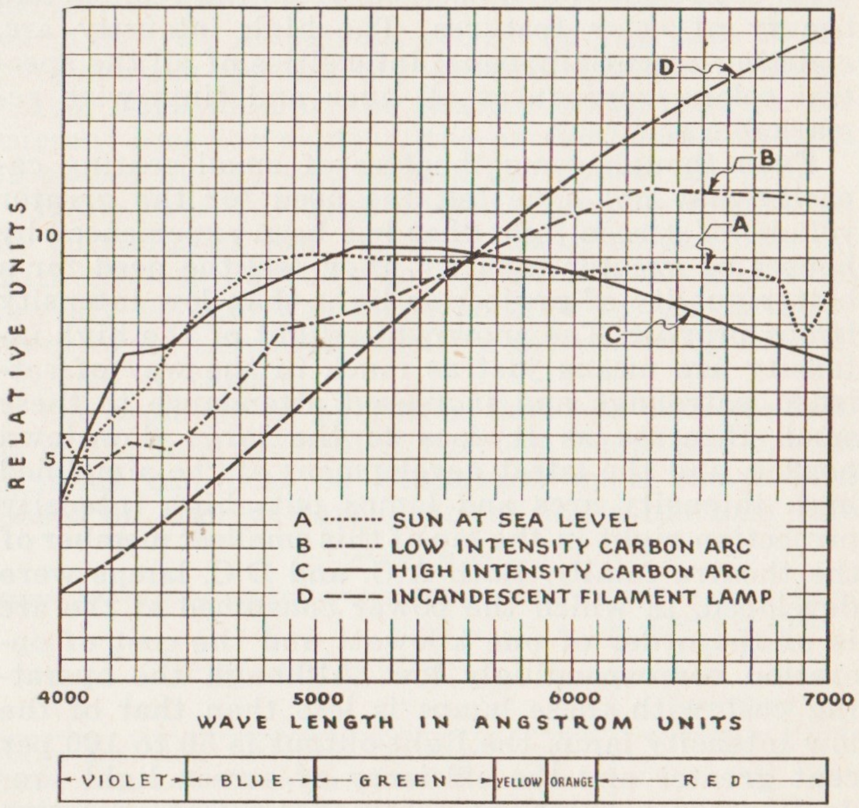


Figure 16

From the curves in Figure 16, it can be seen how closely the color distribution of the light from the high intensity carbon arc approaches that of sunlight as compared with the light from the low intensity arc and that of the incandescent filament lamp. This is the quality of projection light for which theatrical color film is processed. It is the only quality of light that gives natural color reproduction with standard 35mm color film. Low intensity lamps give a light of yellowish tint which distorts color values and detracts from the realism and beauty of color features. The high intensity arc, emitting essentially equal intensities of all the spectral colors, reproduces all hues and tints with remarkable accuracy.

Even though some theatres of small seating capacity may not have felt the need for the greater volume of screen light that has been experienced by houses of greater capacity, they feel the need for a better quality of projection light than low intensity lamps provide. The snow-white light of the high intensity arc means just as much in the way of satisfied patronage and increased attendance to these small theatres as it does to the large downtown houses, and the latest development of the simplified high intensity arcs and lamps puts high intensity projection right in the lap of this smallest member of the theatre family. Both A.C. and D.C. lamps were developed, in which the power consumed at the arc is of the order of one kilowatt and the cost of operation correspondingly low. Although the operating cost with these lamps is less than that of the low intensity lamp, the light output is 50 to 100 per cent greater and the efficiency of screen light production the highest yet obtained. Cost of operation is therefore no longer a justification for any theatre, however small, to be deprived of the increasingly important advantages of high intensity projection.

One make of alternating current high intensity lamps avoids the flicker sometimes observed when the A.C. high intensity arc is operated on 60-cycle current by operating through a frequency changer which supplies 96-cycle current to the arc. Since the cut-off frequency of the two-blade shutter at standard projection speed is 48 cycles per second, this combines with a 60-cycle light source to give a slow beat or fluctuation in the screen light which, under certain conditions, may be disturbing to the observer. By using a frequency of 96 cycles at the arc one full cycle of current occurs during each 90 degree shutter opening, and disturbing flicker is eliminated. Regardless of the phase relation between the current and the shutter, the same amount of light is passed during each period the shutter is open.

Low power D.C. high intensity lamps are operated at currents as low as 40-42 amperes arc current with 27.5 to 28 volts or less across the arc. This low arc voltage was made possible by the development of an improved negative carbon designated as "Orotip" C carbon.

The economy of operation that has been realized from the improvement in carbons, lamps and optical systems can best be illustrated by a comparison based on current carbon prices and a uniform rate

TABLE II

Type of Lamp and Trim	*Cost per Hour per 1,000 Screen Lumens (Per Cent)*
Early D.C. Low Intensity, Condenser Type	100
Later D.C. Low Intensity, Condenser Type	72
Early D.C. High Intensity, Condenser Type	60
"Hi-Low" Reflecting High Intensity	38
Low Intensity D.C. Reflecting	24
Present D.C. High Intensity, Condenser Type	22
D.C. Simplified High Intensity	11
"One-Kilowatt", High Intensity	10.5

for electric power. As a representative figure a power rate of 4 cents per kw. hr. is assumed in Table II on preceding page.

When it is considered that the record of progress in the production and utilization of carbon arc projection light shows a 10:1 improvement in brightness of the source, a 30:1 improvement in efficiency of screen light production, and a 90:1 improvement in the volume of light on the screen, together with marked improvement in color quality and steadiness, it must be recognized that projection lighting practice has kept fully abreast of progress in all other stages of the industry. A matter for further consideration is the fact that this tremendous technical advance in screen illumination has been accompanied by a 7:1 reduction in operating cost per unit of light on the screen. The expectation of further progress in projection lighting as need arises is fully justified by developments which have not as yet passed beyond the experimental stage.

CHAPTER VI

Direct Current High Intensity Arcs With Rotating Positive Carbon

The correct combinations of positive and negative carbons for use in direct current high intensity lamps in which the positive carbon rotates are given in Table III, together with the range of current recommended for each combination.

TABLE III

"National" High Intensity Projector Carbon Combinations for Rotating Positive High Intensity Arcs—Direct Current

Arc Amps.	*Approx. Arc Volts*	*Positive Carbon*	*Negative Carbon*
Condenser Type Lamps			
75- 90	54-60	11mm x 9" "National" High Intensity White Flame Projector	11⁄32" or 3⁄8" x 9" "National" "Orotip" Cored Projector
125-150	68-78	13.6mm x 22" "National" High Intensity White Flame Projector	7⁄16" x 9" "National" "Orotip" or Heavy Duty "Orotip" Projector
170	75	13.6mm x 22" "National" Super High Intensity White Flame Projector	7⁄16" x 9" or 1⁄2" x 9" "National" Heavy Duty "Orotip" Cored Projector
Reflector Type Lamps—Older Models (Hi-Low)			
60-85	48-58	9mm x 20" "National" High Intensity White Flame Projector	5⁄16" x 9" "National" "Orotip" Cored Projector
Reflector Type Lamps—Newer Models			
75-85	50-60	9mm x 20" "National" High Intensity White Flame Projector	5⁄16" x 9" "National" "Orotip" Cored Projector
100	50-55	11mm x 20" "National" High Intensity White Flame Projector	11⁄32" x 9" "National" "Orotip" Cored Projector
115	60-65	11mm x 20" "National" High Intensity White Flame Projector	3⁄8" x 9" "National" "Orotip" Cored Projector

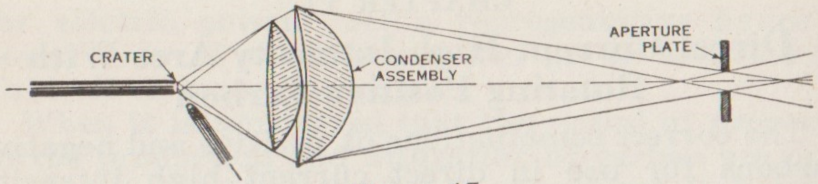


Figure 17

Figure 17 shows a diagram of a typical condenser type high intensity lamp with rotating positive carbon. The crater of the positive carbon faces the condenser lens system and the crater is focused on the film aperture. The total light from the high intensity arc is made up not only of the crater light but the light from the tail-flame, arc stream, and incandescent negative carbon as well. The total candle power is generally about 40 per cent higher than the candle power of the crater alone. However, it is impossible to use all of the light for projection purposes because of the large size and shape of the complete source. At maximum screen light, only the crater is focused on the aperture so that the distribution of light on the screen is essentially determined by the distribution of the brightness across the face of the crater and the size of the crater image on the film aperture. It is necessary to have some spill-over around the aperture to insure adequate coverage of the rectangular opening by the circular crater image.

Early high intensity arcs with rotating positive carbons were operated at currents of from 50 to 110 amperes but subsequent development of carbons by the laboratories of National Carbon Company, Inc., permits operation up to 150 amperes with the regular trim and 170 amperes with the super high intensity trim. Experimental carbons have been operated at currents well over 1,000 amperes.

A comparison of current, arc voltage, and screen light for both the regular and super high intensity trims is shown in Table IV. The increase in light

with the super carbon is due to the higher and broader brightness curve as indicated in Figure 18. The brightness curve shows the amount of light emitted in the forward direction per unit area across the crater. For example, assume we are looking directly into the crater. For each square milli-

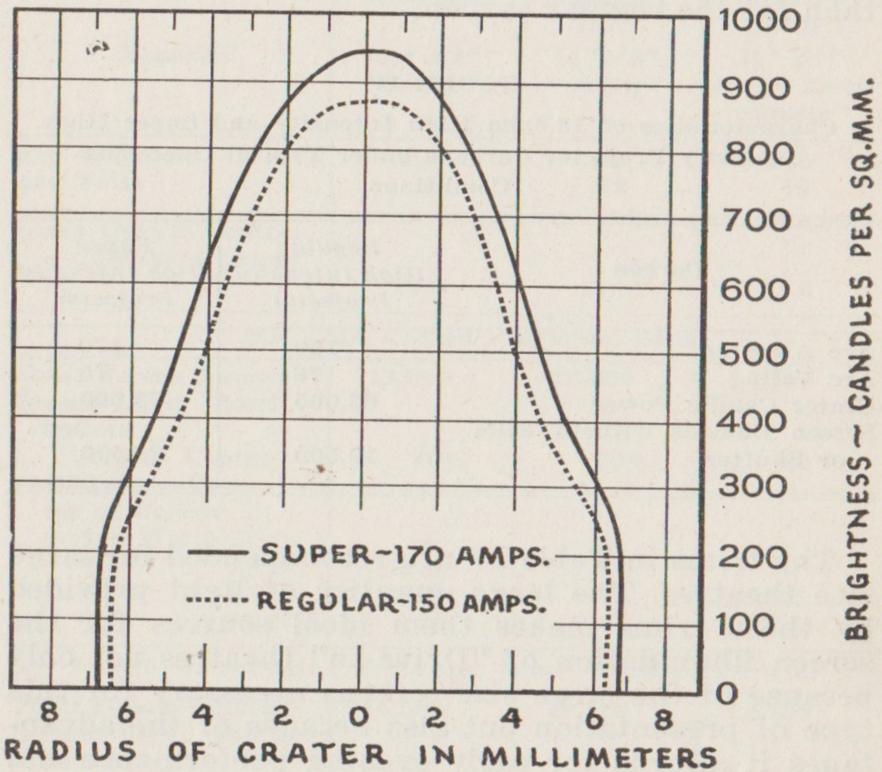


Figure 18

Brightness Distribution Across Crater of 13.6mm H. I. Carbons

meter (0.00155 square inch) at the center of the crater of the super carbon, the light coming toward us would be equivalent to that from 940 candles. For the same point on the crater of the regular carbon we would have an intensity equal to that of 860 candles. For a given optical system, i.e. condensers and objective lens, the light on the screen is governed by the brightness of the carbon plus the area of the usable high-brilliancy portion of the crater. Thus it is apparent why the available lumens on the screen for a given optical system and screen light distribution are higher for the super carbon than for the regular carbon.

TABLE IV

Characteristics of 13.6mm High Intensity and Super High Intensity Projector Carbons under Typical Operating Conditions

Carbon	*Regular High Intensity Projector*	*Super High Intensity Projector*
Arc Amperes	150	170
Arc Volts	78	75
Crater Candle Power	63,000	78,000
Screen Lumens without Film or Shutter	19,500	21,500

The trims in Table IV are recommended for large size theatres. The large quantity of light provided by these trims makes them ideal sources for the screen illumination of "Drive-In" theatres not only because of the large size screens necessary for this type of presentation but also because of the advantages it affords for early evening performance and for overcoming the varied atmospheric conditions encountered in open air projection.

Table V shows the total screen lumens as well as the foot-candles at the center of various size screens obtainable with high amperage high intensity arcs. The values given are for coated projection lenses with the optical systems adjusted for 80% side to center distribution as well as for maximum light at the center of the screen.

TABLE V

Screen Illumination with High Intensity High Amperage Carbon Arcs

Carbon Trim			
Positive	*13.6mm x 22" "National" H.I.*	*13.6mm x 22" "National" H.I.*[1]	*13.6mm x 22" "National" Super H.I.*[1]
Negative	*7/16" x 9" "Orotip"*	*1/2" x 9" "Orotip"*	*1/2" x 9" Heavy Duty "Orotip"*
Arc Amperes	125	150	170
Arc Volts	68	78	75
Lamp Optical System—Condenser Lenses at	f2.0	f2.0	f2.0
5" E.F. f/2.0 Coated Projection Lens			
Total Screen Lumens[2]	11,500	16,000	18,500
Screen Light Distribution[3] Side to Center	80%	80%	80%
Ft.-Candles—Center of Screen[4] Screen Width 15 ft.	—	—	—
" " 20 ft.	22.0	—	—
" " 25 ft.	14.1	19.7	22.1
" " 30 ft.	9.9	13.7	15.3
5" E.F. f2.0 Coated Projection Lens—Maximum Light[5]			
Total Screen Lumens[2]	14,500	19,500	21,500
Screen Light Distribution[3] Side to Center	60%	60%	60%
Ft.-Candles—Center of Screen[4] Screen Width 15 ft.	—	—	—
" " 20 ft	—	—	—
" " 25 ft.	20.4	—	—
" " 30 ft.	14.1	19.5	21.9

[1] Heat filters may be necessary with 150 and 170 amperes arcs. Light values will be reduced approximately 20% if "AK10" or phosphate glass is used. *(Continued on next page)*

[2] Screen lumen figure is for systems with no shutter, film or filters of any kind.
[3] Per cent screen light distribution refers to ratio of light intensity at side of screen to that at center.
[4] Ft.-Candle values at center of screen assume 50% shutter transmission, no film or filters of any kind.
[5] Maximum light is value with system adjusted to produce maximum light intensity at center of screen.

Operation of High Intensity Condenser Type Lamps

Lamp manufacturers specify the distance from the positive carbon crater to the rear condenser lens and the distance from the front condenser to the film aperture, as well as the protrusion of the positive carbon from the contact jaws or flame shield. These distances should be maintained accurately and the positive crater should be accurately aligned with the condensers, film aperture and projection lens. Some lamp manufacturers supply devices for properly aligning the carbons and optical system. One device employs a dummy condenser and a dummy projection lens, each made of light weight metal to fit the respective holder, and mounted in place of the real lens where alignment is to be checked. This is accomplished by moving the respective elements so that a straight steel rod will pass in turn through the positive carbon contact, the center of the dummy condenser lens, the center of the aperture, and the center of the dummy projection lens. The optical alignment should be checked periodically and always checked after any adjustment of the equipment involving moving of the lamp house or projector head.

All "National" High Intensity projector carbons are pre-cratered to reduce the amount of time necessary to burn in the crater of a new carbon; however, when burning in a new carbon sufficient time should be allowed to form a good crater of proper depth before the changeover is made.

