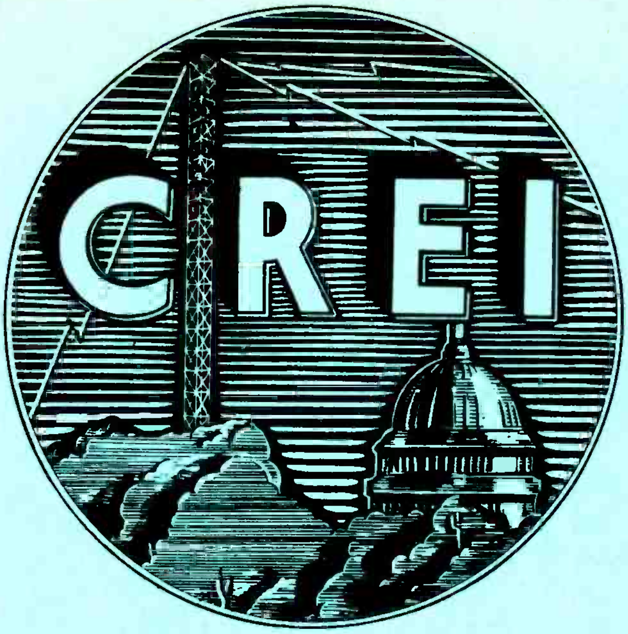

SPECIALIZED TELEVISION ENGINEERING

TELEVISION TECHNICAL ASSIGNMENT

STUDIO LIGHTING TECHNIQUE

Capitol Radio Engineering Institute
Washington, D. C.

728D

TELEVISION TECHNICAL ASSIGNMENT

STUDIO LIGHTING TECHNIQUES

FOREWORD

From the technical viewpoint, television is an application of the science of electronics, but from the artistic viewpoint, television is the skillful use of light on a scene. Much of the latter technique can be acquired solely through experience, but certain fundamental principles can aid greatly in guiding the staff to a successful rendition of the program.

This assignment deals first with the lighting units that have been found necessary in a television studio, and with their placement. Numerous illustrations are employed to make the text clear, and a great deal can be learned from a careful study of these pictures.

The second part deals with light units. It is necessary to know these in order to appreciate the characteristics of the various light sources employed, the characteristics of the studio sets themselves, and the significance of the readings obtained on light meters. It may be that the expert can tell by eye whether the lights are correctly placed and whether or not the scene is properly illuminated, but undoubtedly the trend will be more and more toward actual measurements by instruments and checking on the actual reproduced picture, since the eye is a notoriously poor judge of light intensitites.

Television, like a chain, is no better than its weakest link in the sequence that starts in the studio and ends in a picture on the receiver screen. Therefore, there is no incongruity in claiming that television lighting, the pickup tube, video amplifiers, the synchronizing generator, deflection circuits, etc., are each of paramount importance to the proper functioning of the system. They are all; and the importance of each can be stressed in turn as if the whole system depended solely on it.

Hence, with no apology, we recommend this assignment to the earnest attention of the student. A knowledge of the function of illumination, how it is measured, and how it is used, will stand the television engineer in good stead no matter in what part of the system he is placed.

E. H. Rietzke,
President.

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STUDIO LIGHTING TECHNIQUE

A television program begins in the studio, and the first requirement is that the studio sets be adequately and correctly illuminated. Unless this requirement is met, the picture will be of poor quality regardless of how well the electronic equipment operates. It is therefore important for the television engineer to have a clear idea as to the use and placement of the lighting units, in order that he can properly evaluate the results obtained.

LIGHTING UNITS

INTENSITY OF LIGHT REQUIRED.— While the units in which light is measured will be developed farther on in this assignment, it will be of value at this point to note the amount of light required adequately to illuminate a scene. This varies with the type of pickup tube employed: the iconoscope, for example, requires more light than the orthicon, and the orthicon requires far more light than the image orthicon.

Another consideration is the type of pickup required; i.e., whether it is of a lantern slide, motion picture film, direct studio pickup, or pickup of an outdoor scene. In the case of lantern slide and motion picture projectors, greater control can be had in the directing of the light through the slide or film by means of reflectors and/or condenser lenses (as was described in the assignment on optics), so that a single projection incandescent lamp or arc is sufficient, particularly in view of the fact that the scene to be televised is of very small area (1" × 3/4" in the case of motion picture film).

In the case of a direct studio pickup, large scenes of appreciable depth must be illuminated, and the light is literally poured on the scene from batteries of lamps, spots, etc. A good deal of the illumination is reflected by the scene in directions other than that where the camera lenses are located, and is therefore wasted; hence, an enormous amount of light is required because of the necessarily wasteful method of application. A typical studio scene is shown in Fig. 1. Note the lights in the upper right-hand part of the picture.

In the case of an iconoscope, the intensity of illumination is on the order of 1,500 foot-candles, although values as low as 650 foot-candles may be permissable, at least for *foundation* or *key* lighting (to be explained shortly). The significance of 1,500 foot-candles will be explained later; suffice it to say at this point that the illumination of the earth by the sun on a bright mid-summer's day may be as high as 10,000 foot-candles, or over six times as great, whereas in motion picture work a value of 400 foot-candles is often cited.

The amount of light required in any case depends upon several factors·

1. The speed of the lens.
2. The depth of field desired.
3. The signal-to-noise ratio deemed desirable.
4. The comfort of the performers.

In the case of the iconoscope,

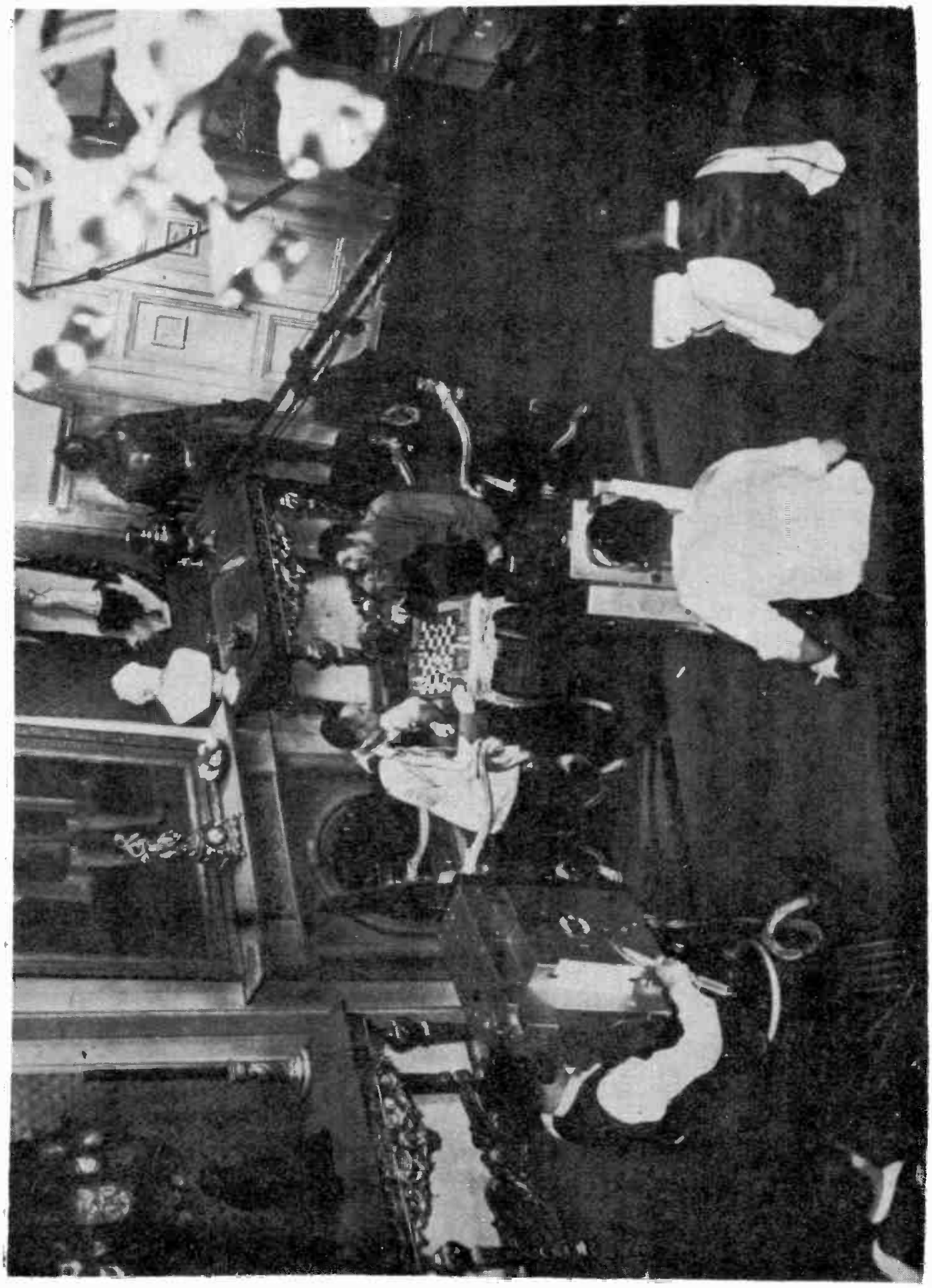

Fig. 1.--Studio scene from "Game of Chess" recently presented over NBC's television station WNBT. Note bank of Birdseye lamps in upper right-hand part of the picture.

the 1,500 foot-candles required is exceeding uncomfortable to the performers*, but is necessary if an adequate signal-to-noise ratio is to be obtained even when as fast a lens as f/3.5 is employed. The depth of field for such a lens is small, especially in the longer local lengths, but such matters are relatively unimportant compared to the obtaining of a satisfactory signal-to-noise ratio.

If an image orthicon tube is employed, the increased sensitivity can be utilized in several ways. The light intensity can be reduced, thus decreasing the lamp load and discomfort to the performers. It also permits outdoor scenes under poor conditions of natural lighting to be televised. On the other hand, in the studio—where the light intensity can be set—the greater sensitivity can be utilized to stop the lens down and therefore increase the depth of field, or the signal-to-noise ratio can be increased over that for the iconoscope.

It is therefore clear that the light requirements must be based on judgement of the operating staff as to what factor should be adjusted if and when a more sensitive pick-up tube is developed. The recent development of the image orthicon, with its almost unbelievable sensitivity and range, has opened up entirely new possibilities with regard to lighting technique, placement of actors with respect to depth of field, and signal-to-noise ratios. The advantage can be easily prorated between all of the factors, in view of the fact that the lighting required for the image orthicon can be as low as 0.1256 ft.-candles and as high as 12,560 ft.-candles, with a value of 300 ft.-candles for studio use (including key and modeling lights,—to be explained later).

The National Broadcasting Company in its Radio City television studio has employed as much as 75 kw of electrical power for lighting purposes. On the other hand, at the Second Television Broadcast Conference the image orthicon was employed under lighting conditions such that direct viewing was none too comfortable. Nevertheless, the studio lighting requirements for the image orthicon, while considerably less than that for the iconoscope, will be appreciable, particularly with the advent of color television, and lighting and lighting units will continue to be an important phase of television.

LIGHT SOURCES.—There are several light sources available for television. One that is often employed, particularly for small objects like test patterns, is the Kleig light, which is also used in motion picture work. This consists

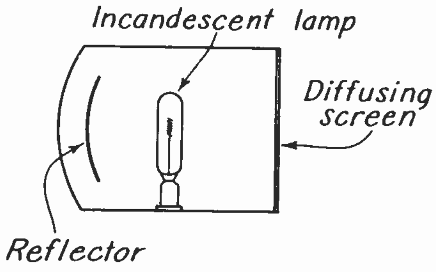

Fig. 2.--Kleig light used as an illuminant.

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*Light from incandescent sources contains a greater proportion of infra-red (heat) rays than light from the sun, and hence is more uncomfortable to the performers. This holds even when infra-red filters are employed.

of an incandescent source, backed by a reflector, and usually has a diffusing screen in front. It is sketched in Fig. 2. It is capable of a very intense and fairly uniform beam, and comes in various sizes, the largest exceeding 1 kw.

A very useful light source that is used in general studio lighting is the Birdseye type lamp, named after its inventor. This is illustrated in Fig. 3. It is now available for sale everywhere in sizes as low as 150 watts, although 300-watt and 500-watt sizes are preferred for television work. It is an incandescent light with a parabolic-shaped glass envelope that is silvered on the inside. It thus acts as a self-contained reflector, and the filament is carefully positioned at the focal point of the parabolic reflector.

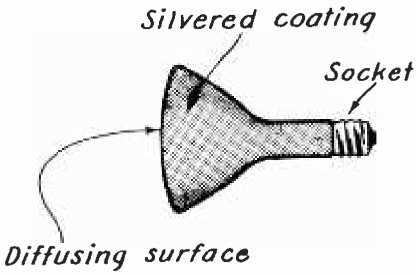

Fig. 3.--Birdseye lamp.

It is a characteristic of a parabola that light emanating from the focus is specularly reflected from the parabolic surface in such manner that the rays all emerge parallel to one another.* However, the front glass face is slightly frosted on the inside so that the light is somewhat diffused upon passing through it; nevertheless, a well-defined beam of light is produced with relatively little loss to the sides or rear of the lamp.

Special flexible sockets are available to enable the lamp to be swiveled in any direction desired, and some lamps have a flexible bellows arrangement just ahead of the socket to accomplish the same result. In this way a bank of three lamps for example, or of six lamps in two rows of three each can be built up to function as a unit, and the individual lamps turned so that their beams fall on the same area of the surface to be illuminated.

A quite common arrangement is to use a number of banks of Birdseye lamps for a scene. Each bank can be independently tilted and swiveled so as to direct the light as desired. Control can be by means of ropes or cables from a lighting bridge at the rear of the studio, where one or more men operate the controls as well as the electrical switches turning the lights on or off.

In addition to the general lighting, spot lights and flood lights are employed to illuminate specific parts of the scene. By this means special shadows or lack of shadows can be achieved, so as to produce special dramatic effects as well as to enhance the effect of depth. This will be discussed in somewhat greater detail farther on.

The main objection to all of the above sources is that they are relatively inefficient in that they develop and radiate far more heat (infra-red energy) than visible radiation (light). The result is that when the level of illumination is sufficiently bright for the iconoscope, the accompanying heat is so great as to require special

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*This is proved in the specialized mathematics section.

air-conditioning for the studio. Even then the temperature may rise from 70° to 80° during an hour's run when a large stage production is being presented.

To obviate the liberation of such a large amount of heat, special more efficient lamps are now available. The ordinary fluorescent light represents such a source, but is of low intrinsic brightness, and hence requires a large amount of space for a given amount of total light radiated.

Another source that shows great promise is the high-pressure mercury arc lamp. When an arc is formed in mercury vapor at the low pressure occurring at ordinary room temperature, the light is generated at certain discrete wavelengths, principally in the bluish-green part of the spectrum. The characteristic light of the mercury vapor rectifier tube represents such an illuminant.

If the current density is increased by restricting the cross section of the tube, and the pressure and temperature of the vapor is permitted to increase, the spectrum becomes more nearly continuous, and the color approaches daylight in character. (Incandescent lights have an inherently continuous spectrum, and if hot enough, approach daylight in color.) The luminous efficiency of the mercury arc becomes very high: in a light developed by the General Electric Company about 23.6 per cent of the electrical energy is converted into visible light, as compared to but a few per cent for the ordinary incandescent light!

Nevertheless, considerable heat is concentrated in a small space within the lamp itself because of the small size of the arc stream, and water cooling is required to carry this heat away. This is a disadvantage, since water connections and protective circuits are required, so that portable spotlights are rather awkward to handle. On the other hand, an intense source of light (approaching a point source) of relatively small dimensions is obtained, and the radiated energy contains so little infra-red (about 6.1 per cent) *that the light is actually much cooler than noon sunlight.* This is of particularly great advantage to the performers.

In Fig. 4 is illustrated such a lamp, showing how it is hung from the ceiling of the studio. The water-pipe connections, as well as the flexible conduit for the copper wires, are clearly shown. The canopy attached to the ceiling has a motor in it to swivel the lamp below it in a horizontal plane through a full 360°. To raise or depress the beam through a full 180° another motor within the reflector swings the reflector about the arc sources, which remain stationary in a horizontal plane. Both motors are operated by remote push-buttons located on a lighting console, from which point the lamp can also be turned on or off.

