COLORED LIGHTING*

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SYNOPSIS: Colored lighting has assumed a very important position in illuminating engineering in recent years. However, many people are uninformed as to the methods of obtaining color in lighting, and the media which are available. In this paper the spectral limits of the various colors are given, also the relative luminosity of the various portions of the spectrum from a 150 or 200-watt gas-filled lamp. The characteristics, advantages and disadvantages of various colored media are discussed. These media include colored glass lamps, colored glass accessories, gelatine filters, and colored lacquers and spray coatings for lamp bulbs. The transmission factors of many samples of such media have been measured, and are given in this paper. The data show that many of these colored media are much less efficient than they could be in order to produce satisfactory colors. The need for standardization of such media is very evident from the data given. Two examples of recent large installations of colored lighting are described, with connected-load data. A bibliography of colored lighting is also included.

Electric lighting by high-efficiency incandescent lamps has given colored light its much deserved opportunities. It has found extensive application in theatres, public buildings, stores, show-windows and electric signs. It has great potentiality but its proper use calls for taste, artistic sensibility, and knowledge of the psychological powers of color. However, it is not the purpose of this paper to discuss the fields or characteristics of colored lighting, but rather to consider the means whereby color is produced.

As is well known, the radiant energy from an incandescent filament contains all the primary colors. Colored light results if we interpose between the filament and the illuminated surface some medium which absorbs the energy in certain spectral regions. The eye is not analytical, and two colored lights so obtained may appear identical in color when compared on a white surface, but they may be entirely different in spectral character. For example, yellow light may be produced by subtracting from the radiant energy all spectral colors except the yellow, or except the red and

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green in the proper proportions. However, an object which appears yellow when viewed under white light might have a totally different appearance under these two "yellow" lights.

The limits of wave-length for the spectral colors are somewhat indefinite. Any observer's choice of limits for a particular color depends to some extent on the experimental conditions. This is not surprising when it is considered that more than one hundred different hues may be observed in the dispersed spectrum under proper conditions. The most definite colors, with their approximate spectral limits, are given in the first two columns of Table I. In the third column are given data showing the percentages of the total light from a 150 or 200 watt gas-filled lamp which are within these spectral regions. These data are based on the standard visibility data and a color temperature of 2800°K for the filament.

TABLE I.—TABLE SHOWING THE APPROXIMATE WAVE-LENGTH INTERVALS FOR CERTAIN SPECTRAL COLORS, AND THE PERCENTAGES OF THE TOTAL LIGHT FROM A 150-OR 200-WATT MAZDA C LAMP WHICH IS OF THOSE PARTICULAR COLORS.

Color	Approx. Spectral Region μ	Percent of total luminosity of 150 watt gas-filled tungsten lamp which is in indicated spectral region.
Violet	0.400–0.430	0.01
Blue	0.430–0.485	1.5
Blue-green	0.485–0.502	2.0
Green	0.502–0.530	10.7
Yellow-green	0.530–0.562	25.3
Yellow	0.562–0.590	26.6
Orange	0.590–0.620	22.4
Red	0.620 to limit	11.5

It is evident that any change in the spectral limits assigned to a particular color will result in a change in the luminosity value given in the third column; however, the data given in the table are approximately correct.

Certain spectral colors are more "colorful" than others, that is, a smaller amount of the color need be added to white to produce a distinguishable tint; expressed in another way, a very "colorful" color will stand a greater dilution, with white light or a less "colorful" light, without losing its color identity. The following is approximately the order of "colorfulness" of the primary colors: Red, violet, blue, green, orange, yellow. This order is based upon the purity of color as obtained by practicable colored media and not upon monochromatic colors isolated from the spectrum.

From a consideration of the luminosity in various portions of the spectrum, and the "colorfulness" of various spectral regions, some idea may be gained as to the maximum efficiency of color production which may be expected. In general colored glasses, gelatines, etc. do not give pure colors. For example, if a certain medium transmitted only the spectral red, its maximum transmission when used with a gas-filled lamp would be approximately 11 per cent. Red is very colorful, however, and a considerable amount of orange and yellow light can be transmitted without loss of the predominant red hue. Thus a very fairly satisfactory red can be obtained with a luminous efficiency of about 15 to 20 per cent. In addition to the advantage of the higher efficiency there is often a further advantage, in that objects which reflect no red light do not have the brown or black appearance in the diluted red light which they might have in a pure spectral red light.