When an arc is struck the positive crater is subjected to both thermal and mechanical shock, particularly if the arc is struck at full current. Occasionally this shock causes the lip of the crater to be cracked or a chip broken away so that the burn-in period is increased by the time necessary to form a symmetrical crater. This will occur more frequently when contact is made on the lip of the crater. The ballast resistance should be wired so that the operating current after striking is about one-third full load. The current is promptly boosted to normal after the arc is struck. A step-up switch having three terminals is available for this purpose.

Positioning of Carbons

In order to obtain the best results from high intensity carbon arcs particular attention should be paid to the proper positioning of the positive and negative carbons. The effect on the crater candle power by a variation in the position of the positive carbon with respect to the negative is shown in Figure 19. The arc current is held constant in these tests. The letters A and B on the curve indicate the values of crater candlepower corresponding to the positions A and B of the carbons illustrated in the sketches below the curve. At position "A" the bottom edge of the arc flame between the two carbons is located so that its continuation passes through the crater face of the positive carbon. At position "B" the positive carbon has been moved forward so that the flame sweeps underneath it. The arc will burn steadily in either position. However, it is evident from the curves that maximum crater candlepower is obtained with the carbons at position "A". At position "B" the crater candlepower is reduced by as much as 10 per cent.

In most high intensity lamps with rotating positive carbons the negative should be in the same vertical plane as the positive; that is, the carbons should be accurately aligned as viewed from above. Due to the current lead arrangement in some lamps, however, better positive crater formation is obtained by positioning the center line of the negative slightly off the center line of the positive. The lamp manufacturers' instructions for positioning the carbons

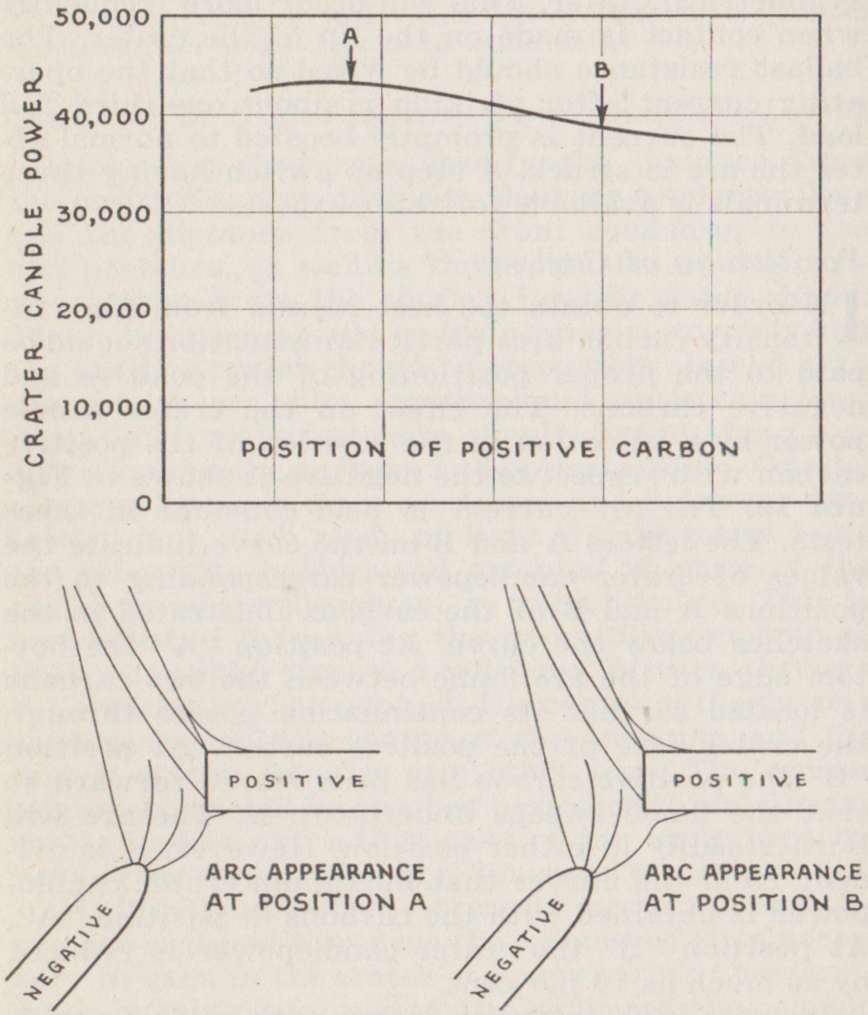


Figure 19

should be strictly adhered to, because certain lamp characteristics may alter the generally recommended positioning of the carbons.

Operation of the lamp with the positive carbon set ahead of its correct position not only reduces the volume of light but may also result in short carbon life. A protrusion of ⅛ inch beyond the proper setting may decrease the life of the positive carbon as much as 10 per cent.

The use of too short an arc gap may make it impossible to adjust the positive carbon feed to the rate at which the carbon is being consumed. Likewise, if the negative carbon feed is adjusted to feed the negative carbon faster than it is being consumed, the arc will be shortened and the same difficulty encountered.

When super high intensity carbons are used with the highest speed condensers, it may be necessary to provide means of filtering out some of the heat in the light beam to prevent damage to the film. Heat filters are available which will dissipate as much as 50% of the heat generated by the arc while reducing the light only 20%. The lamp manufacturers should be consulted in the selection of the proper type of cooling devices or heat filters best adapted to their equipment.

CHAPTER VII

Simplified High Intensity Arcs (Reflector Type)

THE "Simplified High Intensity" type D.C. and the "One Kilowatt" D.C. and A.C. arcs with coaxial non-rotating carbons have brought to both the medium and small size theatres the same high levels of screen brightness and the same snow-white quality of light as the condenser type high intensity arc provides for the largest theatres.

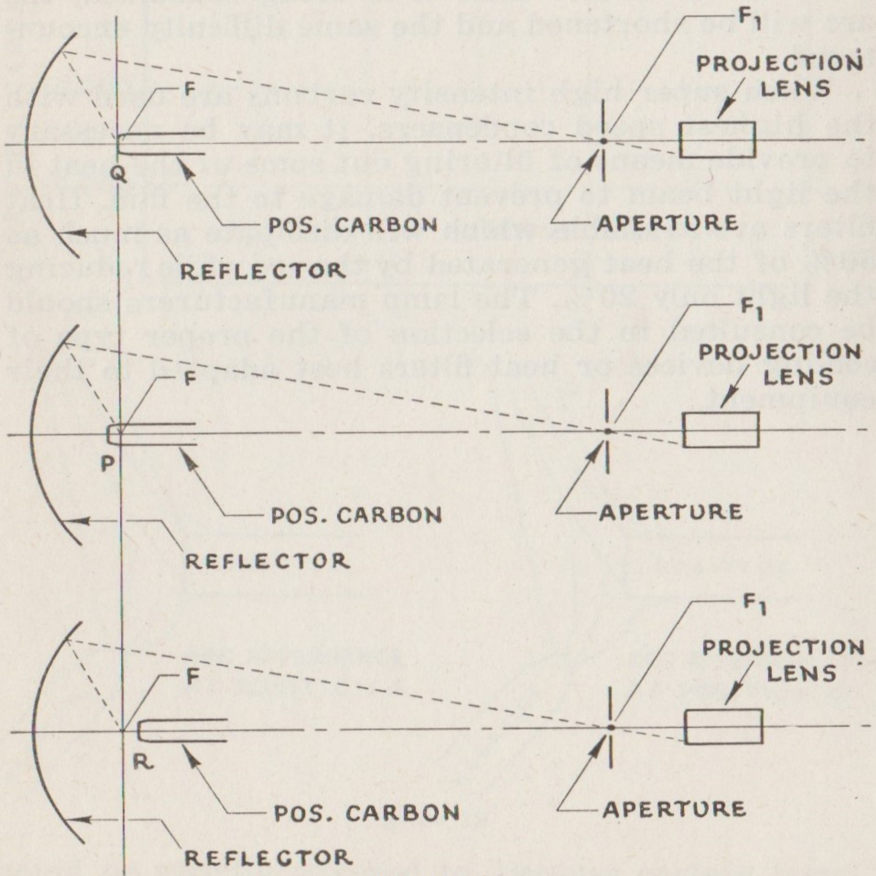


Figure 20

Optical System of Simplified High Intensity Lamp, Showing Relation of Position of Positive Carbon to the Light Ray Traveling to the Center of the Film Aperture

While the lamps designed to operate these arcs are fully automatic there are certain operating precautions with which the projectionist must be familiar to obtain maximum efficiency from these arcs. The fundamental factors important to the operation of these reflector type high intensity arcs will be described in this chapter under sub-headings, which are not necessarily listed in order of relative importance, because any one factor if neglected will result in lowered efficiency of light production.

Effect Upon Screen Light of Changing the Current and Position of the Arc

The light source and the film aperture are placed at the two foci, F and F_1, of the elliptical reflector, Figure 20, which gathers the light from the crator

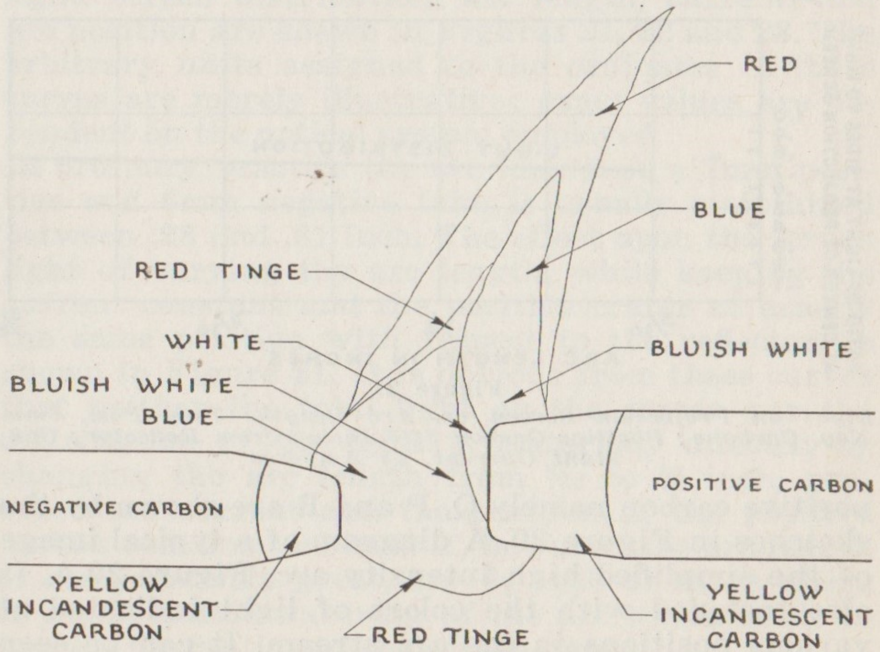


Figure 20A

of the positive carbon and directs it to the film aperture. The illumination of the aperture in turn is imaged on the screen by the projection lens.

The path of the projected ray is from one focal point F to the margin of the mirror and to the other focal point F_1, which is located at the center of the aperture. Three positions of the crater of the

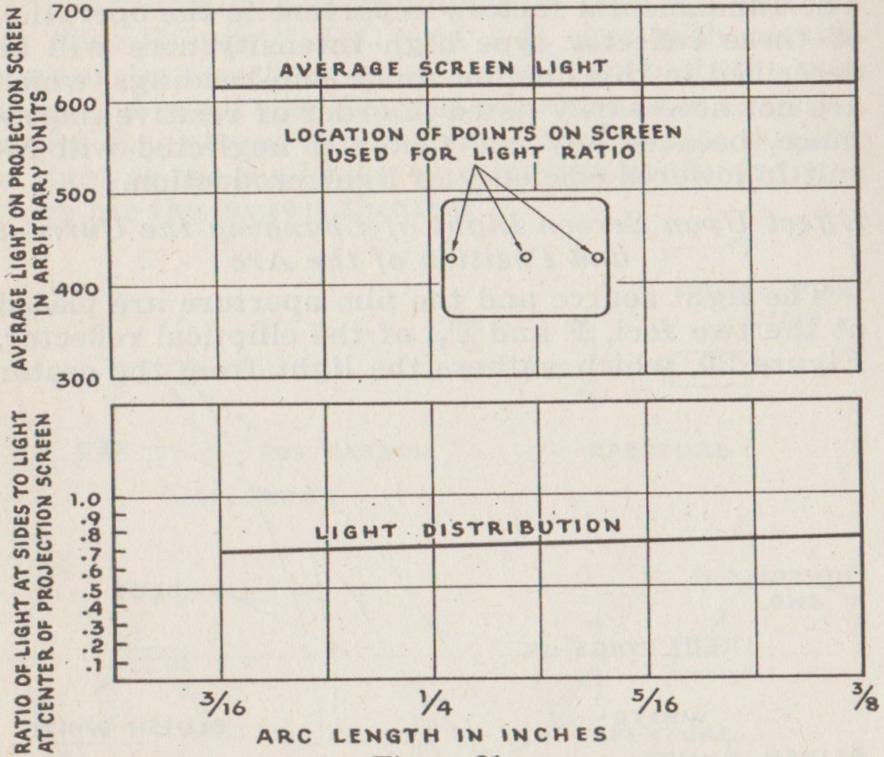


Figure 21

Light on Projection Screen vs. Arc Length: 7mm Pos., 6mm Neg. Carbons; Positive Carbon 3.76 Inches from Reflector; Constant Current, 45 Amperes

positive carbon namely Q, P and R are shown by the sketches in Figure 20. A diagram of a typical image of the simplified high intensity arc, Figure 20 A, is also included with the colors of light indicated at various positions in the arc stream. It can be seen that if the crater is positioned at Q the white light from the center of the crater is focused at the center of the film aperture and projected on the screen. This is the ideal location to obtain the best quality and in-

tensity of screen light. If the crater is moved ahead to position P, the ray traveling to the center of the aperture originates from the cooler position of the carbon back of the crater. This results in a change of color and intensity of the light at the center of the aperture and projection screen thus giving it a yellowish or reddish tinge. Similarly if the carbon recedes to position R, the ray traveling to F_1 originates from the arc stream in front of the crater, which is blue in color and the screen light is affected correspondingly.

Even within the range of allowable movement of the crater for satisfactory screen color, there are changes in total screen light and distribution of light over the screen. The relations between screen light, screen distribution, arc length, current, and arc position are shown in Figures 21, 22 and 23. The arbitrary units assigned to the ordinates in these curves are merely illustrative; exact values are dependent on the optical system employed.

In ordinary practice the arc length of a 7mm positive and 6mm negative trim is usually maintained between .28 and .31 inch. The effect upon the screen light of varying the arc length, while keeping the current constant and the positive crater at exactly the same position with respect to the reflector, is shown in Figure 21. It is obvious from these curves that neither the total light on the screen nor the distribution of the light is materially affected by changing the arc length from 3/16 to 3/8 inch, provided the current and the position of the positive carbon remains constant. If, however, the arc length is comparatively great, say 3/8 inch or more, there is a perceptible wavering of the arc which tends to cause a fluctuation of the screen light.