The arcs operate on high voltage (840 volts) so that stepup transformers are required. These, however, are located remote from the studio in a noise-proof room, and high-voltage leads are run up to the studio ceiling and thence to the lamps.

Copper tubing is employed for the water supply, and approximately 1 $^1/_2$ gallons per minute are used per luminaire. Special electrical interlocks shut off the current if the water supply fails. It is to be noted that the water carries off approximately 55.6 per cent of the power supplied in the form of heat.

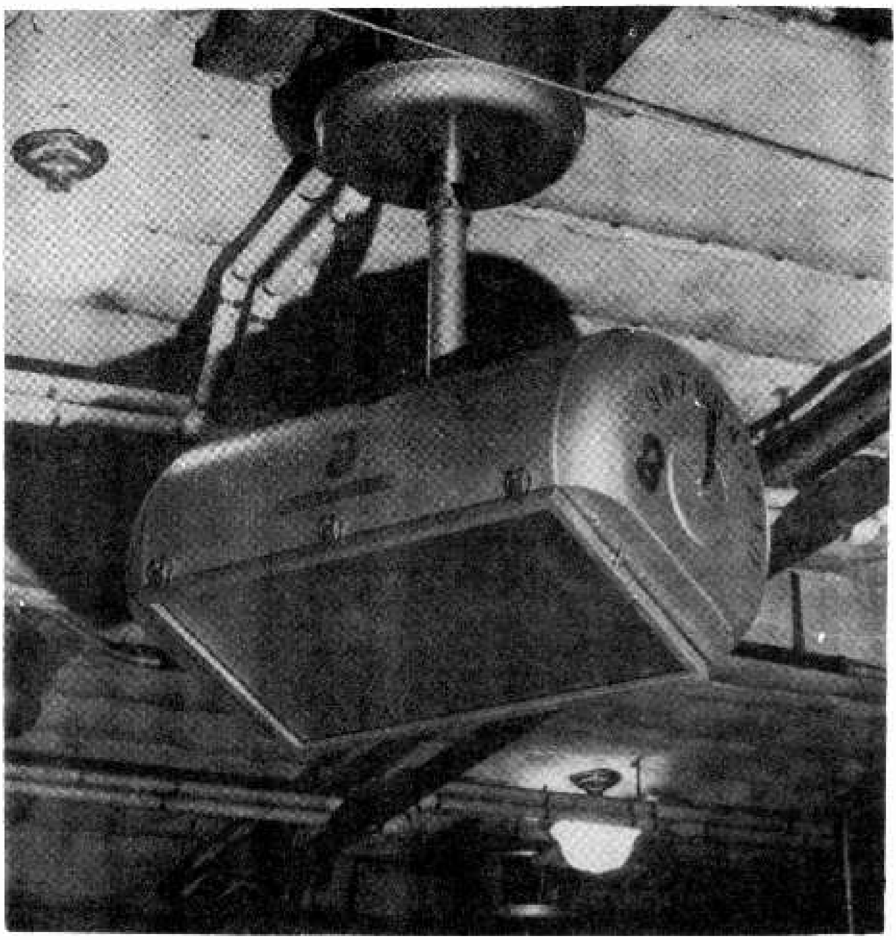


Fig. 4.—G.E. Television-Studio Luminaire, showing canopy and lamp reflector unit.

Like most gaseous discharge devices, the light is at any instant proportional to the current through the gas; for an a.c. supply, the light has a very noticeable and objectionable flicker. To obviate this, three tubes are employed in each unit, with each tube connected to a separate phase of a three-phase supply. They are arranged along a line representing the focal axis of the parabolic cylindrical reflector. In Fig. 5 are shown the three arc tubes, as well as the elevating motor for the reflector.

The reflectors are normally of aluminum, having a special treatment on their inner reflecting surface known as Alzak-finish. During the war polished chromeplated copper was employed as a substitute, and while the reflection coefficient was 18 per cent lower than that for the Alzak aluminum, the beam was more concentrated, so that the more distant luminaires could actually pour more light on the set than the softer (more-diffusing) beam of the aluminum reflector. The glass front of the lamp is made of Peblex diffusing glass, and is approximately 21 by 33 inches in size.

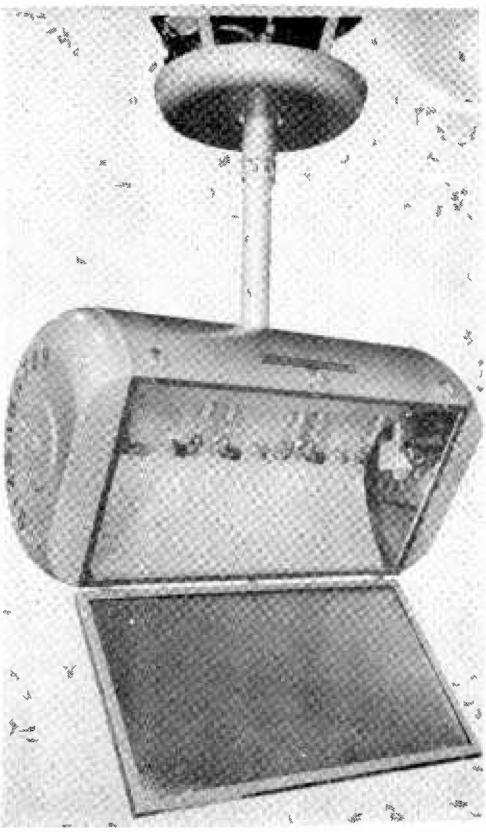


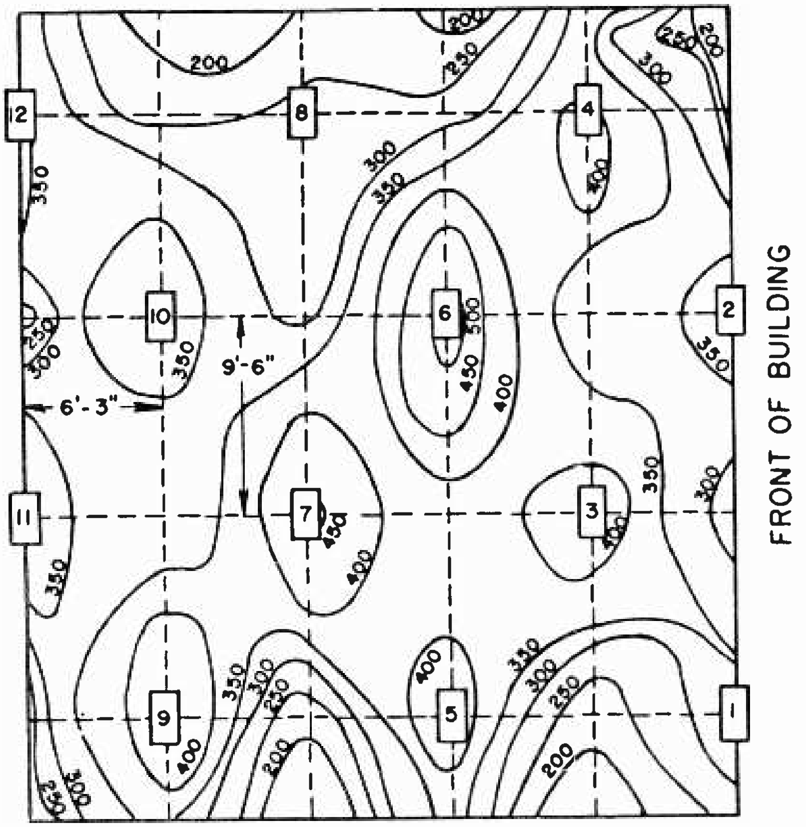
Fig. 5.—G.E. Luminaire with door open, showing three arc lights and elevating motor.

The electrical power required is 3,510 watts, corresponding to 1.4 amperes at 840 volts for each tube. The tube or bulb for each arc is made of clear quartz, of approximately 2 mm inside diameter, 6 mm outside diameter, and 25 mm long between electrode tips. The average life is about 75 hours, which is considerably less than that of an incandescent source.

The intensity of illumination from an actual lamp is not absolutely uniform, and is generally greater in the center of the beam. At a height of about 14 feet, 8 inches, a luminaire will illuminate an area of about 120 sq.ft. at an average intensity of 315 ft.-candles or lumens per sq.ft., but the intensity at the center of the beam will be as high as 500 ft.-candles and as low as possibly 200 ft.-candles at the edges of the illuminated area. This matter of light distribution will be discussed in more detail farther on in this assignment.

STUDIO LAYOUT AT STATION WRGB.—The layout of the lamps at Station WRGB of the General Electric Company is shown in Fig. 6. It will be observed that there are 12 of them spaced 9'6" along the long dimension of the reflector, and 6'3" along the short dimension. This provides for a flexibility in application to the lighting requirements of almost any scene contemplated. The loops and curves are isolux lines; they represent lines on the floor along which the intensity of illumination is that given by the number next to the line.

In actual use the lamps throw their light in a more nearly horizontal direction on the stage set rather than vertically downward as shown in the figure. It is found possible to build up the intensity over a 10-×15-×10-foot scene to 650 or more ft.-candles of general lighting with the upper portions of the scene reaching 1,000 ft.-candles. Supplementary floor lamps then build up the intensity of illumination to a higher level



(Courtesy Proc. of the I.R.E.)

Fig. 6.--Isolux chart of studio illumination. ☐ Type L-71 Novalux water-cooled floodlight with 3A-H6 Mazada lamps. Nominal input 3,500 watts.

Mounting height to light center 14 feet, 8 inches
Total lighting load 40 killowatts
Average illumination at floor level 315 foot-candles
Illuminated area approximately 1,500 square feet.
Lumens per watt per square foot of illuminated area 11.8
Average age of lamps at time of test 20.8 hours

necessary for good pictures.

TELEVISION LIGHTING TECHNIQUE

Television lighting technique, like microphone placement, is best learned by actual practice. However, certain general rules are available for guidance and will be given here. Practice of course varies with each company, and depends in great measure upon the artistic ideas of the director, much as in the case of motion picture work.

KEY AND MODELING LIGHT.—If the stage were illuminated uniformly, the result would be an uninteresting scene, flat and with little effect of depth. A certain amount of exaggeration in lighting is required even in an ordinary live talent stage presentation, and in the case of television and motion pictures, where the third dimension is lacking in the reproduced scene, the effect of depth has to be accentuated by the use of light and shade; in short—by the proper kind of lighting. Unfortunately, however, such exaggeration is rather limited in television owing to the limited contrast range of the system.

Fundamentally, two kinds of lighting are employed:

1. Foundation or key lighting. This is the general uniform illumination that acts as a foundation upon which additional spot lighting is superimposed. The intensity of key illumination may be anywhere from 650 to 1,000 ft.-candles for an iconoscope, and about 200 ft.-candles for an image orthicon.

2. Modeling lights. These are concentrated beams of light that add to the foundation lighting at certain desired points of the stage, in order to accentuate certain highlights or shadows. If possible, a 2 to 1 ratio of modeling light or better is used. If the key lighting is 650 ft.-candles, then the maximum illumination at points where modeling lights are employed will be 1,300 ft.-candles. It is of interest to note that as high as 2,500 ft.-candles have been used, although here the amount of modeling was small.

Modeling lights are generally spotlights. NBC in its Radio City studios seems to favor the Birdseye type of spot for foundation as well as modeling, since this gives more lumens per watt than the ordinary spot having a separate lamp, reflector and lens, or the standard incandescent light and exterior scoop. In one arrangement, called the single-six mounting, six 500-watt lamps are mounted in a line along a pipe, to which is screwed at the center a second pipe to form a tee (see Fig. 7), the whole then being suspended from the ceiling. The wattage consumption is 3 kw. In order to conserve space, the single-six unit is sometimes replaced by a double-three unit of equal illuminating capacity.

Where a reinforcing light, background flooding, or a general-purpose strip-light of minimum space is desired, a single-three unit is provided, as shown.

The double-three unit is also mounted on a stand and used as a floor board for modeling purposes. One unit illuminates the stage from the right and one from the left to furnish a rough modeling angle or to soften the shadows. The lights are often called upon during a presentation to make way for the cameras, and hence frequently are brought in and taken out several times during a single sequence.

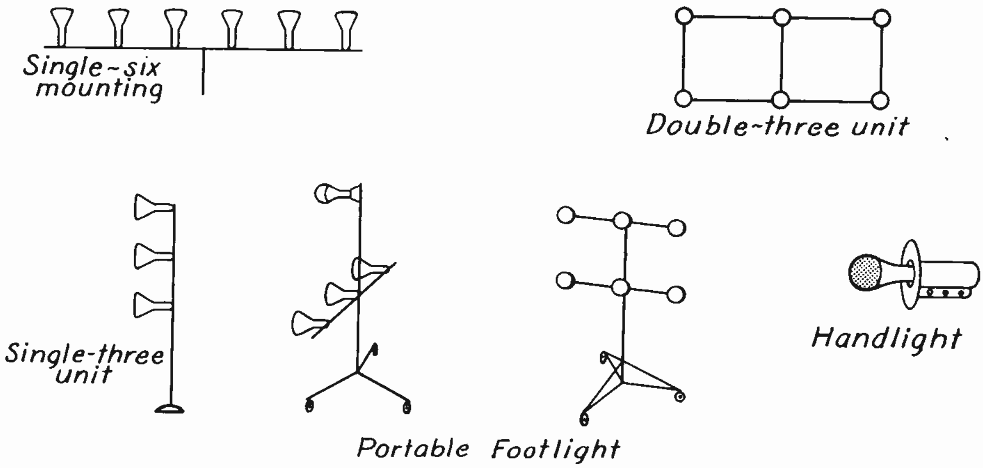


Fig. 7.--Modeling and Key lights.

Another modeling light is the portable footlight. This is a light, as shown in Fig. 7, that is mounted low on a small truck and operates just ahead of the close-up camera. It adds more light to the close-up in order to enhance the half-tone values of such a subject.

The hand light is used to reinforce the floor lights and can be used to build up the light to the contrast limit of the tube. It is normally used with the wide-angle camera either as a spotlight for highlights of great contrast or as a diffusing lamp for softer modeling purposes.

Finally, it is to be noted that very little painted scenery, particularly doors, windows, etc., are employed, particularly as regards the painting of highlights on such objects. This is because the cameras move around a good deal during a sequence, so that painted highlights for one viewing position will be incorrect for another viewing position. On the other hand, outdoor sequences in a play are very readily reproduced from film taken for that purpose.

EXAMPLES.—Several examples of studio lighting and camera setups will now be given. In Fig. 8 is shown a choral group being televised. The lights are situated overhead a little in front of the scene and about centered on it. Overhead lights close to the setup prevent the shadows from the cameras and microphone boom from being thrown across the floor into the studio scene itself. At the same time note the hand light at the extreme left, directly over the camera, used to furnish some modeling light.

It is also of interest to note how close to the scene the cameras and microphone boom are located. The microphone on the end of the boom is kept just above the area of the scene focused in the cameras.

The boom enables it to be moved from one part of the scene to another to pick up sounds from any part of the stage.

