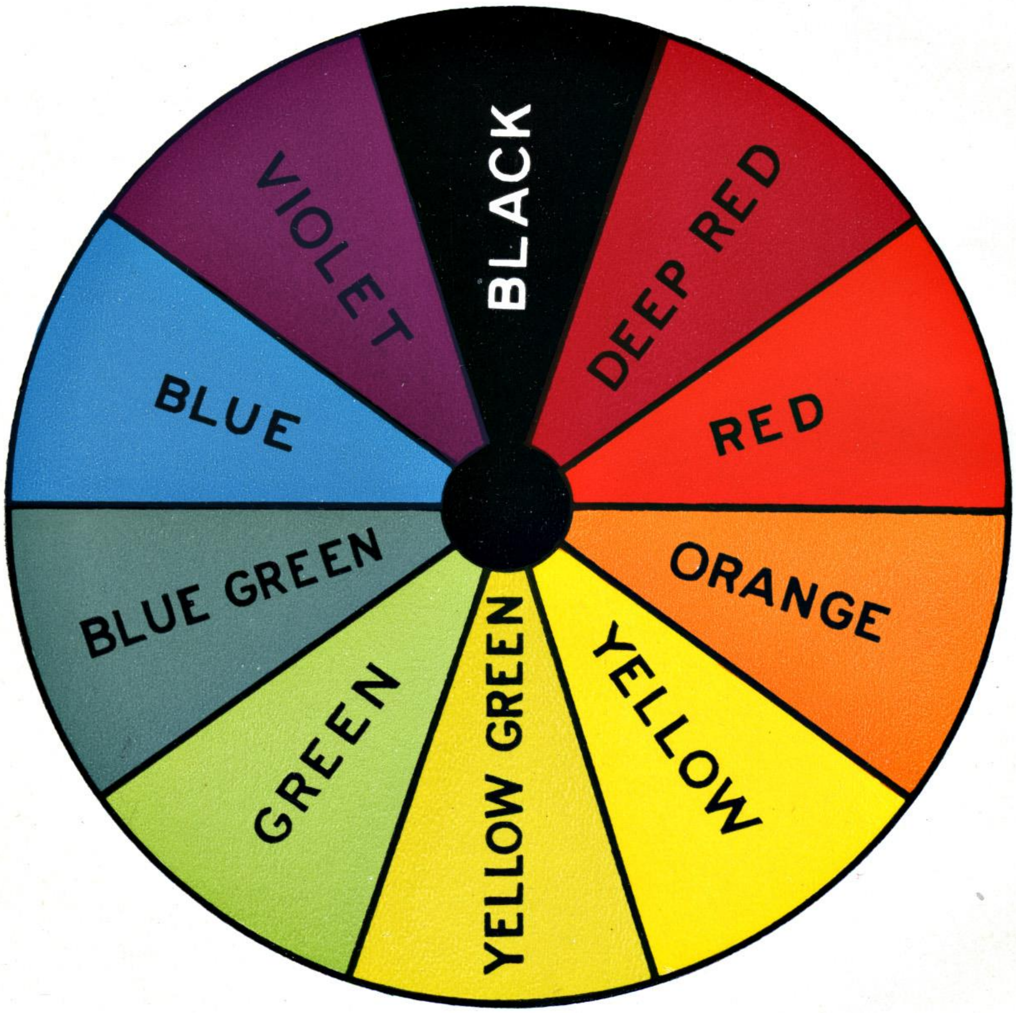
The Photography of Colored Objects

Eleventh Edition
(Revised)

Eastman Kodak Company
Rochester, N. Y.


BLACK
DEEP RED
RED
ORANGE
YELLOW
YELLOW GREEN
GREEN
BLUE GREEN
BLUE
VIOLET

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1932

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PREFACE

THIS book is a statement of the theory underlying the photography of colored objects and the application of that theory to those branches of practice which are of the most frequent occurrence.

While purely scientific terms and phraseology are not employed, no attempt has been made to be entirely "practical." No pretense is made of being unbiased, though it is hoped that there is no conscious bias. The Eastman products are freely discussed, but the loss of generalization caused by this procedure will be compensated by the advantage to be gained from definite information.

The introduction in 1931 of new panchromatic films and plates of high general sensitivity having very high sensitivity to green and red light necessitated a thorough revision of the book, and it is in this revised form that the eleventh edition is presented. In view of the particular suitability of the new materials for use with artificial light, especially incandescent tungsten lamps, a chapter on "Photography by Artificial Light" has been added. The chapter on "Three-Color Photography" has been completely rewritten.

The large number of friends who have kindly assisted in the compilation of this volume makes it impossible to acknowledge all by name. We hope that all will understand that although they are not named, we are none the less grateful to them for their various suggestions and that we shall also be grateful for suggestions for the improvement of future editions.

EASTMAN KODAK COMPANY,
1932 ROCHESTER, N. Y.

CONTENTS

THE PHOTOGRAPHY OF COLORED OBJECTS

CHAPTER I

THE NATURE OF COLOR

AT the beginning of this book, which is essentially concerned with the analysis and photography of color, it will be well to get a definite idea as to what is meant by "color," and with what physical phenomena color is associated.

The nature of color is involved in the conception we obtain as to the nature of light. The nature of light has long been a source of speculation. It was once generally held that perception of light depended on the reception by the eye of small discrete particles shot off from the source of light; just as at one time it was held that the perception of sound depended upon the impact upon the ear drum of small particles shot off from the sources of the sound. This theory of light has the advantage that it immediately explains reflections; just as an india-rubber ball bounces from a smooth wall, while it will be shot in almost any direction by a heap of stones, so these small particles would rebound in a definite direction from a polished surface, such as a mirror, while a rough surface, as paper, would merely scatter them. This theory of the nature of light appeared adequate until it was found that it was possible, by dividing a beam of light and slightly lengthening the path of one of the halves, and then re-uniting them, to produce periods of darkness similar in nature to the nodes produced in an organ-pipe, where the interference of waves of sound is taking place. It could not be imagined that a reinforcement of one stream of particles by another stream of particles in the same direction could produce an absence of particles, while the analogy with sound suggested that, just as sound was known to consist of waves in the air, so light also consisted of waves.

Light cannot consist of waves in the air, partly because we know that it travels through interstellar space, where we imagine that there is no air, but also because the velocity of light, 186,000 miles per second, is so great that it is impossible that it could consist of a wave in any material substance with which we are acquainted. It is, however, supposed that there must exist, spread through all space and all matter, what is termed the ether, and that light consists of waves in this ether.

Just as in sound we have notes of high frequency, that is, with many waves per second falling upon the ear, which form the high-pitched or shrill notes, and also notes of low frequency, where only a few waves per second fall upon the ear, forming the bass notes—so with light we may have different frequencies of vibration, some falling upon the eye at very short intervals, while other waves are of only half or even less frequency.

Since the velocity of light is the same for waves of different frequencies, it is clear that the waves of high frequency will be of shorter wave length than those of low frequency, the length of a light wave being the distance from the crest of one wave to the crest of the next.

The wave length of the light, like the velocity, varies with the medium in which the light is traveling. For instance, when light is traveling through glass, it will only have about two-thirds of the wave length of the light traveling in the air. But it is convenient to consider simply the wave length of light as the length of the wave in free ether, or for practical purposes, in air. White light consists of waves of various lengths; *i.e*, a mixture of waves of all lengths in certain proportions forms what we term white light. If instead of allowing this heterogeneous mixture of waves to fall upon the eye, we omit waves of some frequencies, then a sensation of color will be produced in the brain. Thus color is associated with wave length. White light consisting of waves of different lengths may be regarded as being made up of light of various colors, and by different devices may be split up into these colors.

We can analyze white light or discover the composition of any light with the spectroscope, an instrument in which light is examined after being passed through a prism. The prism spreads the light into a band of different colors, which is known as a spectrum. If the light analyzed is white, these colors merge into one another without any break, but there will be a break or breaks (absorption bands) if the light examined is colored. Figure 1 shows the relative length of the waves corresponding with light of various colors, the diagram being drawn to scale. Since waves of different lengths correspond with different colors, a scale may be made in which the different wave-length numbers correspond in position with the different colors of the spectrum. A simple arrangement of the normal spectrum is shown in fig. 2, the numbers representing the lengths of the waves in Millimicrons (mμ) which are millionths of millimeters, and the color ranges being indicated.

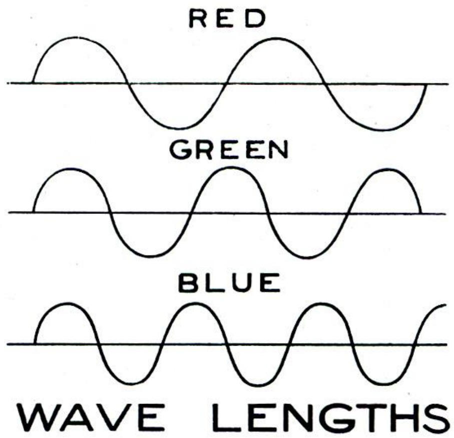


FIG. 1

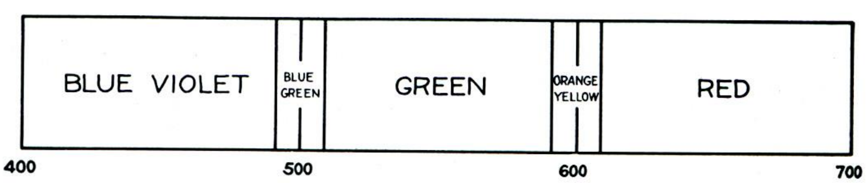


FIG. 2

It will be seen that the visible spectrum extends from 400 to 700 and is equally divided into regions which may be broadly termed:

Blue-violet	400 to 500
Green	500 " 600
Red	600 " 700

Light-filters, that is, transparent media absorbing certain waves and transmitting others, can be constructed which will absorb some particular region of spectrum, and they are generally called after the color they transmit; thus, if we make a filter which only lets through the portion of the spectrum between 400 and 500, then we should call that filter a blue-violet filter, a filter letting through from 500 to 600 would be a green filter, and a filter letting through from 600 to 700 would be red in color. Thus, from the spectrum, we already derive the idea that light can be divided into three colors which we may call the primary colors, red, green, and blue-violet.

Remembering this conception of light, let us consider why we term a given filter red. It will appear red because it only lets through red light, but white light consisting of blue-violet, green, and red is falling upon it, so that clearly it is red because it stops or absorbs the blue-violet and green light.

Similarly, a piece of red paper is red because it reflects red light, but it has falling upon it white light consisting of blue-violet, green, and red, so that it must absorb the blue-violet and green light, not reflecting them, but only reflecting the red light. We are therefore justified in saying that anything which absorbs blue-violet light and green light together will be red.

It is this aspect of color, namely, that objects are colored because they absorb portions of light, which must be clearly and definitely understood if the best results are to be obtained in the photography of colored objects. Unfortunately, however, the conception of color as an absorption is not common though it is the most useful one, and it will be necessary somewhat to elaborate this idea in order to prevent misconceptions arising. We should form the habit of considering a red object, not as one that reflects red, but as one that absorbs blue-violet and green.

The importance of this definition is that it defines "red" without reference to the color of the incident light. Take a scarlet book and examine it by a light containing no red; such, for instance, as the mercury vapor lamp, in which red is almost entirely wanting. The book will no longer reflect red light because there is no red light for it to reflect, but it will still absorb the blue-violet and green light of the lamp, and will look black; it has not, of course, changed its nature, and we should still be justified in saying that it is red if we define red as we have done above.

In the same way, a yellow object is not one which reflects yellow light (there is very little yellow light indeed in the spectrum, and if an object reflected only yellow light it would be so dark as to be almost black), but a yellow color is due to blue absorption. The other two components of white light, green and red, are reflected, so that we should be justified in saying that yellow light consists of green light plus red light, but for our purpose let us consider yellow simply as a lack of blue; yellow is white minus blue, so that if you have a beam of yellow light and add blue light to it, you will get white light.

Now what is green? Well, since white light consists of blue light, green light, and red light, green is clearly white light minus red and minus blue; and a green body is one which

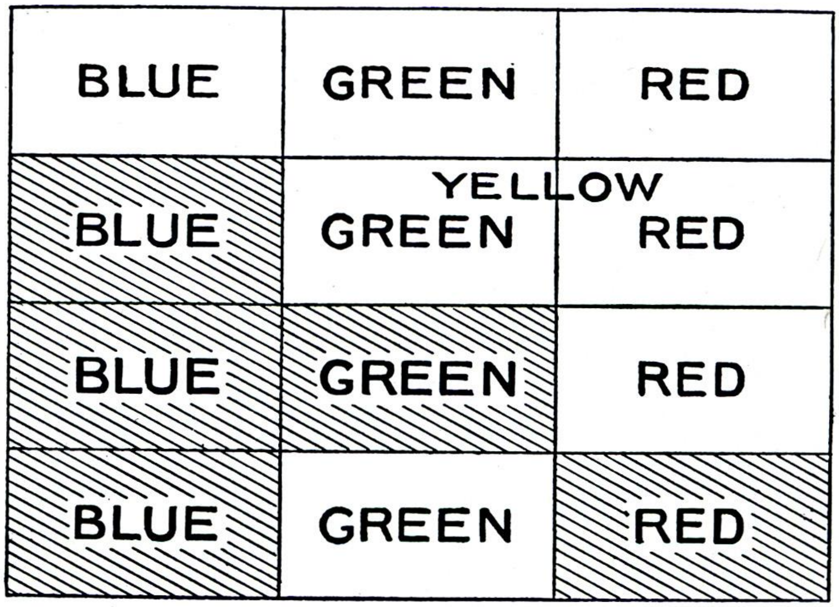


FIG. 3

absorbs both red and blue. The difference between a green object and a yellow object is that the yellow object absorbs blue only, whereas the green object also absorbs most of the red light which the yellow object reflects.

We can now make clear what is meant by complementary colors. Consider the top line of the diagram (fig. 3). This represents the components of white light. The next line under this shows the blue blotted out leaving the mixture of green and red—that is, yellow. We should say, then, that yellow is complementary to the blue. In the same way, in the next line all blue and green are blotted out, leaving only red, so that red is complementary to blue-green. In the bottom diagram all blue and red are blotted out, leaving only green; green is complementary to this blue-red mixture, which is usually known as magenta.

In general, then, the light absorbed by an object may be said to be complementary to that reflected by it.

So far we have only considered intense colors. We have

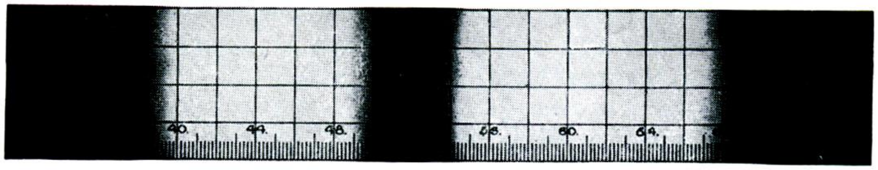


FIG. 4. ERYTHROSINE ABSORPTION SPECTRUM

imagined that a red object absorbs the whole of the blue-violet and the green light, that is to say that its absorption is complete. But most things have only partial absorption—the absorption is incomplete. Partial absorption can be of two forms: it can be gradual, or it can be sharp; thus, if when taking a photograph of a spectrum, there is put in front of the

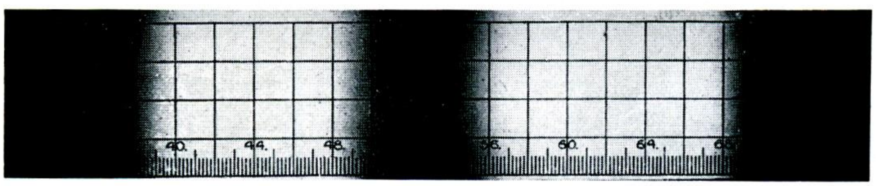


FIG. 5. ROSINDULINE ABSORPTION SPECTRUM

spectroscope a solution of erythrosine, then that erythrosine will absorb a sharp band of green from the spectrum between 500 and 540, as is shown in the photograph (fig. 4). But if you put in front of the spectroscope slit a cell containing rosinduline, you will get a gradual diminution of intensity between about 490 and 560, with the least light transmitted about 520 (fig. 5). Thus different dyes and different substances give different classes of absorption, the two kinds being roughly subdivided into (1) sharp absorptions, and (2) gradual absorptions.

Let us examine the effect of a single sharp absorption band in different parts of the spectrum. First, consider a sharp absorption band situated in the red about 650 and producing a total absence of red in this part. The remaining color consists of all the blue-violet and all the green, with some of the red. The actual visual effect of the mixed color is what one might term a "sky-blue." We may term this "sky-blue" a *residual* color due to the absorption band in the red. Imagine this band to shift so as to absorb the orange; absorbing between 580 and 620, the color will be a light violet-blue, because there is a great deal of red being transmitted and less green. If the band shifts into the yellowish

CHART SHOWING RESIDUALS

POSITION OF ABSORPTION BANDS

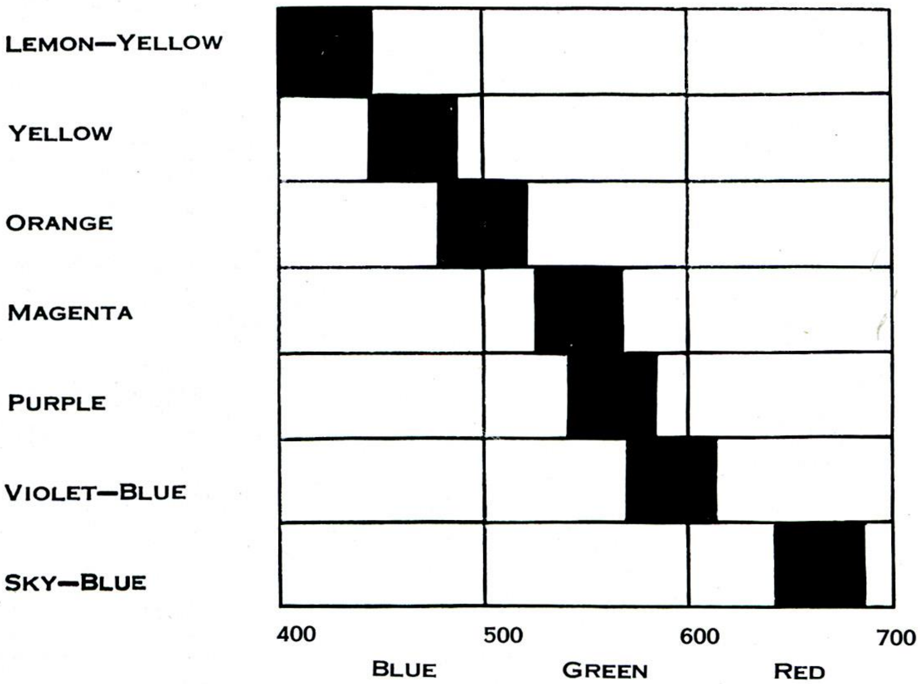


FIG. 6

green from 560 and 600, it will absorb a great deal of the green and none of the red, and the color will become bluish purple; as it shifts lower in the green towards the blue, this purple becomes a reddish purple, so that when the band is situated at from 520 to 560, we have what is generally known as magenta in color. As the band shifts towards the blue, the blue fades out of the magenta, green taking its place. When the band is from 470 to 520 the color is a sort of orange, and as the band moves into the blue-violet, the orange becomes a yellow, and finally a lemon-yellow. So that if we imagine a single band to pass down the spectrum, we get a change from light sky-blue through purple, magenta, orange, and yellow, to lemon-yellow. In figure 6 there is shown a chart of these residual colors each due to a single sharp absorption in the spectrum. It is convenient to memorize this chart since by means of it the approximate position of the absorption band corresponding to any color can be found.