There are three general methods of producing colored light: (1) colored glass bulbs, (2) colored accessories, glass, gelatine, etc. and (3) superficial colorings. In comparing the relative merits and fields for these various methods many viewpoints must be considered. Some of these are discussed here with the hope of aiding the user to choose the method best suited to his purpose. Demands for natural colored glass lamps often arise from a lack of acquaintance with colored glass accessories which in general offer a better solution, and which in many cases prove to be less expensive and are more easily maintained.

Colored-glass bulbs in a limited range of colors are available, but in general most of the problems involving colored light can be solved without the use of such bulbs, which are necessarily expensive. Their use is justifiable in some cases, e.g. where space is extremely limited or other special considerations enter, but in most cases colored glass accessories or superficially colored bulbs represent better practice.

Colored-glass accessories are now available for use with incandescent lamps to produce colored light in the show-window, on the stage, in signs, and for displays of many types, both exterior and interior. Wherever the installation is of a more or less permanent character such accessories should be used if possible, since the renewal part is merely an easily obtained regular lamp. The glass is permanent in color, hence the maintenance is simplified and the user is saved the trouble and expense of obtaining special colored lamps. These glass accessories are of various kinds.

Colored-glass caps are available in various sizes and colors for use in electric signs. The smaller sizes usually have spring clips which hold them on the lamp bulbs.

Colored glass globes are available with a number of types of holders which adapt them for use with reflectors of prismatic glass, of silvered glass and of porcelain enamel. These may be used with high wattage gas-filled lamps for show-windows, foot-lights, border-lights, cove-lighting, billboards and in numerous other places where colored light is desired.

Reflectors and projectors, with *colored glass plates or lenses* in the aperture, are available for many purposes. They have been used on the stage, in large interiors and for floodlighting. In addition to these previously mentioned colored media, colored glass, lenses, roundals, sheets, globes, etc., are available for various purposes.

Colored gelatines of various tints and pure colors are quite satisfactory for many temporary installations. However, many of these are not permanent in color, and they also become brittle after being used for a while. Practical devices of this character are becoming more generally available, and can be used very satisfactorily instead of colored glass bulbs in many applications of colored light. The colored glass and gelatine accessories can be obtained in relatively pure colors such as red, deep amber, canary, green and blue. Tints are obtainable by mixing uncolored light with pure colored light. In some instances they are also obtainable from a single unit by using pieces of colored glass on a colorless diffusing glass.

Superficial colorings for tungsten lamps can be subdivided into (a) solutions in which the lamp or device is dipped and (b) liquids containing suspended pigments which are sprayed on the lamps.

The solutions applied by dipping usually consist of analine dyes dissolved in a celluloid or varnish vehicle. It is also possible to grind insoluble coloring materials, such as pigments, fine enough so that they will be held in suspension in these vehicles. The analine dyes fade under the influence of heat and light, hence these dips are unsatisfactory for large lamps on account of the bulb temperatures encountered. Some of these fade even with lower wattage vacuum lamps, but many of them may be used with fair satisfaction with these lamps. Even the vehicles used for dissolving the dyes usually disintegrate or scorch when used on the higher wattage lamps. Hence, even if the coloring material is a permanent pigment, the permanency of the coating is dependent on the vehicle. The analine dyes provide fairly pure colors, and by mixing and diluting them a great variety of tints is obtainable. The lamp dips must be fairly pure in color if tints are to be obtained by mixing them. These dips usually give a transparent coloring, though some give some diffusion.

The spray method was developed by one of the authors in order to be able to use materials which would be permanent on large lamps. The insoluble but permanent coloring materials were finely ground and suspended in a vehicle which was found to be permanent. Thus are combined permanent diffusing and coloring materials with a permanent vehicle. Experiments indicated that tinted light could be obtained efficiently in this manner, for example the flametint lamp, but that the more or less opaque insoluble coloring media would not yield relatively pure colored light at the highest possible efficiencies. The color of a pigment is usually different when seen by transmitted light rather than by reflected light. It is quite probable that when such a pigment is used in a sprayed coating a portion of the light gets through by multiple reflections between the minute insoluble grains of the pigment. Hence extremely pure colored lights such as red, green and blue cannot be obtained by this process when these more or less opaque coloring materials are used. Even colored light of the deeper tints is produced less efficiently by this process than by means of dyes or colored glass. However, this process is applicable to larger lamps than the dipping process and results are more permanent. Also, the light is well diffused, and the lighted lamp has a much better appearance than a dipped lamp with colored transparent coating. These lamps may be used with satisfaction where it is inconvenient or unsatisfactory to use colored glass accessories. They are more satisfactory as to permanence of color and coating than are the dipped lamps.