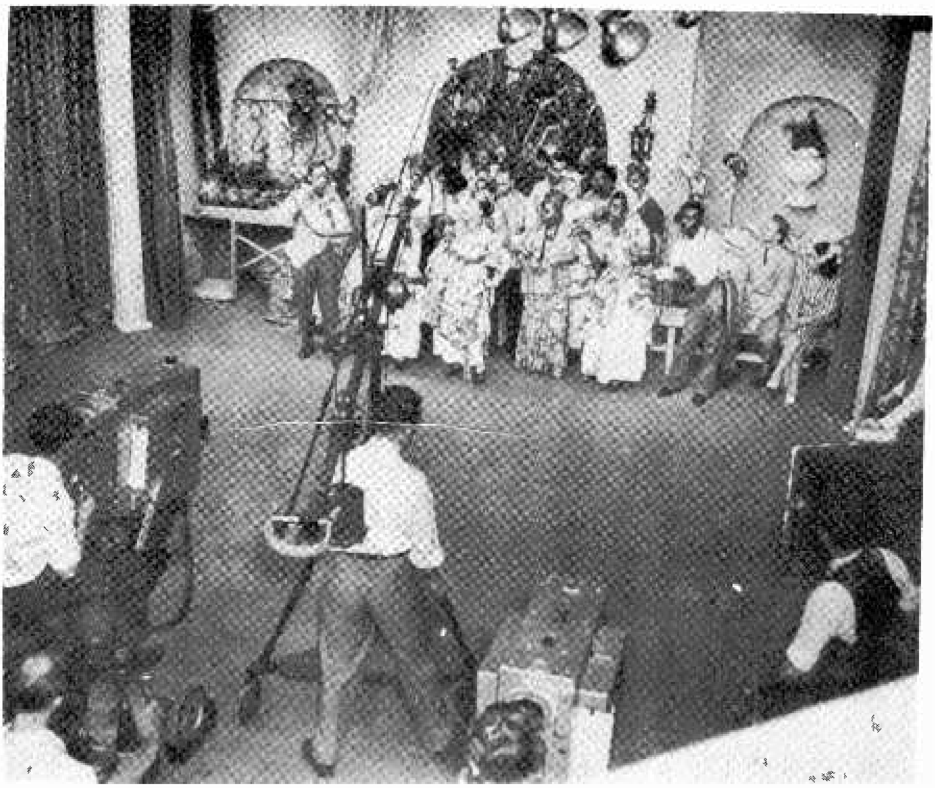


Fig. 8.--The Hall-Johnson Choir televised in the studio of NBC in Radio City.

In Fig. 9 is shown another type of scene. Here the acrobats, although only three in number, may operate—as shown—in a closely spaced group, or over the entire stage. The close-up camera must be able to follow the action quickly and accurately, although when the action is spread out, the wide-angle camera is employed to take in the entire scene.

Note the double-three spotlight employed to illuminate most strongly the group. At the same time pronounced shadows are to be avoided, particularly in this type of scene, as the shadows (at least in black-and-white television) can distract the audience markedly from the actors, themselves. The absence of pronounced shadows in Fig. 9 indicates the use of considerable overhead and cross lighting in this scene.

Fig. 10 shows the position of the camera and the multiple spotlight for a small compact scene. It shows a chef (Fred Benrath) featured in a series of programs by Station W6XYZ, located on the Paramount lot in Hollywood. Such a scene often requires close-ups of the dishes, etc., hence lighting is concentrated in a small area by means of the group of spotlights shown in the immediate foreground, close to the scene. For similar reasons, the camera is also very close to the performer; in this way all significant motions in such an intimate scene can readily be followed.

(Courtesy NBC)

Fig. 9.--Gymnastics are popular in television as well as in vaudeville. Owing to the rapid motion, special manipulations are required.

In Fig. 11 is shown the large number of lights employed in televising a piano and an organ. Note the placement of the overhead and floor lights, including the two horizontal single strip spotlights. In this scene it is particularly important to illuminate horizontal surfaces above the floor level, namely, the keyboards.

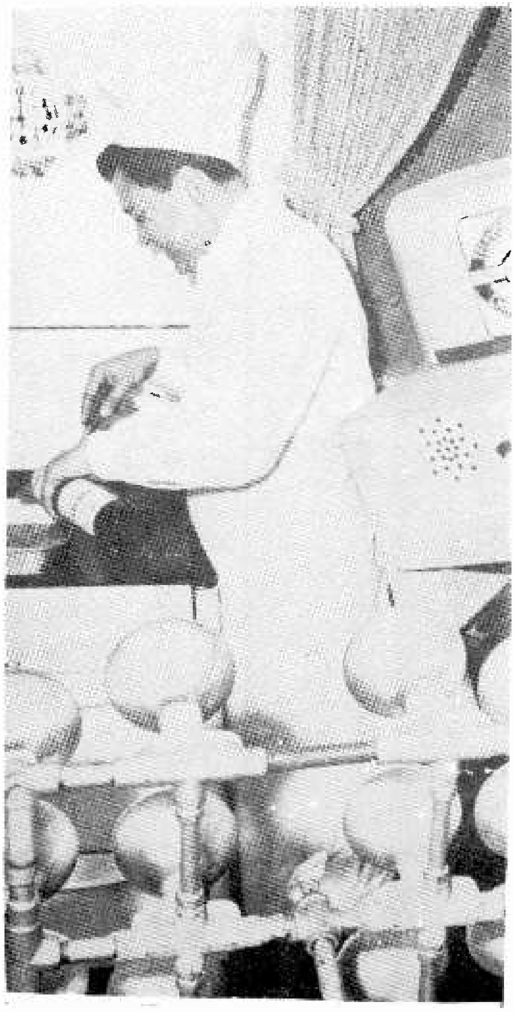


Fig. 10.--Lighting and camera placement for an intimate, compact scene.

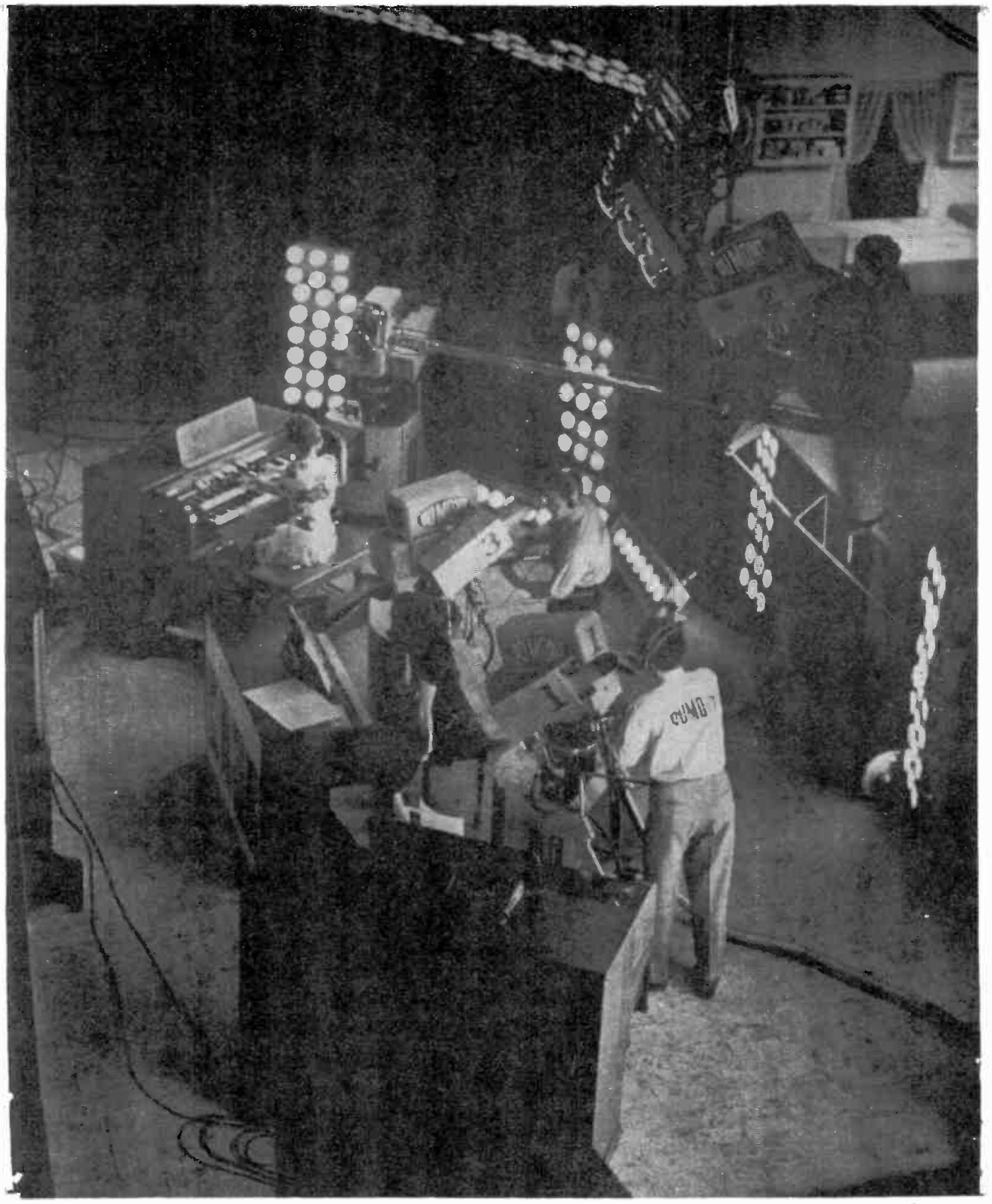


Fig. 11.--See and Hear: John Wanamaker department store effectively utilized the facilities of WABD, DuMont station in New York, to demonstrate its musical instruments. Here a battery of cameras are trained on a piano and organ during the Wanamaker commercial.

Fig. 12.--A camera on a dolly comes in for a closeup of the cast of "Blithe Spirit" televised over station WNBT, NBC's television station in New York.

Also note the use of three cameras: One for each instrument when it plays solo, and the center one capable of wide angle operation if both instruments play simultaneously.

There is every reason to believe that television plays will be as popular as radio plays are at present. In Fig. 12 is shown a scene from the play "Blithe Spirit". An important point to note here is that provision must be made for the camera to approach the scene for a closeup without the camera interfering with the lighting of the set.

The arrangement shown in Fig. 12 shows how this can be accomplished, and also makes it clear how much premilinary planning and arranging is necessary in order that a successful show will be put on the air.

The lighting on the hair indicates that considerable illumination is coming from overhead. This is for the benefit of the hands on the table, which are thereby accentuated in this scene depicting a spiritual seance.

Fig. 13.--Keeping Trim: James Davies, physical director of Parmount Pictures, shows two screen starlets how to keep that trim Hollywood figure during W6XYZ telecast from the Paramount lot in Movieland.

Fig. 13 shows another small group picture. Here the lighting is such as completely to subordinate the background and thus bring out the three figures in bold relief. One of the main functions of lighting is to guide and direct the spectator to those parts of the scene upon which it is desired to have him focus his attention; poor lighting arrangements can distract his attention from the main action.

OUTDOOR PICKUPS.—Outdoor pickups are in general more difficult because of the lack of control of the lighting in such cases. As an example, consider Fig. 14. Here the light clearly comes from the left, and from behind, as can be told by the highlights on the characters and the shadows. This makes it difficult to bring out the detail in the shaded portions of the scene, as in the face of the diver.

The Louis-Conn fight may well turn out to be the beginning of popular commercial television. Extremely favorable reports concerning the television reproduction of this event were given by all newspapers and commentators, and sports will undoubtedly be one of the major attractions of television. In the case of prizefights (which are almost invariably held at night) the ring is sufficiently well lighted to enable a satisfactory picture to be obtained by an orthicon picture tube.

However, with the advent of the image orthicon tube, the lighting will be more than sufficient for the purpose. In Fig. 15 is shown the setup employed in the Louis-Conn fight. The cameras were at a distance from the ring, but by the use of telephoto lenses, the action was made to appear as if it were a closeup. The telephoto

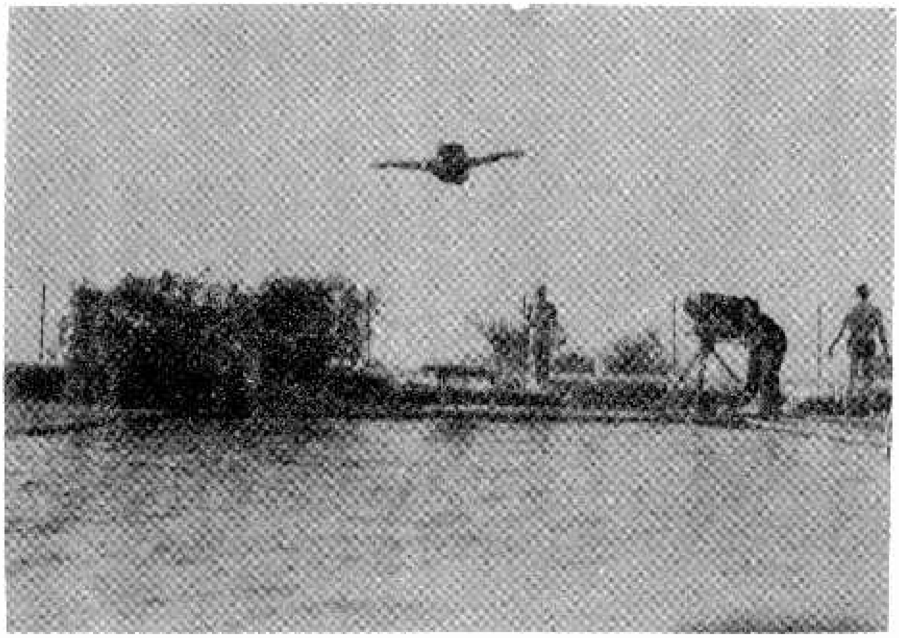
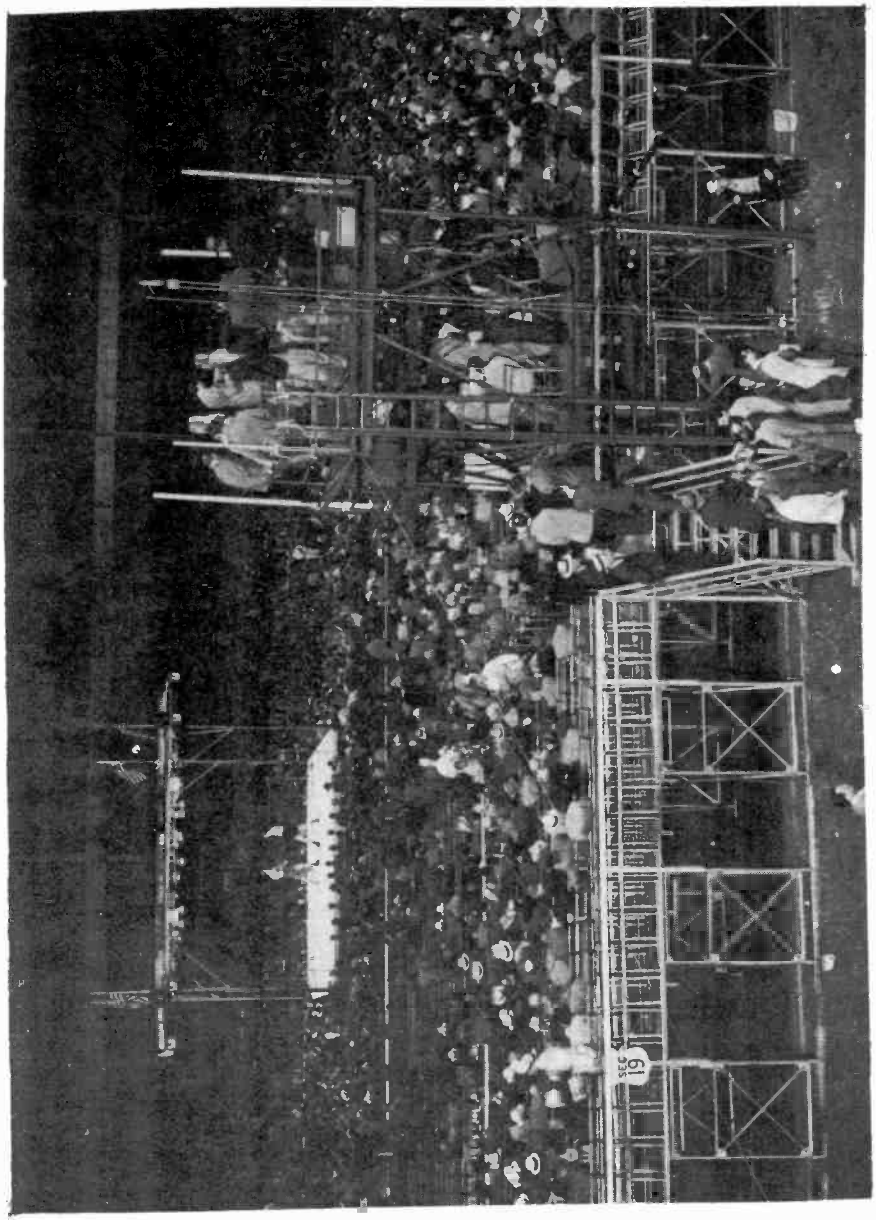


Fig. 14.--Diverse Action: Aquatic sports are a regular feature at the Don Lee Station, W6XAO. The reason: there's a swimming pool atop Mt. Lee, site of the Don Lee transmitter. These programs are great favorites of W6XAO viewers.