It will be seen that there is one class of color which does not enter at all into this series, namely, the greens. There is really no visual suggestion of green in any color formed by using a daylight spectrum and absorbing one narrow band only. In order to get a green we must have an absorption both in the red and in the blue. If we absorb the extreme blue and also the extreme red, we shall at once get a green, and as these two bands vary with regard to each other, we shall obtain various shades of greens. Thus, if the blue absorption band is weak, and the red absorption band is very strong, we get blue-greens; if the red absorption is weak, and the blue strong, yellow-greens result.

Green is almost the only common color due to two absorption bands, and other colors which on analysis prove to have two absorption bands generally tend to be mere variants in hue of some colors, which we have already discussed under the heading of simple absorption bands. A brown color is fairly common, and the bands of a brown are of a gradual absorption type generally extending through the blue-green—that is to say, a brown is really a degraded orange, and is a variant on the color described as orange, resulting from a single absorption band in the blue-green.

It is clear, therefore, that if a thing is colored sky-blue it is absorbing the deep red, a violet-blue object absorbs the orange, a purple the yellow-green, a magenta the central green, an orange the blue, a yellow the blue-violet, and a lemon-yellow only the extreme violet. If a sky-blue object be looked at through a piece of yellow glass, it will be found to look bright green in color, so that a green color is produced by the absorption both of the red and of the blue, the blue object absorbing the red light and the yellow glass the blue light.

Natural colors do not generally show sharp absorption bands, though the absorption bands produced by the stains used in microscopy are often fairly sharp. The same rule holds true, however; if a magenta object in nature does not signify a clean sharp absorption band in the green, it still means that that object absorbs far more of the green than of any other color, and, as regards photography, we can apply the rules deduced from theoretical residuals to natural colors.

In fig. 7 we see a sharp absorption band depicted, which would give rise to a violet-blue color. An actual violet-blue however, will have an absorption band of the type shown by the gradual absorption shaded in the opposite direction in the diagram.

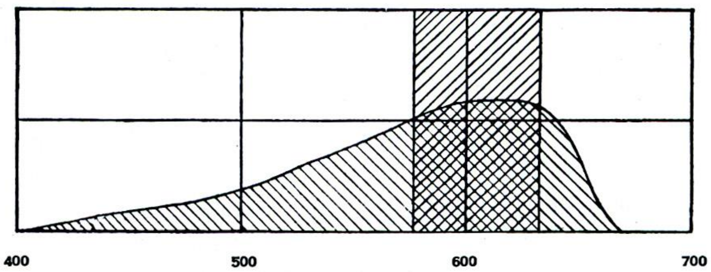


FIG. 7. THEORETICAL AND ACTUAL VIOLET

Similarly, fig. 8 shows an ideal green, having sharp red and violet absorption, and a natural green with its gradual ending, and absorption of the green itself.

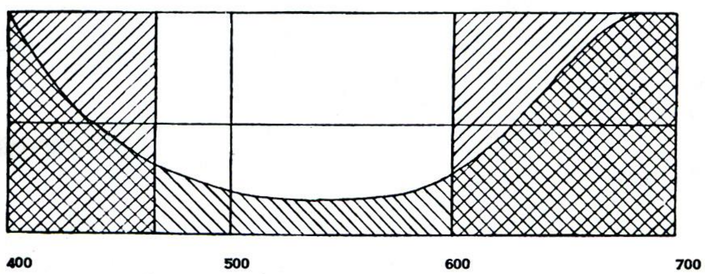


FIG. 8. THEORETICAL AND ACTUAL GREEN

The sharpness of absorption bands is of great importance in respect of the purity of the colors produced by them. The side of an absorption band, which is toward the red end of the spectrum, generally has a sharp edge, as shown in fig. 7, while that which is toward the blue end has a gradual edge, a considerable amount of absorption remaining even in the transmitted portions of the spectrum. As a result, colors which are bounded by the sharp edges—that is, reds, oranges, and yellows—are bright colors, while colors which are bounded by the gradual edges—blue-greens, blues, and violets—are dark colors. A green will, as a general rule, have a sharp edge at its blue limit and a gradual edge at its red limit, and will consequently be of intermediate brightness.

If we divide the spectrum at 500 and at 600, so that we get three portions, 400 to 500 which we may term blue-violet, 500 to 600 which we may term green, and 600 to 700 which we may term red, then examination of the sensitivity curve, given in Chapter II, fig. 10. will show that about 77 per cent of the whole light should be "green," about 16 per cent should be "red," and about 7 per cent should be "blue." A red object will reflect nearly all the incident "red" light, while a bright green object will reflect only about one third of the "green" light, and a bright blue object one quarter of the "blue" light. The green object will, therefore, appear brightest, the red object somewhat less bright, and the blue object relatively much darker.

A yellow, having only a single sharp absorption edge, is very bright. A yellow object usually reflects even more red light than a red object, and much more green light than a green object.

As a result of measurements of the light transmission of a number of colored gelatin filters, it was found that

Red filters	transmit	about	75%–80%	of red light
Green filters	"	"	33%	of green light
Blue filters	"	"	12%	of blue light
Yellow filters	"	"	85%	of yellow light

Similarly a bright scarlet printing ink reflected over 80% of red light, while the brightest light blue ink obtainable, reflected only 40% of blue light.

This variation in the reflecting power of differently colored objects is of the greatest importance in three-color reproduction.

CHAPTER II

THE SENSITIVENESS OF THE EYE AND OF PHOTOGRAPHIC MATERIALS TO COLORED LIGHT

WE have seen that the eye distinguishes light of different wave lengths, because of the different color sensations which light of different wave lengths produces in the brain; thus, a ray of light containing waves of a length of 460 mμ would be called violet, while if the waves were of the length of 650 mμ, the resultant impression on the eye would be said to be deep red. But the sensitiveness of the eye is not the same for waves of different lengths, and if we attempt to represent in monochrome the spectrum of sunlight as it appears to the eye, it will look something like fig. 9, the

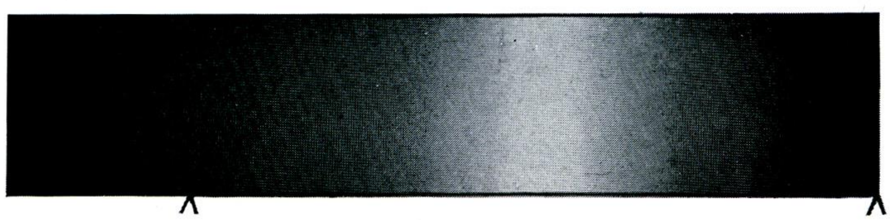


FIG. 9. THE LUMINOSITY VALUE OF THE SPECTRUM AS IT APPEARS TO THE EYE

green light appearing brightest, and the yellow, orange, and red light on one side, green, blue-green, and blue on the other appearing progressively darker until the violet appears very dark, and the visible spectrum ends.

The eye cannot perceive at all waves below 400 mμ, which are known as ultra-violet light; neither can it perceive rays which are above 700 mμ, so that to these we must regard the eye as insensitive. The eye is very little sensitive to the extreme violet rays between 400 and 450. The blue affects it more, and appears, as we say, bright. Between 500 and 600 the green appears as the brightest part of the spectrum; above 600 we have the bright reds, but the intensity rapidly falls off as the waves get longer, until beyond 700 we see practically nothing. We may also draw a curve showing the sensitiveness of the eye to the spectrum. This curve, shown in fig. 10, has a maximum at about wave length 554, but this only holds for intense light. As the intensity of the light diminishes, not only does the eye see less, but its relative sensitivity to the colors changes somewhat, shifting towards the blue. In fig. 10, A is the visibility curve of the average normal human eye at normal or high intensity; B is the visibility function of the human eye at low intensity levels. This shift is what is known as "Purkinje's Phenomenon." The explanation offered for it by Professor Schaum is sufficiently interesting and little known to be worth repetition. It is known that the retina consists of rods and cones, of which the cones are considered to be color-sensitive, and the rods color-blind. In the part of the retina exactly opposite

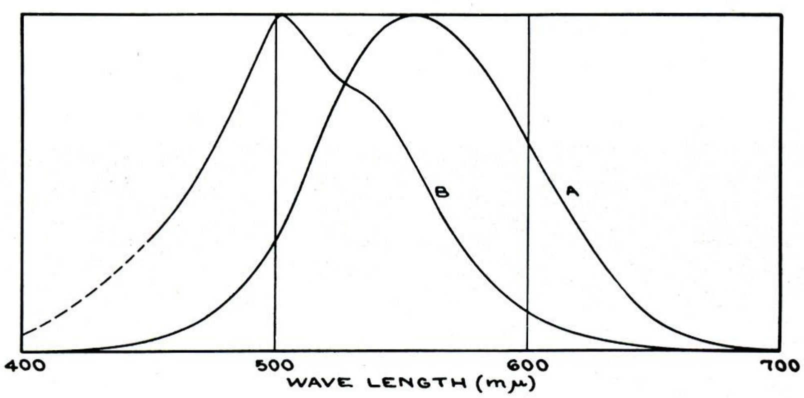


FIG. 10

the center of the pupil there is a small depression which contains no rods, but only cones, and here it is found that the Purkinje phenomenon is non-existent, so that the intensity maximum remains constant. We may conclude that the color-sensitive cones alone display no Purkinje phenomenon, and that the phenomenon is due to the association of these cones with the color-blind rods. It is found that the sensitivity curve for this region containing only cones is identical with the curve of sensitivity for great intensities of light, so that this is the curve of the cones. On the other hand, since the rods are much more sensitive to feeble intensities of light than the cones, as is shown by the fact that the sense of light remains after color can no longer be distinguished, the sensitivity curve of the rods will correspond with the curve for minimum intensity; so that for minimum intensity, the sensitivity curve is due to the rods alone, and as the intensity grows, the curve is more and more influenced by the cones, until with maximum intensity the curve of sensitivity is almost entirely determined by the cones.

It is for the reason that in very weak lights the eye has a maximum sensitiveness to a particular color, namely, a green, that the safelights supplied for use in the darkroom, when panchromatic materials are handled, are of this green color. The plate is sensitive to all colors, but an amount of green light can be used, if discretion is shown, that is sufficient to see by, without too much danger of fogging the plate, whereas if a red were to be chosen, so much more would have to be used to make objects visible, that the panchromatic material would inevitably be fogged.

Just as the eye is unequally sensitive to light of different colors, so a photographic film or plate is unequally sensitive to light of different colors. If we photograph the sunlight spectrum on ordinary photographic materials, we shall get the result shown in fig. 11.

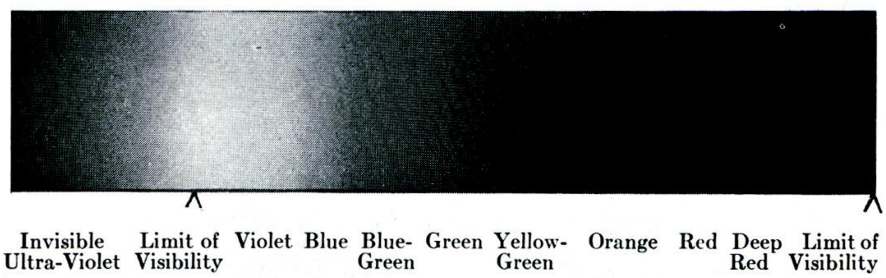


FIG. 11. THE LUMINOSITY VALUE OF THE SPECTRUM AS IT APPEARS TO AN ORDINARY FILM OR PLATE

It will be seen that the sensitivity of photographic materials to different colors differs very markedly from that of the eye. The eye can see waves of no shorter length than 400 mμ: photographic materials can see very much shorter waves, and can detect light which is quite invisible to the eye, this light being usually called ultra-violet, because it is beyond the violet. Also, the maximum of sensitivity of an ordinary film or plate is in the violet, and all the red, orange, and nearly all the green light is invisible to it. That is to say, it perceives objects only by the blue and violet light which they reflect, and this is a grave fault in the material when regarded as an instrument for perceiving and recording colored objects, because the record which it makes of colored objects differs entirely from that which the eye makes.

For many years photographers were so accustomed to the incorrect rendering of colored objects in monochrome which is given by ordinary photographic plates, that a kind of photographic convention was set up in their minds, so that a picture of a landscape in which grass is rendered as a dark patch, and a blue sky is almost white paper, was accepted without any feeling of its incorrectness; the more experienced a photographer, indeed, the more fixed this convention became, so that photographs taken under conditions which correctly reproduce the luminosities of the subject may sometimes appear over-corrected to a worker who has become accustomed to a "photographic rendering," and in whose mind the reproduction of a scarlet as dead black would raise no question whatever.

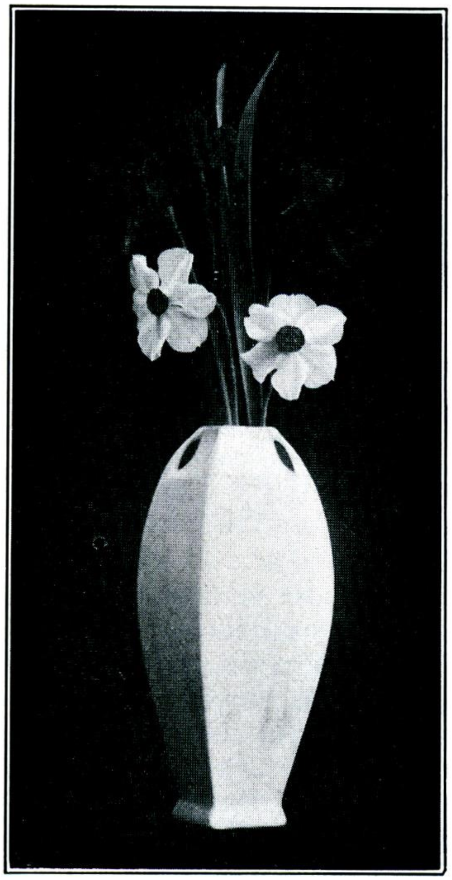


FIG. 12. DAFFODILS AND NARCISSI ON ORDINARY PLATE

Recently, however, many photographers have become more critical in this respect, and it is now generally recognized that, so far as possible, photographs should correctly translate into monochrome the luminosity values of color as seen by the eye.

Let us take a simple example of a colored object such as that presented by a yellow daffodil. If we photograph side by side a daffodil and a narcissus on an ordinary plate or film, we shall find that although to the eye the yellow daffodil appears almost as bright as the white narcissus, yet in the print, fig. 12 the daffodil appears much darker, the difference being especially marked in the more deeply colored trumpet of the flower. Clearly the light which is reflected from the daffodil is deficient in some essential constituent, which has much action on the photographic material, although its loss does not make the flower seem much darker to the eye. If we examine the light reflected from the flower by means of a spectroscope, it will at first sight appear that we have the same spectrum as we got at first from white light, but on closer inspection we shall see that while the green, orange, and red regions are fully present, the blue light is dimmed, and the violet light is almost completely absent. We

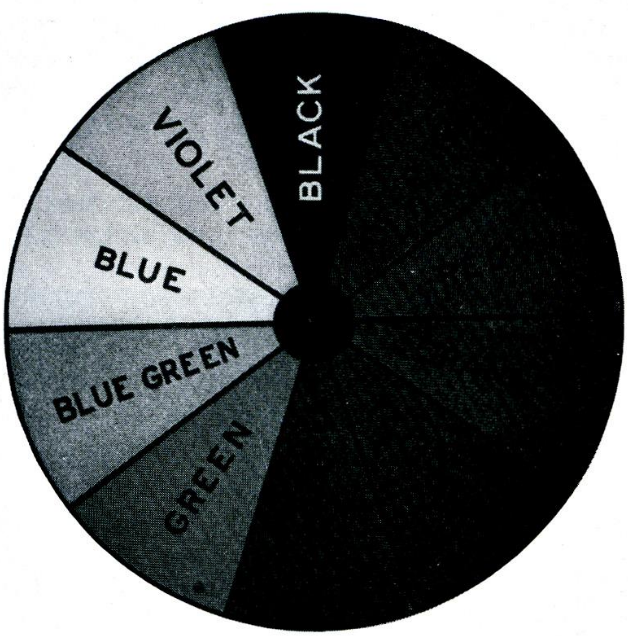


FIG. 13. COLORED CHART ON ORDINARY PLATE

thus see that the reason why the daffodil looks different from a white flower, appears "yellow" in fact, is that it fails to reflect all the constituents of white light, and absorbs the violet and blue constituents. These violet and blue constituents of white light are those which have a strong action upon a photographic plate, although to the eye they appear dark.

The frontispiece of this book shows a chart which is intended to represent the spectral colors both in hue and also approximately in brightness: the strong photographic action of the violet and blue rays, and the feeble action of the green, orange, and red rays is shown in fig. 13, which is a photograph of the frontispiece taken upon an ordinary fast plate. In this photograph the violet, blue, and blue-green patches, which are darkest to the eye, are reproduced light, while the rest of the chart appears dark.

The insensitivity of films or plates to the colors which are bright to the eye, and sensitivity to those which are dark to the eye is of much importance not only in commercial, but also in artistic photography; in landscape photographs, for instance, the grass, which because it absorbs the violet and blue rays and also some of the red rays, appears green, is always reproduced too dark, and white clouds are lost against the blue sky, although to the eye they appear much brighter, because the light from the blue sky is deficient in red rays, and these rays being bright to the eye, their absence produces a strong effect. To photographic materials, however, which are blind to the red rays, their presence or absence is indifferent, and consequently the blue sky and white clouds appear of nearly the same intensity.

It was found by Vogel in 1873 that, by treating plates with dyes, they could be given, besides their usual sensitivity, a

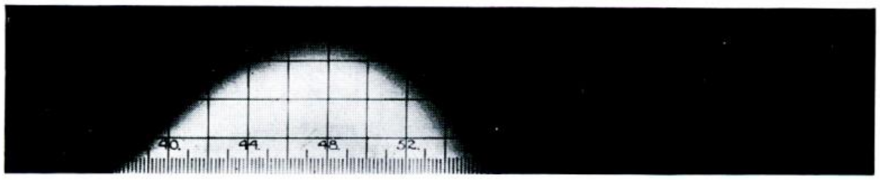
FIG. 14. PHOTOGRAPH OF THE SPECTRUM ON AN ORTHOCHROMATIC FILM

secondary sensitivity in approximately the region of the spectrum which those dyes absorb. Thus, if a film is treated with a solution of erythrosine, which absorbs the yellowish green, it will be sensitive to the yellow-green, besides being sensitive to the blue and violet. Films or plates which have been treated in this way are those which are known as "orthochromatic," the word implying that they can render objects in their true color values. These orthochromatic materials give a photograph of the spectrum of the type shown in fig. 14, and it will be seen at once, on comparing this with the appearance of the spectrum to the eye (fig. 9) that, although the orthochromatic film is better than the ordinary film, it cannot be described as at all comparable in sensitiveness with the eye. It has an enormous excess of sensitivity in the blue and violet, it has the sensitivity to the ultra-violet which the eye has not at all, it then has little sensitivity to the blue-green, a secondary maximum of sensitivity in the yellow-green, and an absence of sensitivity to the red. It may be assumed that if we take the blue to include the whole spectrum up to 500, the green to be the spectrum from 500 to 600, and the red from 600 upwards, that the sensitivity of the orthochromatic film or plate is distributed in the ratio of 20 parts in the blue, one part in the green, and none in the red. If we assume, for the sake of argument, that the eye sees the three parts of the spectrum as of equal intensity, then the orthochromatic material, besides the fact that it is not sensitive to the red, has only 1/20 of the sensitivity in the green that it would require to be equal in sensitivity to the eye.