If the current is increased but the arc length and position of the arc with respect to the mirror are held constant, there is a very definite increase in screen light, but very little change in light distribution, as illustrated in Figure 22, determined for 7mm carbons. For an increase in current from 40 to 50 amperes, or 25 per cent, the light on the screen is increased by 47 per cent. This increase in light is accompanied by an increase in crater depth and carbon consumption. If the arc current is too low, the crater is very shallow and the light is not uni-

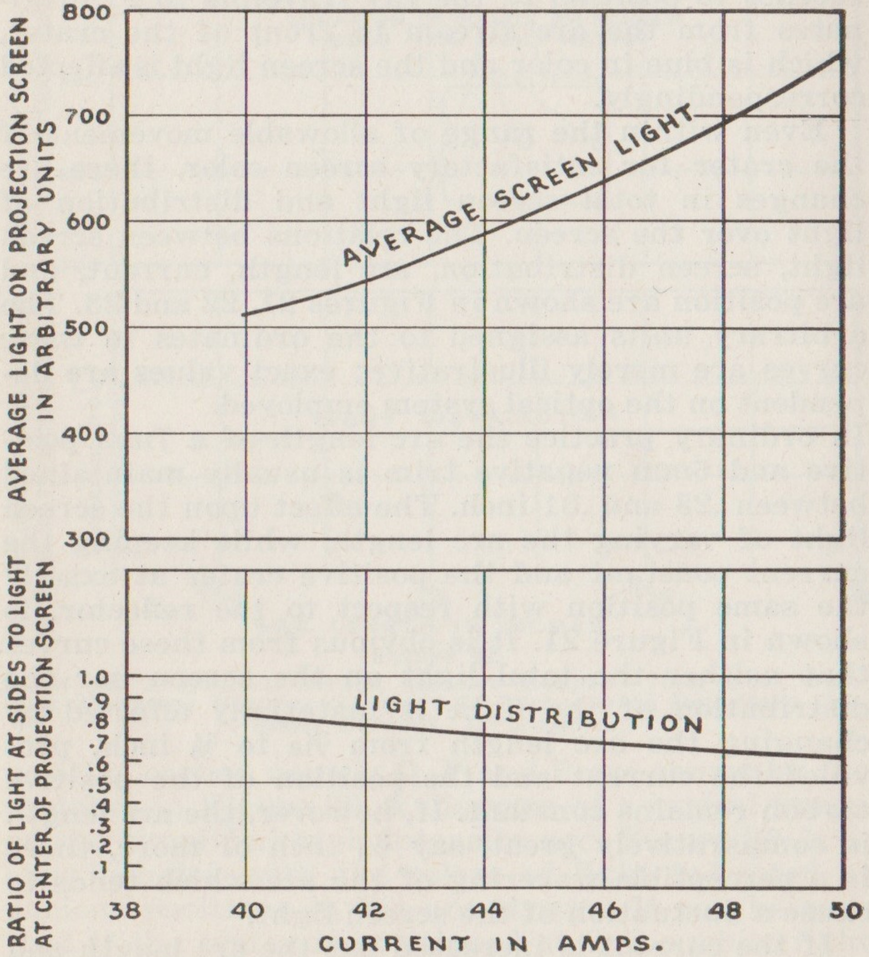


Figure 22

Light on Projection Screen vs. Current: 7mm Pos. 6mm Neg. Carbons; 5/16 Inch Arc Length; Positive Carbon 3.76 Inches from Reflector

form in color. If the current is too high, the carbon consumption is excessive and the light is unsteady.

If the current and arc length are maintained constant but the arc itself is moved with respect to the

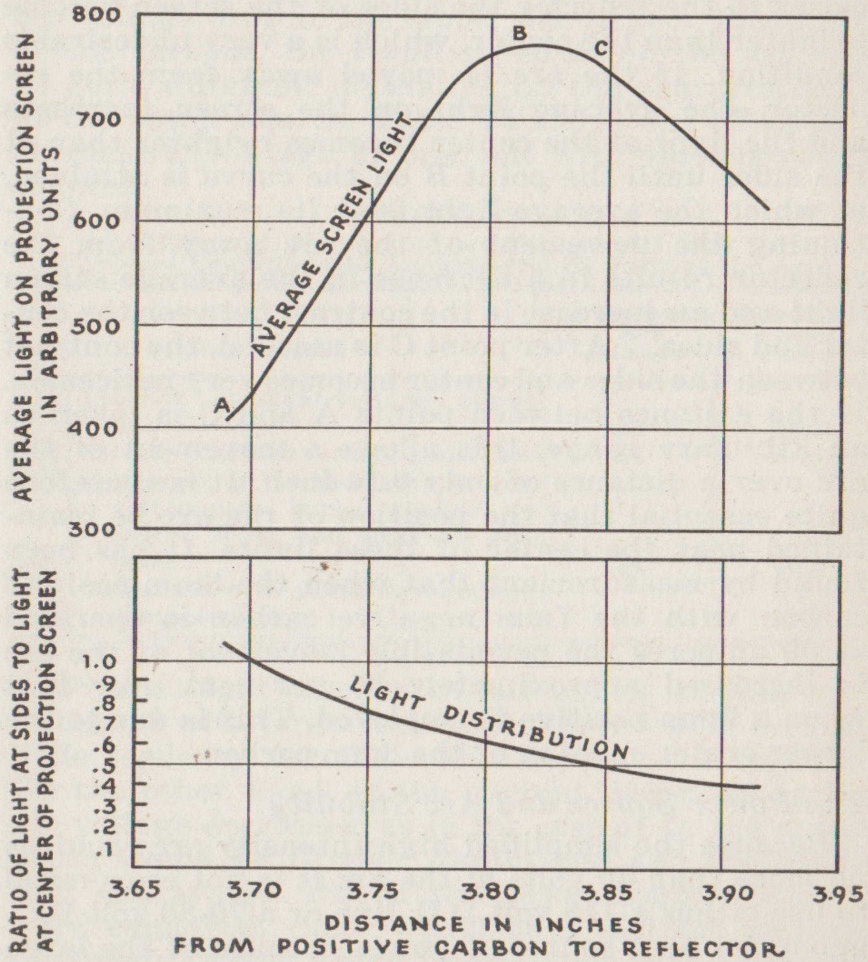


Figure 23

Light on Projection Screen vs. Position of Arc: 7mm Pos., 6mm Neg. Carbons; 45 Amperes; 5/16 Inch Arc Length

reflector, the screen light and distribution vary as indicated in Figure 23. To maintain a good distribution of light upon the screen, it is necessary to hold the position of the crater within close limits.

At A in Figure 23, the light at the sides of the screen is equal to that at the center of the screen and the edge of the positive crater is 3.70 inches from the center of the reflector. If the arc is moved closer to the reflector the sides of the screen become brighter than the center, which is a very undesirable condition. If the arc is moved away from the reflector, the average light on the screen increases and the light at the center becomes brighter than at the sides until the point B on the curve is attained, at which the average light is at its maximum. Continuing the movement of the arc away from the reflector results in a decrease in the average screen light and an increase in the contrast between the center and sides. After point C is reached, the contrast between the sides and center becomes very noticeable. If the distance between points A and C is taken as an arbitrary range, this allows a movement of the arc over a distance of only 0.14 inch. It is therefore quite essential that the position of the arc be maintained near the center of these limits. It has been found by measurement that when the 8mm positive carbon with the 7mm negative carbon is operated at 60 amperes the permissible movement of the arc is increased approximately 35 per cent over that when a 7mm positive is employed. This is due to the larger crater opening of the 8mm carbon.

The Power Source and Arc Stability

Because the simplified high intensity arc requires no more than 40 volts at the arc it is not economical to use either a 115 volt D.C. line or a 70-80 volt D.C. generator as a source of power because of the large amount of power wasted in the necessary ballast. Lower voltage generators and rectifiers are available which provide a constant voltage source near enough to the arc voltage to permit the use of small ballast resistances and are characterized by a comparatively large increase of current when a small

decrease of arc voltage takes place. This is a decided advantage in maintaining stability of the arc. If for some reason there is a disturbance in the high intensity effect, such as, for example, a decrease in the voltage drop in the crater due to poor alignment of the carbons, the resultant effect on the arc may be quite different, depending on the characteristics of the power source. Table VI shows the effect of a decrease in voltage of one volt with various power sources.

TABLE VI

Effect of Decrease of Arc Voltage of 1 Volt
(Original Conditions 45 Amperes and 35 Volts at the Arc)

	Power Source	Momentary Arc Voltage	Momentary Arc Current
(A)	115-volt constant-voltage power line	34	45.6
(B)	45-volt constant-voltage generator	34	49.5
(C)	Generator or rectifier with falling volt-ampere curve similar to source B at and near 45 amperes	34	49.5
(D)	Generator with rising volt-ampere characteristic	34	44.4

With a slight increase of current in the arc, such as occurs with power source A, there would be very little tendency for the crater depth to be restored. On the other hand, if the current decreases as the arc voltage decreases, as in the case of D, the crater depth would be further diminished and the condition aggravated. But if the power sources B or C were employed, there would be a distinct increase of current, which would immediately tend to restore the proper crater depth. This in turn would increase the arc voltage and cause a restoration of arc current, arc voltage and crater depth to their normal values.

Power source D corresponds to the series arc generator operated in the range where an increase in current produces an increase in voltage. The 70-80 volt generators of the constant voltage type commonly used for low intensity mirror arc or high-low reflector lamps with rotating positive carbon are intermediate in effect between power source A and power sources B and C. Power sources B and C are typical of the units that have been developed for use with the simplified high intensity and "One Kilowatt" lamps.

In those instances where either straight D.C. or a high voltage motor-generator set is used as a source for operating an 8mm positive and 7mm negative carbon trim it is necessary, in order to obtain arc stability, to burn this trim at or near the maximum recommended current (65 amperes or above); at the same time the negative carbon should be set so that the positive carbon burns off slightly at the top. Care should also be taken to see that the auxiliary magnets used for stabilizing the arc are of the proper strength.

Magnetic Flux Used to Stabilize the Arc

It is an established fact that every conductor carrying an electric current is surrounded by a magnetic field which is generated by the current. Figure 24 illustrates the magnetic field which surrounds the carbons and the arc in a condenser type high intensity lamp. Because of the angular position of the carbons in these lamps the magnetic lines of force generated by the current are crowded below the arc and are less dense above the arc. The resultant effect of this combination of magnetic lines is a force upward (indicated by the arrow) which, in conjunction with the natural flow of the arc stream, projects the tail flame of the arc in an upward and forward direction from the positive crater as shown in the photograph in Figure 25.

In the simplified high intensity type lamps where both carbons are held in a horizontal position the

magnetic lines of force are distributed uniformly around the carbons and there is no concentration of magnetic flux beneath the arc such as that which occurs when the negative carbon is inclined to the positive as in Figure 24. Consequently there is no magnetic force in any direction influencing the position of the arc stream. Operated under these conditions the tail flame surrounds the arc in almost a uniform layer as shown in Figure 26. To obtain

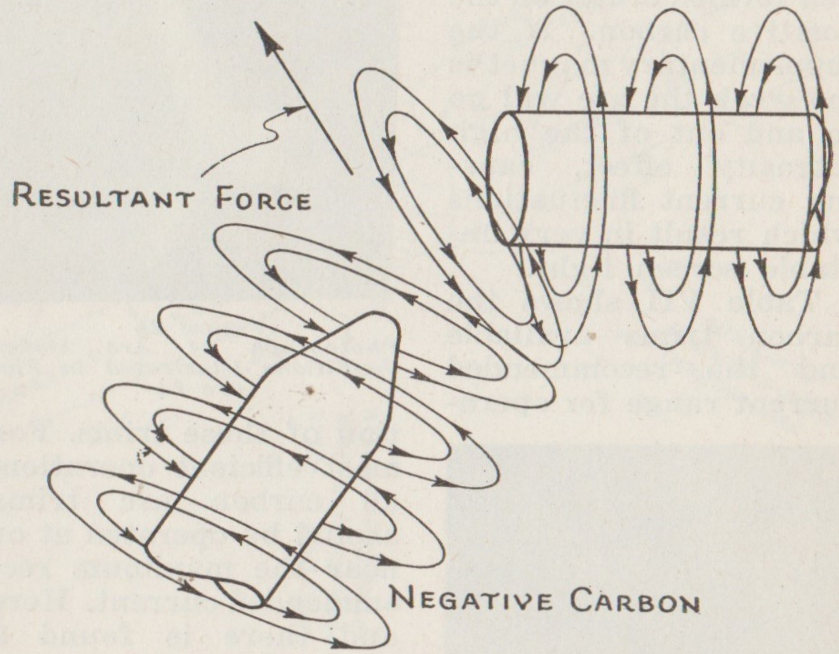


Figure 24
Illustrating the Distribution of the Magnetic Flux About the Carbons Set at an Angle Less than 180 Degrees

an efficient high intensity effect from these arcs the present day lamps are equipped with an auxiliary magnet. The magnetic flux from this auxiliary source is illustrated diagramatically in Figure 27, and is of such direction as to supply the required upward force on the arc stream thereby causing the tail flame to be lengthened and driven upward as illustrated in Figure 28. Under these conditions the tail flame becomes comparatively stationary and constant in both length and direction. The axis of the negative carbon is placed slightly below that of the positive to compensate for the angular direction of the arc stream and to maintain a well formed crater on the positive carbon. If the supplementary magnet is too weak the arc will go in and out of the high intensity effect, causing current fluctuations which result in very unstable screen light.

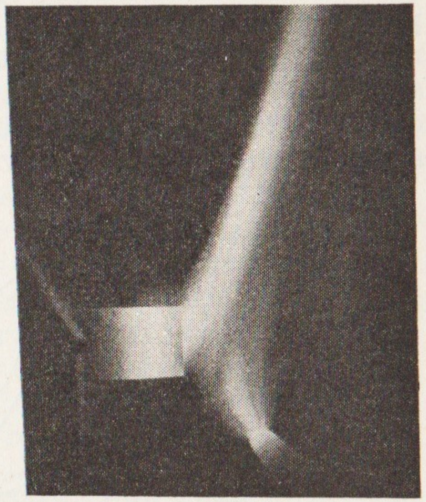


Figure 25
Photograph of Arc Under Conditions Illustrated in Figure 24

Table VII shows the carbon trims available and the recommended current range for operation of these trims. For most efficient operation, all carbon arc trims should be operated at or near the maximum recommended current. Here and there is found a projectionist who uses a trim of larger diameter than indicated in order to save trimming or cut carbon cost. By so doing he sacrifices quantity, quality and steadiness of light. Compared with other expenses in a theatre, the cost of carbons

Figure 26
Photograph of Arc Without Auxiliary Magnet

is negligible—only a few cents a day. The product which the theatre sells to its audience is the picture on the screen. A film costing hundreds of thousands of dollars, poorly lighted, loses its effectiveness with resultant loss of patronage. It is sound

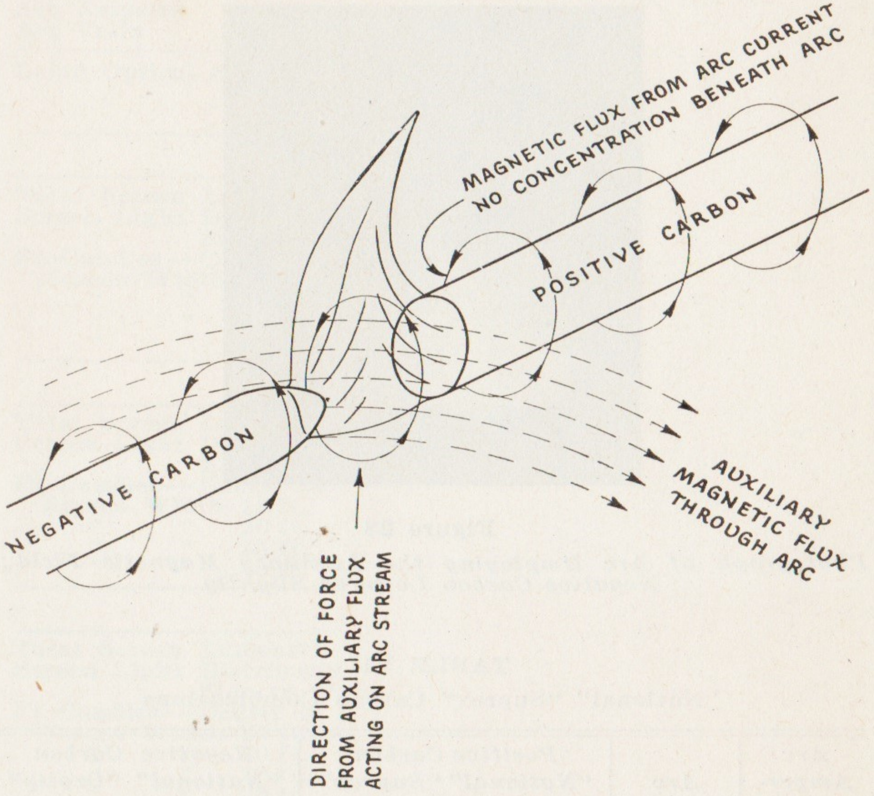


Figure 27
Illustrating Distribution of Magnetic Flux from Auxiliary Magnet

economy, therefore, to use only the best quality of carbons, in correct combination and operated within the manufacturer's recommended current range.