(Courtesy NBC)

Fig. 15.--Televising of Louis-Conn fight, showing distance between fight ring and camera stand, as well as lighting of ring.

lens is destined to play an important role in outdoor pickups, where the camera placement is often of necessity at a considerable distance from the scene to be televised. This lens is essentially a long focal length lens in action that nevertheless does not require a correspondingly long image distance. It does not therefore need to extend

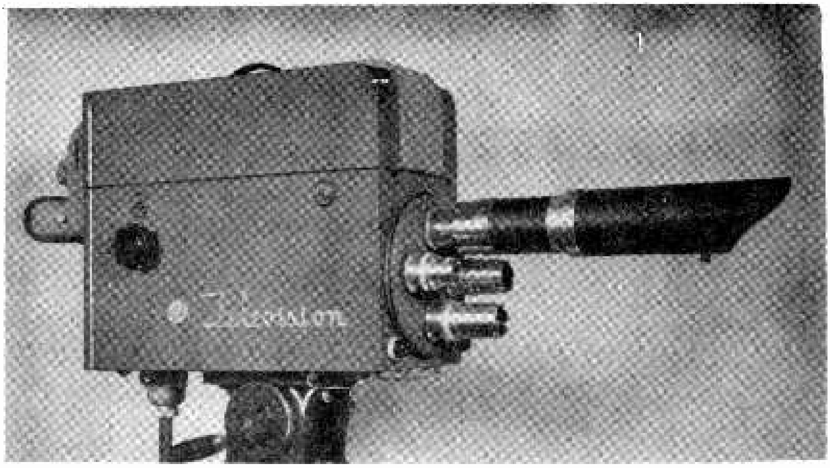


Fig. 16.--Focus on Sports: Pictured here is the RCA orthicon camera and 40-inch telephoto lens.

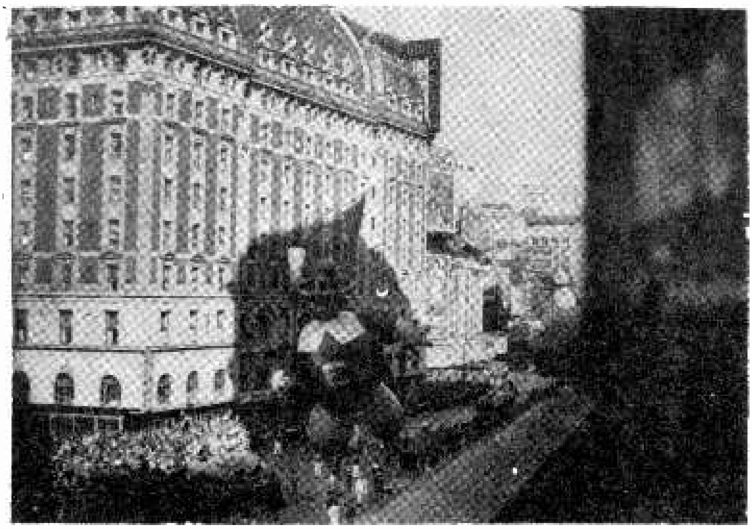


Fig. 17.--Great Day or the Kids: Televising of Macy's Thanksgiving Day parade up Broadway delighted thousands of youngsters who saw the spectacle via television. An NBC orthicon camera and parabolic microphone scan and listen to the gaiety.

beyond the camera box as far as an actual long-focal-length lens does, and yet gives the same large image of a distant scene that the latter does. A closer view of it is shown in Fig. 16.

Figs. 17 and 18 show two more outdoor scenes. In Fig. 17 the camera is placed on the roof of a building on the street where the parade is being held, and a microphone set in a parabolic reflector acts as a very directional pickup of the sounds toward which it is pointed. Difficulty in televising the street scene may be encountered because of the deep shadows cast there by the nearby high buildings.

In Fig. 18 is shown the televising of a football game. Owing to the wide sweep of action encountered, especially when the ball is kicked, exceptionally skillful handling of the camera is required.

One of the major difficulties in outdoor pickups, such as a football game, is the rapid variations in lighting that may occur as a cloud passes by. In the case of the image orthicon, large variations in light intensity do not render the tube temporarily inoperative, as is the case when an orthicon is employed. The latter has a tendency to momentarily lose the signal when a flashlight goes off, as will be explained in a later assignment.

The image orthicon has been found to be so sensitive, that in the twilight hours of a football

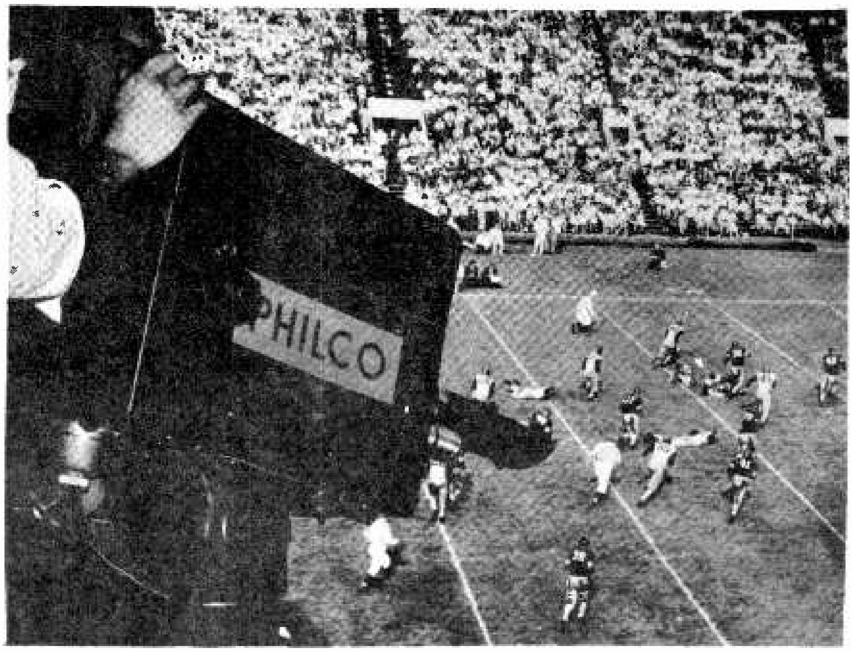


Fig. 18.--Up Stream Rutgers: Telecasts of football classics are highly popular with viewers. Philco camera, above, is shown here televising one of the grid contests at Franklin Field, Philadelphia. WPTZ has aired all of the U. of P. home games for many years.

game, the cameramen viewing the image in the view finder were not aware that the spectators were beginning to leave the stands because it was getting too dark to see the game.

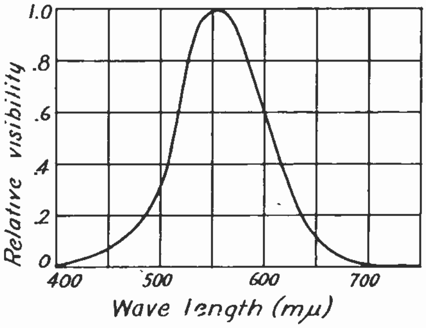
LIGHT UNITS AND MEASUREMENTS

Regardless of how much occasion the television lighting engineer will have to perform photometric measurements, it is essential that he have a working knowledge of light units and how they are employed in lighting measurements. Accordingly, the various units will now be explained, as well as how they are employed.

THE LUMEN.—The lumen is the basic unit of light; it is a measure of the energy radiated in the light frequency range, with suitable weighting applied to the measurement to take into account the variable sensitivity of the eye to the various frequencies (colors) of light. The radiation of light from a lamp is very similar to the radiation of radio waves from an antenna, but there is one important difference, and that is that the antenna radiates waves that are generally of one frequency, or of a narrow band of frequencies, whereas the usual light source radiates energy that covers a wide range of the spectrum.

Thus, an incandescent lamp radiates more infra-red energy (waves of frequency lower than those that can be perceived by the eye) than it does in the light range. Hence, the *total* radiation of the lamp gives no indication of its *luminous* efficiency. Even if only the luminous energy is measured, no true measure of the effectiveness of the lamp is obtained because the sensitivity of the eye varies markedly with the frequency of the light.

In Fig. 19 is shown the visibility curve of the eye. From the figure it is apparent that the eye is far more sensitive to green light (500 to 578 mμ*) than it is to violet (446 mμ) or red (650 mμ). For example, one watt of green light causes the same sensation as 10 watts of red light. To put it another way, for equal energy content, green light produces ten times as much luminous effect to the observer as red light.



(Courtesy Hardy & Perrin, "The Principles of Optics.")
Fig. 19.--Visibility curve of the eye.

The lumen is an attempt to measure the light energy (or rather power) with reference to the ability

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*The symbol mu represents the millimicron, which is 10^{-9} meter, or one-millionth of a millimeter in wave length. Another unit often used to measure the wave length of light is the Angstrom (A). This is one-tenth of the mμ; i.e., 1 mμ = 10A.

of this energy to affect the eye. Thus, one watt of green light at 555 mμ corresponds to 621 lumens; one watt of red light at 650 mμ corresponds to but 62.1 lumens.

One unfortunate complication that arises is that for some other light-detecting device, such as a photocell, the sensitivity curve may be different from that of the eye, whereupon the lumen rating (as determined by the eye's sensitivity) will not indicate the relative photo-cell currents that flow when different colors are flashed on it. However, since most light-detecting instruments are for the purpose of ultimately affecting the eye, the latter is ordinarily the best standard to employ in evaluating the luminous effect of a light source, and ordinarily other light-detecting instruments are designed so far as possible to have the same sensitivity curve as the eye, or else corrections must be applied to their readings.

The most common light employed is white light. This is a collection of light frequencies or colors in suitable proportions to produce the effect knows as white light. Where sources are reasonably white in character, their outputs can be compared directly on a lumen basis, without having to take into account that the energy content of the lumen varies with the color.

On the other hand, when the light picked up is that reflected from an illuminated scene, color can no longer be ignored. Specifically, in television, if the curve for the pickup tube differs markedly from that of the eye, the scene reproduced by it may appear quite different to the eye from the actual scene viewed directly. For example, the image orthicon is markedly sensitive to infra-red rays, whereas the eye cannot perceive these at all. Green leaves and grass reflect infra-red rays very strongly. As a result, the reproduced scene on the picture tube may show leaves and grass as nearly white, whereas they should appear much darker to correspond to their effect upon the eye when viewed directly. The reproduction of colors in the proper black-and-white half tones is a matter that has engaged the earnest attention of film and camera manufacturers long before television came into being.

CANDLEPOWER.—The fundamental purpose of a light source is to radiate light in all or in certain specified directions; the fundamental function of an object is to intercept some of the light and reflect it to the eye or other detector in order to be seen. It is therefore important to know how many lumens the source radiates in each and every direction, and how well the illuminated object reflects light, and in what directions.

Consider the light source first. Suppose it is a point source which radiates equally well in all directions. Then one can imagine a sphere drawn around it, as shown in Fig. 20(A), where S is the source. Consider an area A on this sphere, that is $1/4\pi$ of the total area of the sphere. The corners of this area can be joined to S to form a pyramid, as shown in (B). The opening at the vertex S represents a *space angle*, just as the opening between two intersecting lines forms an ordinary *plane angle*.

The above space angle is said

to have a magnitude of *one steradian*. Clearly there are 4π such steradians to the entire sphere.

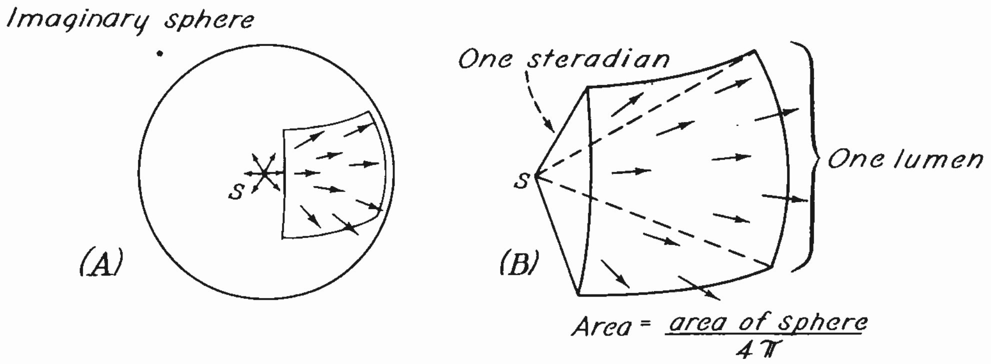


Fig. 20.--One lumen through one steradian represents an intensity of one candle.

The steradian corresponds to a radian in ordinary plane angle measurements, since a radian is the angle whose bounding arc is $1/2\pi$ part of the circumference of the circle.

If the source radiates one lumen through the above steradian, it is said to have an *intensity* of *one candlepower* in that general direction. If it radiates one lumen through every one of the 4π steradians surrounding it, it is said to have a uniform intensity of one candlepower in all directions. Thus, candlepower is a measure of the intensity or concentration of light from a source in a given direction; i.e., it is lumens *per* steradian. Of course, if the radiation from the source varies with direction, then a much smaller space angle than a steradian must be employed if a rough average value is to be avoided; theoretically, an infinitesimal space angle should be used, and the ratio of the infinitesimal number of lumens to the infinitesimal space angle through which they pass* must be taken in order to get the candlepower in the specific direction desired, rather than an average value over a range of directions.

Note that the radius of the sphere is immaterial since as one goes farther away from the source, the surface intercepted by one steradian increases at exactly the same rate as the lumens spread out, so that the ratio,—lumens per unit space angle or steradian—remains unchanged. This means that the candlepower of a source is independent of the distance, although the lumens it radiates on a surface *of fixed area* decreases as the distance of separation is increased.

The candle or candlepower is a more easily reproduced and a more easily measured quantity than

*It is to be noted that the ratio of two infinitesimals need not in itself be an infinitesimal, but can be a finite number. This is the basis of differential calculus. Thus, candlepower = dL/dw, where L is lumens and w is the space angle.

the lumen. This is because it indicates the number of lumens the source radiates in any given direction, and most intercepting surfaces are sufficiently small and at a sufficient distance from the source so as to involve essentially but one direction; i.e., most objects to be illuminated cover a very small area of the sphere on which they are located (with the source as center) and so require the intensity of the light, or its candlepower, on their area to be known rather than the total number of lumens radiated by the source in all directions.

The ordinary standard of light is the candle, and one form is a spermaceti candle of specified size and shape. Unfortunately, this standard is a rather poor one in that it is not very accurately reproducible, does not radiate equally in all directions (which would be a convenience) and has appreciable surface and hence is not a true point source

ILLUMINATION.—In spite of the fact that the candlepower is a convenient way of measuring and specifying a light source, the fundamental unit is the lumen. Thus, it is the number of lumens the source can throw on an object that determines how brightly the object is illuminated. This quality, illumination, or more accurately the intensity of illumination, is measured by the number of lumens the source throws on a *unit* area of the object, such as one square foot of surface. Illumination is therefore the number of lumens impinging upon a square foot or—in metric measurement—upon a square meter. There is no special unit employed to denote this measurement other than the ones just cited, except if the source can be regarded as a point source.

All sources have an appreciable area from which light is radiated. However, if the distance at which measurements are made is between ten and twenty times the maximum dimension of the source, the latter can be regarded as approximately a point source.

THE FOOT-CANDLE.—For a *point source* it is possible to correlate its candlepower with the illumination of the surface. If the surface to be illuminated has an area of one square foot, is one foot from a point source of one candlepower, and is perpendicular to the light rays, then the illumination may be defined as *one foot-candle.* It may also be defined by the previous expression, that is, one lumen per sq.ft. Thus, one foot-candle is equal to one lumen per sq.ft.

The reason is as follows. Consider the point source of light once again. Assume its intensity is 1 c.p. equally in all directions. This means it radiates 1 lumen through each steradian around it, so that it radiates a total of (4π steradians) (1 lumen) = 4π lumens. Now consider a sphere of one foot radius drawn about the source. The area of this sphere is $4\pi(1)^2 = 4\pi$ sq.ft. On these 4π sq.ft. fall 4π lumens, or 1 lumen per sq.ft. Thus, the illumination is 1 lumen per sq.ft., and it is seen that one ft.-candle is the same as 1 lumen per sq.ft.