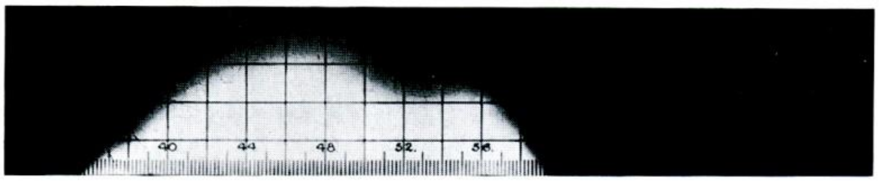
Nevertheless, orthochromatic films and plates are very useful in photographic practice, since, especially if filters are used, they enable a much more truthful rendering of green and yellow objects to be obtained than is possible with unsensitized materials. Verichrome film is an excellent example of an orthochromatic material which gives quite satisfactory results in practical photography.

In the early years of the twentieth century a number of new sensitizing dyes were discovered which made it possible to prepare photographic materials sensitive to the whole of the visible spectrum including the red, and in 1906 Wratten & Wainwright placed on the market a plate of this type under the name of the "Wratten Panchromatic Plate." The manufacture of these plates was undertaken by the Eastman Kodak Company in 1912 and before long panchromatic films of various types were placed on the market and the use of these materials has increased rapidly.

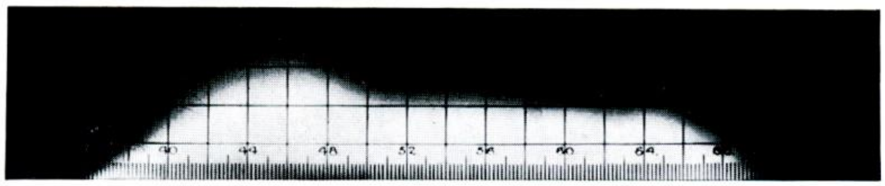
The Kodak Research Laboratories undertook an extensive investigation on the preparation of sensitizing dyes with the result that improvements in panchromatic plates and films were made from time to time, and, finally, in 1930 the discovery of entirely new sensitizers made it possible to introduce new materials of far greater general speed and sensitive-



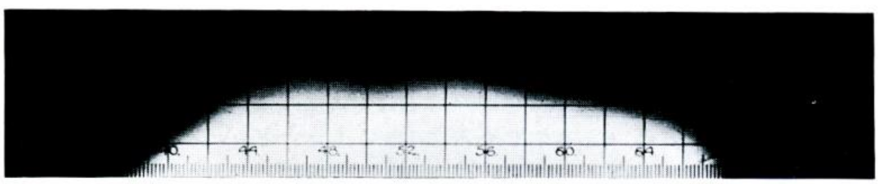
Ordinary



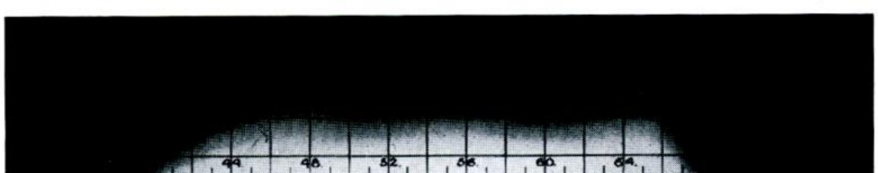
Orthochromatic



Panchromatic (Type A)



Orthopanchromatic (Type B)



Hyperpanchromatic (Type C)

FIG. 15. SENSITIVITY TO SUNLIGHT OF DIFFERENT TYPES OF PHOTOGRAPHIC MATERIAL

ness to color than anything previously known.

The panchromatic materials supplied by the Eastman Kodak Company are now of three types:

A. Materials of the same type as those made prior to 1931.

B. Materials of extremely high color sensitiveness corresponding approximately to the color sensitiveness of the eye. These may perhaps be termed "orthopanchromatic" materials.

C. Materials of high total sensitiveness with extreme sensitiveness to the yellow, orange, and red portions of the spectrum. These may be termed "hyperpanchromatic" materials.

The spectral distribution of sensitiveness to sunlight of these three types of panchromatic materials is shown in fig. 15, and to tungsten light in fig. 38.

The materials coming under Class A are:

Eastman Process Panchromatic Film
Commercial Panchromatic Film
Ciné-Kodak Panchromatic Safety Film

Materials of Class B are intended especially for the photography of colored objects and for use with filters. They are:

Wratten Process Panchromatic Plates
Wratten M Plates
Wratten Panchromatic Plates
Eastman Portrait Panchromatic Film

Materials of Class C are intended for use where the shortest possible exposure is required and especially for use with artificial light sources such as incandescent lamps. They are:

Eastman Supersensitive Panchromatic Film
Wratten Hypersensitive Panchromatic Plates
Supersensitive Aero Panchromatic Film
Ciné-Kodak Supersensitive Panchromatic Safety Film
Eastman Supersensitive Panchromatic Motion Picture Negative Film.

In order to attain the same relative sensitivity as the eye, it is necessary even with the most sensitive panchromatic materials, to use absorbing color filters, and it is the consideration of these color filters, and of the effect which they will have on the total sensitivity, which must now be undertaken.

CHAPTER III

COLOR FILTERS

If we photograph a daffodil and a narcissus on a panchromatic plate or film, we shall obtain a result, fig. 16, which

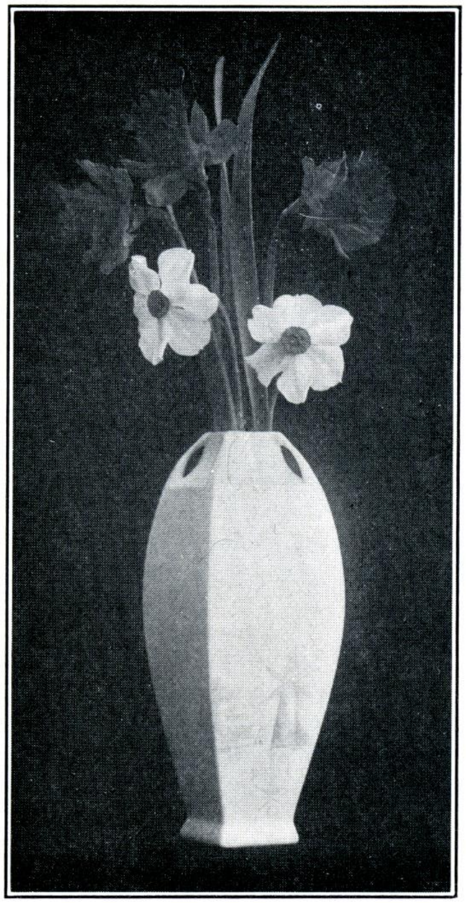


FIG. 16. DAFFODILS AND NARCISSI ON PANCHROMATIC PLATE WITHOUT FILTER

approximates much more closely to the truth than did that which we got with the ordinary plate, fig. 12. It will be noticed that in order to photograph the flowers they were placed in a vase; this was a white vase with a blue landscape painted upon it, and although the daffodils appear bright in the photograph, as they do to the eye, yet the blue design on the vase is almost invisible, although to the eye it stands out most distinctly.

A comparison of fig. 17 with fig. 9 will show the reason for this; the panchromatic plate is sensitive to green, orange, and red light, just as the eye is, but it is still very much too sensitive to the blue and violet light, and to the invisible ultra-

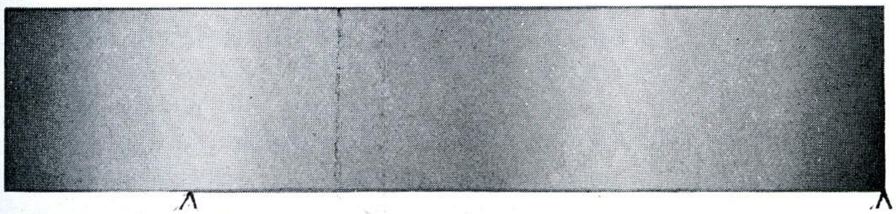


FIG. 17. THE SPECTRUM PHOTOGRAPHED ON A PANCHROMATIC FILM OR PLATE

violet rays. Owing to the great intensity of these blue, violet, and ultra-violet rays in sunlight, most of the photographic action, even on a panchromatic plate, is produced by them, so that the advantage gained by sensitizing the plate to the

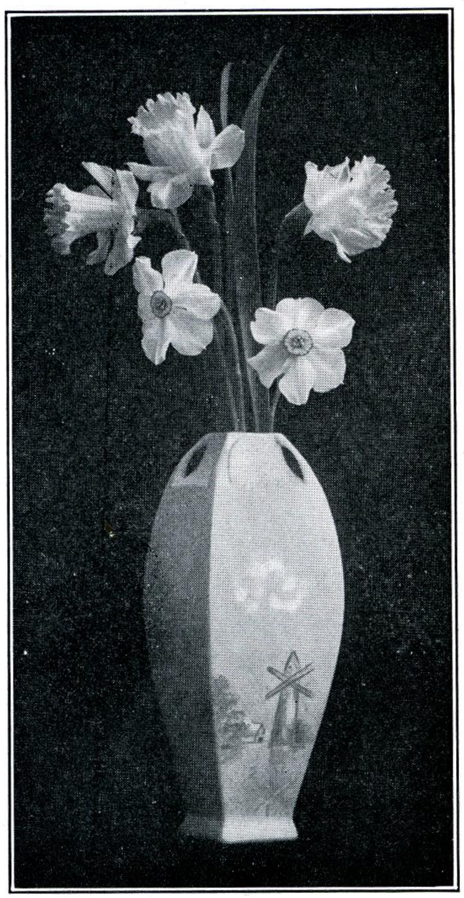


FIG. 18. TAKEN ON A WRATTEN PANCHROMATIC PLATE WITH FILTER

green and red rays is largely lost by their effect being drowned by the violet and ultra-violet rays. With artificial light (excepting mercury vapor and enclosed arc) the more actinic rays are weak, and panchromatic material gives at once manifestly better results than ordinary material.

In daylight we can secure a similar result if we modify the light reaching the film or plate by passing it through a light filter (usually attached to the lens), which removes all the ultra-violet light and as much of the blue and violet light as is necessary. *Such a filter is called an "orthochromatic" filter.*

Fig. 18 shows a photograph of the daffodils and narcissi in the vase taken through such a filter on a Wratten panchromatic plate, and it will be seen that not only are the flowers rendered correctly in their relative tone values, but also the design on the vase is clearly defined, as it appears to the eye.

Orthochromatic filters are designed to remove the ultra-violet, and as much of the violet light as is necessary to compensate for the extra sensitivity of the material to those rays.

Now in removing this light, the orthochromatic filter increases the necessary exposure, because if we remove those rays to which the material is most sensitive, we must compensate for it by exposing for a longer time to the action of the remaining rays, and the amount of this increased exposure will clearly be dependent both on the proportion of the violet and the blue rays, which are removed by the orthochromatic filter, and also upon the sensitivity of the material for the remaining rays (green, orange, and red), which are not removed by the filter.

The number of times by which the exposure must be increased for a given filter with a given material is called the *multiplying factor* of the filter, and this *depends upon the material with which it is used, and the light source.* It is meaningless to refer to filters as "two times" or "four times" filters.

Since it is always desirable that we should be able to give as short an exposure as possible, what is required in a filter, is that it should produce the greatest possible effect with the least possible increase of exposure, so that a filter will be considered most efficient when it produces the maximum result with the minimum multiplying factor.

The ideal filter will, therefore, absorb *all* the ultra-violet light, and as much as is needful of the violet and blue light, but will transmit all the orange and red light which falls upon it. If a filter transmits any of the ultra-violet light, which it should absorb, or absorbs any of the green, orange, or red light, which it should transmit, then it will be more or less inefficient from that cause. An inefficient filter will, therefore, have a high multiplying factor compared with the correction which it will give, while, on the other hand, a low multiplying factor for a filter may be due simply to insufficient correction. An efficient filter will have a low multiplying factor but will also give good correction.

For orthochromatic work, all filters which are not a clear yellow should be disregarded; if the filter is laid down on a sheet of white paper, it should appear a bright or pale yellow, according to its depth, but it should not appear brown, and if it does appear brown, then it will be unsatisfactory in correction, and will require an unnecessarily long exposure.

Nor is it sufficient for an orthochromatic filter to be yellow, for a yellow filter may still be inefficient, and the great criterion as to the efficiency of an orthochromatic filter, which is clear yellow in color, and which therefore absorbs only a minimum amount of the rays which it should transmit, is that the filter should completely absorb the ultra-violet light.

We have seen that photographic materials are extremely sensitive to ultra-violet light. Now some substances which are quite without color to the eye strongly absorb ultra-violet light; Chinese white, for instance, which is often used by artists for the highlights in drawings, and which appears quite white to the eye, absorbs ultra-violet light, so that when the drawings are photographed by an arc lamp upon wet collodion plates, which are chiefly sensitive to the ultra-violet, the

Fig. 19. Diagram Painted in Chinese White on White Card

Chinese white appears a dirty gray. Fig. 19 shows such a photograph of a diagram painted in Chinese white on a white card, the diagram being almost invisible to the eye but photographing as shown.

Moreover, ultra-violet light is far more easily scattered by traces of mist in the atmosphere than visible light is, so much so, that when Professor R. W. Wood took photographs by means of the ultra-violet light only, using a special lens and filter, he found that if one could see the rays which he was using, even the clear atmosphere of the United States would appear to be continually filled with mist; so that the well-known photographic haze, which so often spoils the distance in photographs, is due to the ultra-violet light, and our orthochromatic filter must be adjusted to cut out all of the ultra-violet light, and just so much of the violet light as is necessary to produce exactly the effect of "atmosphere" which is seen by the eye. If too much violet light is removed by the filter, all effect of atmosphere will be lost; but this effect, known as "over-correction," will be discussed later.

Some yellow dyes, while removing violet light quite satisfactorily, transmit a great deal of ultra-violet light, and it is indeed possible to use such dyes to produce an anti-orthochromatic filter; that is, a filter which will exaggerate, instead of diminishing, the false tone rendering to which photographs are prone.

The dyes which were used originally for the making of orthochromatic filters, while they gave clear yellow films and were stable to light, were unsatisfactory in that, except when very strong, they transmitted more or less ultra-violet light, and only the introduction of new dyes made it possible for the first time to prepare orthochromatic filters of almost ideal efficiency, combined with great stability to light. Such filters are prepared by us under the registered name of "K" filters.

To illustrate the advance which the introduction of these filters marked there is shown in A and B (fig. 20) two photographs of the spectrum produced by the light of an electric

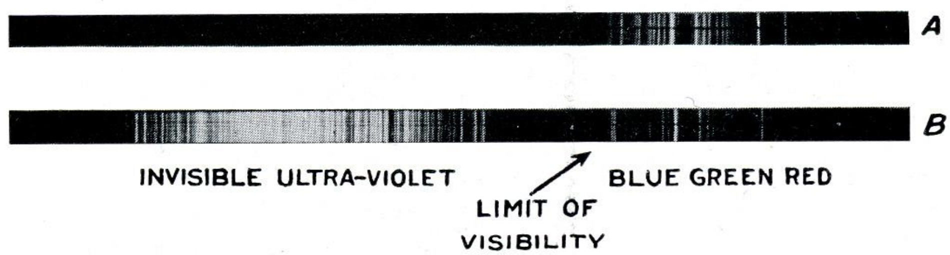


FIG. 20. (*A*) K FILTER (*B*) OLD FILTER

arc burning between iron poles, the first taken through the K2 filter, the second through one of the best of the earlier filters, which is of almost the same depth to the eye, and which requires about the same increase of exposure. It will be seen that while the green and red portions of the spectrum are as bright through the K2 filter as through the older one, the violet portion is much fainter and the ultra-violet is altogether absent, while the old filter is shown to transmit a very considerable amount of ultra-violet light.

Since the use of a filter is to compensate for the excess sensitivity of even orthochromatic or panchromatic materials to the violet and ultra-violet rays, it follows that materials of different degrees of sensitivity will require filters of different kinds to produce the same effect as is seen by the eye. In the first place it is clear that no matter what filter be used, orthochromatic materials which are not sensitive to red can never render tone values as they appear, from the very fact that the materials are red blind and that, except in a few unfortunate cases, the eye is not. The most perfect filter, in fact, with such a plate can only give a result similar to that seen by a "color-blind" person. But even so it is not a matter of indifference what filter is used with a non-red-sensitive orthochromatic material. If the filter be too strong, the photograph will appear over-corrected. This over-correction will show itself chiefly in the manner previously referred to, that is, the atmosphere in the distance will be lost; but also other unpleasant effects may be observed. In landscape, the sky may appear too dark (this is also the effect of under-exposure) and light grass may appear almost white; while in flower photography, yellow flowers may be indistinguishable from white ones. These defects are produced by a filter which too completely removes the violet and blue light, instead of simply diminishing them to the required extent.

Provided, however, that a filter is satisfactory in this respect and does not produce over-correction, while at the same time it completely removes ultra-violet light, little is gained by adjusting a filter to a special orthochromatic material, and the K1, K1½, and K2 filters, which have almost ideal efficiency, and are free from any tendency to produce over-correction, will give results as satisfactory as can possibly be obtained on materials which are not sensitive to red.

With panchromatic materials the filter to be chosen for the correct rendering of the brightness of colors will depend upon the material used as well as upon the nature of the source of light. In this present discussion it will be assumed that the photographs are taken by sunlight, consideration of the use of artificial light sources being left to Chapter VI.

With the new materials of the orthopanchromatic and hyperpanchromatic types filters which give full correction require only a moderate increase in exposure while very light filters will give quite satisfactory results.

From the point of view of correction, it is of as great importance that the film or plate should be strongly sensitive to the green, orange, and red light, as that the filter should be efficient and of sufficient depth, so that panchromatic material used without a filter at all, will, in most cases, give results superior to the much less color-sensitive orthochromatic material used with a filter increasing the exposure four or five times. Moreover, the correcting action of such weak filters increases with the color-sensitivity, while the more color-sensitive the material, the lower the multiplying factor of the filter. Consequently, for satisfactory orthochromatic work the first essential is that the material shall be of the right type, and then the choice of filter must be governed largely by the exposure which can be given.

With the orthopanchromatic materials full correction for sunlight is obtained by the use of the K2 filter, so that this filter is ideal for use with Wratten Panchromatic Plates or Eastman Portrait Panchromatic Film (see fig. 21).