In order to summarize the various characteristics of colored media, they have been given approximate ratings as shown in Table II.

TABLE II.—APPROXIMATE RATINGS OF VARIOUS METHODS OF OBTAINING COLORED LIGHT.

Medium	Transmission*	Color permanence	Cost of maintenance	Resistance to weather
Colored glass bulbs	E	E	F	E
Colored glass accessories	E	E	E	E
Colored gelatine	E	P	F	P
Lamp dips and lacquers	E	P	F	P
Spray coatings	F	E	G	G

E=excellent; G=good; F=fair; P=poor.

Practical efficiencies of color production. Little or no authoritative information has been published regarding the transmission factors of commercial colored media. That such information is desired is indicated by the inquiries which come to us.

During the past two years we have measured samples of all the types of colored media referred to above. In no case has the number of samples measured been sufficient to establish an average value for the manufactured product, but in a number of cases the measurements have served to establish a standard to which the product should conform. The data are also incomplete as to the product of many of the manufacturers. The main value of such information as we have is in giving a general idea of the magnitude of the transmission values for different colored media now available.

The question of color photometry is still unsettled; however, it is not the purpose of this paper to discuss it. The data here given were all obtained by means of the Kingsbury type of flicker photometer. The flicker photometer furnishes the best practicable means yet proposed for photometry of lights as extreme in color as those encountered here. By means of this instrument it is possible

*Ratings on transmission are based on the best obtainable without undue sacrifice of color purity. Actual samples by any method may grade anywhere from E to P with most of these media.

to obtain quite definite results, and to interpret them in terms of the values which would be obtained by an observer of average color-vision. In no case was the colored light measured directly against the unaltered light from a tungsten lamp. By the use of color filters of intermediate hue which had previously been carefully standardized by a number of observers the color difference was in most cases reduced to a degree which did not make the measurements extremely difficult. An integrating sphere was used in all cases, in order to obtain average transmission values. The data are given in Table III.

TABLE III.—Observed Transmission-factors of Various Colored Media.

	Medium	Average and range of transmission—per cent.			
		Red	Green	Blue	Amber
Vacuum Lamps	Natural colored glass bulbs	(Transmission factors depend on hue, saturation and actual mixture of coloring materials used. They can be as high as those of colored glass accessories.)			
Vacuum Lamps	Lamp dips and lacquers	(Transmission factors depend on hue, saturation, and actual mixture of dyes used. They can be as high as those for colored glasses but the dyes are not permanent.)			
Vacuum Lamps	Sprayed lamps (standardized values)	8 to 10	4 to 5	2 to 2.5	50 to 60
Vacuum Lamps	Sign-lamp caps 10 watt size	11 to 17	9 to 12	2 to 3	30 to 54
Gas-filled Lamps	Color caps for 150 watt lamps	20 17 to 22	7 6 to 8	4 3 to 5	26 21 to 33
Gas-filled Lamps	" (2nd lot)	22 19 to 26	10 6 to 16	11 9 to 13	40 38 to 46
Gas-filled Lamps	10" colored glass roundels	7 6 to 9	8 5 to 9	4 4 to 5	37 33 to 43
Gas-filled Lamps	Gelatine filters for show window reflectors	5.2 4.8 to 5.7	17 17 to 18	1.3 0.9 to 2	48 45 to 50

In measuring the transmission of thick colored glass accessories it is necessary to allow sufficient time for them to reach a sensibly constant temperature before measurement. In measuring the 10-

inch glass roundels it was found that the transmissions at the end of five minutes differed from the values immediately after lighting by the following amounts; red, −15 per cent; green, −6.5 per cent; blue, +3.5 per cent; amber, −15 per cent.