INVERSE SQUARE LAW.—Suppose now that a sphere of twice the radius, or 2 feet, is drawn about the source. The same 4π lumens pass through this surface (assuming no absorption in the intervening medium). Since the surface of this 2-foot sphere is *four* times that of the one-foot sphere, the number of lumens falling on a square foot of the larger sphere is clearly one-quarter as great; i.e., the illumination is only 1/4 lumen per sq.ft. or 1/4 foot-candle.

This shows that the illumination E varies inversely as the square of the distance of a surface *from a point source.* Expressed in formula form:

$$E = I/d^2 \qquad (1)$$

where E is the illumination in lumens per sq.ft. or in foot-candles; I is the candlepower of the source, and d is the distance in feet from the source to the surface.

As a simple example, suppose a point source of 500 c.p. illuminates a surface 10 feet distant. By Eq. (1) the illumination is

$$E = 500/(10)^2 = 5 \text{ lumens/sq.ft.}$$

or

5 ft.-candles

However, to find the *total* number of lumens falling on the surface, its area must be known. Suppose the area is 2 sq.ft. Then the total flux is 2 × 5 = 10 lumens. Note that E is independent of the area of the surface, since it represents the *concentration* of the light flux on the surface, i.e., so many lumens *per sq.ft.* Also note that E is the number of lumens falling upon a square foot of an illuminated surface, regardless of whether the source of light is a point or not.

BRIGHTNESS.—The purpose in illuminating a surface is to permit it to reflect light in a manner that reveals the nature of the surface. This means that different portions of the surface, by reflecting the light to different degrees, permit the different areas to be distinguished by reason of their difference in contrast. (Of course light sources themselves can be distinguished from one another, too, by the difference in light that they emit.)

It is therefore necessary to have a measure of the amount of light emitted by each elementary area of a surface in order to evaluate the degree of contrast between the various areas. Such a measure is called brightness. It involves fundamentally three quantities: lumens, area, and direction. Brightness is measured by the number of lumens emitted by a unit area *in some specified direction.*

It was shown previously that candlepower is the intensity of light in some specified direction, and is expressed as so many lumens per steradian, where the space angle indicates the specified direction. Hence, brightness may be expressed as the candlepower per unit area of emitting surface by substituting *candlepower for lumens in a specified direction.*

From this viewpoint brightness measures the concentration of candlepower over a surface, where candlepower itself is a measure of the concentration of light in a given direction. Physically, the significance is as follows: A candle and a flashlight bulb may each radiate one lumen per steradian in a certain direction. Each therefore has an intensity of one candlepower.

The brightness may be vastly different. The area of the candle flame may be .002 sq.ft.; that of the flashlight filament may be .00002 sq.ft. The brightness of the candle in the given direction will be 1/.002 = 500 candles/sq.ft., whereas that of the bulb will be 1/.00002 = 50,000 candles/sq.ft. Note, however, that each will illuminate a given area at a given distance to the same extent; i.e., each will flood the area with the same number of lumens. But the flashlight bulb will appear far brighter to the eye or similar pickup device.

The reason is that the flashlight filament has the smaller area, and is therefore imaged by the lens of the eye on fewer nerve endings in the retina. This is shown in

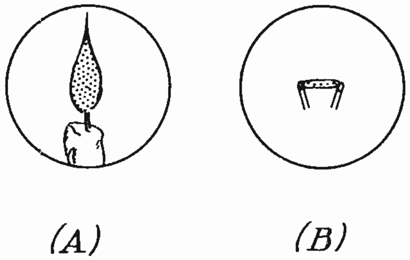


Fig. 21.--The difference in area on the retina on which the light source is imaged determines the difference in brightness.

Fig. 21. In (A) is shown the candle flame imaged on the retina of the eye; in (B) is shown the image of the flashlight filament. The black dots represent nerve endings in the image area; it is clear from the figure that fewer nerve endings are affected by the flashlight filament image.

The number of lumens passing through the lens of the eye is the *same* in either case, hence, the fewer nerve endings in (B) receive a far stronger stimulus (far more lumens) and the light is said to be very bright, even though the bulb does not illuminate the room any more strongly than does the candle.

An important practical conclusion may be drawn from this example. If it is desired to illuminate a room, it is immaterial whether the light source is of small or large area, so long as it radiates the required number of lumens in the desired directions; i.e., so long as it has the desired candle-power pattern. But so far as direct viewing of the light source is concerned, the larger area source is more desirable in that it produces less glare in the eye. Hence, covering the concentrated source with a frosted bulb or with a shade so as to produce a secondary source of greater area and lesser brightness is desirable.

On the other hand, where the difference in brightness of adjacent areas is important, as in distinguishing the details in an object, the maximum difference in brightness is desirable, providing of course that the maximum brightness encountered does not overload the detecting device, such as the eye. This means that the maximum alibity to resolve detail in the case of the eye, or the maximum peak-to-peak amplitude in the electrical signal in the case of a television pickup tube, is obtained when the brightness of the object varies through a maximum extent from one area of the object to the next.

Specifically, in the case of a television pickup tube, a certain minimum amount of light is required by the studio scene from the light source. This is necessary to produce sufficient light on the photosensitive surface to produce a high signal-to-noise ratio, especially in the darker portions of the picture. Then, in order to obtain a strong variation in the signal, i.e., a strong a.c. (video) component, the illuminated object should have sufficient variation in reflecting ability from one portion of its surface to the next, to produce sufficient variation in brightness over its surface.

This also explains the use of key and modeling lights, in studio lighting procedure. Key lighting provides the base for adequate signal-to-noise ratio in the camera's output. Modeling lights, by being concentrated on certain specific areas, further increase the peak-to-peak amplitude of the output signal; they artificially increase the variation in brightness that occurs from the natural or inherent difference in reflecting ability of the various portions of the illuminated surface. In addition, modeling lights create certain changes in the output signal wave-shape that are desirable for artistic reasons as well as signal-to-noise ratio considerations.

Lambert

LAMBERT'S LAW.—The sequence of relations between the intensity of the illuminant (candlepower), the illumination (lumens per square foot or foot-candles), and the brightness of the illuminated surface (candlepower per square foot) require one further factor to be explained before they can be correlated. This factor is the relation between the number of lumens impinging upon the illuminated surface and the number of lumens reflected from it; i.e., the relation between illumination E and brightness B.

Clearly B must depend upon E and upon the coefficient of reflection R. Offhand it might appear that if R is 0.5 for example, then if E is 20 lumens per sq.ft., B should be 20 × .5 = 10 lumens per sq.ft. However, the result is obviously incorrect in that the direction—as denoted by so many lumens per steradian, is absent in the above numerical result. In other words, in order to obtain B from E, it is necessary to know more than just R; not only must the coefficient of reflection be known, but also the amount of reflection *in each direction of space.*

Suppose, therefore, that the above surface not only reflects 50 per cent of the light, but also reflects it equally in all directions. It might then appear that the brightness, whatever its numerical value will turn out to be, will be the same in all directions. However, this assumption will be incorrect, too. The reason can best be understood with reference to Fig. 22.

In (A) is shown a reflecting surface ab, viewed at a sufficiently great distance so that practically all rays from it to the eye are parallel and normal (perpendicular) to the surface. For such normal viewing each dimension of the surface, such as ab, appears of normal size. On the other hand, suppose the surface is viewed at an angle α to the normal as shown in (B). In this case the dimension ab will appear foreshortened to the length cb, and the area will appear correspondingly diminished.

This common effect is noted more strikingly in the case of motion pictures. If the screen be viewed from an extreme side seat in the theatre, the characters appear very thin and hence relatively elongated. Another example is the foreshortening in the apparent height of buildings when viewed at an extreme vertical angle from an airplane.

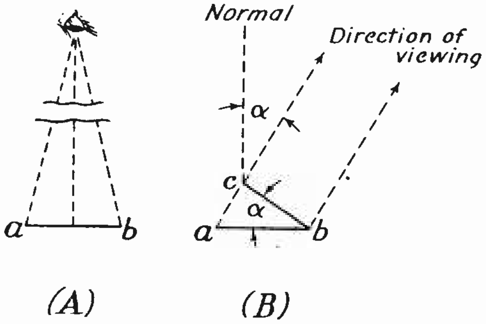


Fig. 22.--Brightness may depend upon the angle at which the surface is viewed.

If the area of the surface appears smaller, then the brightness will appear correspondingly greater, since brightness is candlepower/sq.ft. Thus, if the surface reflects the same number of lumens in all directions, the brightness will appear greater when the surface is viewed from an angle than when viewed from the normal. The increase so far as reduction in area is concerned is readily derived from an inspection of Fig. 22. Thus, the decrease in area is in proportion to the decrease in cb as compared to ab. From the figure it is clear that

$$cb = ab \cos \alpha$$

so that the brightness (depending *inversely* as the area) will be increased by the factor $1/\cos \alpha$.

A large number of surfaces, however, appear to have the same brightness regardless of the angle at which they are viewed. This sheet of paper, for example, appears to be equally bright whether viewed from the normal direction or at a considerable angle to the normal. Evidently, the lumens reflected at various angles must diminish by precisely the same factor, cos α, as the area, so that the ratio or brightness remains unchanged. (This must clearly apply only to diffusely reflecting surfaces. Specular surfaces produce the directional type of reflection mentioned in a previous assignment.

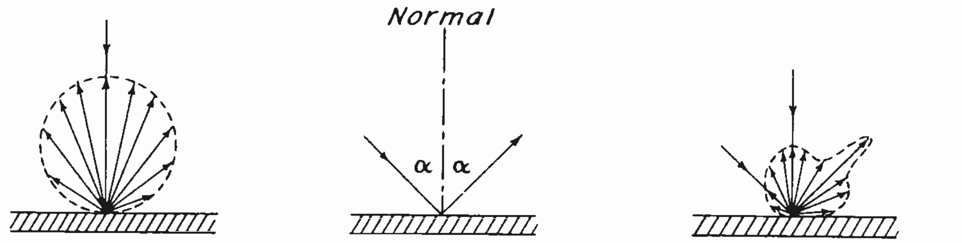
Surfaces which reflect the light in such manner that the *intensity* (candlepower) varies as the cosine of the angle from the normal are said to obey Lambert's cosine law. Such surfaces are also said to be *matte* or truly diffuse; Lambert's law therefore defines a diffusely reflecting surface more exactly: not only does the surface scatter light in all directions, but the intensity of the scattered light varies as the cosine of the angle from the normal.

X Lambert

A specular surface reflects light at the same angle to the normal as the impinging light. Thus, the intensity in this direction is equal to the incident intensity multiplied by the coefficient of reflection, and the intensity in other directions is zero. What is then observed is *not the brightness of the illuminated* *surface*, but rather *the brightness of the source itself;* i.e., a truly specular surface is not seen, but instead produces a virtual image of the source. A specular surface is sometimes called a *glossy surface*.

Some surfaces exhibit partially specular and partially diffuse reflection. This means that the reflected light can be broken up into two components: one that follows Lambert's cosine law, and another that follows the law of specular reflection. An example is a varnished wooden surface. Light reflected directly from the surface of the varnish is specular in nature; light that penetrates the varnish and is diffusely reflected from the wood surface underneath has approximately a cosine law distribution.

Such surfaces are often called semi-matte. It is clear that in a studio set each type of surface may be encountered, although matte and semi-matte surfaces are more common than specular surfaces. The nature of these surfaces is illustrated in Fig. 23. For clarity, the reflection of but one ray is shown in each case. The dotted curves show the polar distribution of the reflected light intensity. Note particularly the circular (cosine) distribution for the matte surface, and the peaked distribution for the semi-matte surface. This distribution is independent of color considerations; it refers to the manner in which the light is reflected rather than to what frequencies (colors) of light are reflected.



Matte surface *Specular surface* *Semi-matte surface*

Fig. 23.--Illustration of matte, specular, and semi-matte surface.

GENERALIZATION OF ILLUMINATION FORMULA.—It will be necessary at this point to generalize the illumination formula given previously. This was

$$E = I/d^2 \qquad (1)$$

It assumed that the intensity I was *normal* to the surface d units from it, as indicated in Fig. 24(A). If, however, the light source is at an angle α to the normal, then the same number of lumens tend to cover a greater surface. Thus in (A) the surface covered is ab, whereas in (B) it is ac. From the figure it is clear that

$$ab = ac \cos \alpha$$

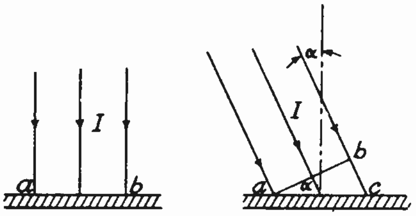
or

$$ac = ab/\cos \alpha$$

If the area covered is greater, then E, the number of lumens per sq.ft., will be correspondingly less, so that Eq. (1) must be changed to

$$E = (I/d^2)\cos\alpha \qquad (2)$$

If $\alpha = 0$ (light normal to surface), $\cos\alpha = 1$, and Eq. (2) reduces to Eq. (1), its more special form. An application of this cosine relationship will appear farther on in this assignment.



(A) (B)

Fig. 24.--The illumination E decreases as the source slants more and more to the surface.

THE FOOT LAMBERT.—In the case of a truly matte surface that obeys Lambert's law, it is possible to express its brightness very simply, since its brightness is the same in all directions. If each square foot of a surface emits or reflects one lumen with a cosine distribution, then the surface is said to have a brightness of one *foot-lambert*. Note the important feature of the foot-lambert; it is a brightness measure that refers directly to the lumens emitted or reflected, rather than to the intensity of the light, that is, lumens per steradian or candlepower. This is because the directional characteristic upon which the intensity depends is implied in the cosine distribution; only for such (matte) surfaces does the foot-lambert have any real significance, even though the brightness of semi-matte surfaces, for example, may be measured in this unit.

The value of the foot-lambert is that where a matte surface is involved, its brightness can be very simply expressed in terms of the incident illumination E and the reflection coefficient R. The relation is simply:

$$B = ER \qquad (3)$$

For example, if the reflection coefficient is 70 per cent, and the incident illumination is 20 lumens per sq.ft., the brightness is 20 × .7 = 14 ft.-lamberts. A question that naturally arises at this point is, "How does the ft.-lambert compare with the other unit for brightness, namely the candlepower per sq.ft.?" The answer is that

$$\text{ft. lamberts} = \pi \times \text{cp per sq.ft.} \qquad (4)^*$$

Hence, the above value of 14 ft.-lamberts corresponds to $14/\pi = 4.46$ candles/sq.ft.

In the metric system the *lambert* is employed instead of the ft.-lambert. It corresponds to the emission or reflection in a cosine distribution of 1 lumen per sq.cm. Since the square centimeter is much smaller than the square foot, the lambert is correspondingly much larger than the ft.-lambert. As a result, the milli-lambert is often employed; this is one-thousandth of the lambert. The conversion factor between lamberts and ft.-lamberts depends upon the relation between the square centimeter and

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*The proof of this involves the integral calculus, and can be found in any standard text on light, such as Hardy and Perrin, "Principles of Optics", page 272-273, McGraw-Hill Book Co.

the square foot. Since

1 sq.cm. = 0.001075 sq.ft.

it follows that

1 ft.-lambert = 0.001075 lambert (5)

However, in this country and in England, the ft.-lambert is used in ordinary light calculations and measurements.

ILLUSTRATIVE EXAMPLE.—It will now be of value to correlate the concepts of candlepower, illumination, and brightness by means of a simple problem.

As an example, suppose a light illuminates a matte surface in the direction shown in Fig. 25. The candlepower of the source *in the direction shown* is 100 cp. Usually the source is pointed in the direction of the surface to be illuminated because its candlepower normal to its own emitting surface is a maximum, especially if a reflector is placed behind it so as to direct the maximum amount of light in that direction.

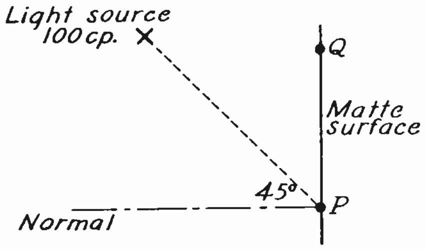


Fig. 25.--Use of the lambert and foot-lambert in calculating the brightness of a matte surface.