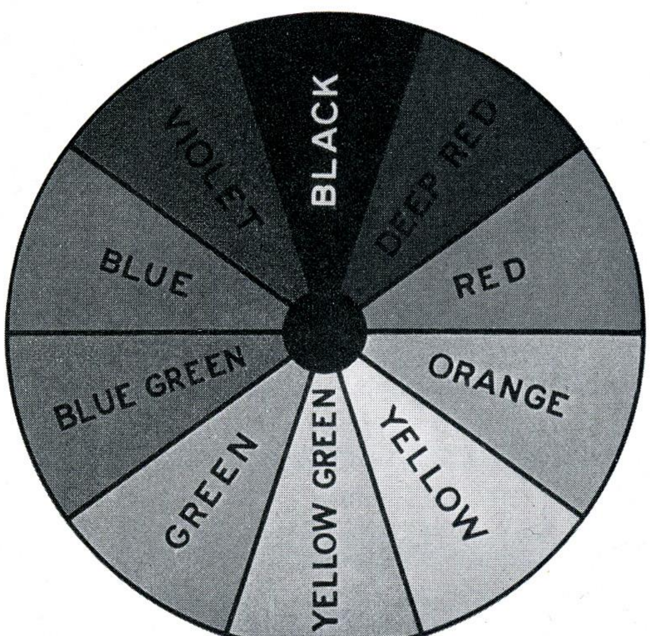


FIG. 21. COLOR CHART ON WRATTEN PANCHROMATIC PLATE WITH K2 FILTER BY SUNLIGHT

This filter is also that most suitable for use with the older types of panchromatic materials; the correction is not quite so good, there being some under-correction in the green, and the increase of exposure required is greater. The K3 filter is now obsolete; it was introduced in 1907 for use with Wratten Panchromatic Plates, but improvements in sensitizing have made it unnecessary and, indeed, undesirable. The extreme sensitiveness to red of the hyperpanchromatic materials makes it necessary to use a filter which will absorb some red if these materials are to be used where correct reproduction is required. For this purpose a new filter (X1) has been introduced with which the Wratten Hypersensitive Panchromatic Plate and other materials of the hyperpanchromatic type (see p. 25) can be used. For use with artificial light sources other special filters are provided (see Chapter VI).

Where short exposure is of greater importance than full correction, the K1 filter should be employed; the latter requires only half the exposure needed for the K2 and notably improves the color rendering as compared with that given without it. This filter is also largely used for hand camera work, and the advantage obtained, even with such a weak filter, is very manifest in the results.

In some classes of landscape work it is desirable to produce over-correction; in survey or aerial photography, for instance, where the utmost clearness and detail are desired, rather than a pictorial rendering, it is necessary to remove all haze and atmosphere, and for this purpose, a strong yellow filter, such as the Wratten "G" or "Minus Blue" No. 12 filter, is best.

During the war a new series of filters was made, prepared from a new dye which was discovered in our Research Laboratories and was named Eastman Yellow. One of these filters was adopted by the U. S. War Department under the name of Aero filter No. 1, and this filter is peculiarly suitable for aerial photography.

For the photography of cloud forms against a blue sky a red filter may be used with great advantage, and the "A" filter is suitable for this work. The results obtained show, of course, a greatly exaggerated contrast, but if the form of the clouds is all that is required, such an exaggeration is not a disadvantage, though we should not recommend the use of so deep a filter in pictorial work.

Contrast filters differ from orthochromatic filters in that it is not desired to obtain in them a gradually increasing absorption, but as sharp a transition as possible between the region of absorption and that of transmission.

A red contrast filter (such as the "A" filter), for instance, when examined in a spectroscope will be seen to give a spectrum like fig. 22 in which the absorption is complete up to the point where the yellow-green passes rapidly through yellow into orange, and at this point the absorption falls suddenly to almost nothing, practically all the orange and red light being transmitted.

A useful strong yellow contrast filter is the "G" filter. This filter absorbs all the ultra-violet, violet, blue, and blue-green light, transmitting the remainder.

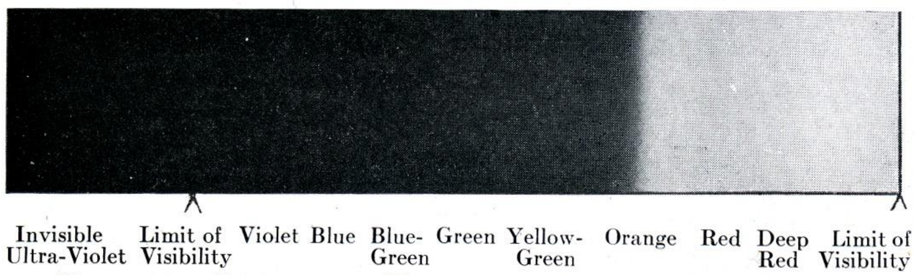
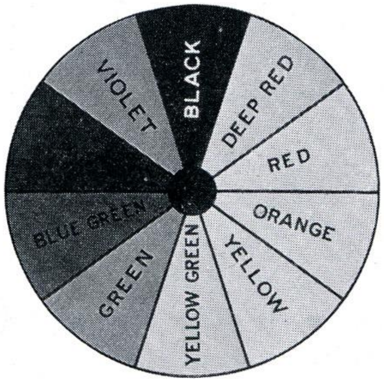


FIG. 22. SPECTRUM TRANSMITTED BY "A" FILTER

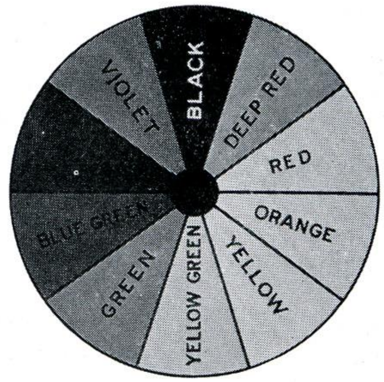
Other contrast filters are as follows:

Filter	Color	Use
A.	Red.	Tricolor work, Mahogany Furniture, Cloud photography
B.	Green.	Tricolor work . . . .
C.	Blue.	Tricolor work . . . .
E.	Orange.	Two-color work, Contrast filter
F.	Strong Red.	Copying Blue Prints, Screen-plate Analysis . .
G.	Yellow	Telephotography, Furniture General Contrast . .
L.	Violet	General Contrast . .
N.	Strong Green.	General Contrast . .
P.	Blue-Green	Two-color work, Copying Typewriting . . .
R.	Deep Red.	Contrast . . . .
Aesculine.	Colorless.	Photography on Process Film of drawings containing Chinese White

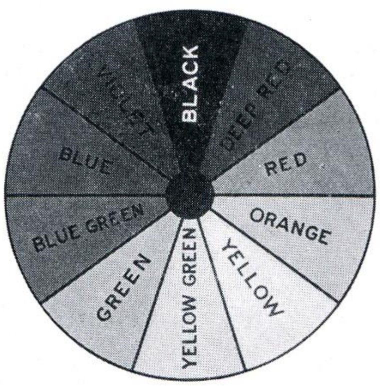
The results obtained by photographing the frontispiece through some of these contrast filters are shown in fig. 23.



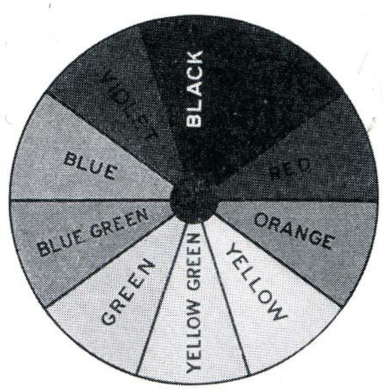
"F" Filter



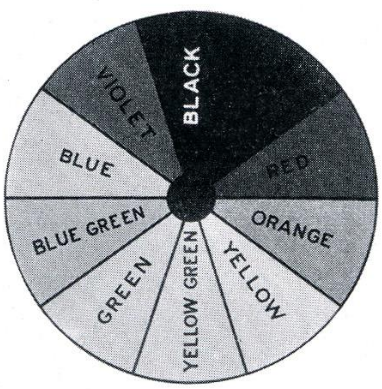
"A" Filter



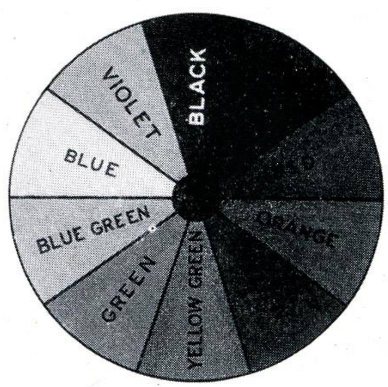
"G" Filter



"B" Filter



"P" Filter



"L" Filter

FIG. 23. COLOR CHART REPRODUCED THROUGH VARIOUS WRATTEN CONTRAST FILTERS

In addition to these contrast filters, special "M" filters are manufactured for use in photomicrographic work, and these are particularly recommended in conjunction with the Wratten "M" Panchromatic plate for photomicrography. A description of these filters, instructions for their use, and multiplying factors for them when used with the "M" plate for daylight and various artificial light sources, are given in our booklet entitled "Photomicrography."

A complete list of Wratten filters, over one hundred in number, with diagrams of their absorption spectra, is given in the booklet "Wratten Light Filters" published by us.

CHAPTER IV

THE MULTIPLYING FACTORS OF FILTERS

SUPPOSE that we have a filter which has a sharp absorption—that is to say, which cuts a clean section out of the spectrum, passing only light between two definite wave lengths, and without any absorption of that light—then, if we wish to find the multiplying factor of this filter, we must consider it in relation to the sensitivity curve of the material used, as well as the nature of the light source employed for photography.

It will be convenient first to consider a filter which does not transmit light below 500 mμ, *i.e.*, which absorbs the whole of the ultra-violet and blue-violet, but does not absorb any

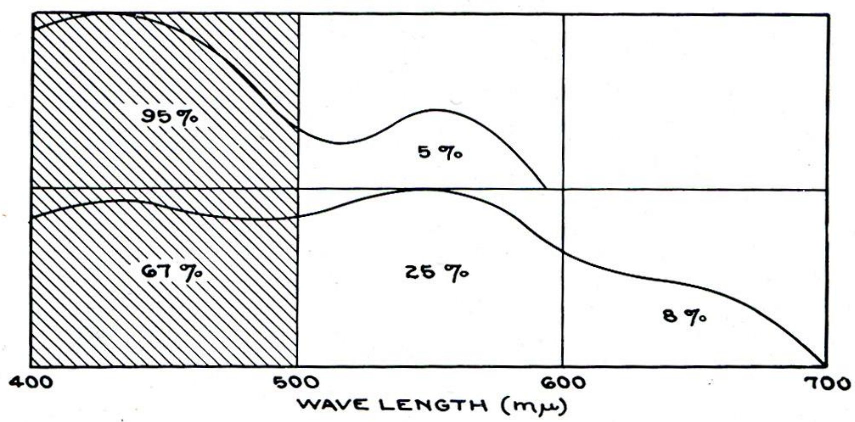


FIG. 24. SHARP-CUT FILTER ON ORTHOCHROMATIC AND PANCHROMATIC MATERIALS

green or any red. This filter will be a bright yellow in color, yellow being, as we have seen, made up of green light and red light—that is to say, yellow being simply an absorption of blue. Consider the effect of this on an orthochromatic film which has 95 per cent of its sensitivity in the blue and 5 per cent in the green, it being assumed that sunlight is being used. The yellow filter will remove all the blue light, *i. e.*, 95 per cent of the active light, and it will increase the required exposure 20 times, so that its multiplying factor is 20.

Now consider the same filter to be used with an orthopanchromatic material under the same conditions. With this 67 per cent of the whole sensitivity is in the blue and 33 per cent in the red and green. The filter will then remove 67 per cent of the active light, leaving only 33 per cent to act; it will increase the exposure 3 times. This example shows at once the intimate relation between the film and the multiplying factor of the filter. It is illustrated diagrammatically in fig. 24 which gives the logarithmic response curves (*i. e.* log of the product of actual sensitivity at a given wavelength by the relative amount of energy at that wavelength) for D. C. Ortho plates (upper) and Wratten Panchromatic plates (lower). The filter is Wratten No. 12.

Take now a filter cutting the spectrum sharply at 550. This filter will be bright orange in color. It transmits all the yellow-green, orange, and red light. It absorbs the blue-violet and blue-green light, *i.e.*, adopting our convention as to the division of the spectrum—it transmits the red and half the green, and absorbs the blue and half the green. The effect of this on the ordinary orthochromatic film is to remove the blue and blue-green sensitivity, 97.5 per cent of the whole sensitivity of the film when photographing by sunlight; the yellow-green region of sensitivity represents the other 2.5 per cent of the sensitivity of the film. The yellow-green is transmitted by the filter undiminished. The filter will therefore increase the exposure 40 times.

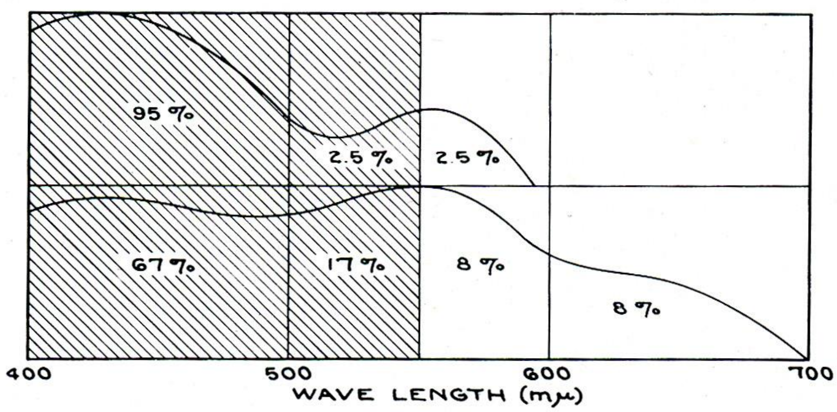


FIG. 25. SHARP-CUT ORANGE FILTER ON ORTHOCHROMATIC AND PANCHROMATIC MATERIALS

On orthopanchromatic material, however, the matter is different; 67 per cent of the sensitivity of the film is in the blue, and is removed by the filter, 25 per cent is in the green, and part of this is removed by the filter; so that the sensitivity left is 8 per cent, due to the undiminished red-sensitivity, and 8 per cent, being part of the green sensitivity—the total residual sensitivity, therefore, being 16 per cent of the original sensitivity, and this filter will, on the Wratten Panchromatic Plate, increase the necessary exposure 6.7 times.

This is illustrated in fig. 25, the filter being Wratten No. 22, and other conditions being the same as in fig. 24. Again, consider a filter cutting the spectrum at 600—that is, transmitting all the red, but absorbing all the blue and all the green. The ordinary orthochromatic material has no appreciable sensitivity in the red, and therefore could not be used in practice with such a filter. The Wratten Panchromatic Plate has 8 per cent of its total sensitivity to sunlight in the red, and consequently this red filter will, on that material, have a multiplying factor of 12.5.

Let us now examine into the multiplying factor of a filter which will give approximately correct reproduction of red, green and blue, as seen by the eye. Such a filter will have a gradual cut, rather than a sharp cut such as we have already discussed. Figure 26 illustrates the determination of the factor of the K2 filter on D. C. Ortho and Wratten Panchromatic Plates, the illumination being sunlight quality.

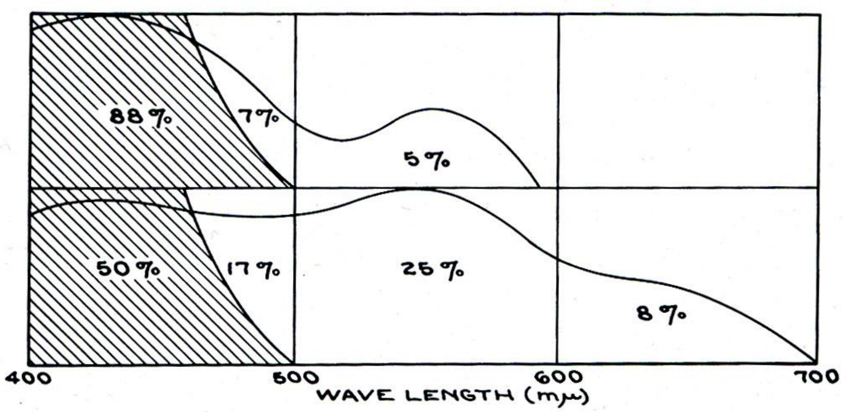


FIG. 26. ORTHOCHROMATIC FILTER ON ORTHOCHROMATIC AND PANCHROMATIC MATERIALS

The orthochromatic material has no red sensitivity. Five per cent of its sensitivity is in the green and 95 per cent in the blue. Of this blue sensitivity 88 per cent is removed by the filter, leaving 7 per cent in the blue which, together with the 5 per cent in the green, gives 12 per cent. The factor is therefore 8½. Since the orthochromatic material has no sensitivity in the red, it is incapable of giving correct orthochromatic rendering. The use of the K2 filter, however, gives results which are much superior to those obtained without a filter.

The panchromatic material has 8 per cent of its sensitivity in the red, 25 per cent in the green, and 67 per cent in the blue. The K2 filter removes 50 per cent of the sensitivity, leaving 17 per cent in the blue which, together with the unaffected green and red sensitivity, gives 50 per cent. The factor is therefore 2, and good orthochromatic rendering is obtained.

The filter factor is dependent not only on the sensitive material but upon the light source used. Let us consider the sharp cut filter shown in fig. 24, but let us assume that instead of being used with sunlight, it is employed with the panchromatic material for photography with the light given by high power incandescent tungsten lamps.

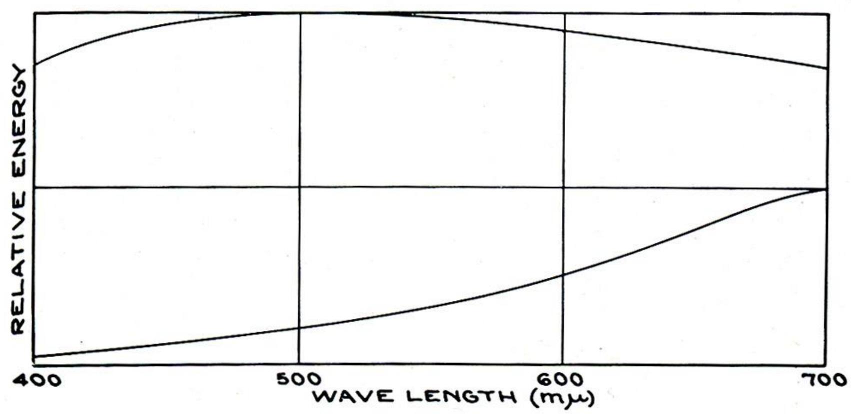


FIG. 27. DISTRIBUTION OF ENERGY IN NOON SUNLIGHT (ABOVE) AND IN THE LIGHT FROM A TUNGSTEN LAMP AT 3000° K (BELOW)

The tungsten light has a much greater part of its intensity in the red and green parts of the spectrum as compared with the blue than has sunlight. This is illustrated in fig. 27, which shows, in the upper curve the spectral distribution of energy in the radiation received from noon sunlight, and in the lower curve the distribution for radiation emitted by a high efficiency (3000°K) incandescent tungsten lamp.

Consequently, whereas with daylight only one-third of the exposure of the panchromatic film is produced by the green and red parts of the spectrum, with the tungsten light one-half of the exposure is produced by those parts of the spectrum which are transmitted by the filter.

This sharp cut filter, therefore, which with sunlight will require a three-fold increase in exposure when panchromatic film is used, with tungsten light will only require a two-fold increase. Moreover, the change in light source will also involve a change in the filter required to produce correct reproduction if we adhere to our criterion; that is, if the reproduction is to be correct as viewed by daylight.

In fig. 28, the upper curve is the logarithmic response curve for a Wratten Panchromatic Plate when used with a high efficiency tungsten lamp. The sharp cut filter is Wratten No. 12, the factor in this case being 2.0. The lower curve illustrates the response of the same plate when used with radiation of sunlight quality. The filter factor (no. 12) is equal to 3.0.