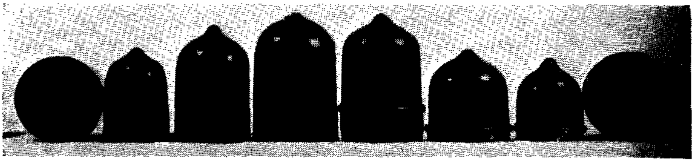
The data given in Table III are of most value in indicating the order of magnitude of the transmission-factors encountered in available colored media. Differences between different media of the same color are largely due to differences in purity of the color produced. For example, three different media designated as red in the above table were examined through a spectroscope with the following results: a natural glass ruby bulb transmitted only the pure spectral red predominantly; a red gelatine filter transmitted predominantly the deep red and deep blue or violet (this filter has a decided purplish appearance); a 150-watt red color-cap transmitted all wave-lengths from deep red to yellow-green.

Our experience has shown that where a high degree of spectral purity is not required, colored glass, gelatine and lamp dips having the following transmission-factors when used with tungsten lamps are quite satisfactory for most applications of colored light: red, 15 to 20 per cent; green, 5 to 10 per cent; blue, 3 to 5 per cent; amber, 40 to 60 per cent.

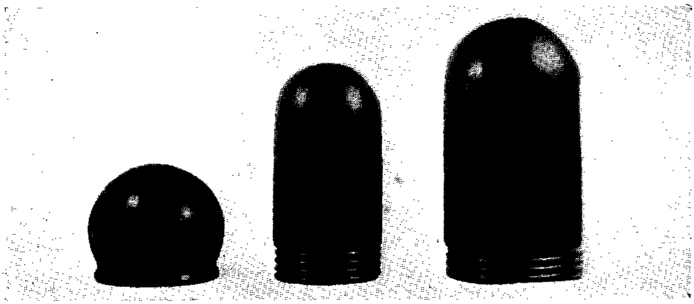
However, high transmission is of less importance than permanency, and in colored gelatine or lacquers the latter factor must be given first consideration. Also, in some applications spectral character or purity may be of greater importance. This is especially true where the colored light is used in show-windows.

A considerable degree of variation in transmission is to be expected in color-caps which are blown in molds, on account of the unavoidable variations in thickness. However, there is room for a great deal of improvement in all of these media. The improvement can be aided by standardization of the nature and concentration of the coloring materials, and thickness of the colored media. Variations in efficiencies of incandescent lamps approaching in value the *avoidable* variations in transmission of the colored media would not be tolerated.

In Figures 1 to 4 are shown illustrations of a few of these colored glass and gelatine accessories, and some reflectors or equipment with which they can be used. They are shown here merely to illustrate the availability and application of such accessories.



(a)



(b)

Fig. 1.—Glass caps for incandescent lamps. (a) for vacuum lamps. (b) for gas-filled lamps.