Table VIII shows the total screen lumens as well as the foot-candles at the center of various sized screens obtainable with simplified non-rotating high intensity carbon arcs. The values are given for both coated and uncoated projection lenses with optical systems adjusted for 80% side to center distribution as well as for maximum light at the center of the screen.

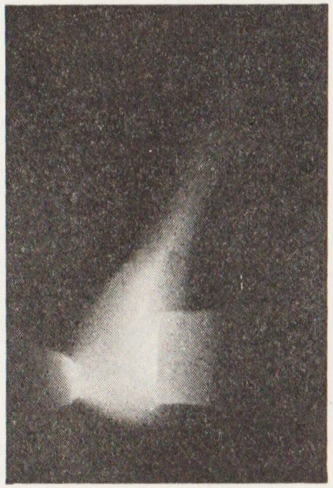


Figure 28

Photograph of Arc Employing the Auxiliary Magnetic Field; Negative Carbon Lowered Slightly

TABLE VII

"National" "Suprex" Carbon Combinations

Arc Amperage	*Arc Volts*	*Positive Carbon "National" "Suprex" (Cored)*	*Negative Carbon "National" "Orotip" (Cored)*
32-40	31 - 40	6mm x 12″	5mm x 9″
40-50	27.5-37	7mm x 12″ or 14″	6mm x 9″
60-70	35 - 40	8mm x 12″ or 14″	7mm x 9″
A.C. — "One Kilowatt" High Intensity Arcs			
52-66	18 - 22	7mm x 12″ or 14″ "Suprex" Cored in both holders	

TABLE VIII

Motion Picture Screen Illumination with Simplified (Non-Rotating) High Intensity Carbon Arcs

	"One-Kilowatt" Arcs	*Higher Powered Arcs*			
Carbon Trim Positive	7mm x 12″ or 14″ "Suprex"	7mm x 12″ or 14″ "Suprex"	7mm x 12″ or 14″ "Suprex"	8mm x 12″ or 14″ "Suprex"	8mm x 12″ or 14″ "Suprex"
Negative	6mm x 9″ "Orotip" C	6mm x 9″ "Orotip" C	6mm x 9″ "Orotip" C	7mm x 9″ "Orotip" C	7mm x 9″ "Orotip" C
Arc Amperes	40	42	50	60	70
Arc Volts	27.5	33	37	36	40
Lamp Optical System	Mirror 11⅜″ Dia. f2.5	Mirror 14″ Dia. f2.3	Mirror 14″ Dia. f2.3	Mirror 14″ Dia. f2.3	Mirror 14″ Dia. f2.3
5.5″ E.F. f/2.5 Uncoated Projection Lens					
Total Screen Lumens[1]	4600	4900	6400	7600	9600
Screen Light Distribution[2] Side to Center	80%	80%	80%	80%	80%
Ft.-Candles—Center of Screen[3] Screen Width 15 ft.	15.8	17.0	22.6	26.8	—
" " 20 ft.	8.8	9.6	12.6	15.2	19.2
" " 25 ft.	—	—	—	9.7	12.2
" " 30 ft.	—	—	—	—	—
5.5″ E.F. f/2.5 Uncoated Projection Lens—Maximum Light[4]					
Total Screen Lumens[1]	5000	5500	7200	8200	10600
Screen Light Distribution[2] Side to Center	65%	60%	60%	65%	65%
Ft.-Candles—Center of Screen[3] Screen Width 15 ft.	19.6	21.3	28.6	—	—
" " 20 ft.	11.0	12.0	16.0	17.8	23.5
" " 25 ft.	—	—	10.2	11.3	15.3
" " 30 ft.	—	—	—	—	7.9
5″ E.F. f/2.0 Coated Projection Lens					
Total Screen Lumens[1]	5900	6600	8600	10300	13000
Screen Light Distribution[2] Side to Center	80%	80%	80%	80%	80%
Ft.-Candles—Center of Screen[3] Screen Width 15 ft.	20.3	22.7	29.8	—	—
" " 20 ft.	11.4	12.8	16.8	20.2	25.0
" " 25 ft.	—	—	10.6	12.9	16.0
" " 30 ft.	—	—	—	—	11.0
5″ E.F. f/2.0 Coated Projection Lens—Maximum Light[4]					
Total Screen Lumens[1]	6500	7500	10000	11000	14000
Screen Light Distribution[2] Side to Center	65%	60%	60%	65%	65%
Ft.-Candles—Center of Screen[3] Screen Width 15 ft.	25.5	29.0	—	—	—
" " 20 ft.	14.4	16.2	22.1	24.2	—
" " 25 ft.	—	10.4	14.1	15.4	19.0
" " 30 ft.	—	—	—	10.8	13.3

[1] Screen lumen figure is for systems with no shutter, film or filters of any kind.
[2] Per cent screen light distribution refers to ratio of light intensity at side of screen to that at the center.
[3] Ft.-Candle values at center of screen assume 50% shutter transmission, no film or filters of any kind.
[4] Maximum light is value with system adjusted to produce maximum light.

CHAPTER VIII

Low Intensity Arcs

THE old type, direct current, low intensity carbon arc lamp was the first type of lamp used in motion picture projection. The positive carbon is mounted above the negative and slightly inclined from the vertical position so as to expose the crater and permit a greater proportion of the crater light to be picked up by the condenser lens. In one style of lamp, both positive and negative carbons are inclined 20 degrees from the vertical, as shown in Figure 29. In another style, the positive carbon is inclined 15 degrees from the vertical and the negative 10 degrees, as in Figure 30.

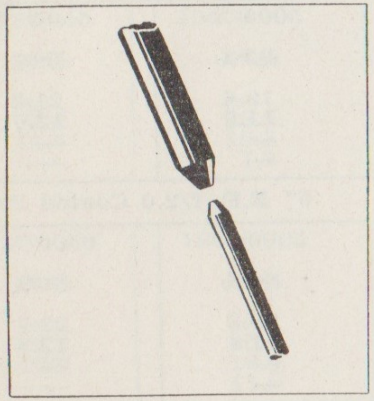


Figure 29

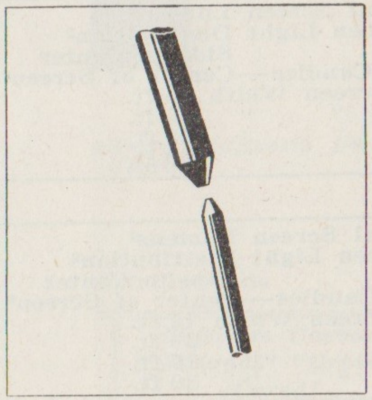


Figure 30

The optical principle of the old type D.C. low intensity projection lamps is illustrated diagrammatically in Figure 31. In this lamp, as indicated by the illustration, a cone of illumination approximately 45 degrees in angular diameter is picked up by the condenser lens and focused on the aperture plate.

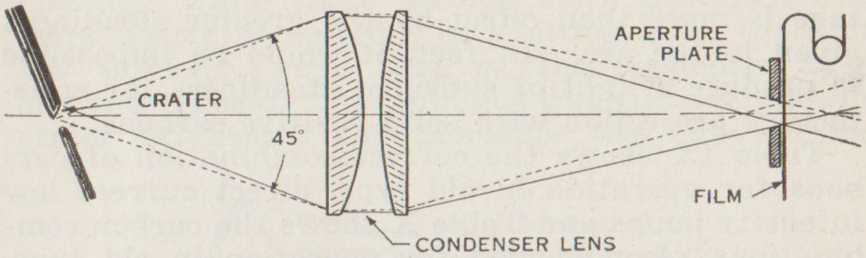


Figure 31

Diagram of Old Type, Low Intensity, D.C. Projection Lamp

The positive carbon used in this type of lamp is always cored, that is, the center of the carbon is filled with a softer mix of carbon known as the core.

TABLE IX

"National" Cored and "Orotip" Projector Combinations For Old Type, Low Intensity Lamps

Arc. Amp.	*Approx. Arc Volts*	*Polarity*	*Size Inches*	*Kind*
25- 50	51-56	Positive	5/8 x 12	"National" Cored Projector
		Negative	5/16 x 6	"National" "Orotip" Solid or Cored Projector
50- 65	56-59	Positive	3/4 x 12	"National" Cored Projector
		Negative	11/32 x 6	"National" "Orotip" Solid or Cored Projector
65- 70	59-60	Positive	7/8 x 12	"National" Cored Projector
		Negative	11/32 x 6	"National" "Orotip" Solid or Cored Projector
70- 85	60-63	Positive	7/8 x 12	"National" Cored Projector
		Negative	3/8 x 6	"National" "Orotip" Solid or Cored Projector
85-120	63-68	Positive	1 x 12	"National" Cored Projector
		Negative	7/16 x 6	"National" "Orotip" Cored Projector
120-140	68-70	Positive	1 1/8 x 12	"National" Cored Projector
		Negative	1/2 x 6	"National" "Orotip" Cored Projector

While the brilliancy of that portion of the crater occupied by the core is a little lower than that of the surrounding solid carbon, this slight disadvantage is more than offset by the greater steadiness given to the arc. In fact, it would be impossible to produce a light of sufficient steadiness for satisfactory projection with solid positive carbons.

Table IX shows the correct combination of carbons for operation in old type, direct current low intensity lamps and Table X shows the carbon combinations recommended for operation in old type, alternating current projection lamps.

TABLE X

"National" White Flame A.C. Projector Carbon Combinations

Arc Amperage	*Arc Voltage*	*Upper Carbon*	*Lower Carbon*
25- 40	25-28	½"x12"	½"x6"
40- 60	28-32	⅝"x12"	⅝"x6"
60- 75	32-35	¾"x12"	¾"x6"
75-100	35-40	⅞"x12"	⅞"x6"

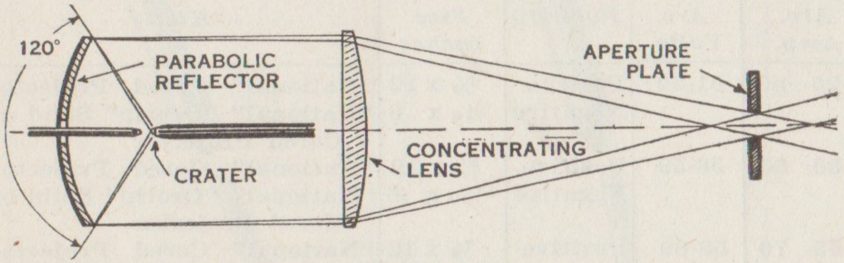


Figure 32

Low Intensity, D.C. Reflector Arc Lamp with Parabolic Mirror

The direct current reflector type of lamp, Figures 32 and 33, operating at currents from 10 to 42 amperes, represented a striking improvement in efficiency over the old type low intensity lamp. However, although optically more efficient, this lamp suffers from the same poor color quality that is characteristic of all low intensity arcs, giving a yellow-white light in comparison with the snow-white light of the high intensity arc. This factor is of increasing importance as color pictures demanding white light become more prevalent and more nearly perfected. In addition, both types of low intensity arcs, that is, the condenser type and the reflector type produce comparatively lower crater brightness and therefore less light on the

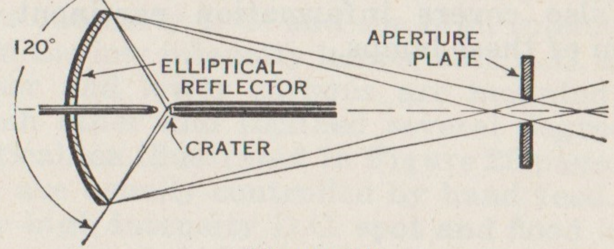


Figure 33

Low Intensity, D.C. Reflector Arc Lamp with Elliptical Mirror

screen. Consequently, these arcs have now been replaced in most theatres by the high intensity arc.

Table XI shows the correct combinations of carbons for use in reflector type low intensity lamps,

TABLE XI

"National" Low Intensity Reflector Arc Carbons

Arc	*Approx. Arc Volts*	*Polarity*	*Size*	*Kind*
10-15	54-57	Positive	9mm x 8"	"National" Cored Projector
		Negative	6.4mm x 8"	"National" Cored or Solid Projector
16-20	54-57	Positive	10mm x 8"	"National" Cored Projector
		Negative	7mm x 8"	"National" Cored or Solid Projector
21-32	54-57	Positive	12mm x 8"	"National" Cored Projector
		Negative	8mm x 8"	"National" Cored or Solid Projector
32-42	54-57	Positive	13mm x 8"	"National" Cored Projector
		Negative	9mm x 8"	"National" Cored or Solid Projector
42-52	54-57	Positive	14mm x 8"	"National" Cored Projector
		Negative	10mm x 8"	"National" Cored Projector

together with the range of current recommended for each trim.

The operating precautions for low intensity old type and reflector type arcs were discussed in detail in previous editions of this handbook and Chapter X, Summary of Operation Precautions, in this edition also covers information pertinent to the operation of these lamps.

CHAPTER IX

Carbon Arc Spot and Flood Lamps, Stereopticon and Effect Machines

THREE types of carbon arc spot and flood lamps are on the market. These are the low intensity A.C., low intensity D.C. and the high intensity D.C. types. In the low intensity lamps, both A.C. and D.C. the upper and lower carbons are mounted in line with each other and inclined several degrees from the vertical, as illustrated in Figure 29 page 64. The carbons are usually controlled by hand feed.

In the high intensity D.C. spot and flood lamp the positive carbon is held in a horizontal position with the negative inclined at sharp angle, as in the high intensity projection lamp, Figure 17 page 42. The carbon feed mechanism is usually motor driven with automatic control.

Stereopticon and effect machines in common use are of two types, the low intensity, D.C. carbon arc and the high intensity, D.C. carbon arc. Both types use the "inclined vertical" trim illustrated in Figure 29 and are usually equipped with automatic, motor driven, carbon fed mechanism. An appreciably whiter light is obtained from the high intensity carbon trim than that produced by the low intensity type.

The direct current, low intensity reflecting arc principle is used in the dissolving slide projector. In this lamp the carbon trim is horizontal, as in Figure 32 page 66, and the carbon feed is automatic, with motor drive.

The types of carbon used in the foregoing lamps are the same as those used in corresponding types of projection lamps and the instructions given in preceding chapters for the care and operation of the several types of arcs apply, as well, to the lamps here described. Carbon trims and recommended ranges of current are given in Table XII.

TABLE XII

A.C., Low Intensity, Spot and Flood Lamp

Amps.	Approx. Voltage	Upper Carbon	Lower Carbon
30-60	35	⅝" x 12" "Nat'l" White Flame A.C. Proj.	⅝" x 6" "Nat'l" White Flame A.C. Proj.
60-80	35	¾" x 12" "Nat'l" White Flame A.C. Proj.	¾" x 6" "Nat'l" White Flame A.C. Proj.