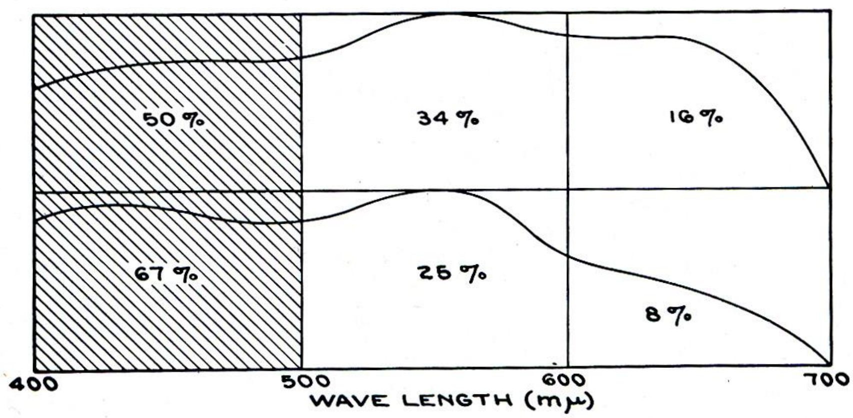


FIG. 28. SHARP CUT FILTER WITH PANCHROMATIC FILMS USED WITH SUNLIGHT (BELOW) AND TUNGSTEN LIGHT (ABOVE)

With tungsten lamps *almost full correction* upon the Wratten Panchromatic Plate or Eastman Portrait Panchromatic Film is obtained by the use of the K1 filter.

The following table of approximate filter factors is given for the most commonly used filters and for three different light sources. Filter factors vary, of course, with the particular batch of material used and must be modified as is indicated by experience.

A point of some interest, which is occasionally referred to in the photographic press, is the multiplying factor of two filters used, the one on the top of the other. It is often put as follows: Suppose we have two filters—a three times filter and a five times filter—how much will they increase exposure if used together? The increase can be found neither by adding nor multiplying the separate factors of each filter, but the answer must depend entirely on the nature of the filters, and somewhat on the film and light source. For instance, one might be a deep violet filter, and the other a strong yellow, in which case it might be impossible for the two combined to let

FILTER FACTORS

Filter	*Panchromatic* Type A Sunlight and White Flame Arc	*Panchromatic* Type A Incandescent Tungsten	*Panchromatic* Type B Sunlight and White Flame Arc	*Panchromatic* Type B Incandescent Tungsten	*Panchromatic* Type C Sunlight and White Flame Arc	*Panchromatic* Type C Incandescent Tungsten	*Orthochromatic* Sunlight and White Flame Arc	*Orthochromatic* Incandescent Tungsten
K1	2½	2	1½	1½	1½	1½	4	3
K2	3	2½	2	1½	2	1½	8	5
G	4½	3	3	2	3	2	24	14
E	8	4	8	3	4	2½	..	..
A	10	5	10	5	4½	3	..	..
F	20	10	18	9	10	5	..	..
B	12	12	6	6	8	8	24	16
C5	4	8	6	12	6	12	3	4
X1	5	4	3½	3	4	4	..	..
X2	6	5	4	3½	5	5	..	..

through any light. On the other hand, with a panchromatic film or plate, if one were a K2 filter and the other a K1 filter, the effect would be negligible, and the multiplying factor (and correction) of the combined filter would be the same as that of the first one used alone.

If the material is to be taken as the common orthochromatic material, and the filters are clear yellow filters, one being a K1 filter and the other a filter between K1 and K2, the combined multiplying factor would be about 7.

While this paragraph may serve to inform some who have puzzled over the question, it is not to be taken as recommending the use of two filters together. Such a procedure is not at all desirable, especially on optical grounds.

A table of filter factors for orthochromatic and the three types of panchromatic materials is given above for the most commonly used filters. The factors for the panchromatic carbon arc are identical with those for incandescent tungsten, with the exception that the factors with the green filters (B, X1 and X2) are somewhat higher with the arc.

CHAPTER V

THE RENDERING OF COLOR CONTRASTS

IT should be clear by now that by orthochromatic photography we intend to imply the use of a fully color-sensitive material, such as a panchromatic plate or film, combined with a filter of necessary transmission, to give approximately the same tone-rendering as that seen by the eye. It must be remembered in the first place that, to the eye, objects are picked out from their surroundings by contrast, and this contrast may be of two kinds; it may be tone contrast, that is the contrast of light and shade, or it may be color contrast.

In the case of tone contrast, if we imagine ourselves to be dealing with a monochromatic scene, of a color within the limits of sensitivity of the material used, any film or plate will render tone contrast of considerable range as seen by the eye; but in the case of color contrast the question will require more careful thought. Suppose that we have two objects, the one contiguous to the other, and separated from each other to the eye purely by their color contrast, such as a green field containing a patch of red. The contrast between them is marked to the eye, although the tone contrast is very nearly nothing, that is to say, the two are of much the same visual luminosity.

If we photograph them upon an ordinary material both are black to it, and we get our contrast represented by one uniform field of black; the color contrast has disappeared, and we have a totally unsatisfactory rendering of that which we are photographing. If, however, we photograph them upon a green sensitive material, then the green will be distinguished from the red as brighter, and we shall get a certain degree of contrast of a kind, but if we photograph them upon an orthopanchromatic material with a K2 filter, so that we get a rendering of both colors in their true luminosity values to the eye, the contrast again disappears, and the colors are represented by a uniform field of gray.

What then must we do to obtain a satisfactory rendering of this color contrast? Clearly it is not possible to render the color contrast accurately in monochrome, so long as we retain the rendering of correct luminosity values for our colors, and consequently we must sacrifice the correct rendering of either the red or the green. If we use a paler filter or a green filter, the green will appear the brighter and the red the darker;

if we use a deep orange filter, the red will be brighter, the green darker; and which we shall use must be governed by circumstances.

As a general rule, if we must correct wrongly for the rendering of color contrast, it is usually better to over-correct towards the red, since red is a strong color, while green is a weak. For example, in a field of grain of a deep yellow color, we may have poppies standing out which are nearly as bright as the grain, and it is necessary to decide whether we shall render them as brighter or as darker than the grain. Probably on an actual measurement of luminosities they would be a little darker than the grain, but remembering the way in which the strong red attracts the eye, it would seem that a more faithful rendering would be given by over-correcting and rendering the poppies as brighter than the grain.

Again, the top of a yellow straw stack against a deep blue sky may give a result with perfect orthochromatism where the stack is indistinguishable from the background. Here again it is probably better to over-correct, though the individual worker must decide for himself. A thing to guard against always is the danger of basing one's consideration of monotone rendering upon photographs; we are likely to take our conception as to the tone value of bright green grass, for instance, from photographs which usually have shown it as too dark, if not black.

Frequently, in a spring landscape, the hedges and grass are almost the brightest things in the whole landscape, and they should clearly be rendered as light grays; but so uniform is the belief among photographers that grass is black, that a rendering as light gray will often provoke the comment that the photograph is over-corrected.

The most important case of color contrast occurs in the copying of pictures, and for this purpose Dr. C. E. K. Mees of the Kodak Research Laboratories some time ago suggested a special method, which may be explained here. This method depends upon the use of tricolor filters, the material being exposed first through one filter and then through another, in order to get the desired color-rendering. It is first necessary to remove a common misconception, which one frequently finds repeated in text-books and the technical press, namely, that the effect of printing from the three tricolor negatives on one piece of paper would be to give an orthochromatic result. This would give an isochromatic result, that is to say, one in which all colors are rendered of equal strength, independently of their visual brightness; this results in an excess of brightness in the red and blue, especially in the blue, and insufficient brightness in the green, the whole color-rendering being wrong.

Suppose that we put a set of filters in front of our lens, fitted in a slide-past holder, so that we can expose through the three filters in succession. Then we may give an exposure through the three filters, in proportion to their ratio upon that material. Supposing, for example, that we have a plate and a set of filters, such that the blue requires 6 times the normal exposure, the green requires 12 times, and the red requires 18 times, if we give through the blue twice the normal exposure, the plate will be ⅓ exposed. Now give through the green 4 times the normal exposure—the plate is now ⅔ exposed—and superpose on this an exposure through the red filter of 6 times the normal exposure; we have now a negative combining our three color negatives in one; but it will not be correct rendering at all, it will give all blues much too light, and greens too dark, and the results will be unsatisfactory.

With the Wratten filters, owing to the fact that the green transmits a certain amount of blue, correct color-rendering is obtained by giving ⅔ of the exposure through the green and ⅓ through the red. Thus, in the example just given, where the ratio of exposures for the three filters was 6—12—18, the correct rendering would be obtained, together with correct exposure, by giving about 8 times the normal exposure through the green and 6 times through the red. Since the proportion of the mixed exposures of green and red gives a correct orthochromatic result, we can exaggerate red or green by increasing the exposure of the one filter and diminishing the exposure of the other. For instance, if we give 9 secs. exposure through the red, and 6 secs. through the green, we shall have exaggerated red at the expense of green; on the other hand, if we give 10 secs. through the green and 3 secs. through the red, we shall exaggerate greens at the expense of reds. If we want to diminish greens altogether, and bring up reds and blues, we can use our red filter and blue filter, and so obtain the rendering that we desire by altering the relative exposures through the three tricolor filters.

This method may sound rather far-fetched, but as a matter of fact it has been successfully adopted by some very skilled picture copiers.

A very important point about this method is that, while the work is being done, it will be known how far it is from correct rendering, so that instead of more or less over or under-correcting by a filter of which the action is somewhat uncertain, it can be said quite definitely that: "The reds were exaggerated 50% because it was necessary to pick out a red against the green in the shadows",—a statement which is much more scientific and more useful than a statement such as "a rather dark filter was used in order to get over-correction."

A word of warning is necessary here as to the quality of the filters required for this. It will be seen that the three images are literally superposed upon one another, and that the very smallest shift in any one of these images will produce a double image in the result, consequently a much higher grade of filter is required than for ordinary reproduction purposes. It is not sufficient that the images should be of the same size, but they must actually fall on the same place on the focusing glass. This can only be accomplished by the use of filters cemented in optical flats of the very highest quality, or else by the use of gelatin film alone. It will save disappointment if the fact is emphasized that what are usually known as "first-class cemented filters" will not do for this, and even when using flats, care should be taken always to insert them the same way.

Color Contrast for Special Purposes

The type of color contrast which we have been describing is a necessary departure from orthochromatism, in order to enable us to some extent to make up for the failure of monotone when it is necessary to render color. But there is another case of the photography of color contrasts, which is to the technical worker of as great, if not greater importance, and that is the photography of colored objects, as such, in order to obtain the best possible results, generally for reproduction purposes.

General Principles.—If a color is to be rendered as black, it must be photographed in its absorption band (see Chapter I) by light which is of such a wave length that it is completely absorbed by the color. That color then appears as black as it can be made. A useful example is given by a photomicrograph of a section stained with eosine: this section is pink; if it is viewed by blue light, owing to the fact that eosine does not absorb blue, it looks comparatively light. By green-blue light

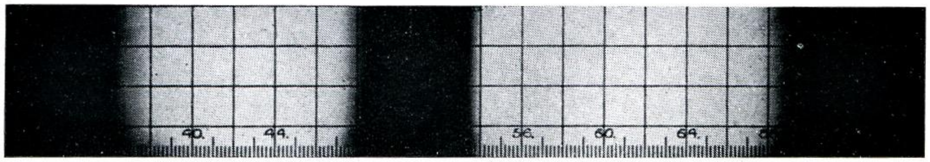
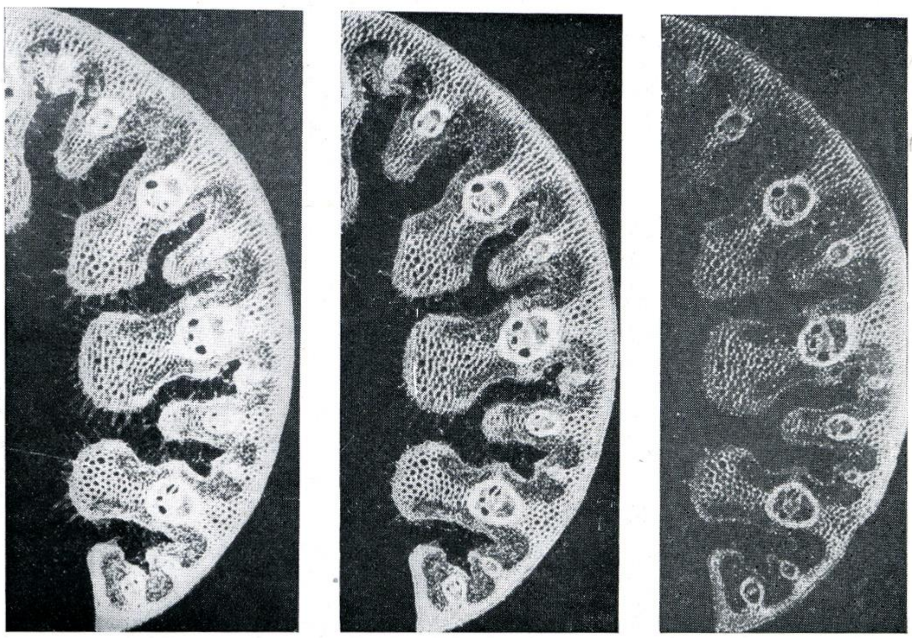


Fig. 29 Absorption of Eosine



500-540 570 640

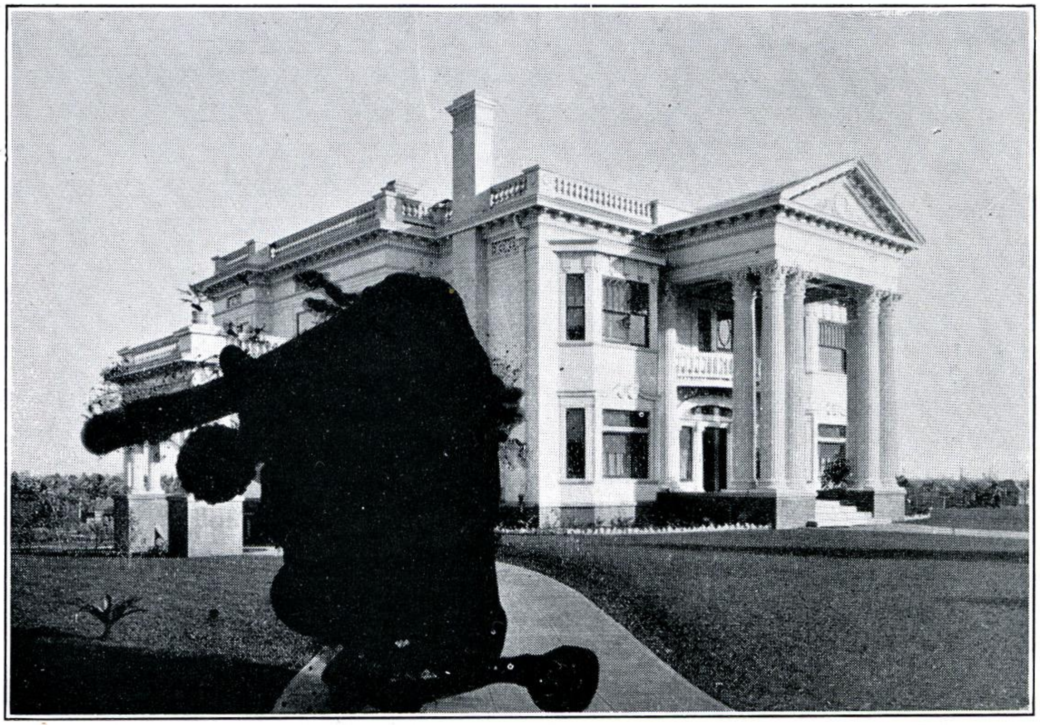
Fig. 30. Negatives Made by Means of Light of Above Wave Lengths

of a wave length about 500 to 540, which is absorbed completely by eosine (the absorption-spectrum of eosine is shown in fig. 29), the section is entirely black, as is shown by the first illustration; being blocked up in detail, this gives the maximum degree of contrast (fig. 30). Photographing at 570, on the border of the absorption band, we get a considerably lessened contrast, which for this particular section will give us the best result. There is plenty of detail in the section, while at the same time the contrast is sufficient for reproduction purposes. Photographing at 640 in the red, and in the light which is completely transmitted by the section, the photograph has no contrast, is very flat, and results are useless, so that for the maximum contrast we must photograph in the absorption band.

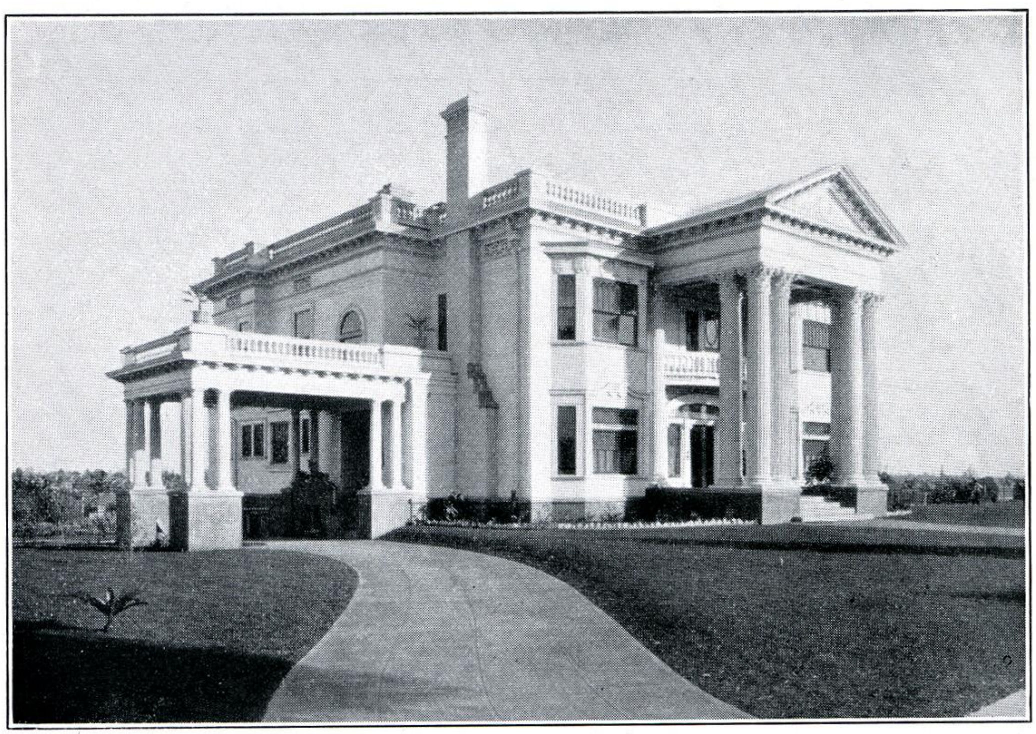
For example, it is sometimes necessary to copy a print of which the paper has become yellow with age. An ordinary plate is sensitive only to the ultra-violet, violet, and blue rays, which are more or less absorbed by the yellow paper, so that if a negative is made of such a print on an ordinary plate, the reproduction of the yellow paper will appear dark, or, in any case, dirty. If a color-sensitive material is used with a yellow contrast filter, the yellow stain will have no effect and will fail to photograph. It should be noted that the yellow filter for such a purpose should not be an orthochromatic filter if the best results are required, but a much stronger filter, such as the Wratten "G" filter, because an orthochromatic filter is adjusted to photograph objects in their relative luminosities as seen by the eye. If the stain be examined through the strong "G" filter there will reach the eye no light which is not yellow, and so the stain will not appear different from the white ground.

Fig. 31 shows two photographs of a Velox print which had been splashed with yellow dye so as to leave a yellow stain. In the upper photograph, taken on an ordinary film, the stain appears quite black, while in the lower one, for which a panchromatic film has been used with a "G" filter, the stain has entirely disappeared, only a trace, which cannot be reproduced, being visible in the negative.