It is desired to find the brightness of the matte surface at point P, for which the angle with the normal is 45°. For some other point Q the angle will be different, and the candlepower of the source may also be different in that direction. However, if the source is sufficiently far away, or the surface is not too large, such variations in directions will be small, so that the variations in brightness from one point of the surface to the next will also be small.

Returning to the point P, we may assume that an ordinary source of light at a distance of 15 feet may safely be regarded as essentially a point source. Indeed, this was implied when it was stated that the source was one of 100 cp instead of 200 cp per sq.ft. *brightness*, or some other such value. With the assumption that the source is approximately a point, the intensity of illumination at P can be readily calculated by Eq. (2). It is

$$E = [100/(15)^2] \cos 45^\circ$$
$$= 0.314 \text{ lumens/sq.ft.}$$

Next assume that the surface has a reflection coefficient of 0.9. Then the number of lumens reflected per sq.ft. is

$$0.314 \times .9 = 0.283 \text{ lumens/sq.ft.}$$

From the definition of the foot-lambert, it is recognized at once that the brightness of the matte surface at P is simply 0.283 foot-lamberts.

Suppose it is desired to calculate the brightness in lamberts. From Eq. (5),

$$0.283 \times .001075 = 0.000304 \text{ lambert}$$

In terms of candlepower per

sq.ft., the reflected brightness of 0.283 ft.-lamberts corresponds to $0.283/\pi = 0.09$ candles/sq.ft., by Eq. (4). It will be further instructive to compare the above value of reflected brightness with a possible value of brightness of the emitting source. Suppose the source shown in Fig. 25 has an area of 0.5 sq.ft. as projected in the direction shown. This area may be that of a ground-glass disc placed in front of the lamp filament so as to act as a secondary source of light. The brightness of the source is then simply

$$B = 100/0.5 = 200 \text{ candles/sq.ft.}$$

This is $200/0.09 = 2,222$ times as bright as the illuminated surface. Since the reflection coefficient of the latter is 90 per cent, it may seem strange that the efficiency of illumination is apparently very low. The fallacy is in assuming that brightness and total energy radiated are the same.

A moment's reflection will show that this is not so. If the ground glass had been 0.25 sq.ft. instead of 0.5 sq.ft. in area, the brightness would have been 400 instead of 200 candles/sq.ft., *yet the total light emitted would have been the same,* and the light intensity in the direction of the scene would still have been 200 cp.

This matter has been stressed previously: the brightness of the source and that of the illuminated scene have no direct relation. A small very bright source may furnish the same illumination on the scene as a large and less bright source; source brightness in itself is of no consequence so far as illumination is concerned; it is only of practical consequence in determining the size and volume occupied by the source, and also in many cases as to how well it may be focused by a reflector or condenser lens system into a narrow beam.

From a mathematical viewpoint the brightness of the source is of value only in permitting the candlepower to be computed *if the area of the source is also known.* From the same viewpoint, the candlepower of the source is of value only in permitting the illumination on the object to be computed by the inverse-square law, *if the source can be regarded as a point.* The illumination then permits the brightness of the illuminated surface to be computed very simply if the coefficient of reflection is known and if the surface obeys Lambert's law; i.e., if it is a matte surface.

On the other hand, the reflected brightness of the surface is important because the surface is imaged on the photo-sensitive cathode of the pickup tube as a corresponding surface, and determines the lumens falling on each unit area of the photo-cathode. This in turn determines the photo-emission from such an area. *If the source itself were being televised,* then similarly its brightness would be important.

LIGHT METERS.—Owing to the approximations involved in any light calculations, the results require to be checked by actual measurements. The discussion that follows considers a typical light meter and how it is employed: specifically, just what it measures. Present-day instruments usually incorporate photo-electric devices, and do not depend upon the eye as a measuring or comparing device. A typical instrument is illustrated in Fig. 26.

The photo-electric device consists of a copper disc oxidized on one side to form a film of cuprous oxide. Over this film is a very thin and transparent metallic film. When light shines through this transparent film onto the copper oxide layer, it liberates electrons into the copper which then flow around through the galvanometer and transparent film back into the cuprous oxide to complete the circuit.

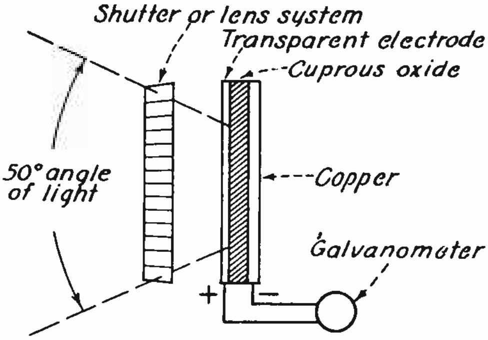


Fig. 26.—Copper-oxide type of light meter.

It will be observed that no polarizing voltage is required as in the case of a photo-tube; as a result, the instrument is very compact. In the smaller types built as exposure meters for photographic camera use, the photo-electric unit and the meter are built into one casing; in the larger and more expensive types the meter is a large, separate unit that connects to the photo-electric unit through a sufficiently long flexible cable. This permits the photo-electric unit to be moved around more readily in order to explore any part of the scene.

The current developed depends upon the amount of *lumens* falling upon the photo-surface. Generally what is desired to be measured is the brightness of the scene, or else the intensity of illumination falling upon the scene. If the latter is to be measured, then the photo-surface is placed at any part of the scene, *but facing the light source*, so that its area picks up the lumens radiated to that region; therefore, the reading is proportional to the incident illumination, and is calibrated either in lumens per square foot (or inch) or more often in foot-candles.

However, what is desired to be read is really the *brightness of the illuminated scene*. Hence, the photo-surface *should face the scene* rather than the light source. But here a new complication enters, and that is that the reading will depend ordinarily not only on the brightness of the scene but also upon the distance of the photo-surface from the scene. An obvious error will occur if the photo-surface is so close to the scene as to block the area to be measured from the light source.

The variation in reading with distance is obviated in a very simple manner. A series of shutters or a series of little lens-like surfaces molded into a transparent plastic cover fitting over the photo-surface is employed. The shutter arrangement is shown in Fig. 26. By either method light from only a certain angular span can get to the photo-surface. The angle of view is normally made 50° to correspond to that of a photographic objective.

The action can then be understood with reference to Fig. 27.

The scene is taken as a surface S. Two positions for the meter are shown, M_1 and M_2. Position M_2 is made twice the distance from S as M_1. It will be observed that for a constant angle of view θ, position M_1 collects light from area A_1; position M_2 collects light from area A_2. From the geometry of the figure, A_2 is four times A_1, since the areas are proportional to the square of the distance.

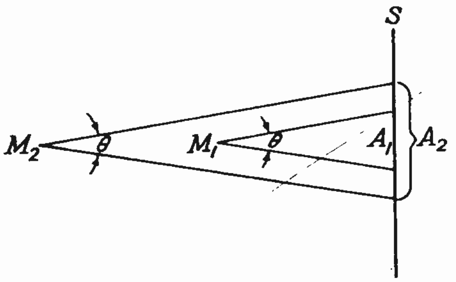


Fig. 27.--**Showing how the exposure meter can read brightness independent of the distance from the scene.**

However, the number of lumens picked up varies *inversely as the square of the distance* from S, *and directly as the area and brightness of pickup.* The two factors of area and distance consequently exactly balance one another, so that the reading depends only upon the brightness of the surface. It is possible, however, for the readings for the two positions to be different. This is because the readings really are those of the *average* brightness of the area viewed. If the brightness varies over the scene, as it certainly must for a picture of any entertainment value, then the brightness reading for area A_2 may be quite different from that for A_1.

Indeed, if the meter is moved sufficiently far back to pick up light from all parts of the scene, then *the average brightness of the entire scene* will be measured. On the other hand, if the meter is moved up close to the scene, then the average brightness of a small area of the scene will be measured; i.e., essentially the brightness of an element of the scene will be measured. If the meter be moved horizontally across the scene at any desired height, and close to it, then it will produce a reading that varies in a manner similar to the signal produced in the pickup tube when the beam scans that particular line of the target or mosaic, as the case may be.

It is thus evident that the meter can give an indication not only of the average brightness of the scene, but also of the variation in brightness from point to point of the scene, depending upon its distance from the scene, and so, by an intelligent use of the meter, a great deal of information can be obtained. However, in ordinary television studio measurements, it is sufficient to know the intensity of *incident* illumination. Thus, the light meter normally faces the light sources, and reads the lumens per sq.ft. falling on the scene at that point. For such purposes no shutters are needed in front of the photo-sensitive surface; it is exposed directly to the light sources.

LIGHTING CALCULATIONS

GENERAL CONSIDERATIONS.—Studio

lighting calculations resolve themselves into evaluating the number of lighting units of a specified type, required to flood the scene with the requisite number of lumens per sq.ft.; in short—to obtaining the necessary intensity of illumination. What the scene does with the light, how it reflects or absorbs it, is not the immediate concern of the key or foundation lights. These have merely to flood the set uniformly with a specified intensity: 800 to 1,000 ft.-candles for an iconoscope, and about 200 ft.-candles for an image orthicon.

After the foundation lighting is provided, modeling lights are employed as demanded by the particular set and artistic considerations. The picture on the monitor tube is the final arbiter; if a part of the scene appears too dark because the materials there are too highly absorbing of light, auxiliary spots are employed to brighten up this part of the scene.

Small scenes, such as test patterns, titles, etc., present no particular problem since they require but few lamps. Here the effectiveness of placement of the lamps is not so important since the electrical load is relatively small. Large sets, on the other hand, require a large number of lamps, and the beam characteristics of these, and even their placement, are important if the electrical system is not to be overloaded.

Accordingly, an analysis of the requirements of a large scene will be made here. Suppose the set is 15' × 8' in extent, and E = 800 ft.-candles. Then the total number of lumens required will be

$$L = 15 \times 8 \times 800 = 96{,}000 \text{ lumens}$$

Since the number of lumens determines the number of electrical watts, with due account being taken of the wastage of lumens on other parts of the studio, it is clear that the greater the scene area, the greater is the electrical power required.

Actually the scene has depth as well as frontal area, and the greater the depth, the greater the number of lumens required. However, in a deep set, appreciable light will be reflected from one part of the set upon another part, thus reducing the total amount of incident light required, just as acoustic reverberation in an auditorium increases the loudness of sound. This factor will be ignored in the lighting calculations; to compensate, the depth of the studio set will be likewise ignored.

The frontal area of a fairly large set was given as 15' × 8'. Since the aspect ratio of the picture is 4:3, a scene 15 feet wide should have a height of 15 × 3/4 = 11 $^1/_4$ feet instead of 8 feet. However, since most scenes have to do with human performers whose activities are limited to a height of 6 feet or less, it is in general unnecessary to illuminate more than a height of 8 feet.

Similarly, large sets are seldom televised across their entire width; a stage 25 feet wide will require possibly 15 feet to be intensely illuminated at any one time. Sometimes, however, as many as four scenes are set up simultaneously on the stage, which—in the case of the NBC Radio City television studio—has a useful width of 32 to 35 feet. If a break in the form of a closeup of some item is available between scenes, then the lights can be swiveled rapidly from one scene to the next. If no breaks are available, then all scenes, or at least adjacent scenes, must be illuminated to full intensity simultaneously. It is not advisable to swing the lights from scene to the next while the first is being televised because the moving shadows produced are very noticeable on the television screen. In such a case, possibly 25 to 30 feet of scene will have to be illuminated simultaneously and uniformly. However, calculations will be made here for a set having a frontal area of 15' × 8'; it is this area that will be regarded as requiring maximum illumination.

BEAM CHARACTERISTICS.—An ordinary room surrounds its source of light, hence the latter preferably illuminates equally well all around, and at most a reflector is employed above the lamp to direct the light downward, since the ceiling requires little illumination. A stage, motion picture, or television set, on the other hand, is illuminated from the front only (with some occasional and special back lighting), hence the sources of light should be much more directional in order not to waste light (lumens) on the surrounding studio walls, floor and ceiling. It is therefore important to know the directional characteristics of the light source.

Measurements were made in the CREI laboratory on a 300-watt internally silvered lamp of the Birdseye type. The procedure is illustrated in Fig. 28. The lamp L is set up at one point in a darkened room, and a circle of suitable radius, with the lamp as the center, is drawn on the floor. (The radius used was 8 feet, but any other value can be used.) The circle is marked off in 5° angles; only about 35° to 40° to each side of the 0° mark is necessary, as the lamp concentrates the light into a very narrow beam.

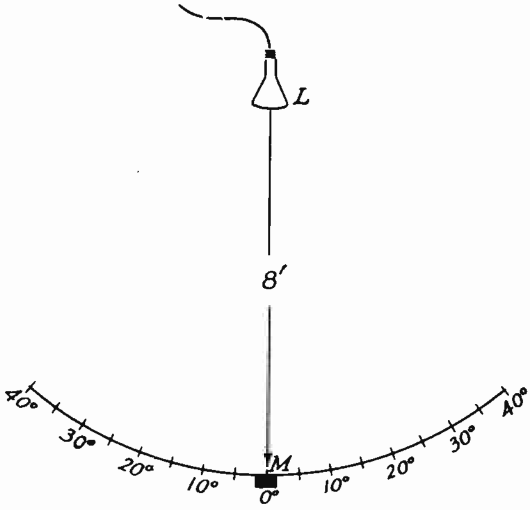


Fig. 28.--Test setup to measure illumination from 300-watt spotlight.

A light meter M is then set up at each of these angular positions, and the readings noted. A simple but rough means is to set it up on a stool at the same height as the lamp. The meter is rotated slightly through various angles until a position is found on the stool for which the meter reads a maximum. This means that the photo-sensitive surface is then normal to the radius of the circle; i.e., it is then facing the lamp. This process is repeated at each angular position along the circle.

The meter used was a Model 614 Weston foot-candle meter. This instrument does not have a series of shutters in front of its photosensitive surface, hence it does not read brightness, but rather the lumens falling on its surface. Since the surface is of fixed area, the reading is consequently proportional to the lumens per its area, that is, to the *intensity of illumination*, E. In short, the meter scale can be calibrated to read lumens per sq.ft., or the alternative unit of foot-candles, as is actually the case.

The readings have been plotted in polar coordinates in Fig. 29. These are averaged for various positions of the lamp filament, as its orientation will cause some variation in reading, and in actual practice the position of the filament will depend upon the particular socket into which it is screwed. One precaution that should to taken is to clean carefully the front surface of the lamp before performing the test.

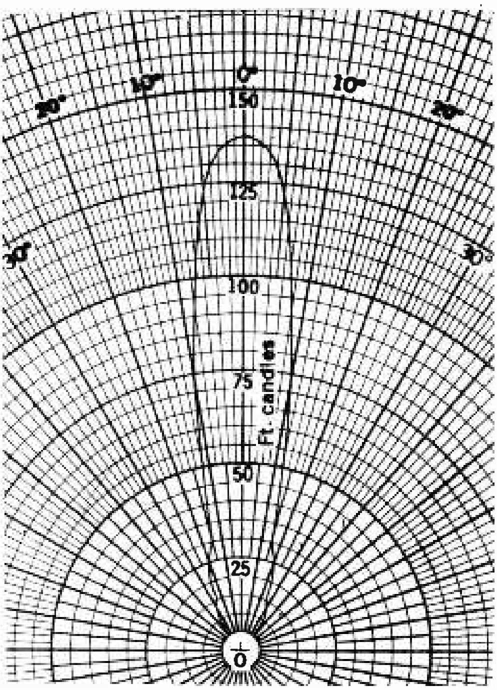


Fig. 29.--Polar distribution of intensity of illumination for a 300-watt internally silvered spotlight.