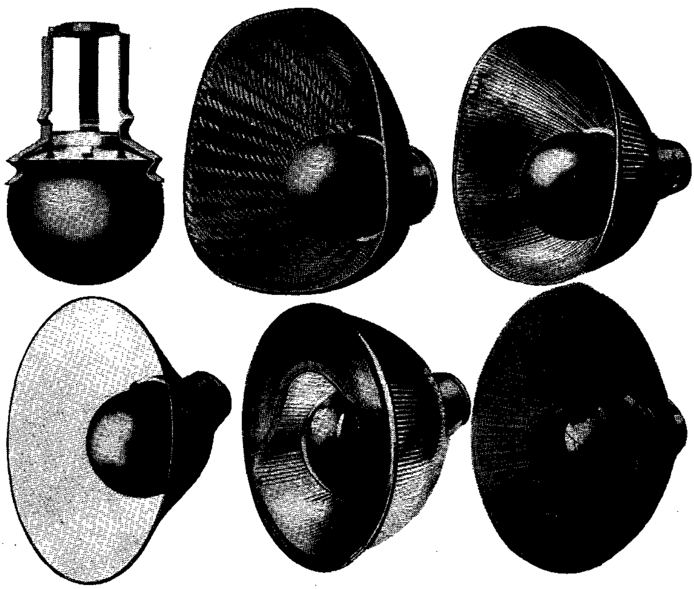
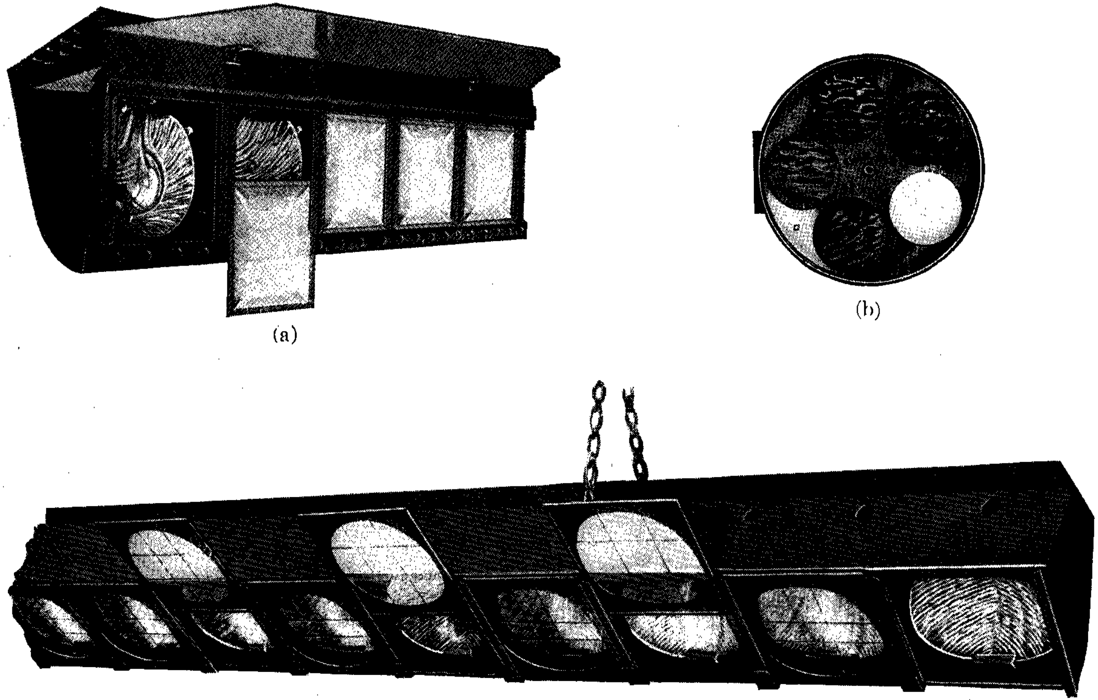


Fig. 2.—Glass color-cap, and some reflectors equipped with it, for gas-filled lamps up to 200 watts.



(a)

(b)

FIG. 3—Typical colored-lighting equipment for the theatre. (a) Footlights, (b) Color wheel for spotlights. (c) Border lights.

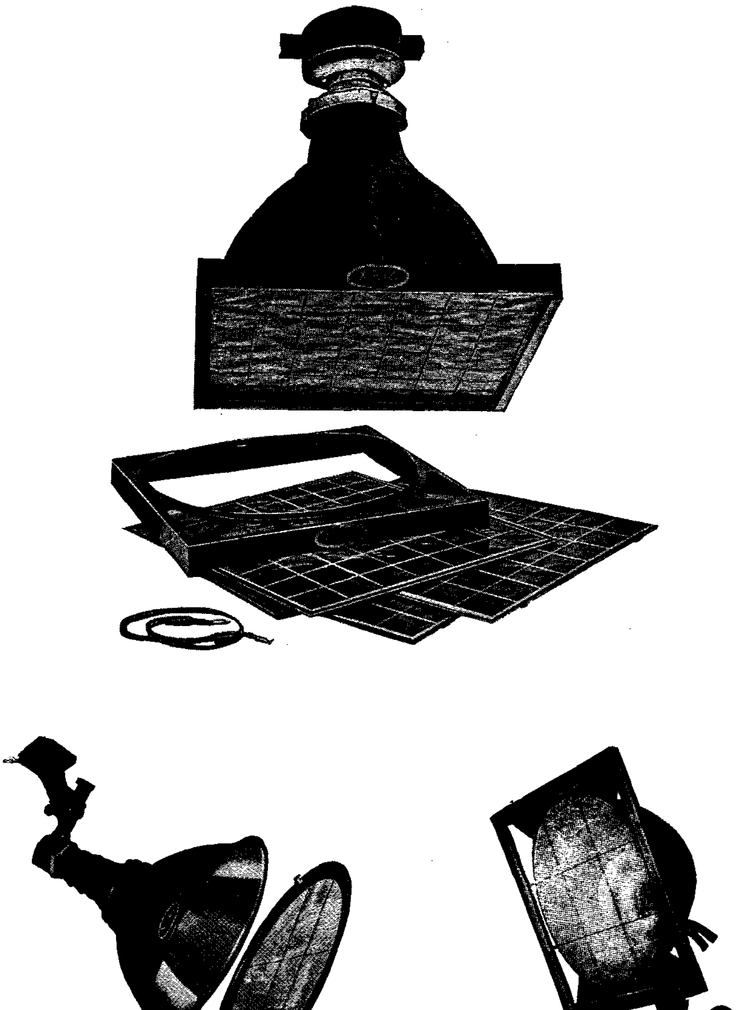


Fig. 4—Examples of lighting equipment and gelatine color filters

FIG. 4.—(Cont'd) Example of lighting equipment and gelatine color filter.