Another difficulty is sometimes met with in copying prints due to the fact that the prints are of a brown color, such as is given by sepia toned prints. This brown color has a very much stronger absorption for the violet light, to which the plate is sensitive, than for the yellow-green and orange light, which represents the maximum sensitiveness of the eye, and



Commercial Film



Commercial Panchromatic Film with "G" Filter

FIG. 31. PHOTOGRAPHS OF VELOX PRINT WITH YELLOW STAIN

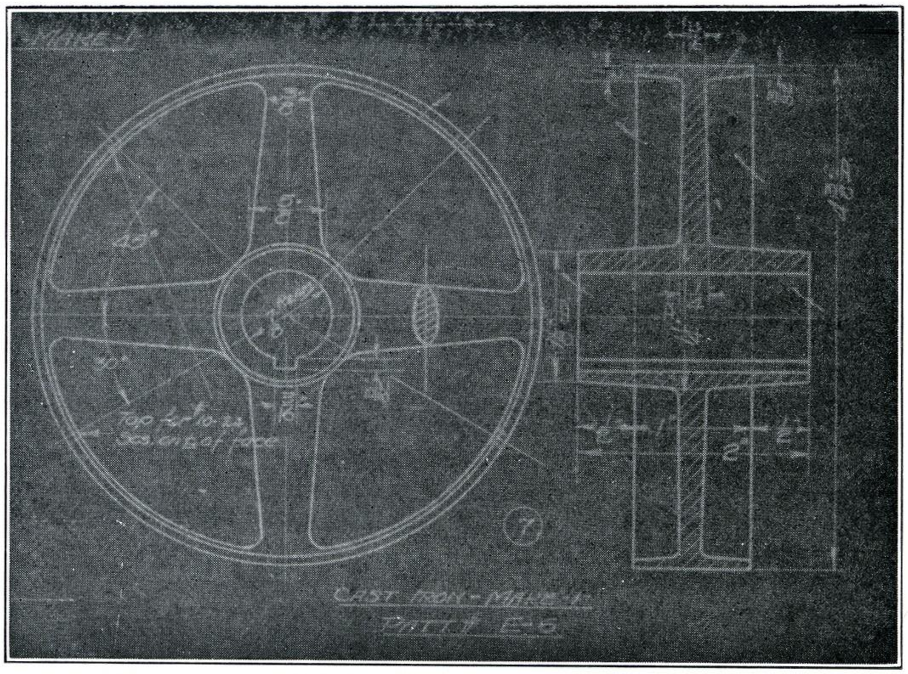
consequently such prints when photographed on a non-color sensitive plate give negatives having far too much contrast, and with blocked up shadows, and it will generally be found that no increase of exposure will reproduce satisfactorily such photographs. The obvious course is to photograph them as the eye sees them, that is by means of a fully correcting filter and a panchromatic film or plate.

A difficult task without the proper material and filter is the photography of engineers' and architects' blue prints. Orthochromatic materials with yellow filters do not give the best results with such subjects because a great deal of the yellow-green light to which such materials are sensitive is reflected by the blue, and in order to obtain really first-rate results the "A" or "F" filter should be used with Process Panchromatic plates, thus photographing the print by red light which is completely absorbed by the blue color. With such a plate and filter the results from a blue print are in every way as satisfactory as could be obtained from a black and white print in the ordinary way, (see fig. 32).

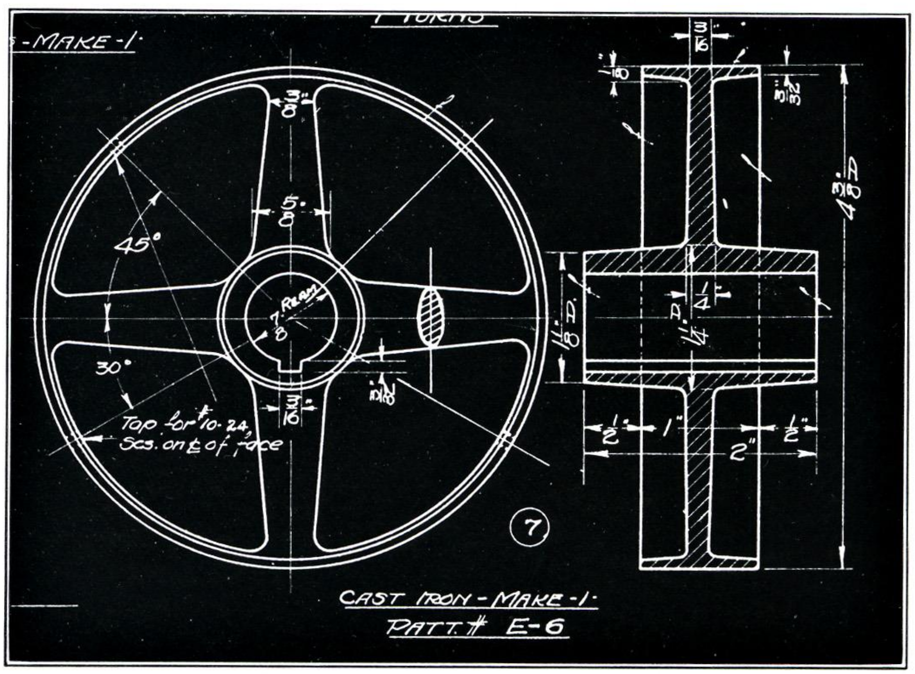
Suppose, to take another example, we have a sheet of purple typewriting, with corrections in red ink; the typewriting absorbs the whole of the orange and green, the red ink absorbs only the green. If we photograph through the green filter, "B", of the tricolor set, we shall get both the typewriting and the red ink completely black, and therefore the greatest contrast which can be obtained (fig. 33). If, on the other hand, we photograph through the red "A" filter, the typewriting will appear plainly visible, but the red ink will show so little contrast that it easily can be intensified out of existence, and we can make a reproduction of the sheet showing the typewriting only (fig. 34).

Most commercial work, such as catalogue illustrations of carpets, wall papers, linoleums, china, marble, etc., can best be accomplished by the aid of the K2 filter on the panchromatic film or plate, but occasionally a red or green filter will be found extremely useful. For general commercial photography the following set of filters will be found to cover most requirements: K1, K2, X1, X2, tricolor set (A, B, C4 and C5), strong red (F), and strong yellow (G).

For one branch of commercial photography, furniture work, the tricolor red "A" and the yellow "G" filters are invaluable; the "A" filter used with panchromatic materials giving a splendid rendering of the grain of red mahogany such as can



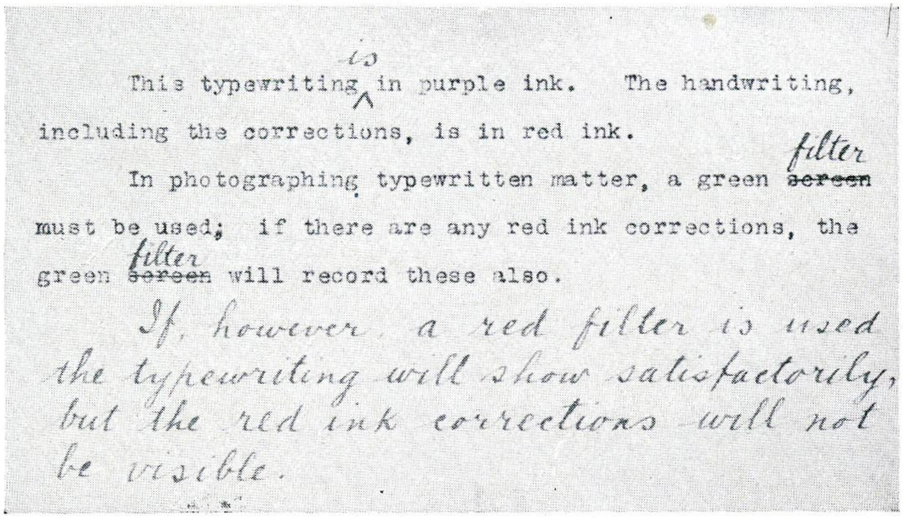
(*a*) Blue print photographed on Ordinary Plate



(*b*) Blue print photographed on PROCESS Panchromatic Plate through "A" Filter

FIG. 32

be obtained in no other way. For satinwood and inlaid work the "G" filter is required, so that for furniture photography

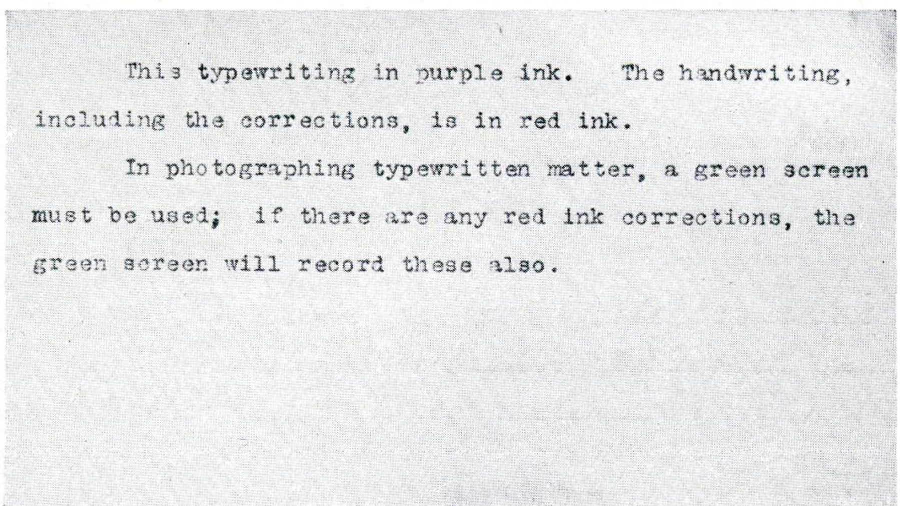

This typewriting is in purple ink. The handwriting, including the corrections, is in red ink.

In photographing typewritten matter, a green ~~screen~~ filter must be used; if there are any red ink corrections, the green ~~screen~~ filter will record these also.

If, however, a red filter is used the typewriting will show satisfactorily, but the red ink corrections will not be visible.

FIG. 33. TYPEWRITING AND RED INK THROUGH GREEN "B" FILTER

a set comprising the K2, G, and A filters should be obtained.

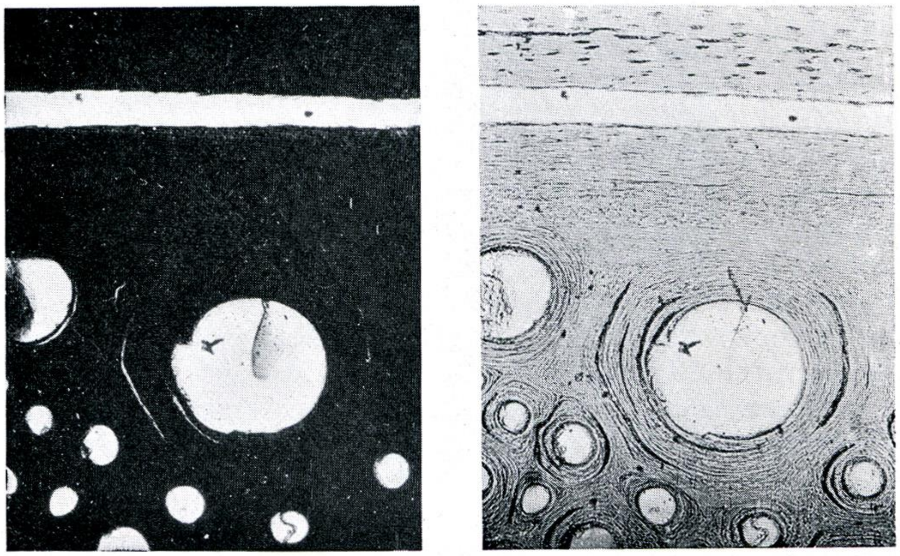

This typewriting in purple ink. The handwriting, including the corrections, is in red ink.

In photographing typewritten matter, a green screen must be used; if there are any red ink corrections, the green screen will record these also.

FIG. 34. TYPEWRITING AND RED INK THROUGH RED "A" FILTER

Subjects for which a correct orthochromatic rendering is particularly desirable are postage stamps and reproductions of colored advertisements, such as posters.

In copying maps, a K2 filter must be used if the map contains several colors, but in the maps which more often come to the commercial photographer, such as real estate or land development maps, a contrast filter is frequently required to accentuate some special color in the original.



Whalebone Section
Photographed for Contrast

Whalebone Section
Photographed for Detail

Fig 35

By the application of this principle, viz.: to use a filter that absorbs the color which is to be rendered as black, we can pick out, in fact, any color from a combination of colors, and in two, three, or four printings obtain a facsimile result.

The second principle of importance is that, where a uniformly colored thing is to be photographed, and the best rendering is to be obtained, it must be photographed not in its absorption band, but in the transmission or reflection region of the color. For instance, in photographing the eosine-stained section, we get the greatest contrast by photographing in the absorption region of the stain; but we obtain that contrast at the expense of the loss of detail in the section, and we get the greatest detail in the photograph where we used the red light. Owing, however, to the fact that we must keep contrast against the *background* in this case, our best final result was a compromise between contrast and detail, obtained by photographing on the border of the absorption band. A very good example, however, of the use of light, such as is transmitted by the stain, is shown by the two photographs of a whalebone section, which are reproduced here from the little book on "Photomicrography." The one on the left shows the section photographed for contrast by means of light which is absorbed by it; the one on the right shows the same section photographed in order to show detail by the light which it transmits (fig. 35).

Perhaps the most important application of this method occurs in the photography of furniture, where the results are simply surprising to the uninitiated. If a piece of reddish mahogany is photographed on an ordinary film, no trace of grain is usually visible. The photograph is made by blue light to which both the red darker portions and the yellow light portions are black; to give an increased exposure simply results in the photography of a plentiful crop of normally invisible scratches. If, however, a panchromatic material sensitive to the red is used, with an orange or, better still, a red filter, the results are entirely different; the scratches disappear, and the grain comes up in the most wonderful way; in fact, so startling is the difference, that probably many readers might think that the example shown in fig. 36 is faked, but if they try the experiment they will get similar results.

It must be noted that for this purpose the material must be red sensitive, as red mahogany has a strong absorption in the greenish yellow of the ordinary orthochromatic film, and it may be well to remark again at this point, as at the beginning, that the whole of the discussion of this book is based on the use of materials that are panchromatic. Ordinary and regular orthochromatic materials may be ruled out when we are dealing with technical work, which requires us to work in any region of the spectrum which may be necessitated by the color of our object.

A useful example of this same principle of photographing in the colored light which is reflected from the object, is given by the photography of prints for reproduction purposes. We have already referred to the case of brown prints, and in the same way a red silver print, when being photographed on wet plates for half-tone work, is well known as a most difficult subject, requiring usually a large amount of fine etching. These, and other cases of the same kind, can be dealt with very easily by using Eastman Panchromatic Film or Wratten Panchromatic Plates with a medium filter. The prints then become as easy to copy as any black-and-white subjects.

On Wratten Panchromatic Plate through Orange Red "A" Filter

On Ordinary Plate

FIG. 36

CHAPTER VI

PHOTOGRAPHY BY ARTIFICIAL LIGHT

IN the early days of photography, almost the only source of light available was the sun. Daylight is, however, from many points of view, an inconvenient source of light for photographic purposes. The photographer has very little control over it. It varies in intensity and in color through the day and from one season of the year to another. These variations make the judging of exposure time a difficult task, so that the photographer has to acquire considerable skill and experience in order to avoid obtaining results showing the effects of incorrect exposure. Artificial light sources, on the other hand, are constant in intensity and color if they are operated under proper conditions. This applies particularly to electric lamps in their various forms, and these, together with flash lamps, are the only artificial light sources used to any extent in modern photographic practice. In addition to being under control, they are readily available when required, and their use is not confined to a small portion of the day.

The possibility of working at any time under evenly uniform conditions is certainly an advantage in such divisions of photography as cinematography, photo-engraving, portraiture, color work, and, indeed in all commercial work.

There are three classes of electric light source in common use in photographic studios. They are (1) high efficiency gas-filled tungsten filament lamps, (2) arc lamps, and (3) gaseous conductor lamps.

On account of their convenience in use and especially since the introduction of panchromatic emulsions, tungsten lamps are employed to an increasing extent. They are used very largely in cinematograph studios in sizes up to 30 kilowatt, and in portrait studios in sizes up to 1500 or 2000 watt. Arc lamps are also employed in portrait and cinematograph studios, and particularly in photo-engraving shops. The best known gaseous conductor lamp is the mercury vapor tube, but a number of other types giving light of various colors are in use, particularly the neon tube, which is sometimes used in conjunction with mercury tubes. With increasing use of panchromatic materials the mercury vapor tube is falling into comparative disuse.

If we consider the spectrum of the light given by these sources, we find that the tungsten lamps and, in general, the arcs, have a continuous spectrum, while the gaseous conductor lamps have a discontinuous or line spectrum. There is no sudden break in the spectrum of the tungsten and arc lamps, while the spectrum of a mercury vapor tube, for instance, is confined to a number of intense narrow lines separated by empty spaces. The spectral characteristics of a light source are usually shown by means of graphs known as spectral energy distribution curves, obtained by plotting the relative energy of light of each wave-length against the wave-length. A convenient qualitative comparison of the energy distribution from light sources is obtained from wedge spectrograms, a number of which are shown in figure 37.

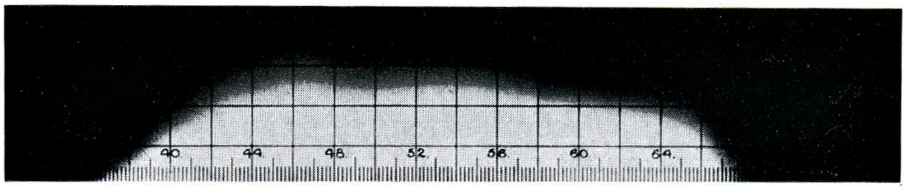
The distribution of energy throughout the spectrum is characteristic of the temperature of the light source, the maximum of energy moving towards the blue as the temperature increases.

The distribution can thus be stated as corresponding to that of a hot "black body" at a given temperature, the temperature scale being measured in Centigrade degrees starting from the "absolute zero" instead of the freezing point of water. The temperatures are thus stated as K° (Kelvin), these being known as the "color" temperatures. The following table gives the wave-length for the maximum energy corresponding to various color temperatures:

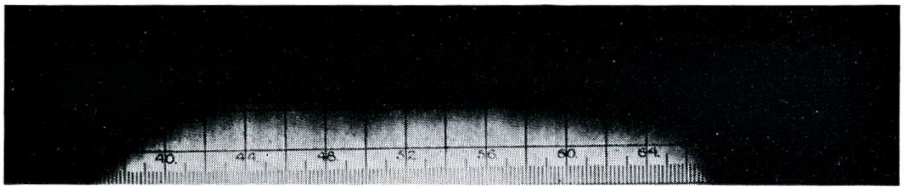
Color Temperature	*Wave-length of Maximum Energy*
1000°K	2880 mμ
2000	1440
2500	1152
3000	960
3500	823
4000	720
6000	480
8000	360
10000	288

The maximum enters the visual region of the spectrum at a temperature of about 4000°K. and leaves it at a temperature of about 7000°K. The maximum energy of sunlight, which has a color temperature of about 5400°K., is thus in the green region (compare fig. 27).