It will be observed from Fig. 29 that the beam is fairly constant over about 10° of arc, namely, from 137 ft.-candles at the center to 123 ft.-candles 5° to either side. Beyond this the illumination falls off rather sharply. The circular area that will be illuminated reasonably uniformly at a given distance can be calculated approximately in a very simple manner, as shown in Fig. 30. Thus, assuming a 5° spread for the uniform portion of the beam, the radius x of the circular area of a scene illuminated is, by trigonometry,

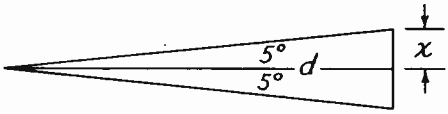


Fig. 30.--Approximate geometry involved for small beam angles.

$$x = d \tan 5^\circ = .0875d \qquad (6)$$

For a distance d = 8 feet, the radius is therefore,

$$x = (.0875)(8) = 0.7 \text{ foot}$$

DISCUSSION OF BEAM CHARACTER-

ISTICS.—However, it must not be construed that the number of lumens radiated beyond the 5° angle all around the axis is necessarily small just because the intensity of illumination in such directions is low. For greater angular spreads the *amount of area* illuminated is much larger than for the 5° cone of rays, so that even if the intensity E (= lumens per sq.ft.) is low, the total number of lumens radiated, which is the product of E by the area, may be large.

Calculations for the beam shown in Fig. 29 show that within a 20° angular spread, 1,215 lumens are radiated, whereas the total number of lumens radiated is more than 2,500 lumens. Thus, even if the lamp is placed sufficiently close to the scene so that the latter subtends an angle of 20° at the lamp (Fig. 31), less than 50 per cent of the total number of lumens radiated are used.

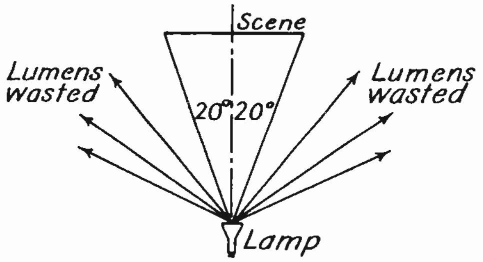


Fig. 31.--Lumens wasted by not being captured by the scene area.

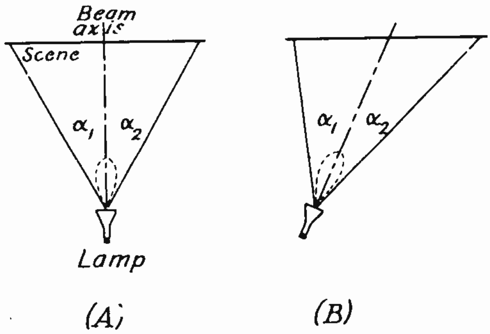
Even if the lamp is moved very close to the scene, the subtended angle is not increased very much owing to the tangent relation given in Eq. (6), as is also clear from the geometry involved in Fig. 31. Moreover, the increase in lumens captured by the scene proceeds very slowly as the lamp is moved closer to the scene if the beam intensity falls off rapidly with the angle from the beam axis.

Thus, although less than 50 per cent of the total lumens is used, little advantage is gained by moving the lamp very close to the scene, and the practical disadvantages of the lamps blocking the cameras is apparent. Hence, a very narrow beam is desirable to permit the lamps to be located sufficiently far away from the scene, and preferably above it, in order to facilitate camera and microphone manipulations. The ideal beam would drop to zero beyond a certain angular spread; for actual beams the above loss must be accepted.

Another conclusion that may be drawn is that so long as the peak portion of the beam falls on the scene, and the total subtended angle is the same, the position of the lamp with respect to the scene is of secondary importance. To make this clearer, consider Fig. 32. In (A) the axis of the beam is perpendicular to the scene area, and the left-hand subtended angle α_1, equals the right-hand subtended angle α_2. (The polar characteristic is shown in dotted lines.)

In (B) the beam axis is inclined to the scene surface, and α_1 is greater than α_2, and the left-hand rays are therefore more nearly normal to the surface as well as closer to it. As a result, the intensity of illumination of the left-hand side of the scene will be greater than that of the right-hand side, but if $\alpha_1 = \alpha_2$ is about the same in either case, the total number of lumens falling on the scene will be about the same.

So far as uniformity of illumination is concerned, neither arrangement fulfills this requirement. Thus, additional lamps will be required to provide this feature. However, since no one spotlight is sufficient for the intensity required anyway, the use of additional spotlights is indicated in any event. The important practical point is that the location of the lamps is not critical; so long as the scene intercepts as much of their light as is practicable (which means somewhat less than 50 per cent), various positions and orientations can be employed as may be required by other practical considerations.



(A) (B)

Fig. 32.--**The position of the lamp is of secondary importance if the peak of the beam strikes the scene.**

ILLUMINATION OF A FLAT SURFACE.—Since the lamp placement is not critical, any arrangement can be employed to enable the required number of lighting units to be calculated. An arrangement that simplifies the calculations is that in which the lamps are displaced at suitable distances from one another, so that their beams overlap on the scene in order to build up the intensity in between the peaks of the individual beams to a uniform value.

Since the polar characteristic of Fig. 29 refers to the pickup along a circle of which the light source is the center, and since the actual scene is assumed to be a flat surface, corrections must be applied to the measured readings in order to make them applicable to the actual flat scene.

The nature of this correction will be apparent from Fig. 33. Owing to the geometric properties of a circle, all radii or rays, such as OA and OC, are perpendicular to its circumference and are of equal length. The readings that are represented by the polar diagram are for these two conditions.

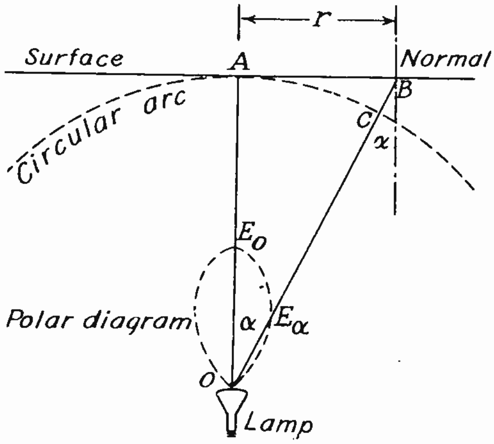


Fig. 33.--**Geometry of light rays on a flat surface.**

The flat surface, on the other hand, can be perpendicular to but one ray from the lamp. Assume this is the axial ray OA. Then a ray at angle α makes an angle α with the normal to the surface at B, and moreover, distance OB exceeds OA by CB; from geometrical considerations $OB = OA/\cos \alpha$.

Since the intensity of illumination varies *inversely* as the *square* of the distance, the intensity E'_α observed at B should equal $E_\alpha \cos^2\alpha$ where E_α is measured at C on the circular arc. However, since OB is at an angle α to the surface, an additional factor of $\cos\alpha$ enters as per Eq. (2), hence finally,

$$E'_\alpha = E_\alpha \cos^3\alpha \tag{7}$$

The distance r of point B from A, can be found as per Eq. (6), namely:

$$r = OA \tan\alpha \tag{8}$$

It is therefore possible to calculate the intensity of illumination on the flat surface owing to the beam characteristic measured. All that it is necessary to do is to multiply the measured intensity at any angle by the cosine cubed of the angle; the distance on the surface from the point at which the axial beam strikes is then found by multiplying the axial distance by the tangent of the angle. This has been done for the 300-watt lamp assumed 8 feet from the flat surface, and the computations are shown in Table I.

Then E'_α is plotted versus r, the distance along the surface, in Fig. 34 (curve A). It will be observed that the intensity falls off rapidly with distance r from the point where the axial ray strikes the surface; this is a result of the beam characteristic of Fig. 29 as further modified by the $\cos^3\alpha$ relationship.

An important point to note about curve A is that at 3 feet on either side of the beam axis the intensity has fallen to a low value from its maximum of 137 ft.-candles. At 16 feet distance, the corresponding value of r is doubled, or 6 feet on either side of the beam axis, and the intensity is *one-fourth*, so that the peak intensity is 137/4 = 34 ft.-candles, approximately.

The corresponding angle is about 20° to either side of the axis; as was mentioned previously, this means that about half the total number of lumens will be captured by the scene, or about 1,215 lumens fall within a circle of 3-foot radius on the scene. If the scene is wider than 6 feet, more lumens will be captured, but since the intensity will be variable over the scene, additional lamps suitably placed will be required to make the intensity more uniform, as well as to increase it owing to the overlapping of the beams.

SPACING OF LAMPS.—Curve A of Fig. 34 shows that the illumination will fall rapidly as one moves away from the point where the beam axis strikes the scene. At a distance of 1.4 feet, the intensity has dropped to about 68.5 ft.-candles, or to half of the peak value of 137 ft.-candles. Accordingly, if another lamp is placed 2 × 1.4' = 2.8' from the first, the overlapping beams will build up the intensity to 137 ft.-candles. However, the overlap is sufficiently great to cause the individual peak values to go up to 156.5 ft.-candles.

Moreover, intermediate points have a resultant intensity determined by the shapes of the individual lamp curves. The actual intensity curve for the two lamps is represented by curve B. The center portion is by no means constant: its maximum value is 156.5 ft.-candles; its minimum value in this range is 131 ft.-candles; and the average intensity is around 143 ft.-candles (for a lamp-to-scene distance of 8 feet).

Nevertheless, over a screen distance of about 4.3 feet, the intensity is fairly constant at 143 ft.-candles, and then falls off quite sharply. This means that the resultant beam for two lamps

TABLE I

α	COS α	COS$^3\alpha$	E_α	E'_α	TAN α	r
1°	1.000	1.000	137	137	.0175	.14
2	.999	.997	136.9	136.4	.0349	.279
3	.999	.997	134.9	134.4	.0524	.419
4	.998	.994	129.8	129.0	.0699	.559
5	.996	.988	122.5	121.1	.0875	.700
6	.995	.985	110.5	109.4	.1051	.841
7	.993	.980	99.3	97.3	.1228	.982
8	.990	.970	89.1	86.4	.1405	1.124
9	.988	.965	77.2	74.5	.1584	1.267
10	.985	.956	70.9	67.8	.1763	1.410
11	.982	.946	54.0	51.1	.1944	1.555
12	.978	.935	48.9	45.7	.213	1.704
13	.974	.924	41.9	38.8	.231	1.848
14	.970	.911	34.0	31.0	.249	1.992
15	.966	.900	29.0	26.1	.268	2.14
20	.940	.831	18.8	15.6	.364	2.91
25	.906	.743	19.03	10.42	.466	3.73
30	.866	.650	11.25	7.31	.577	4.62
35	.819	.550	8.68	4.77	.700	5.60

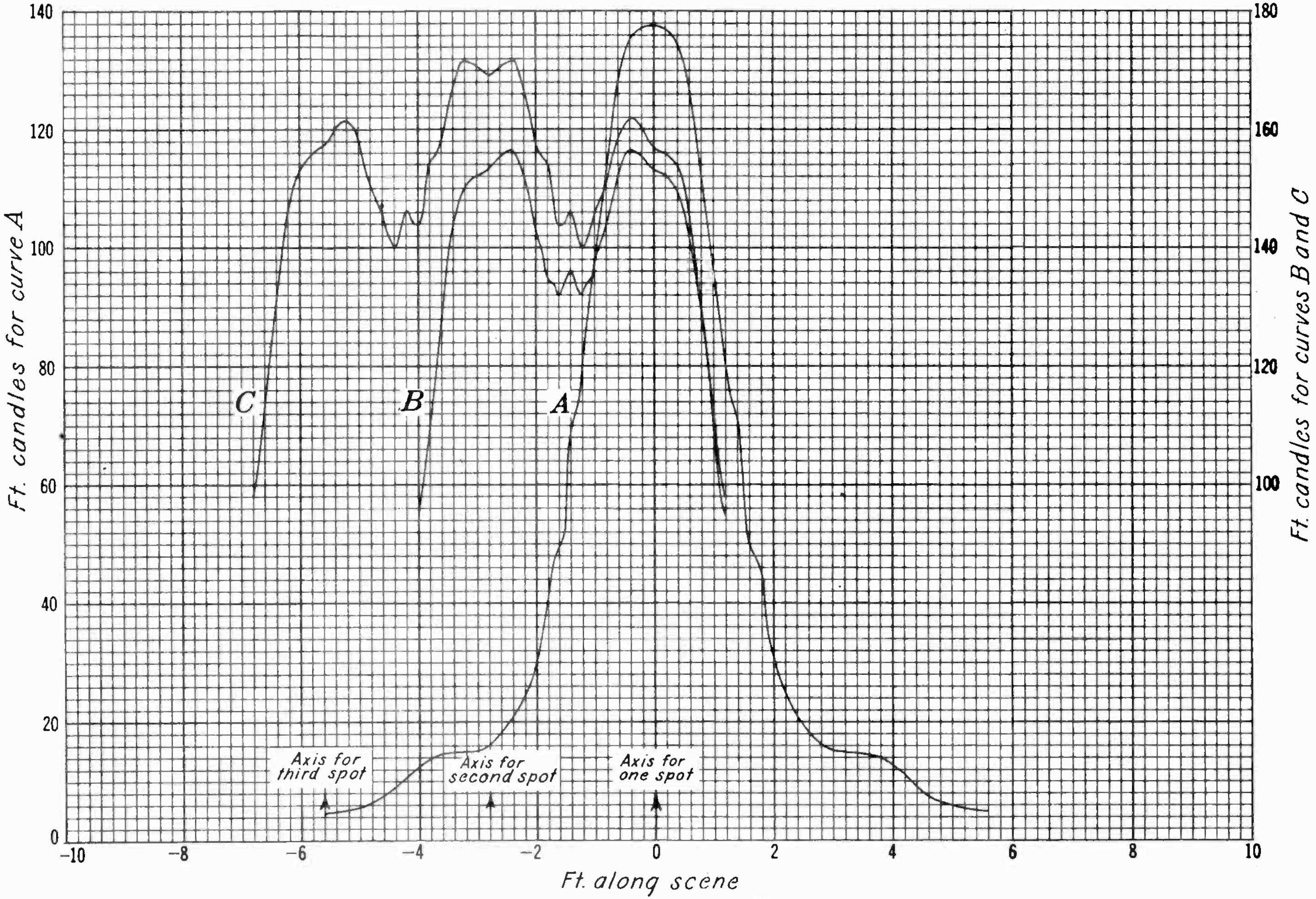


Fig. 34.--300-watt spot illuminated at 8' on line along scene.

approaches the ideal beam more closely than does the beam for an individual lamp; it may be expected therefore that the lumens wasted off the scene will be less, *on a percentage basis*, than that for one lamp alone.

For a 16 foot distance, the average intensity is

$$E = (143)(8/16)^2$$

$$= 36 \text{ ft.-candles (approximately)}$$

and the distance covered is

$$r = 4.3 \times (16/8) = 8.6 \text{ feet}$$

It is necessary to double the lamp spacing from 2.8 to 5.6 feet to preserve the geometry of the arrangement.

When 3 lamps are employed at spacings of 2.8 feet and at a distance of 8 feet from the surface, curve c is obtained. The intensity is even more uniform over the top portion on a percentage basis: from 171.6 to 139.2 ft.-candles, or an average value of about 155 ft.-candles, and the distance covered is 7 feet. At 16 feet the average value of E is 155/4 = 39 ft.-candles approximately, and the distance covered is 2 × 7 = 14 feet.

CALCULATION OF NUMBER OF LAMPS REQUIRED.—It is now possible to calculate the number of lamps required. Suppose a scene 15 × 8 feet is to be illuminated to an intensity of 800 ft.-candles for foundation or key lighting, and that the lamps are 16 feet distant from the scene. From the foregoing graphs it has been found that two lamps cover a distance of 2 × 4.3 = 8.6 feet, which is slightly greater than the height dimension, and three lamps cover 14 feet. Thus, six lamps, arranged as shown in Fig. 35, will cover an area of 14 × 8.6 = 120 sq.ft., approximately.

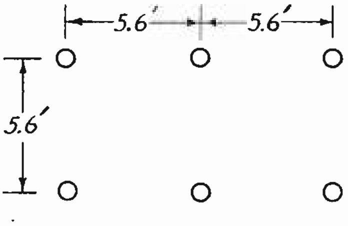


Fig. 35.--Arrangement of lamps to cover an area of 120 sq.ft.

The average illumination of any two lamps along the height will be approximately 36 ft.-candles, but the presence of neighboring lamps in the back will raise this value up to close to 39 ft.-candles, the average value for three lamps in a row. In short, about 39 ft.-candles can be expected as an average illumination over the 120 sq.ft. of scene.