D.C., Low Intensity, Spot and Flood Lamp

Amps.	Approx. Voltage	Polarity	Size and Kind: "National" Cored Projector	Size and Kind: "National" "Orotip" Cored Projector
30-40	52-54	Positive	⅝" x 12"	......
		Negative	½" or 9/16" x 6"	......
40-50	54-56	Positive	⅝" x 12"	......
		Negative	......	5/16" x 6"
50-55	56-57	Positive	¾" x 12"	......
		Negative	......	5/16" x 6"
55-65	57-59	Positive	¾" x 12"	......
		Negative	......	11/32" x 6"
65-70	59-60	Positive	⅞" x 12"	......
		Negative	......	11/32" x 6"
70-85	60-63	Positive	⅞" x 12"	......
		Negative	......	⅜" x 6"
85-100	63-66	Positive	1" x 12"	......
		Negative	......	⅜" or 7/16" x 6"

D.C., High Intensity, Spot and Flood Lamp

Amps.	Approx. Voltage	Positive Carbon	Negative Carbon
85-95	58-62	11 mm x 20" "National" High Intensity White Flame Projector	11/32" x 9" "National" "Orotip" Cored Projector
125-150	68-78	13.6 mm x 22" "Nat'l" High Intensity White Flame Projector	7/16" x 9" "National" "Orotip" Cored Projector

TABLE XII—Continued

D.C., Low Intensity, Stereopticon and Effect Machines

Amps.	Positive Carbon	Negative Carbon
40-50	⅝" x 6" "National" Cored Projector	5/16" x 6" "National" "Orotip" Cored Projector
50-55	¾" x 6" "National" Cored Projector	5/16" x 6" "National" "Orotip" Cored Projector
55-65	¾" x 6" "National" Cored Projector	11/32" x 6" "National" "Orotip" Cored Projector

D.C., High Intensity, Stereopticon and Effect Machines

Amps.	Positive Carbon	Negative Carbon
60-65	11 mm x 6" Copper Coated "National" High Intensity W. F.	5/16" x 6" "National" "Orotip" Cored Projector

D.C., Reflector Arc, Dissolving Slide Projector

Amps.	Approx. Voltage	Polarity	Size and Kind
15-20	54-57	Positive	10mm x 8" "National" Cored Projector
		Negative	7mm x 8" "National" Cored Projector
21-32	54-57	Positive	12mm x 8" "National" Cored Projector
		Negative	8mm x 8" "National" Cored Projector
33-42	54-57	Positive	13mm x 8" "National" Cored Projector
		Negative	9mm x 8" "National" Cored Projector

CHAPTER X

Summary of Operating Precautions

THE modern motion picture projector is a very reliable mechanism. Although subjected in some instances to intense heat it will, if given proper care, last a long time and give excellent service. It is essential, however, that reasonable attention be given to the maintenance of all elements of the projector, and particularly to the projection lamp. For that reason this chapter is devoted to a résumé of operating precautions which will aid the projectionist in obtaining maximum efficiency and reliability in the operation of projection lamps.

(1) *Use the Right Carbons*

It is highly important that the correct type and combination of carbons be used. Projector carbons are manufactured to meet the specific requirements of a certain type of lamp and the combinations recommended have been carefully determined by laboratory and service tests. Highest light-producing efficiency is obtained when carbons are operated at or just below the maximum current recommended by the manufacturer.

(2) *Store Carbons in a Dry Place*

Carbons should always be stored in a dry place. They are porous and will absorb moisture if stored in a damp location, with the result that sputtering or flashing at the arc will be experienced. "National" Projector Carbons are thoroughly dry when they leave the factory but there is always the possibility of exposure to dampness during shipment or storage. For this reason, the practice of some projectionists of laying a few carbons in the lamp house or on the top of a rheostat before burning is to be commended. Carbons are not perishable. A damp carbon, after being thoroughly dried, is as good as ever.

(3) *Keep Lamp Parts Clean*

Carbon holders must be kept clean and their contact with the carbons firm. The projectionist should give frequent and careful attention to the holders, removing all effects of corrosion or burning so that smooth, firm contact of full area is maintained. Defective contact between carbons and holders is a frequent cause of spindling.

It is likewise essential that feed rollers on high intensity condenser and high intensity reflector lamps be kept clean and in good condition to insure steady and accurate rotation of the positive carbon, to maintain a symmetrical crater and prevent possibility of jamming.

The lamp housing and mechanism should be cleaned regularly and thoroughly and all moving elements of the lamp kept lubricated with oil or grease as specified by the lamp manufacturer. Complaints sometimes arise from hard grease clogging the feeding mechanism and interfering with the feeding of the carbons. Such troubles can be eliminated by cleaning out the hard grease and replacing with a grade of proper consistency.

(4) *Maintain Carbon Alignment*

Carbons must be kept in proper alignment. Poorly formed craters and lowered efficiency of light production are invariably encountered when the correct alignment of the carbons is not maintained. Particular attention should be given to the lateral alignment of carbons.

It is equally important, in attaining full efficiency of light production, that the crater of the positive carbon be kept in correct position relative to the optical system. Modern lamps are equipped with gauge pins or with means for projecting the arc image on a chart at the side of the lamp housing to indicate the correct location of the positive crater. The feed of the positive carbon should be regulated to maintain the crater as near as possible to this position throughout the burning period. The feed of the negative carbon should also be adjusted to maintain correct and uniform arc length during operation. In some types of lamps having automatic feed, operation with too short an arc prevents adjustment of the feed mechanism to a point which maintains the carbons in proper relative position.

(5) *Care of Optical System*

Keep condensers and reflectors clean and well polished. When reflectors begin to show disintegration of the silver coating or a grayish color, they should be resilvered or replaced.

Instructions for adjusting the position of the optical elements of the lamp are provided by the manufacturer. These should be carefully followed when the lamp is installed and the correct position maintained by adjustment whenever necessary.

If it is found that a more desirable screen illumination is obtained with the positive crater out of the indicated position, it will usually be found that the condenser or reflector has also been displaced. In such cases, the optical system should be adjusted so that best results are obtained with the positive crater in the position indicated as correct.

Alignment of the lamp with the projector head should be checked from time to time and adjusted when found incorrect. A good device for checking alignment of the lamp mechanism and optical system consists of a dummy lens barrel made of light metal with a hole drilled through the center. The dummy lens is placed in the projector lens holder and a straight steel rod inserted through the carbon holders, through the center of the aperture and through the dummy projector lens. In condenser type lamps a dummy condenser with hole in the center is also used.

(6) *Magnets*

If the magnet becomes too weak the arc will go in and out of high intensity effect causing the current to increase rapidly for short durations. This results in very unstable screen light.

(7) *Care of Rheostats*

Damage to rheostats sometimes results from operation with a short arc at an arc voltage appreciably below normal. This practice throws a greater portion of the line voltage on the rheostat than it is designed to carry, so that the arc current can be held down to normal value only by cutting out some of the parallel connected resistors. This may force the remaining resistors to absorb so much wattage in excess of their radiating capacity that destructive temperatures result. With correct adjustment, ample range of current control should be afforded by normal operation of the rheostat.

Keep all electrical contacts clean and firmly tightened so that the full area of contact is maintained.

(8) *Effect of Draft on the Arc*

All projection lamps should be adequately ventilated. The recommended practice as set forth in the report of the Projection Practice Sub-Committee of the Society of Motion Picture Engineers (Journal of the S.M.P.E. Vol. XXXIX, September, 1942, pp. 158) is as follows:

"The carbon arc exhaust system shall be a positive mechanical exhaust system independent of all other ventilating systems of the theatre. Each projector, spotlamp, stereopticon, or floodlight machine, if of the carbon arc type, shall be connected by a flue to a common duct, which duct shall lead directly out of doors. Reduction of the ventilation to each projector as required shall be accomplished by means of a local damper between the projector lamp-house and the projection room ceiling, and in addition, by means of the damper on the lamp-house proper if provided.

"This exhaust system shall be operated by an exhaust fan or blower having a capacity of not less that 50 cubic-feet of air per minute for each arc lamp connected thereto. The exhaust fan or blower shall be electrically connected to the projection room wiring system and shall be controlled by a separate switch, with pilot lamp, within the projection room proper. There shall be at no time less than 15 cubic feet of air per minute through each lamp-house into this exhaust system. Fig 34 shows the general arrangement. The ducts shall be of non-combustible material, and shall be kept at least 2 inches from combustible material or separated therefrom by approved non-combustible material, not less than 1 inch thick."

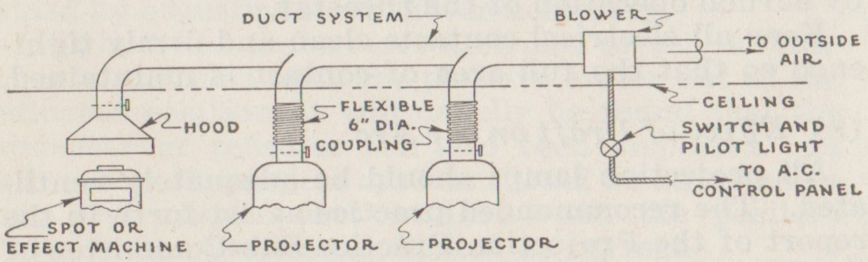


Figure 34
Ventilation System

It has been determined by test that the maximum draft that can be tolerated by the various arcs used in projection falls within the limits established by the Committee. Frequently, however, exhaust fans or blowers are used which exhaust too great a volume of air causing the arc to waver with resultant unsteady light on the projection screen. This condition can be corrected by placing a by-pass in the exhaust duct to regulate the volume of air drawn from the lamp-house. If no exhaust fan or blower

is used and the exhaust from the lamp is connected to a chimney to the outside of the projection room some method of preventing downdraft must be provided, such as a directional hood over the chimney. Downdraft will cause arc wavering and may even cause outages by actually blowing the arc out.

(9) *Electrical Instruments*

Particular attention to the care of electrical instruments will be well repaid. Ammeters, voltmeters and wattmeters are necessarily of somewhat delicate construction and the best instrument may be ruined by misuse.

Meters should never be placed where they will be exposed to high temperature, vibration, or strong magnetic fields. Such conditions may quickly impair their accuracy.

They should be calibrated at regular intervals, at least once a year.

The projectionist should not attempt to adjust or repair electrical meters. When attention is required they should be returned to the supplier who either has proper facilities for making the needed repairs and adjustments or will send them to the manufacturer.

The contacts on all external connections to electrical meters should be kept clean and firmly secured.

Careful attention to the foregoing precautions, and to the more specific instructions given in earlier chapters for the type of lamp in use, will afford the projectionist using "National" Projector Carbons screen illumination of maximum steadiness, brilliancy and uniformity.

CHAPTER XI

Carbon Arc Projection of 16-mm Film

THE projection of 16-mm film has passed beyond the limitations of the living room and small classroom. This film is now being shown before groups of such size that the use of comparatively large screens is necessary for a satisfactory presentation. This has created the need for a larger volume of projection light than is available from the incandescent lamp, a need which has been met in a very efficient manner by the adaptation of the high intensity carbon arc to 16-mm projection.

Carbon arc lamps designed especially for 16-mm projection are now available. These lamps are operated through a rectifier connected directly to a 110-volt, single phase, alternating current supply with a current demand of less than 15 amperes from the supply line. "National" "Pearlex" High Intensity carbons have been developed especially for use in these arc lamps. The carbon trim consists of a 6-mm x 8½-inch "National" "Pearlex" cored positive carbon and 5.5-mm x 6-inch "National" "Pearlex" cored negative carbon. The trim is designed to operate at 30 amperes direct current with 28 volts across the arc. The burning life of the trim is approximately one hour, ample for the projection of a 2000 ft., 16-mm reel at sound speed of 24 frames per second. The carbons are operated in a coaxial position and the light is collected and projected by a reflector in the same manner as that employed in the conventional simplified high intensity arcs used for the projection of 35-mm film. All of the operating precautions discussed in the previous chapter on "Simplified High Intensity Arcs" apply to the operation of these lamps.

The composition of the core of the positive "National" "Pearlex" carbon is somewhat different from

that of the "Suprex" high intensity positive carbon used for the projection of 35-mm film in that the proportion of light emission at the longer wavelengths namely the yellow, orange and red is increased. Figure 35 shows the spectral energy distribution of the light from this arc. This modification is made because 16-mm color film is usually processed for showing to small groups by projection with the more yellow light from the incandescent lamp.

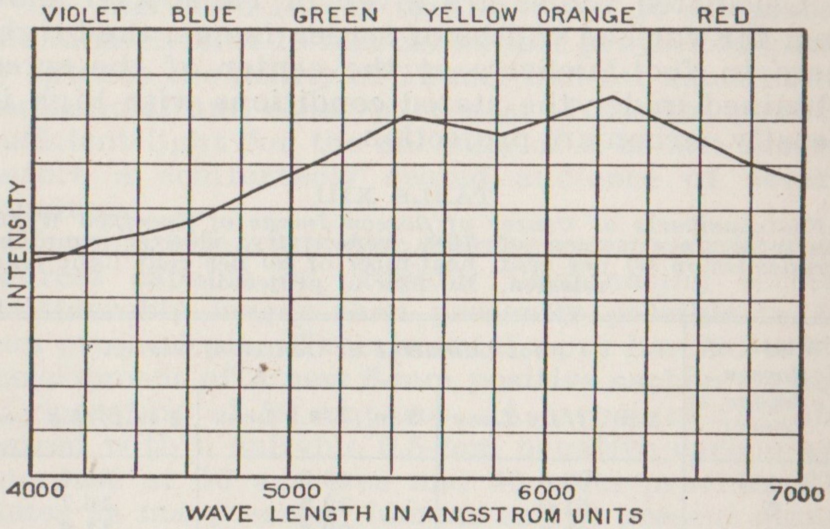


Figure 35

Spectral Energy Distribution of Light Projected on Screen from the High Intensity Carbon Arc Developed for 16-mm Projection

With a projection system employing a 10¼-inch diameter f/1.6 mirror and a 2-inch focus uncoated f/1.6 projection lens, with no shutter, film or heat-filter, the "National" "Pearlex" carbon trim operating at 30 amperes D.C. with an arc voltage of 28 volts projects 2300 lumens to the screen. A representative figure for shutter transmission on commercial types of 16-mm projectors is 60 per cent, and 80 per cent is a representative transmission factor for the type of heat filter used on 16-mm carbon arc projectors; therefore, the screen light available with shutter running and heat filter in place is about 1100 lumens. This is obtained with 80 per cent side to center distribution of screen brightness, which is consistent with good projection practice. Some projectors have no heat filter but use a rear shutter, or blower, or a combination of the two to maintain low film temperature. With this construction somewhat greater screen illumination may be expected, other factors being equal.

Calculated values are given in Table XIII showing, for various widths of screen image, the brightness in foot-lamberts at the center of the screen obtained under the stated conditions with high intensity carbon arc projection.