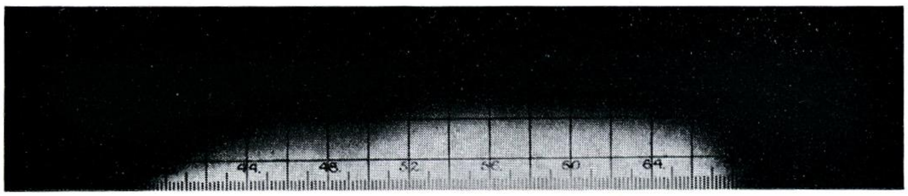
The energy of the shorter, violet and blue, wave-lengths of tungsten light is very low, but it increases rapidly towards



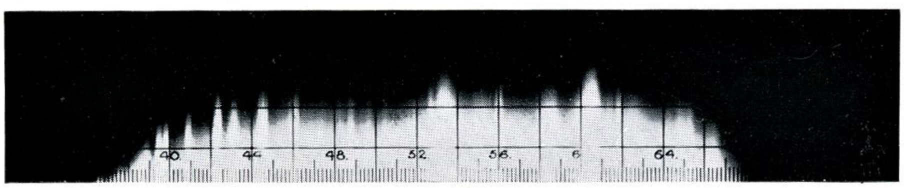
Sunlight



White Flame Carbon Arc

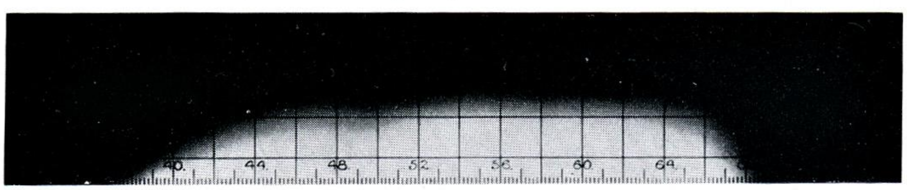


Tungsten

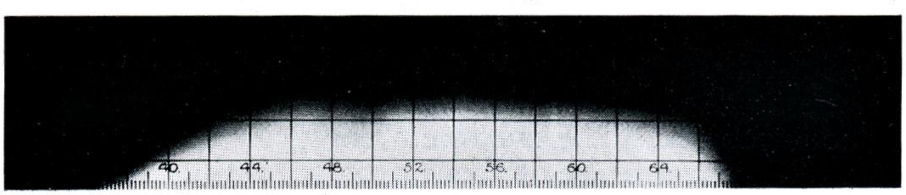


Panchromatic Carbon Arc

Mercury Vapor in Glass



Photoflash Lamp



Eastman Flash Powder

FIG. 37. WEDGE SPECTROGRAMS OF LIGHT SOURCES (ON WRATTEN PANCHROMATIC PLATES)

the longer wave-lengths of the red end of the spectrum. The modern, high efficiency gas-filled tungsten lamp has considerably more energy in the violet and blue than has the gas-filled lamp run at moderate efficiencies, while this in turn has more energy in this spectral region than the older vacuum type of tungsten filament lamp. Now, the spectral region which is represented in the tungsten lamp by a relatively very low energy level is that to which a normal non-color sensitized photographic emulsion is most sensitive. This means that very long exposures or else a very high intensity of light is required in photography by tungsten light when ordinary emulsions are used.

With color-sensitized emulsions, however, the case is quite different. These are sensitive to a spectral region in which the proportion of energy from a tungsten lamp is increasing. For this reason orthopanchromatic and, particularly, hyperpanchromatic materials are especially suited for use when tungsten illumination is employed.

It is quite common practice to use tungsten lamps having bulbs of blue instead of clear glass, either exclusively or in conjunction with clear-glass bulbs, in an endeavor to get more closely orthochromatic rendering on panchromatic materials. At the time of writing there is considerable variation in the spectral characteristics of blue-bulb lamps from various manufacturers, and it is not possible to make generalizations about them.

The arc has the advantage of being the source of artificial light of highest efficiency, and its spectral quality is closer to that of daylight than that of tungsten lamps. The spectral distribution of energy of an ordinary neutral cored carbon arc is practically identical with that of a "black body" at 4000°K., while the color temperature of a high efficiency tungsten lamp is about 3100°K. The color temperature of noon sunlight in the latitude of Washington is, on the average, about 5400°K. In the high intensity arcs, *e.g.*, sun arcs, the carbons have a core impregnated with the fluoride of cerium, so that the spectrum consists of a continuous background on which is superimposed a large number of bright lines due to the core material. The lines are so numerous, however, that for practical purposes the spectrum is continuous. The high intensity arc matches noon sunlight fairly well in color; it is relatively rich in blue and violet radiation. The flame arcs also have carbons with cores containing metallic salts, and in their case also the spectrum consists of a continuous background on which a large number of lines is superimposed. Many carbons giving flames of different colors are available, but the most used are the white flame and panchromatic (orange) carbons. The white flame arc is more or less of sunlight quality, while the panchromatic carbons give a light which is strong in yellow, orange and red, and can be used interchangeably with tungsten lamps.

The light from a mercury vapor tube is very rich in radiation of the violet, blue and green regions of the spectrum, and it is deficient in red light. In photographic work, using mercury light, therefore, red objects are rendered too dark. On the other hand, the light emitted by a neon tube is very red in color and red objects are accentuated in brightness. For this reason combined neon and mercury vapor light is sometimes employed to produce a better rendering of color subjects than either one of the two separately. Tungsten lamps are sometimes mixed with mercury vapor tubes for the same reason.

Flash-powders, and the more recently introduced flash-lamps of the Vacublitz and Photoflash types, provide a very intense source of light of high actinic value and of very short duration. The color of the light from flash-powders varies from one brand to another, but on the average it may be taken as corresponding to a color temperature of about 3800°K. It thus approaches the plain carbon arc in color, and has relatively more energy in the blue and violet than the tungsten lamp. The color temperature of the light from a Photoflash lamp is higher than that of the average flash-powder; it is over 4000°K.

Let us consider very briefly the uses to which these light sources are put in practical photography.

Portrait Studio—In the portrait studio there are many types of lighting employed. They may, however, be broadly divided into two groups according to the purpose for which they are used. For normal work there is (1) a general flood of illumination lighting the subject being photographed, and (2) this is picked out with spotlights, pick-up lamps and head-lamps to give high-lights and modelling.

Before the introduction of panchromatic film, general illumination in a studio was provided by mercury vapor tubes, and white flame and high intensity arcs. Since 1927, however, incandescent lighting has been increasingly used for all kinds of studio illumination.

The general lighting is very conveniently provided by a bank of, say, five incandescent tungsten lamps of 1000 or 1500 watt size in a diffusing reflector, arranged overhead, or by one or more carbon arc lamps of 20 to 45 ampere capacity. The intensity of this general lighting varies according to the nature of the subject being photographed, but it is usually of the order of 40 or 50 foot-candles. For very short exposures, mercury vapor tubes are sometimes used in addition to the incandescent lamps, while mixed mercury and neon light is also employed. Spotlights are used to give a condensed beam of light of high intensity; carbon arcs or 500-watt incandescent projector lamps in a lamphouse provided with a reflector or reflector and condenser are employed. Pick-up lamps give a broad beam of well-diffused but brilliant light, and may conveniently employ a 500 or 1000-watt tungsten lamp. A headlamp is hung just above the sitter, and may be used to throw directly downwards a circular beam of light. It usually consists of a tubular housing containing a reflector and a 500 or 1000-watt tungsten lamp. The carbon arc lamps employed in portrait studios are of 20 to 45 ampere capacity, and, like tungsten lamps, are equipped with reflectors and diffusing arrangements. White flame or panchromatic carbons are used, according to the color characteristics of the subject and the rendering desired.

The particular arrangement of the lighting will, of course, vary with the subject. A studio lighting designed primarily for portraiture, for instance, is not entirely satisfactory for groups, because the angle at which the light falls on the subject, if correct for one case, is unsuitable for the other. Further, the subsidiary lights are used with less advantage in a broad subject like a group than in a close-up of a head.

Cinematograph Studio.—The general principles of lighting a cinematograph stage are the same as those employed in the portrait studio, although the lighting is considerably more elaborate, and the average intensity is much higher owing to the speed at which the pictures are taken, the exposure being only about 1/50 second.

Since 1927 the bulk of cinematograph studios have been illuminated with tungsten lamps, although occasionally arcs are still used where sharp shadow formation is required to simulate sunlight. The average level of illumination for general lighting usually lies between 150 and 500 foot-candles; it is obtained from banks of 2500 watt tungsten lamps arranged in suitable reflectors. To produce highlights in a scene already brilliantly illuminated, the intensity desired may be anything up to 4000 foot-candles. Spotlights for the purpose may contain an incandescent projector lamp of high consumption, up to, say, 3 kilowatts. Still higher intensities are required for sun lighting, an average figure being about 4000 foot-candles, and in this case tungsten lamps consuming 5 or 10 kilowatts or high intensity arcs are used.

Photo-engraving.—In photo-engraving, the copy board is generally lighted by an arc lamp hung on each side. In the earlier days these were usually open arcs and later the enclosed carbon arc came into use. These are still convenient for wet collodion but they are unsuitable for color work owing to the deficiency of red and especially of green light. Open arcs with white flame carbons are now used, and appear to be quite satisfactory.

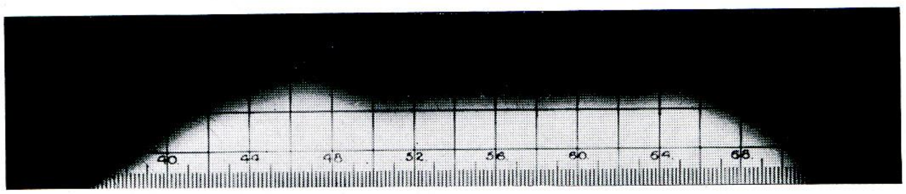
Commercial Photography in General.—For commercial photography any of the light sources mentioned in the preceding paragraphs are used according to the nature of the subject and the particular effects required in its reproduction. For certain types of work, particularly press work and interior photographs of large groups, or in places where no source of electrical supply is available, flash powder and the Photoflash lamp are extensively used.

Color Photography.—For color photography, such for example as color portraiture, the most important things about a lighting system are the quality of the light, and its constancy. Light sources in which considerable parts of the visible spectrum are missing, such for instance as the mercury vapor tube, are obviously useless unless supplemented by another source emitting the missing radiations. For color work the use of panchromatic photographic materials is essential, and the light source employed should contain light of all the colors it is desired to photograph and in suitable proportion in relation to the curve of color sensitiveness of the emulsion. The incandescent tungsten lamps, white flame and panchromatic carbon arcs fulfill these demands.

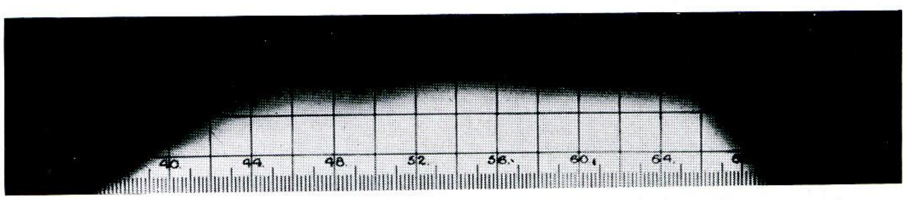
It has been shown in earlier sections of this book that the choice of conditions for the correct orthochromatic rendering of colored objects involves a knowledge of the spectral characteristics of the lighting, the spectral sensitivity of the film or plate, and the filter. The principles already discussed for selecting a photographic material and filter to give best rendering with a given lighting apply equally to artificial illuminants.

The hypersensitive panchromatic materials, which have a high total sensitiveness with extreme sensitiveness to the yellow, orange and red portions of the spectrum, are particularly suitable for use with tungsten light or with panchromatic carbons. For satisfactory orthochromatic rendering in these circumstances a new Wratten Filter, X2, is used. The orthopanchromatic materials, which have a very high sensitivity in the green, may also be used for photographing by tungsten or panchromatic carbon light. For this purpose the Wratten X1 filter has been worked out to give best rendering. The factors of these two filters are shown in the following table:

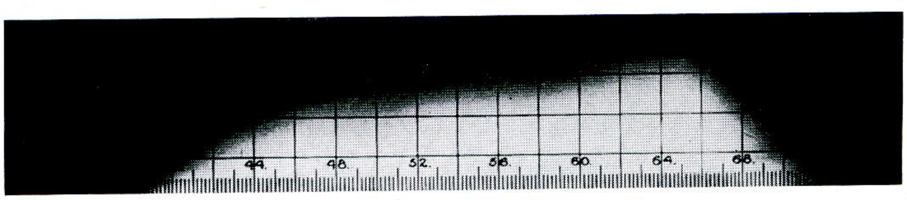
Material	*Light Source*	*Filter*	*Filter Factor*
B. Orthopanchromatic	Tungsten	X1	3
	Panchromatic arc	X1	4
C. Hyperpanchromatic	Tungsten	X2	5
	Panchromatic arc	X2	6



Panchromatic (*Type A*)



Orthopanchromatic (*Type B*)



Hyperpanchromatic (*Type C*)

FIG. 38. SPECTROGRAMS ON THREE TYPES OF PANCHROMATIC MATERIAL, BY TUNGSTEN LIGHT

In Fig. 38 are shown wedge spectrograms of the three types of panchromatic material, made in tungsten light. It is interesting to compare these with the spectrograms of the same materials in sunlight (fig. 15, p. 24).

CHAPTER VII

LANDSCAPE PHOTOGRAPHY

THE application of the principles, which have been set down in the earlier chapters of this book, to the photography of landscapes, presents difficulties of which most workers are only too well aware. The discussions which follow papers on "Orthochromatism" in photographic societies usually turn on these difficulties, and the variety of conflicting opinions expressed should be sufficient warning to prevent any writer from too dogmatically stating what should be done.

To M. André Callier, a Belgian worker who is both a first-rate landscape photographer and a scientific investigator of great knowledge, we are indebted for the framework of this chapter, and for many of the points with which it deals. We are indebted to Dr. E. Deville, Surveyor General, Canada, for the two views of Jasper Park, in the Canadian Rockies.

Landscape photography presents several features which entirely distinguish it from those branches of work with which the rest of this book is concerned. In the first place, landscapes display, as a rule, in northern climates a less marked scale of contrast than the subjects with which we are accustomed to deal in the studio. At the same time, however, the sky is usually of much greater intensity than any other portion of the gradation scale, and it follows that, in order to obtain detail in the shadows (seen by the eye because of the expansion of the iris), it is often necessary to over-expose the sky.

This over-exposure, which destroys differences in intensity which are perceived by the eye (clouds for instance), can be removed by the use of contrast color filters which, by absorbing the sky light, *seem*, in certain cases, to lengthen the scale of intensities which the material is capable of rendering.

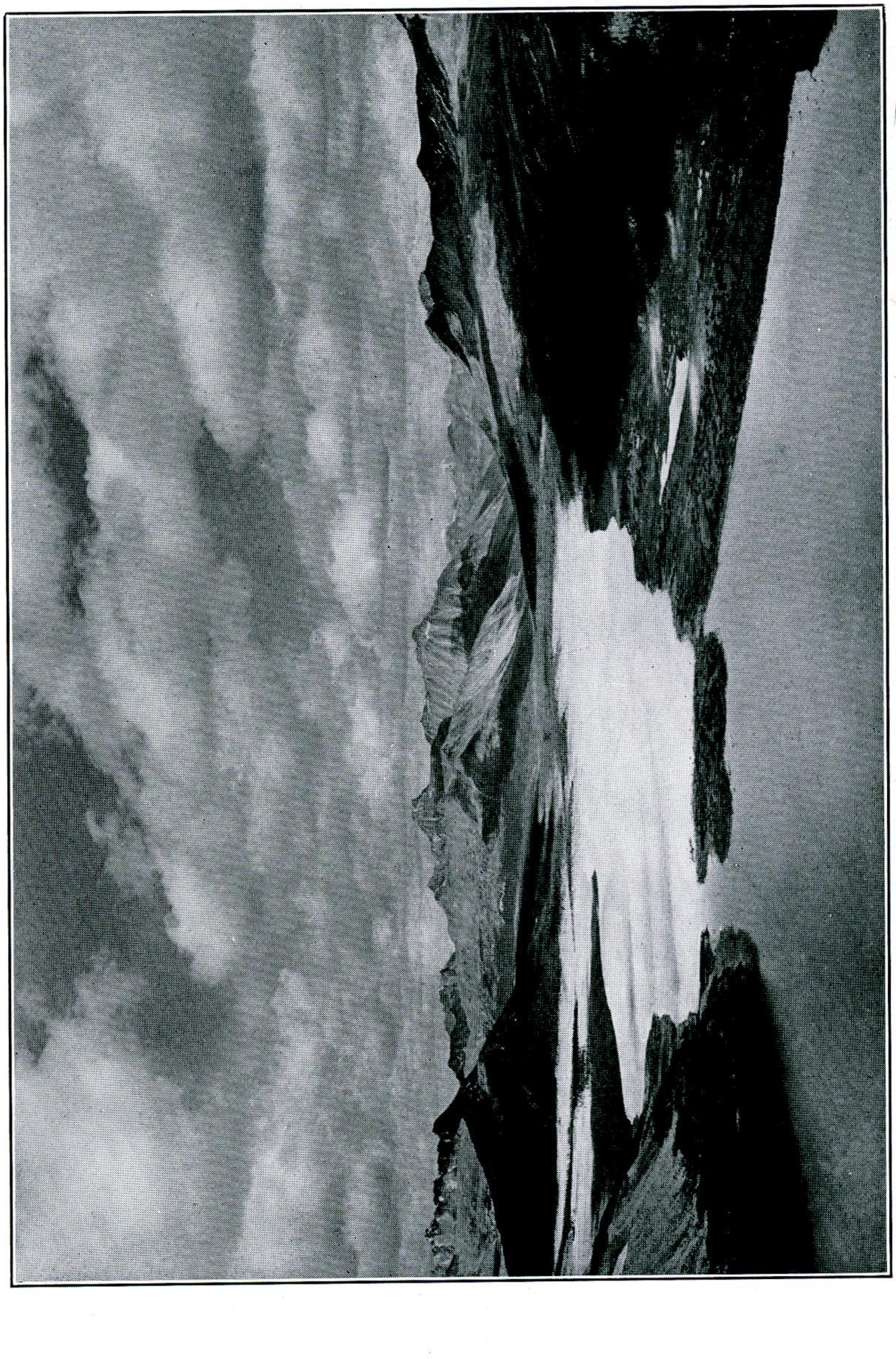
It is desirable to point out that, if such deep filters be employed, it is absolutely necessary that the exposure should be ample.

Insufficient exposure will result in a thin sky in the negative, and in general hardness in the foreground, and the resulting picture will give a general impression of *over-correction*.

True over-correction in landscape work probably is very rare; it may, of course, be caused by the deliberate use of very

Courtesy of Dr. E. Deville

FIG. 39. WRATTEN PANCHROMATIC PLATE WITH "G" FILTER



Courtesy of Dr. E. Deville

FIG. 40. WRATTEN PANCHROMATIC PLATE WITH "G" FILTER

strong yellow filters (and on this point it may be well to add a reminder that, as explained in Chapter III, filters which are necessary with a slightly color-sensitive material may over-correct panchromatic material), but as a general rule the appearance of over-correction is caused by under-exposure.

Here it should be pointed out that the factor given by the makers of exposure meters and calculators, in reference to sea and sky subjects and distant landscapes, must be used with caution. Thus it is usually stated that $\frac{1}{10}$ of the exposure found necessary for average landscape is all that is required for sea and sky, but this is only true when no filter is used; if a filter is put on the lens cutting out all the ultra-violet and some of the violet and blue, it will no longer be true, and a negative made with, say, a factor of $\frac{1}{10}$ will be under-exposed, and have the appearance of over-correction. On the other hand, too much exposure may be given, and so the contrast desired entirely flattened out. That is to say, not only should a suitable filter be used, but an exposure be given that is correct for the degree of contrast required.