For the scene 15 × 8 = 120 sq.ft., or of equal area but slightly different dimensions, the six lamps can be expected to furnish the same 39 ft.-candles of average intensity of illumination by a slight variation in spacing. The required value is 800 ft.-candles, hence

$$\frac{800}{39} \times 6 = 123 \text{ lamps}$$

will be required.

This requires 123 × 0.3 = 36.9 kw of electrical power. As stated previously, any reasonable placement of these 123 lamps will afford about the same amount of illumination. Thus, one bank spaced as per Fig. 35 may be placed with respect to the scene in a certain position; another similar bank may be placed slightly staggered with respect to the first so as to fill in the hollows in the intensity distribution produced by the first, and so on until all 123 lamps are employed.

Another arrangement, employed by NBC in their original Radio City studio, is to use six 500-watt lamps in a bank, with their sockets spaced about 10 inches from one another. The beams are all parallel, and produce a certain overall beam. About twenty such banks are used at a maximum, and by swiveling the individual banks, any part of the scene can be built up to the desired intensity. The overall beam of the 120 lamps can be arranged to be fairly flat on top. with sharply sloping sides, so that it approaches the ideal beam shape in form.

With regard to the previous calculation, how much power will be required for a scene 25 feet by 10 feet? The area is 250 sq.ft., hence by simple proportion the number of lamps required will be

$$\frac{250}{120} \times 123 = 256 \text{ lamps total}$$

and the power requirement will be

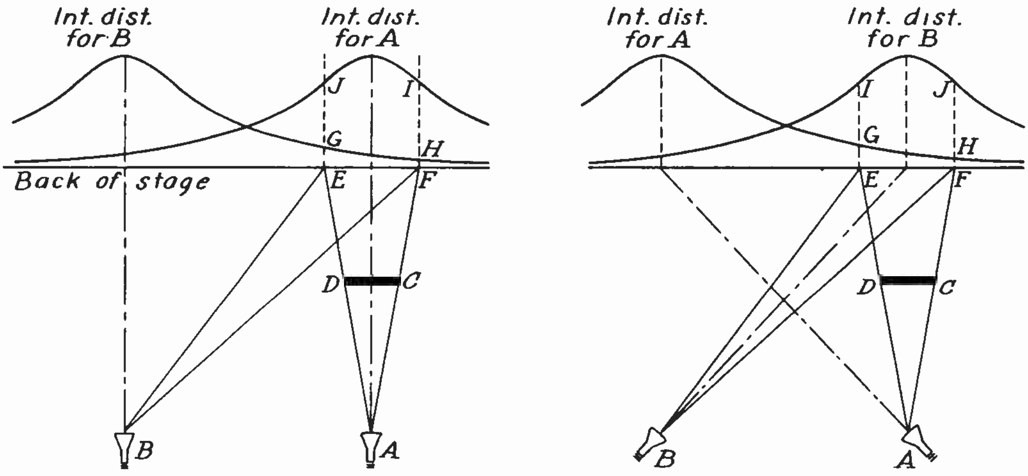
$$256 \times 0.3 = 76.8 \text{ kw}$$

PLACEMENT OF LAMPS.—It has been mentioned that the placement of the lamps is not critical so far as obtaining the maximum number of lumens, uniformly distributed on the scene, is concerned. It is therefore possible to arrange the lamps so as to obtain other practical advantages, such as the elimination of strong shadows. This will be made clearer by reference to Fig. 36.

In (A) the lamps A and B are shown spaced, with their beam axes normal to the stage. A performer or piece of stage scenery DC casts a shadow EF on the back of the stage with respect to illumination from A. Thus, the intensity EJ at E is blocked by edge D; the intensity FI at F is blocked by edge C, and no light from A over the portion of the curve J to I therefore falls on the portion of the rear wall EF. However, some light comes from B, but at this angle to the axis of B, the intensity is only from EG to FH in value, and far less than the intensities ranging from EJ to FI that have been blocked off.

In (B) the two beams are shown crossed. Now the obstacle DC blocks off the range of intensities GE to HF from A, but the higher intensities from EI to FJ from B cover the distance EF of the rear wall, so that the reduction in intensity of illumination and hence the degree of shadow is greatly reduced over that in (A). Nevertheless, the number of lumens received by the scene area is about the same in either case, as was previously demonstrated in Fig. 32; the placement of the lamps is not critical in this respect, and can therefore be varied to eliminate strong shadows. The interested student can also check the reduction in degree of shadow produced by DC with respect to lamp B when the beams are crossed.

It is to be stressed that any sensible arrangement of the lighting fixtures will provide an efficient utilization of the lumens radiated. It is not necessary to work out the lamp placement and orientation on paper; if sufficient lumens have been provided, then experimental manipulation is sufficient to provide the required amount of uniform illumination, and a light meter can be used to check the result.



(A) (B)

Fig. 36.--Method of reducing shadows by crossing beams.

Finally—as mentioned previously—the picture on the monitor tube will reveal any further adjustments that are required.

MODELING LIGHTS.—It was stated previously that modeling lights are arranged according to the artistic demands of the program director or other such personage. It will be of value to note some uses for these lights at the present time. In the NBC studio in Radio City, for example, three 300-watt Birdseye-type lamps are used in a large scene, on the floor, to take out face shadows below the chin, and six 300-watt lamps overhead are used as top-lighting, to enhance the hair and attire of the female performers, particularly in a model show. This amounts to 2.7 kw total modeling over an entire scene.

If the scene is small, such as a setting for two people, then one 300-watt lamp may be used on the floor, and two 300-watt lamps above for top lighting. This amounts to but 0.9 kw in electrical power. However, additional modeling may be desirable in some special scenes, although the amount of power required will be far less than that required for key lighting.

CONCLUSIONS

This concludes the assignment on Studio Lighting. It is divided essentially into three parts:

1. General considerations and examples of lighting of various types of scenes, so as to give the student an idea of the arrangement of spotlights, cameras, and the microphone and boom.

2. Definitions of lighting units, such as lumens, candlepower,

intensity of illumination, and brightness. This part of the text prepares the student for the next section.

3. The third and concluding section deals with the determination of the beam characteristic of a internally silvered spotlight widely used in studio lighting, and then shows how this characteristic can be employed to determine the number of lamps required for foundation or key lighting, as well as the lamp placement, with particular reference to the avoidance of strong shadows.

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TELEVISION TECHNICAL ASSIGNMENT

STUDIO LIGHTING TECHNIQUE

EXAMINATION

1. Explain in your own words what is meant by key lighting and modeling lights.

2. How is light flickering or ripple minimized in the mercury-arc luminaires?

3. (A) What is the particular value of overhead lighting of a television set?

   (B) What is the function of a spot?

   (C) What difficulty does a specular surface in a set cause?

4. Two matte white objects having each a reflection coefficient of .85 are illuminated by lights of two different wavelengths and wattage content. One light has a wavelength of 560 mμ, and a wattage content of .005 watt; the other has a wavelength of 640 mμ and a wattage content of .015 watt. In spite of the higher power content of the second source, the matte surface illuminated by the former appears brighter. Why is this so? Explain briefly but fully.

5. A lamp has an intensity in a certain direction of 32 candle-power. A surface of 2 sq.ft. is placed at a distance of 125 feet from it, and normal to the direction to the lamp.

   (A) What is the intensity of illumination on the surface?

   (B) How many lumens fall on the surface?

   (C) The surface is revolved through an angle of 20° to its previous position. What is the intensity of illumination on it now?

6. (A) What is the brightness of a source of light?

   (B) Explain in your own words how this differs from candle-power.

7. (A) State Lambert's Law. What is its significance?

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7. (B) It is not desirable to view a motion picture or television screen at an angle of possibly greater than 45° to the axis of the screen because of the foreshortening of the width of images appearing on the screen. In ordinary projection work, the incident light is nearly normal to the screen. In view of the above, is it desirable to use a truly matte surface for the screen or a semi-matte surface? Give reasons for your answer.

8. (A) What is the value in employing the unit of foot-lambert?

(B) What is the restriction as to its use?

9. A point source having a uniform intensity of 1,000 cp, illuminates a matte surface 20 feet away, and whose normal makes an angle of 30° to the direction to the point source. The reflection coefficient of the surface is .75. What is its brightness in *candles/sq.ft.* and in *candles/sq.in.?*

10. (A) In the attached figure is plotted the intensity of illumination in ft.-candles versus distance in feet along the surface of the scene for a 500-watt 6-hour type of photo flood internally silvered spotlight. The light is 8 feet from the scene. It will be observed that the peak intensity is 380 ft.-candles on the axial point (0 feet) and that it drops to 185 ft.-candles, or approximately one-half, at 1.6 feet from the axial point. Hence, assume three lamps, spaced 2 × 1.6 = 3.2 feet between sockets. Draw the overall intensity curve.

(B) What are the maximum, minimum, and average intensities over the relatively flat portion of the curve?

(C) What is the approximate length of the scene that is fairly uniformly illuminated?

(D) Suppose a square of 9 lamps spaced as above (3 lamps on a side) is employed. What area will be covered?

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10. (E) Suppose an area of 200 sq.ft. is to be illuminated to an intensity of 800 ft.-candles. How many lamps are required, and how much power is needed?

1. Key lighting supplies the necessary illumination on the subject to give the required signal to noise ratio on the mosaic of the camera tube. It must be sufficient to cause the least reflective surfaces to register. Modeling lights are spot lights that artificially increase the variations in brightness of surfaces of varying reflective ability. They are used mostly for artistic reasons, accentuating highlights & shadows.

2. Three lights are used in one unit, being connected in each phase of the three phase supply.

3. (A) With overhead lighting, shadows from the cameras and microphone booms will not be thrown into the scene.

   (B) The function of the spot is to accentuate highlights of the scene. Also by means of spots attention can be drawn to points of the main action.

   (C) A specular surface reflects light only at the same angle as the angle of incidence - none in other directions. At the angle of reflection the brightness of the source, not the brightness of the illuminated object will be observed.

4. The surface illuminated by the 560 mu light seems brighter because the eye is about five times more sensitive to light of this wavelength than to light of 640 mu.

5. (A) $E = I/d^2 = 32/125^2 = .00205$ lumens/sq.ft.

   (B) Lumens on surface $= .00205 \times 2 = .0041$ lumens

   (C) $E = \frac{I}{d^2} \cos\alpha = \frac{I}{d^2} \cos 20°$

   $= .00205 \times .9397 = \overset{.00193}{\cancel{.00216}}$ lumens/sq.ft

6. (A) Brightness of the source is the candle-power per unit area of surface.

(B) Candle power is the intensity of the light in some particular direction, and is expressed in lumens per steradian. Two sources of different surface areas ~~may~~ having the same candle power would differ in brightness. With the same candlepower, the lumens per unit area of surface of the source would be greater from the source of smaller area, therefore its brightness would be greater.

7. (A) Lamberts Law states that a diffuse (matte) surface scatters light in all directions, the intensity varying as the cosine of the angle from the normal.

Viewing a surface at an angle from the normal, the apparent surface decreases as the cosine of the angle. If the intensity of the scattered light also varies as the cosine of the angle the brightness remains the same regardless of the viewing angle.

(B) Use matte surface. with semi-matte there would be more light reflected normal to surface. With foreshortening of the width, when viewing from angle, outlines would not be clear, and this condition would be even worse with less light reflected at the angle from the semi-matte surface.

8.(A) The value of the foot-lambert is that brightness is expressed in terms of only illumination and reflection coefficient.

(B) Its use is restricted to matte surfaces.

9. $E = 1000/20^2 \cos 30°$

$= \frac{1000}{400} \times .866 = 2.165$ lumens/sq.ft.

Brightness $= E \times R = 2.165 \times .75 = 1.622$ lumens/sq.ft or foot lamberts.

Brightness $= \frac{\text{ft.lamberts}}{\pi} = \frac{1.622}{3.1416} = .516$ candles/sq.ft

$= \frac{.516}{144} = .00358$ candles/sq.in.

10.(A) on Graph Paper.

(B) Max E = 445 ft candles
Min E = 365 ft. candles
Ave E = 405 ft candles.

(C) Approx. length of scene = 8.2 ft.

(D) Area covered = $8.2 \times 8.2 =$ ~~64~~ 67.2 sq. ft.

(E) For 800 ft candles, lamps in each square would have to be doubled to 18.
No. of squares = 200/67.2 = 3 for an area approx 8.2 ft × 24.6 ft.
No. of lamps required = 3 × 18 = 54

Power = 500 × 54 = 27,000 watts
or 27 KW

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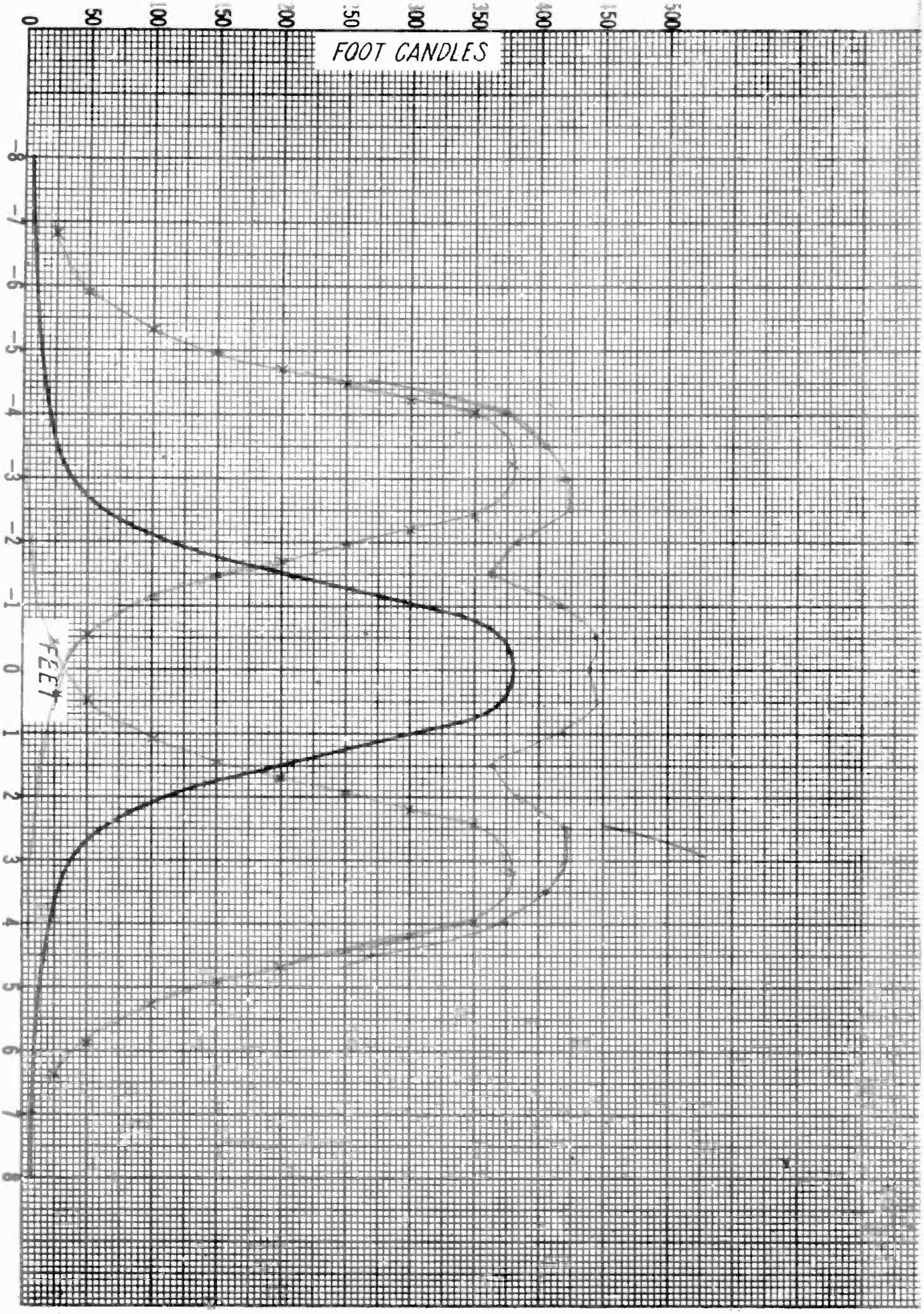

Curve for Examination Problem 10