TABLE XIII

Foot-Lamberts at Center of Screen Image of Specified Width
Matte surface screen of 75% reflectivity, shutter running—Transmission 60 per cent, heat-filter of 80 per cent light transmission. No film in projector

Width of Screen Image (Feet)	*Foot-Lamberts at Center of Screen*		
	2-in., f/1.6 Lens	*3-in., f/2.0 Lens*	*4-in., f/2.8 Lens*
4½	63.0	40.0	20.6
5	51.0	32.5	16.7
6	35.5	22.5	11.6
7	26.0	16.6	8.5
8	20.0	12.7	6.5
9	15.75	10.0	5.15
10	12.75	8.1	4.2
11	10.5	6.7	
12	8.85	5.65	
13	6.9	4.4	
14	6.5		
15	5.65		
16	5.0		

From Table XIII it is evident that, with a matte surface screen of 75 per cent reflectivity, and a 2-inch f/1.6 lens, it is possible with "National" "Pear-

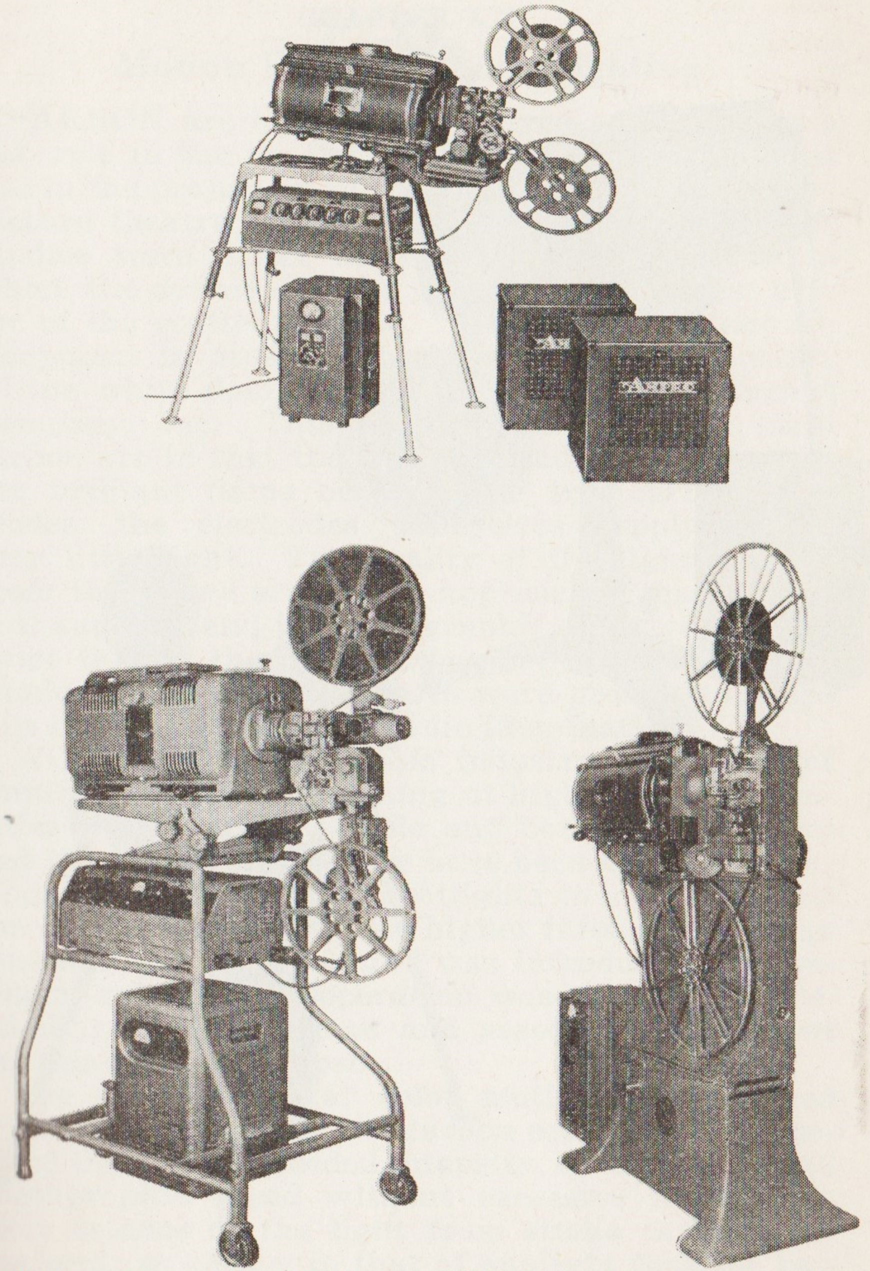
lex" carbons to provide the maximum recommended level of screen brightness of 20 foot-lamberts with an image 8 feet in width, and to fill a 16-foot screen at the minimum limit of brightness of 5-foot lamberts. The calculated image width at optimum brightness of 10 foot-lamberts is 11.3 feet. The recommended optimum brightness of 10 foot-lamberts is identical with the preferred value for viewing 35-mm film as specified by A. S. A. Standard Z22.39—1944.

The increased screen size that can be adequately illuminated with 16-mm carbon arc projectors greatly extends the utility of 16-mm film for educational, commercial and other purposes. It makes possible sufficient light for the showing of a 16-mm picture before a comfortably seated audience of several hundred.

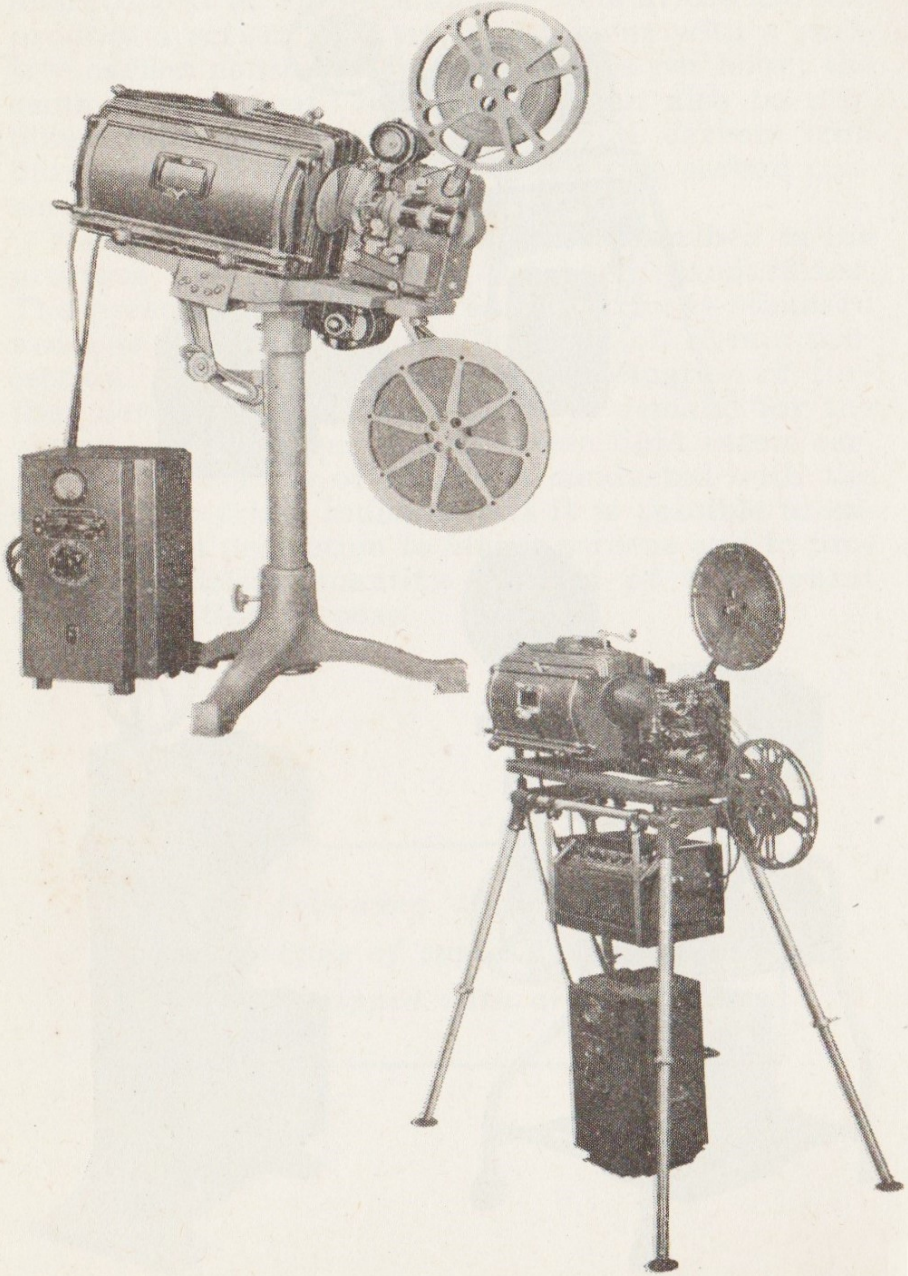
Consideration has also been given to carbon arc sources capable of properly illuminating screens considerably larger than presently possible in 16-mm projections. Experimental work has led to the development of a new 6-mm positive carbon capable of operating at 50 amperes. A carbon of this size paired with a suitable 5.5-mm negative carbon and operated at 50 amperes and 40 volts provides 2½ times as many screen lumens as the present standard "National" "Pearlex" trim at 30 amperes with identical f/1.6 optics. However, to realize this great increase in light output a positive carbon consumption of about 20 inches per hour is reached in comparison with 6 inches per hour of the present standard trim. Since higher burning rate might limit the application of this trim, further work has been conducted to relate light output and life at lower operating currents. In addition the use of a 7-mm positive rather than a 6-mm positive was investigated. "Suprex" positive carbons were considered for the 7-mm size. A 7-mm "Suprex" positive carbon in combination with a 5.5-mm negative carbon operating at 50 amperes and 37 volts at the arc will produce a screen light of 4600 lumens with a positive carbon consumption of 11 inches per hour; the same light output, 4600 lumens, can also be produced with the 6-mm experimental carbon trim burning at 43 amperes with a positive carbon consumption of 13 inches per hour.

None of the newer carbon trims described in the previous paragraph has as yet been standardized. The present "National" "Pearlex" trim is standard and has greatly extended the scope of 16-mm projection. The new trims are in anticipation of further developments in this field. A demand for the use of larger screens and for more light seems certain. The results of the tests conducted with the new carbon trims indicate that it is possible to extend 16-mm projection to larger screens and to provide a sufficient quantity of light of the highest quality for this purpose.

The following two pages show photographs of typical 16-mm projectors equipped with arc lamps.



Photographs of Typical 16mm Projectors Equipped With Carbon Arc Lamps



Photographs of Typical 16mm Projectors Equipped With Carbon Arc Lamps

CHAPTER XII

Motion Picture Studio Lighting

CARBON arc lighting has played as important a role in the production of motion pictures as it has in the projection of these pictures on the motion picture theatre screen. The first arcs used in the studios were direct current plain carbon arcs in which the source of light was the incandescent crater of the positive carbon. The next important development in studio lighting was the introduction of the white flame carbon arc by National Carbon Company, Inc. This arc differed from the plain carbon arc in that the principal source of light was the brilliant flame between the two carbon electrodes, the electrodes themselves supplying but very little light. The quality of the light emitted from this flame arc closely approached that of natural sunlight and its photographic effectiveness was twice that of the plain carbon arc in previous use. Producers of motion pictures were prompt to adopt this improved source of studio illumination.

With the growth of this industry new types of flaming arc carbons burning at higher current densities were made available and both the flame arc and the high intensity arc have been adapted to various types of flood and spotlights to meet demands for greater steadiness and higher intensity of stage illumination. When sound was introduced the necessary quietness of operation was achieved by developing carbons, lamps and associated equipment for this specific purpose.

The development of color motion pictures was greatly facilitated by the carbon arc because it provided light of the needed intensity, color balance and photographic speed without excessive heat. The color balance of the light from studio carbon arcs conforms so closely to that of sunlight that the two are considered essentially equivalent for photographic purposes. It imparts realism to studio scenes and permits natural reproduction of form, color and detail.

The crater brilliancy of the high intensity carbon arc is from twelve to fifty times the brilliancy commercially available with reasonable life from a tungsten filament lamp and, in the case of certain experimental carbons, exceeds the brilliancy of the sun. Because this provides a large volume of light

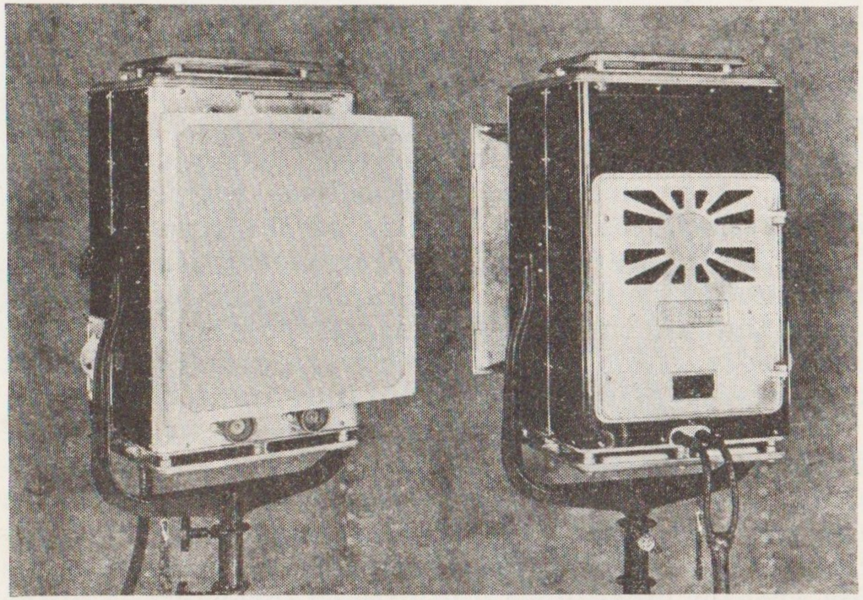


Figure 36

from a source of small dimensions the optical system of the lamp is able to gather it efficiently and direct it accurately onto the set in whatever pattern may be desired. Figures 36, 37 and 38 show some of the types of arc lamps now used in motion picture studios.

The lamp in Figure 36, used for broadside and scoop lighting, contains two white flame arcs connected in series and has a motor driven mechanism. A very steady and extremely quiet arc is main-

tained, permitting operation in close proximity to the microphone without difficulty. Figure 37 illustrates a high intensity arc lamp with rotating mechanism, equipped with 20-inch diameter Fresnel-type lens. It operates at 140-150 amperes with 64-67 volts at the arc. This lamp is used for back, cross

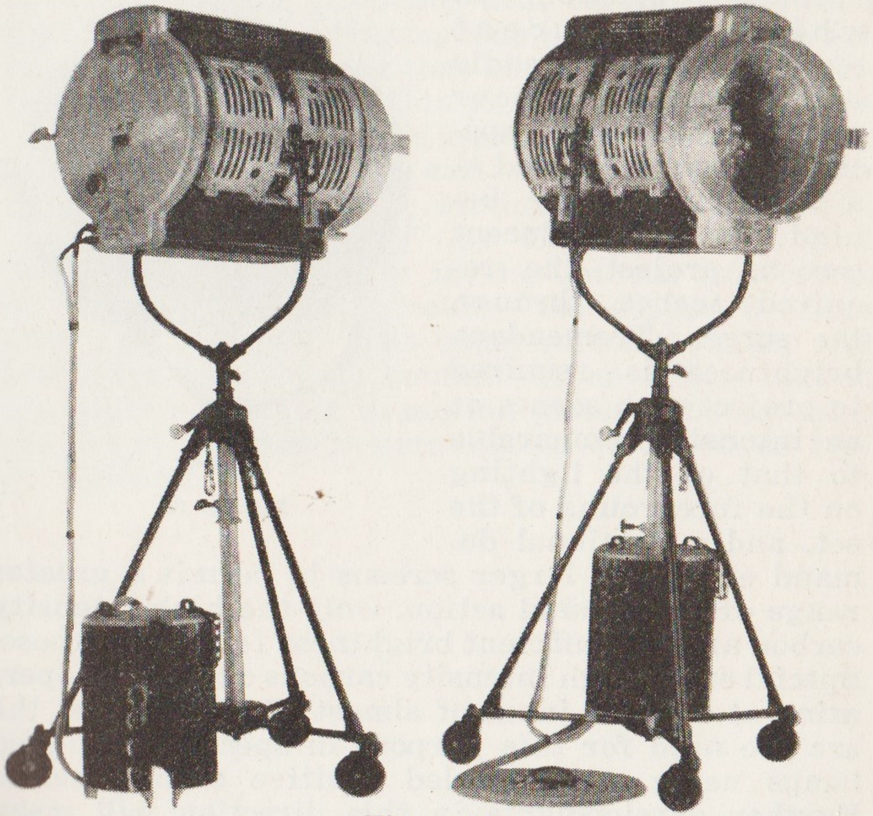


Figure 37

and key lighting and for either wide or narrow-angle front and effect lighting. The M-R Type 450 Super High Intensity Arc Spot Lamp, Figure 38, uses a carbon trim consisting of a 16-mm x 22″ super high intensity MP studio positive carbon and a 17/32″ x 9″ heavy duty cored "Orotip" negative carbon operating at 225 arc amperes and 75 arc volts.