Fig. 5.—Cleveland Public Hall, looking towards stage. Interior dimension of auditorium, length—257 ft., width—120 ft., height—80 ft.. Illumination through crystal glass ceiling by means of Special Reflectors suspended in attic space. The ceiling consists of 40 major panels each 15 feet square, lighted by 8 reflectors each. Each reflector is designed to accomodate one 750-watt or 1000-watt type C lamp. Provision is made for color screen which together with the dimmer equipment, permits the production of various interesting effects. See Figures 6 and 7 for details of installation.

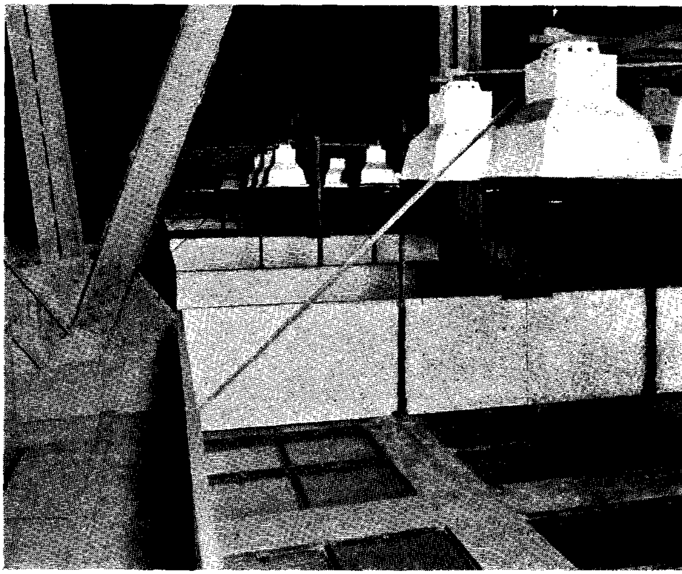


FIG. 6.—Cleveland Public Hall. The object of this view is to show the extent of the equipment and the clean cut appearance of the completed installation. Above each panel provision thru circuit control is made for two 1000-watt blues two 750-watt reds and four 750-watt whites one 500-watt amber also used to working light. The total quantities in this enormous building are of interest. The white lights for general illumination through the ceiling involve a total of 160-750 watt lamps or 120 kw.; blues, 80-1000 watt lamps or 80 kw.; reds, 80-750 watt lamps or 60 kw.; working lights, 40-500 watt lamps or 20 kw. making a total of 280 kw. with everything in operation.

FIG 7

In order to show something of the importance which color has attained in lighting of theatres, public auditoriums, etc., two examples of recent installations will be given.

About a year ago a new public auditorium was completed in Cleveland. A view of the interior of the main auditorium is shown in Figure 5. The lighting is entirely by artificial light. The skylight is lighted by 320, 750-watt gas-filled lamps in mirrored glass reflectors. Of these 160 are clear, 80 have red gelatine filters and 80 have blue gelatine filters. (The blue gelatine filters are now being replaced with glass and 1000-watt lamps are being used with the blue). The lighting units are shown in Figures 6 and 7. In the coves are 630, 200-watt gas-filled lamps in mirrored glass show-window reflectors, of which 210 have red glass and 210 have blue glass filters. The total connected lamp load for the main auditorium, exclusive of stage, is 375 kilowatts, of which 55 per cent is colored lighting. The auditorium is 300 x 215 ft., hence the lighting load is approximately 6 watts per sq. ft.

The Chicago Theatre has 180 kilowatts of colored lighting, of which 150 kilowatts are in the auditorium.

The plans for an auditorium recently designed for a fraternal organization call for 55 kilowatts for lighting the auditorium which is 106 by 75 feet. Three-fourths of this lighting is to be colored.

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The following is a partial bibliography of the subject of colored lighting. It is by no means complete, but many of the articles and books referred to give other references which may be consulted.

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