This lamp is used for extremely long throws, for sharply outlined shadows or to provide a clearly defined beam of light through the general illumination. This is the most brilliant and powerful arc lamp used in the studios.

For "background" or "process projection," in which translucent screens are used on sudio sets to provide a scenic or action background, special projectors, located at a suitable distance behind the translucent screen, project the required scenes through the screen. Tremendous brightness is required to project such scenes at an intensity comparable to that of the lighting on the foreground of the set, and a continual demand exists for larger screens to permit a greater range of foreground action. Only the high intensity carbon arc has sufficient brightness for this purpose. Special super high intensity carbons capable of operating at a power input of almost 17 kilowatts at the arc are used for this purpose in specially designed lamps using water cooled positive carbon heads. Further developments in this direction will make possible carbon arcs of much greater brightness than any in use at present. Where high levels of illumination are required for process projection three overlapping background projectors are sometimes used. These projectors in the form of multiple units are synchronized with each other and with the camera, each projecting the same scene in exact register through the screen.

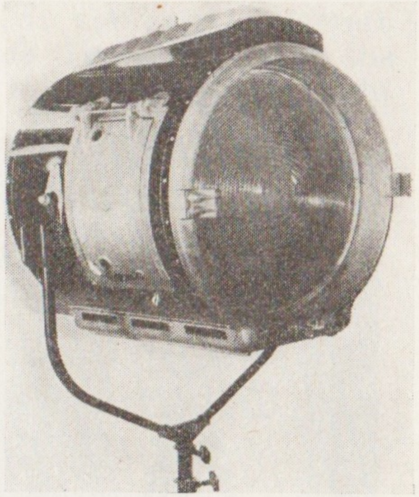


Figure 38

Television Studios

Now that television is assuming greater commercial importance, problems associated with the lighting of television sets will demand increased attention. As these sets become more elaborate and the photographic values become subject to more critical review, it seems probable that carbon arc studio lighting will find advantageous application here for much the same reasons that now give it such an important place in the motion picture studio.

For an interesting and comprehensive discussion of this subject reference can be made to a paper entitled "Carbon Arcs for Motion Picture and Television Studio Lighting" by Bowditch, Null and Zavesky, which appears in the Journal of Society of Motion Picture Engineers—Vol. 46, No. 6 (June 1946), pp. 441-453. The balanced color quality and low infra red (heat) content which makes carbon arc sources valuable in motion picture photography are reviewed from the standpoint of television studio lighting.

CHAPTER XIII

Brushes

MOST theatres are located in districts where direct current power supply is not available. In such cases, the operation of D.C. projection lamps requires the installation of some type of rectifying or converting device to change the alternating current supplied by the power lines to direct current for use at the arc. In many theatres a motor-generator set or some type of synchronous converter is used for this purpose and carbon brushes are required on the D.C. side of all machines of this type.

Reasonable attention to factors affecting the operation of brushes will be well repaid by the improved results and greater reliability of operation thus obtained.

As is true of all rotating equipment, careful attention should be given to the thorough lubrication of bearings. At the same time, care should be exercised to prevent oil getting on the commutator of the machine where it has a tendency to impair the mica insulation of the segments as well as to interfere with the operation of the brushes.

Accurate alignment of the edges of the brushes with the commutator segments and equal spacing of brushes around the periphery of the commutator are likewise essential to good commutation and cool operation of the unit. A convenient way to check brush spacing is to wrap a strip of paper tightly around the commutator and, with a pencil, mark the point at which the corresponding edge of each brush bears on the strip. Measuring the distance between these marks will then show whether or not the brush spacing is equal. If found unequal, this condition should be corrected, the method of correction depending on the construction of the machine.

It is obviously important to keep the brush holders and their supporting studs firmly secured. Loose brush holders permit vibration and displacement of the brushes from the correct position.

When new brushes are installed they should be sanded in to fit the commutator accurately. A good way to do this is to cut strips of sandpaper slightly wider than the brush. Raise a brush and place the strip of sandpaper under it with the rough side against the carbon. Let the brush down on the sandpaper and pull the latter through in the same direction as the commutator rotates, repeating this operation until all of the brushes have been sanded to full contact from edge to edge. It is not advisable to pull the strip of sandpaper back and forth under the brush as there is some play of the brush in its holder and this method of sanding tends to form a double face which prevents full contact from edge to edge.

The tension on all brushes should be as nearly the same as the adjustment provided on the brush holders will permit. The actual value of the tension should conform to the recommendation of the manufacturer of the brush grade in use. In most cases, a pressure of two pounds per square inch of brush contact face will give good results.

Maintenance of a good commutator surface merits careful attention on the part of the operator. Undercut commutators should be carefully inspected for the presence of side mica and where found it should be removed. Burned bar edges, streaks and minor defects in commutator surface can usually be removed by polishing with a commutator stone or with fine sandpaper secured to a block which has been formed to the radius of the commutator. Serious flat spots or deep grooves, however, require turning or grinding of the commutator. This should be done by a shop properly equipped to handle work of this character.

Until the commutator of a new machine becomes thoroughly seasoned, it is possible that the segments may loosen and high or low bars become apparent. The clamp or "V" ring of the commutator should be examined from time to time and, when evidence of looseness is discovered, firmly tightened. This should be done when the machine is hot. Any evidence of failure of the mica insulation of the commutator segments should also receive immediate attention.

All electrical connections on the generating equipment should be kept clean and firm. This precaution includes the brush shunts—the flexible cables by means of which the brushes are connected to the electrical circuit. The terminals should be firmly secured to the brush holders or their mounting at the points provided for this purpose. Loose electrical connections are a frequent source of trouble on electrical equipment but one that is easily avoided by a moderate degree of attention.

The grade of brush used exerts a marked influence on the results obtained. On commutators that are not undercut, that is, those on which the mica is flush with the copper, it is generally desirable to use a brush having a mild abrasive action to keep the mica worn down even with the metallic surface. If the mica is allowed to project above the surface, the brushes will not make firm contact with the copper and the resultant sparking will quickly develop burned bars and flat spots, necessitating regrinding of the commutator. On undercut commutators, which are the general rule today, nonabrasive electrographitic brushes give excellent results on most generating equipment used in the projection room. This type of brush has low friction and excellent commutating characteristics and is hard enough to maintain a good commutator polish under most operating conditions. Sometimes a slight spotting or streaking of the commutator occurs when the arc is struck which the nonabrasive electrographitic

brush cannot entirely remove before striking the arc again. This condition can be remedied by polishing the commutator surface occasionally with smooth sandpaper. However, to avoid the need for this attention, some operators prefer to use a brush with a slight polishing action, enough to remove this incipient burning but not sufficiently abrasive to cause appreciable commutator wear. Graphite or graphite-carbon grades are usually preferred for this purpose. The use of artificially lubricated brushes or the application of lubricant to the commutator surface is not recommended when the mica is undercut and is unnecessary when the proper grade of brush is used.

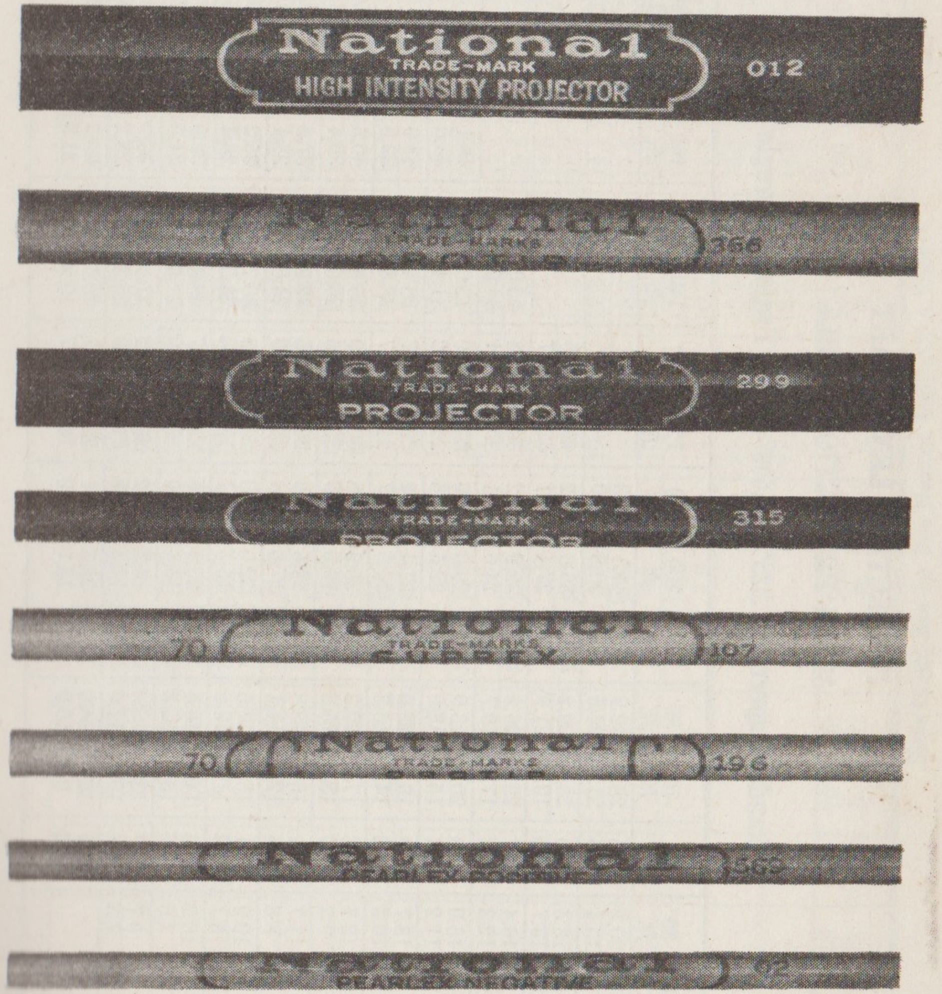
The grade of brush supplied by the manufacturer of the equipment will generally give satisfactory performance since careful attention is given to brush selection by designing engineers. Distributors of "National" Projector Carbons also carry in stock "National Pyramid" Brushes in suitable grades and sizes for all popular makes of motion picture theatre current converting equipment. Replacement brushes of correct grade can thus be obtained without delay from the same source as other theatre supplies. There are cases, however, where operating conditions or other causes indicate the need for a brush of special characteristics. In such cases an outline of your difficulties, mailed to the nearest Division Office of National Carbon Company, Inc., or a discussion of the trouble with a representative of the Company will secure the recommendation of a grade to meet the requirements of your specific case.

"National" "Pyramid" Brushes may be readily distinguished by the trade-mark:

"National"
The Three Pyramids
and Silver Strand Cable

Grade number is plainly stamped on each brush where size permits.

Identification of National Projector Carbons



Each individual carbon is stamped with an identifying trade-mark, as shown in the above illustration.

PROJECTION LENS CHART

35-MM PROJECTION TABLE

Standard aperture: .825″ x 0.600″ — 14° Projection Angle

E.F. in.	40 *ft.*	50 *ft.*	60 *ft.*	70 *ft.*	80 *ft.*	90 *ft.*	100 *ft.*	110 *ft.*	120 *ft.*	130 *ft.*	140 *ft.*	150 *ft.*	160 *ft.*	170 *ft.*	180 *ft.*	190 *ft.*	200 *ft.*
2.00″	16.4 12.3	20.5 15.4	24.6 18.5	28.8 21.6	32.9 24.6	37.0 27.7	41.1 30.8	45.3 34.0									
2.25″	14.6 10.9	18.3 13.7	22.0 16.5	25.6 19.2	29.2 21.9	32.9 24.6	36.6 27.4	40.2 30.1	43.9 32.9	47.5 35.7							
2.50″	13.1 9.9	16.4 12.3	19.7 14.8	23.0 17.3	26.3 19.7	29.6 22.2	32.9 24.6	36.2 27.1	39.5 29.6	42.8 32.1	45.6 34.5						
2.75″	12.0 9.0	15.0 11.2	17.9 13.4	20.9 15.7	23.9 18.0	26.9 20.2	29.9 22.5	32.9 24.6	36.0 26.9	39.0 29.2	42.0 31.4	45.0 33.7	48.1 36.0				
3.00″	10.9 8.2	13.7 10.3	16.4 12.3	19.2 14.4	22.0 16.5	24.6 18.4	27.4 20.6	30.2 22.7	32.9 24.6	35.7 26.7	38.4 28.8	41.1 30.8	43.9 32.9	46.7 35.0			
3.25″	10.1 7.5	12.7 9.5	15.2 11.3	17.7 13.3	20.2 15.2	22.8 17.1	25.3 19.0	27.8 20.9	30.4 22.8	32.9 24.6	35.5 26.6	38.0 28.4	40.5 30.4	43.0 32.3	45.6 34.1		
3.50″	9.4 7.0	11.7 8.8	14.1 10.6	16.4 12.3	18.8 14.1	21.1 15.9	23.5 17.6	25.9 19.4	28.3 21.1	30.5 22.9	32.9 24.6	35.2 26.3	37.5 28.1	39.9 29.9	42.3 31.8	44.7 33.5	47.0 35.2
3.75″		10.9 8.1	13.1 9.9	15.3 11.4	17.5 13.2	19.7 14.8	22.0 16.5	24.0 18.1	26.3 19.7	28.6 21.3	30.7 23.0	32.9 24.6	35.2 26.4	37.3 28.0	39.5 29.7	41.7 31.2	43.9 32.9
4.00″		10.2 7.6	12.3 9.2	14.3 10.7	16.4 12.3	18.5 13.8	20.5 15.4	22.6 16.9	24.6 18.4	26.7 20.0	28.8 21.5	30.8 23.1	32.9 24.6	35.0 26.2	37.0 27.7	39.1 29.3	41.1 30.8
4.25″		9.7 7.3	11.7 8.8	13.5 10.1	15.5 11.5	17.4 13.1	19.3 14.4	21.2 15.9	23.2 17.3	25.2 18.9	27.1 20.3	29.1 21.7	30.9 23.2	32.9 24.6	34.9 26.1	36.8 27.6	38.8 29.7
4.50″			10.9 8.2	12.8 9.6	14.6 10.9	16.4 12.3	18.3 13.7	20.1 15.0	22.0 16.5	23.7 17.7	25.6 19.2	27.4 20.6	29.2 21.8	31.0 23.3	32.9 24.6	34.8 26.1	36.6 27.4

4.75″			10.4 7.8	12.2 9.2	13.9 10.4	15.7 11.7	17.3 13.0	19.0 13.4	20.7 15.6	22.5 16.9	24.2 18.1	26.0 19.5	27.6 20.7	29.4 22.1	31.1 23.3	32.9 24.6	34.7 26.0
5.00″				11.6 8.7	13.1 9.9	14.9 11.1	16.4 12.3	18.1 13.6	19.7 14.8	21.4 16.1	23.0 17.3	24.6 18.4	26.3 19.7	27.9 21.0	29.6 22.2	31.3 23.5	32.9 24.6
5.25″				10.9 8.1	12.5 9.4	14.1 10.6	15.7 11.7	17.2 12.9	18.8 14.1	20.3 15.3	21.8 16.4	23.5 17.6	25.1 18.9	26.7 20.0	28.3 21.1	29.8 22.4	31.3 23.5
5.50″				10.5 7.8	12.0 9.0	13.5 10.1	15.0 11.2	16.4 12.3	17.9 13.4	19.4 14.5	20.9 15.7	22.4 16.8	23.9 17.9	25.4 19.1	26.9 20.2	28.4 21.2	29.9 22.5
5.75″					11.3 8.6	12.8 9.6	14.2 10.6	15.7 11.7	17.1 12.8	18.6 13.9	20.0 14.9	21.4 16.1	22.9 17.1	24.3 18.2	25.8 19.3	27.2 20.4	28.6 21.4
6.00″					10.9 8.2	12.3 9.2	13.7 10.3	15.1 11.2	16.4 12.3	17.8 13.4	19.2 14.4	20.5 15.4	22.0 16.5	23.3 17.5	24.6 18.4	26.0 19.5	27.4 20.6
6.25″					10.5 7.9	11.9 8.9	13.1 9.8	14.3 10.7	15.9 11.7	17.0 12.8	18.4 13.7	19.7 14.7	21.0 15.8	22.3 16.7	23.6 17.7	25.0 18.7	26.3 19.7
6.50″						11.4 8.6	12.7 9.5	13.9 10.4	15.2 11.3	16.4 12.3	17.7 13.2	18.9 14.1	20.2 15.1	21.5 16.1	22.8 17.1	24.0 18.0	25.3 19.0
6.75″						10.9 8.1	12.2 9.1	13.4 10.1	14.6 10.9	15.9 12.0	17.0 12.8	18.3 13.7	19.5 14.6	20.7 15.6	22.0 16.5	23.2 17.4	24.4 18.3
7.00″						10.5 7.8	11.7 8.8	12.9 9.7	14.1 10.6	15.3 11.4	16.4 12.3	17.5 13.2	18.8 14.1	19.9 14.9	21.1 15.9	22.3 16.7	23.5 17.6
7.50″							10.9 8.1	12.0 9.0	13.1 10.0	14.2 10.6	15.3 11.4	16.4 12.3	17.5 13.2	18.7 14.0	19.7 14.8	20.8 15.7	22.0 16.5
8.00″							10.2 7.6	11.2 8.5	12.3 9.2	13.3 10.0	14.3 10.7	15.4 11.5	16.4 12.3	17.4 13.1	18.5 13.8	19.5 14.6	20.5 15.4
8.50″								10.6 7.8	11.7 8.8	12.6 9.4	13.5 10.1	14.5 10.8	15.5 11.5	16.4 12.3	17.4 13.1	18.4 13.8	19.3 14.4
9.00″									11.0 8.2	11.8 8.9	12.8 9.6	13.7 10.3	14.6 10.9	15.5 11.6	16.4 12.3	17.3 13.0	18.3 13.7
E.F. in	40 *ft.*	50 *ft.*	60 *ft.*	70 *ft.*	80 *ft.*	90 *ft.*	100 *ft.*	110 *ft.*	120 *ft.*	130 *ft.*	140 *ft.*	150 *ft.*	160 *ft.*	170 *ft.*	180 *ft.*	190 *ft.*	200 *ft.*

Sizes Given Are To The Nearest Tenth Of A Foot.

MILLIMETER — INCH EQUIVALENTS

Mm	Inches			Mm	Inches			Mm	Inches		
1	0.0394	1/32	+	51	2.0079	2.0	+	101	3.9764	3 31/32	+
2	0.0787	3/32	−	52	2.0473	2 1/16	−	102	4.0158	4 1/32	−
3	0.1181	1/8	−	53	2.0866	2 3/32	−	103	4.0551	4 1/16	−
4	0.1575	5/32	+	54	2.1260	2 1/8	+	104	4.0945	4 3/32	+
5	0.1969	3/16	+	55	2.1654	2 5/32	+	105	4.1339	4 1/8	+
6	0.2362	1/4	−	56	2.2047	2 7/32	−	106	4.1732	4 3/16	−
7	0.2756	9/32	−	57	2.2441	2 1/4	−	107	4.2126	4 7/32	−
8	0.3150	5/16	+	58	2.2835	2 9/32	+	108	4.2520	4 1/4	+
9	0.3543	11/32	+	59	2.3228	2 5/16	+	109	4.2914	4 9/32	+
10	0.3937	13/32	−	60	2.3622	2 3/8	−	110	4.3307	4 11/32	−
11	0.4331	7/16	−	61	2.4016	2 13/32	−	111	4.3701	4 3/8	−
12	0.4724	15/32	+	62	2.4410	2 7/16	+	112	4.4095	4 13/32	+
13	0.5118	1/2	+	63	2.4803	2 15/32	+	113	4.4488	4 7/16	+
14	0.5512	9/16	−	64	2.5197	2 17/32	−	114	4.4882	4 1/2	−
15	0.5906	19/32	−	65	2.5591	2 9/16	−	115	4.5276	4 17/32	−
16	0.6299	5/8	+	66	2.5984	2 19/32	+	116	4.5670	4 9/16	+
17	0.6693	21/32	+	67	2.6378	2 5/8	+	117	4.6063	4 19/32	+
18	0.7087	23/32	−	68	2.6772	2 11/16	−	118	4.6457	4 21/32	−
19	0.7480	3/4	−	69	2.7165	2 23/32	−	119	4.6851	4 11/16	−
20	0.7874	25/32	+	70	2.7559	2 3/4	+	120	4.7244	4 23/32	+
21	0.8268	13/16	+	71	2.7953	2 25/32	+	121	4.7638	4 3/4	+
22	0.8661	7/8	−	72	2.8347	2 27/32	−	122	4.8032	4 13/16	−
23	0.9055	29/32	−	73	2.8740	2 7/8	−	123	4.8425	4 27/32	−
24	0.9449	15/16	+	74	2.9134	2 29/32	+	124	4.8819	4 7/8	+
25	0.9843	31/32	+	75	2.9528	2 15/16	+	125	4.9213	4 29/32	+
26	1.0236	1 1/32	−	76	2.9921	3.0	−	126	4.9607	4 31/32	−
27	1.0630	1 1/16	+	77	3.0315	3 1/32	+	127	5.0000	5.0	
28	1.1024	1 3/32	+	78	3.0709	3 1/16	+	128	5.0394	5 1/32	+
29	1.1417	1 5/32	−	79	3.1103	3 1/8	−	129	5.0788	5 3/32	−
30	1.1811	1 3/16	−	80	3.1496	3 5/32	−	130	5.1181	5 1/8	−
31	1.2205	1 7/32	+	81	3.1890	3 3/16	+	131	5.1575	5 5/32	+
32	1.2598	1 1/4	+	82	3.2284	3 7/32	+	132	5.1969	5 3/16	+
33	1.2992	1 5/16	−	83	3.2677	3 9/32	−	133	5.2362	5 1/4	−
34	1.3386	1 11/32	−	84	3.3071	3 5/16	−	134	5.2756	5 9/32	−
35	1.3780	1 3/8	+	85	3.3465	3 11/32	+	135	5.3150	5 5/16	+
36	1.4173	1 13/32	+	86	3.3858	3 3/8	+	136	5.3544	5 11/32	+
37	1.4567	1 15/32	−	87	3.4252	3 7/16	−	137	5.3937	5 13/32	−
38	1.4961	1 1/2	−	88	3.4646	3 15/32	−	138	5.4331	5 7/16	−
39	1.5354	1 17/32	+	89	3.5040	3 1/2	+	139	5.4725	5 15/32	+
40	1.5748	1 9/16	+	90	3.5433	3 17/32	+	140	5.5118	5 1/2	+
41	1.6142	1 5/8	−	91	3.5827	3 19/32	−	141	5.5512	5 9/16	−
42	1.6536	1 21/32	−	92	3.6221	3 5/8	−	142	5.5906	5 19/32	−
43	1.6929	1 11/16	+	93	3.6614	3 21/32	+	143	5.6299	5 5/8	+
44	1.7323	1 23/32	+	94	3.7008	3 11/16	+	144	5.6693	5 21/32	+
45	1.7717	1 25/32	−	95	3.7402	3 3/4	−	145	5.7087	5 23/32	−
46	1.8110	1 13/16	−	96	3.7795	3 25/32	−	146	5.7481	5 3/4	−
47	1.8504	1 27/32	+	97	3.8189	3 13/16	+	147	5.7874	5 25/32	+
48	1.8898	1 7/8	+	98	3.8583	3 27/32	+	148	5.8268	5 13/16	+
49	1.9291	1 15/16	−	99	3.8977	3 29/32	−	149	5.8662	5 7/8	−
50	1.9685	1 31/32	−	100	3.9370	3 15/16	−	150	5.9055	5 29/32	−

NOTE — The + or − sign indicates that the decimal equivalent is larger or smaller than the fractional equivalent.

MILLIMETER — INCH EQUIVALENTS

Mm	Inches			Mm	Inches			Mm	Inches		
151	5.9449	5 15/16	+	201	7.9134	7 29/32	+	251	9.8819	9 7/8	+
152	5.9843	5 31/32	+	202	7.9528	7 15/16	+	252	9.9213	9 29/32	+
153	6.0237	6 1/32	−	203	7.9922	8.0	−	253	9.9607	9 31/32	−
154	6.0630	6 1/16	+	204	8.0315	8 1/32	+	254	10.0000	10.0	
155	6.1024	6 3/32	+	205	8.0709	8 1/16	+	255	10.0394	10 1/32	+
156	6.1418	6 5/32	−	206	8.1103	8 1/8	−	256	10.0788	10 3/32	−
157	6.1811	6 3/16	−	207	8.1496	8 5/32	−	257	10.1182	10 1/8	−
158	6.2205	6 7/32	+	208	8.1890	8 3/16	+	258	10.1575	10 5/32	+
159	6.2599	6 1/4	+	209	8.2284	8 7/32	+	259	10.1969	10 3/16	+
160	6.2993	6 5/16	−	210	8.2678	8 9/32	−	260	10.2363	10 1/4	−
161	6.3386	6 11/32	−	211	8.3071	8 5/16	−	261	10.2756	10 9/32	−
162	6.3780	6 3/8	+	212	8.3465	8 11/32	+	262	10.3150	10 5/16	+
163	6.4174	6 13/32	+	213	8.3859	8 3/8	+	263	10.3544	10 11/32	+
164	6.4567	6 15/32	−	214	8.4251	8 7/16	−	264	10.3938	10 13/32	−
165	6.4961	6 1/2	−	215	8.4646	8 15/32	−	265	10.4331	10 7/16	−
166	6.5355	6 17/32	+	216	8.5040	8 1/2	+	266	10.4725	10 15/32	+
167	6.5748	9 9/16	+	217	8.5433	8 17/32	+	267	10.5119	10 1/2	+
168	6.6142	6 5/8	−	218	8.5827	9 19/32	−	268	10.5512	10 9/16	−
169	6.6536	6 21/32	−	219	8.6221	8 5/8	−	269	10.5906	10 19/32	−
170	6.6929	6 11/16	+	220	8.6615	8 21/32	+	270	10.6300	10 5/8	+
171	6.7323	6 23/32	+	221	8.7008	8 11/16	+	271	10.6693	10 21/32	+
172	6.7717	6 25/32	−	222	8.7402	8 3/4	−	272	10.7087	10 23/32	−
173	6.8111	6 13/16	−	223	8.7796	8 25/32	−	273	10.7481	10 3/4	−
174	6.8504	6 27/32	+	224	8.8189	8 13/16	+	274	10.7875	10 25/32	+
175	6.8898	6 7/8	+	225	8.8583	8 27/32	+	275	10.8268	10 13/16	+
176	6.9292	6 15/16	−	226	8.8977	8 29/32	−	276	10.8662	10 7/8	−
177	6.9685	6 31/32	−	227	8.9371	8 15/16	−	277	10.9056	10 29/32	−
178	7.0079	7.0	+	228	8.9764	8 31/32	+	278	10.9449	10 15/16	+
179	7.0473	7 1/16	−	229	9.0158	9 1/32	−	279	10.9843	10 31/32	+
180	7.0866	7 3/32	−	230	9.0552	9 1/16	−	280	11.0237	11 1/32	−
181	7.1260	7 1/8	+	231	9.0945	9 3/32	+	281	11.0630	11 1/16	+
182	7.1654	7 5/32	+	232	9.1339	9 1/8	+	282	11.1024	11 3/32	+
183	7.2048	7 7/32	−	233	9.1733	9 3/16	−	283	11.1418	11 5/32	−
184	7.2442	7 1/4	−	234	9.2126	9 7/32	−	284	11.1812	11 3/16	−
185	7.2835	7 9/32	+	235	9.2520	9 1/4	+	285	11.2205	11 7/32	+
186	7.3229	7 5/16	+	236	9.2914	9 9/32	+	286	11.2599	11 1/4	+
187	7.3622	7 3/8	−	237	9.3308	9 11/32	−	287	11.2993	11 5/16	−
188	7.4016	7 13/32	−	238	9.3701	9 3/8	−	288	11.3386	11 11/32	−
189	7.4410	7 7/16	+	239	9.4095	9 13/32	+	289	11.3780	11 3/8	+
190	7.4804	7 15/32	+	240	9.4489	9 7/16	+	290	11.4174	11 13/32	+
191	7.5197	7 17/32	−	241	9.4882	9 1/2	−	291	11.4567	11 15/32	−
192	7.5591	7 9/16	−	242	9.5276	9 17/32	−	292	11.4961	11 1/2	−
193	7.5985	7 19/32	+	243	9.5670	9 9/16	+	293	11.5355	11 17/32	+
194	7.6378	7 5/8	+	244	9.6063	9 19/32	+	294	11.5749	11 9/16	+
195	7.6772	7 11/16	−	245	9.6457	9 21/32	−	295	11.6142	11 5/8	−
196	7.7166	7 23/32	−	246	9.6851	9 11/16	−	296	11.6536	11 21/32	−
197	7.7559	7 3/4	+	247	9.7245	9 23/32	+	297	11.6930	11 11/16	+
198	7.7953	7 25/32	+	248	9.7638	9 3/4	+	298	11.7323	11 23/32	+
199	7.8347	7 27/32	−	249	9.8032	9 13/16	−	299	11.7717	11 25/32	−
200	7.8741	7 7/8	−	250	9.8426	9 27/32	−	300	11.8111	11 13/16	−

NOTE — The + or − sign indicates that the decimal equivalent is larger or smaller than the fractional equivalent.

Decimal Equivalents of Fractions and Equivalents of Fractions of an Inch in M. M.

Fractions	Decim. of an inch	mm.	Fractions	Decim. of an inch	mm.
1/64	.015625	.397	33/64	.515625	13.097
1/32	.031250	.794	17/32	.531250	13.494
3/64	.046875	1.191	35/64	.546875	13.891
1/16	.062500	1.588	9/16	.562500	14.288
5/64	.078125	1.984	37/64	.578125	14.684
3/32	.093750	2.381	19/32	.593750	15.081
7/64	.109375	2.778	39/64	.609375	15.478
1/8	.125000	3.175	5/8	.625000	15.875
9/64	.140625	3.572	41/64	.640625	16.272
5/32	.156250	3.969	21/32	.656250	16.669
11/64	.171875	4.366	43/64	.671875	17.066
3/16	.187500	4.763	11/16	.687500	17.463
13/64	.203125	5.159	45/64	.703125	17.859
7/32	.218750	5.556	23/32	.718750	18.256
15/64	.234375	5.953	47/64	.734375	18.653
1/4	.250000	6.350	3/4	.750000	19.050
17/64	.265625	6.747	49/64	.765625	19.447
9/32	.281250	7.144	25/32	.781250	19.844
19/64	.296875	7.541	51/64	.796875	20.241
5/16	.312500	7.938	13/16	.812500	20.638
21/64	.328125	8.334	53/64	.828125	21.034
11/32	.343750	8.731	27/32	.843750	21.431
23/64	.359375	9.128	55/64	.859375	21.828
3/8	.375000	9.525	7/8	.875000	22.225
25/64	.390625	9.922	57/64	.890625	22.622
13/32	.406250	10.319	29/32	.906250	23.019
27/64	.421875	10.716	59/64	.921875	23.416
7/16	.437500	11.113	15/16	.937500	23.813
29/64	.453125	11.509	61/64	.953125	24.209
15/32	.468750	11.906	31/32	.968750	24.606
31/64	.484375	12.303	63/64	.984375	25.003
1/2	.500000	12.700	1	1.0000000	25.400

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