The aim of many landscape photographers is simply to get the clouds and landscapes on the same plate. Comparatively small correction is sufficient to accomplish this, and hence the majority of such photographers use a very light filter, such as the K1, which, with a panchromatic film or plate, will give enough correction for the case given above, and at the same time enable the camera to be used in the hand.

But those workers, to whom truth of tone is of the first importance, will desire to use filters of greater depth, so that the color values of the foreground shall be correctly translated into monochrome.

Many such workers use comparatively deep filters with materials sensitive to the yellow-green, but not to red, arguing that few landscapes contain red, or even yellow, and that the greens can be satisfactorily rendered by a green sensitive material. On this point the following quotation from a letter from M. Callier may be of interest:

"It is necessary to insist upon the kind of orthochromatic plates which may be used. In spite of the enormous progress realized by plates of this type, such plates show a grave defect in their lack of sensitivity near W. L. 500 (see fig. 15).

"Usually this defect is not of much importance, but there are certain cases where it becomes a great disadvantage. This is so in landscapes, for example, which contain both open meadows and pine trees. If such subjects are photographed by means of plates of the erythrosine type (especially with a filter, if there is also distance to be rendered), there will be obtained in the negative a greatly exaggerated contrast between the densities of the meadows and of the pine trees. The green reflected by the meadows corresponds to the maximum of sensitivity of an erythrosine plate, while that coming from the pines falls exactly into the gap of sensitivity. The only method of obviating this is to use a really compensating filter—that is, a filter which absorbs the violet and ultra-violet, but which also has an absorption about the region 560 corresponding to the maximum of sensitivity of an erythrosine plate. Unfortunately, the increase of exposure required by such a filter is very great.

"From this standpoint the new isocyanine sensitizers represent a great advance over erythrosine, and the fact, that the plates so sensitized are also sensitive to the orange and red, constitutes a second advantage whenever red enters into a landscape."

An important factor in landscape photography which does not enter into studio work is the presence of water particles suspended in the air which, when of large size, condense into mist. It is well known that, if open landscapes are being photographed, a very slight amount of mist results in flat negatives, unless strongly corrected orthochromatic materials be used.

The reason seems to be that the suspended particles of water vapor which are transparent for the longer waves of light, and, therefore, only affect vision slightly, act as a very turbid medium for the deep violet and ultra-violet waves, scattering them, and producing much the effect that would be seen if one were to try and look through a sheet of finely ground glass.

As the water vapor condenses, its selection of the longer wave lengths increases; a fog, for instance, will absorb the blue and green rays from the light of an arc lamp, but will permit the red to pass in greater measure, so that at a little distance the lamp will appear red.

It seems probable that the *scattering* effect of mist near the ground is at a maximum in the ultra-violet, and that this *scattering* decreases as we pass towards the red. In addition, when the sky is blue, the mist reflects this light, and appears blue from that cause.

In order to remove this increased effect of mist in the negative, as compared with the effect seen by the eye, we must absorb the scattered ultra-violet and violet light by means of a filter before it reaches the film. It is to be noted that, to be effective, this filter must absorb the ultra-violet as completely as possible, and that filters, such as the Wratten "K" filters, are, therefore, preferable to even much deeper filters made of other yellow dyes which transmit ultra-violet light.

The removal of the scattering effect of mist will progressively increase as we remove the violet, blue, and greenish blue, by means of deeper and deeper filters, so that, if strong, sharp-cut filters be used, the air will appear too transparent—that is, there will be a loss of "atmosphere." It is therefore, important that the filter should be of gradual cut, corresponding in curve to the sensitiveness of the eye, and that sharp-cut, strong filters should be avoided. In telephoto work, however, the mist intervening in the great aerial distances between the lens and the object to be photographed is a very serious and real difficulty, and a strong contrast filter, such as Wratten "G" filter, is a great advantage. Many telephoto workers who are troubled by the flatness and fogginess of their negatives would gain much by the use—first, of a satisfactory lens hood cutting off all light not required; and, secondly, of a strong contrast filter.

In exceptional cases a red filter may be used with advantage. Thus some photographs have been made of a high building at a distance of about four miles, in which an ordinary film allowed the mist completely to obliterate it. With panchromatic film and the K2 filter, the building was photographed as the eye saw it, but with the deep red "F" filter it was very much plainer, though, of course, the colors in the foreground and intervening distance were over-corrected. It is sometimes stated that a process film is better for rendering distance, but there is no advantage in this where the improved rendering is only to be obtained by eliminating the effect of the mist, as the process film is just as susceptible to the ultra-violet and violet rays scattered by the mist as are other ordinary materials.

It may be repeated that the filter used for telephoto work must either be plain uncemented gelatin, or must be cemented in the very best optical flats. The great equivalent focal lengths of the lenses employed will not permit of the use of ordinary filters if the best definition is to be obtained. The most convenient method of fitting the filter is usually as a cap on the back of the negative lens,inside the camera,which position enables one to employ the smallest possible filter.

While dealing with telephoto work, it may be pointed out that most landscape workers could take a hint from the telephotographer with regard to *hoods*.

Modern anastigmatic lenses are made to work at such great angles that they are seldom fitted with hoods, and the inevitable result is flatness due to fog, caused by the light scattered in the camera. Landscape workers, who do not, or at any rate should not, employ wide-angle lenses, should fit one or more hoods to their lenses, and they will at once see the improvement in their negatives.

Assuming development to be done properly in a safe darkroom then flat and foggy negatives are due to:

(1) Scattered light, removed by a proper hood;
(2) Mist, removed by a proper film and filter;
and rarely (3) Over-exposure.

Mountain work presents a few special difficulties. Great distances are continually occurring in consequence of the purity of atmosphere, and the chief difficulty consists in retaining correct gradation between the sky and the snow-clad peaks outlined against it.

The light of the sky is due to the numberless dust and water particles suspended in the upper air as well as to the molecules of air themselves. The greater reflecting power of these small particles for violet and ultra-violet light causes the sky color to be blue, and as we ascend higher into the air the particles decrease in size, and the sky reflection becomes less, so that the color becomes a deep blue, and at very great heights, the sky is nearly black.

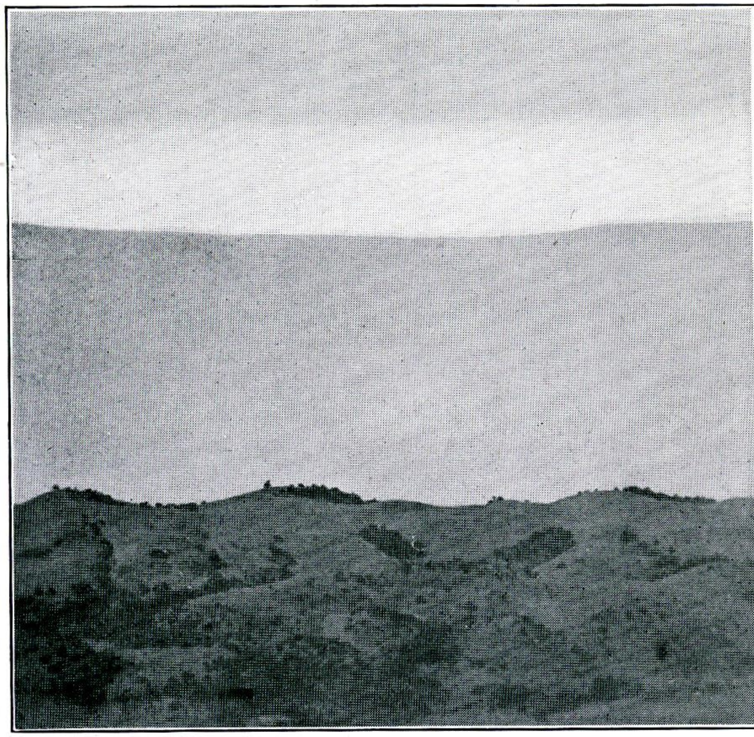
If, therefore, a deep or even medium filter is used, it may happen that the sky light may be cut out too completely, and the sky will appear too dark, with the intensely white snow showing in great contrast against it. It is, of course, true, that this is to a great extent also the effect to the eye, but an entirely truthful rendering may be displeasing when the charm of the sky color is removed, and the effect is certainly exaggerated if the filter used is of too sharp cut.

For ordinary mountain work, a K1 filter with Eastman Panchromatic Film or the Wratten Panchromatic Plate is of sufficient depth to render both sky and pines satisfactorily against the snow, but if there is much color in the near foreground then a K2 may be advisable. For mountain telephoto work, a K2 filter is necessary to remove the haze, a "G" filter being too strong if the distances are free from fog.

The nature of the reflection of the sky also gives us a clue as to the best means of rendering cloud forms. It is clear that the rendering of cloud form depends on causing the cloud to have the maximum effect on the film, when contrasted with the light reflected from the sky. Since the light reflected from the clouds is white, while that from the sky contains a lesser proportion of the longer wave lengths, it is clear that the deeper the filter, the greater will be the contrast. Thus when an ordinary material is used, photographing by means of the ultra-violet and violet light will usually obliterate the contrast, unless the clouds be very strong. Using an orthopanchromatic material and a K2 filter we shall obtain the same degree of contrast as that which is seen by the eye.

With the strong yellow "G" filter this contrast will be exaggerated, while with the tricolor "A" filter we get a very high degree of contrast, making this filter probably the most useful one for the recording of faint cloud forms. By the use of an even deeper filter, such as is obtained by using the "D" and "G" filters together, we can photograph near the limit of the visible red, and owing to the small proportion of this light reflected by the sky, can record wisps of vapor which are barely visible to the eye.

In order to obtain the greatest possible penetration of haze it is necessary to photograph by means of extreme red light. The introduction in 1919 of a dye named "Kryptocyanine" made possible the preparation of photographic materials sensitive to the extreme red, and our Research Laboratories have made plates sold under the name of "Extreme Red Sensitive" plates by which photographs can be taken by light of an average wave length of 750, these plates being used generally with a red filter such as the tricolor "A" red filter. In bright sunlight the exposure at f/8 required with these plates and red filter is about one-fifth of a second. With these plates, Professor W. H. Wright photographed from Lick Observatory the Yosemite Valley 120 miles away and made photographs of Mars which have thrown much light on the atmosphere of that planet. Motion picture film is also made sensitized with Kryptocyanine and is supplied under the name of "Panchromatic K" film. Working in full sunlight, it is possible with an open shutter to use this film with an



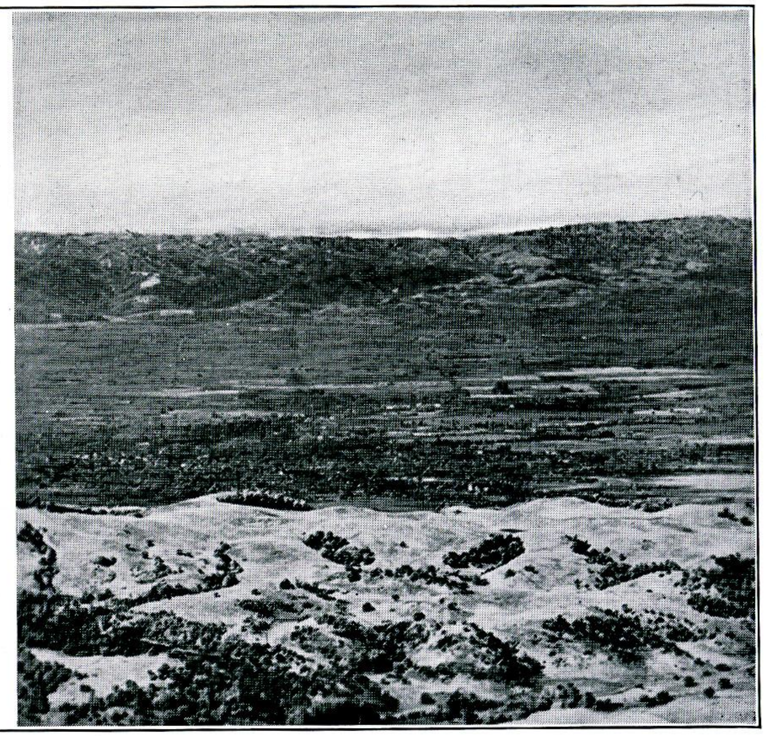


Fig. 41

Fig. 42

Fig. 41. Taken on an ordinary plate

Fig. 42. Photograph of Yosemite Valley, 120 Miles Away, on an Extreme Red Sensitive Plate

aperture of f/2 and get satisfactory exposure, while if the film be hypersensitized by treatment with ammonia, it is possible to get satisfactory results at f/3.5. As was shown originally by Professor R. W. Wood, landscapes taken with extreme red light are very striking in appearance, the blue sky appearing black and green foliage a startling white.

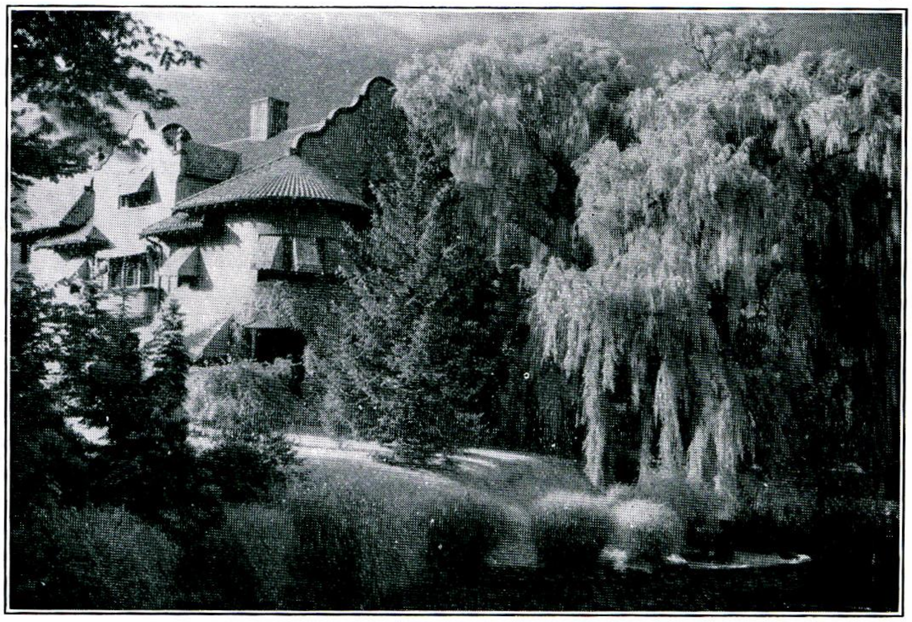


FIG. 43. PHOTOGRAPH ON EXTREME RED SENSITIVE FILM WITH RED FILTER

This is shown in figure 43. It is for this reason that the Panchromatic K film is used for motion pictures, since it produces photographs which look as if they were taken at night, and in this way it is possible to get night effects with negatives taken in full sunlight and thus to avoid the cost of artificial light for those effects.

In aerial photography the use of filters is of the greatest importance. During the war an investigation of the distribution of haze in the air was undertaken by the Kodak Research Laboratories in collaboration with the Science and Research Division of the Bureau of Aircraft Production. In this investigation cameras were used fitted with filters, and photographs were taken from different heights of a series of

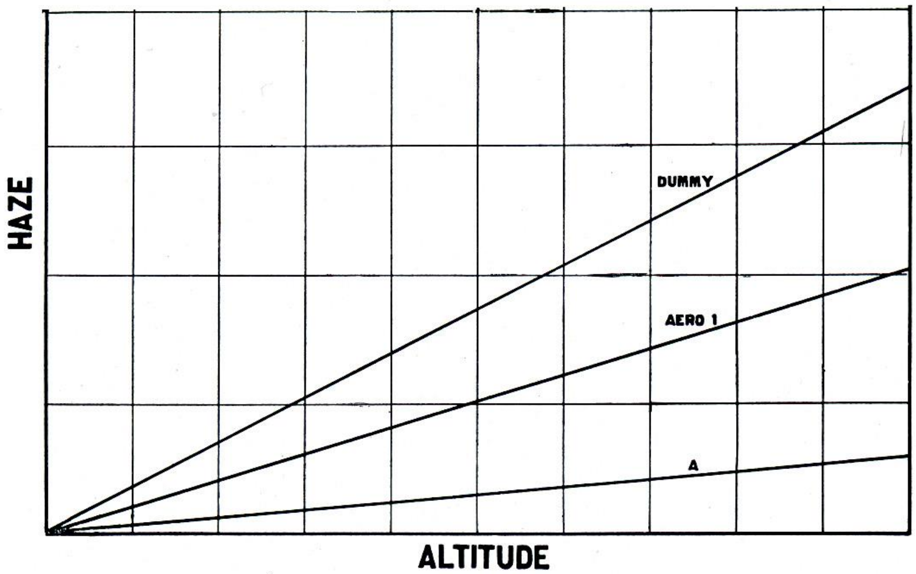


FIG. 44

test objects consisting of areas of painted canvas. By the measurement of the densities obtained in photographs of white and black areas, the amount of haze in the air could be calculated, and curves could be plotted showing the variation of haze with altitude. These curves were of different shapes according to the weather conditions, but they were not infrequently straight lines, as is shown in fig. 44, and from this

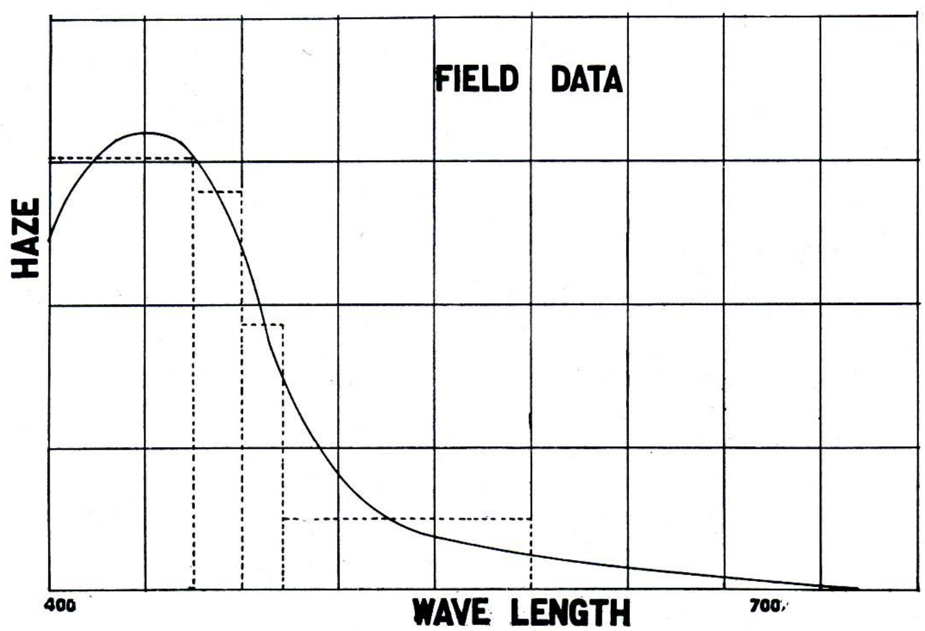


FIG. 45

figure it will be seen that the haze effect increases most rapidly where no filter was used, and is worse with the light yellow Aero No. 1 filter than with a red filter.

From the data obtained in these experiments, a curve showing the distribution of light reflected by the haze according to wave length could be constructed. This curve is shown in fig. 45, where it will be seen that it has a very strong maximum at a wave length slightly greater than 400 and then falls off rapidly towards the green so that the haze effect is very low in the red, yellow and green. The best results in practice are obtained by the use of panchromatic or orthochromatic materials with a very sharp cut filter such as that known as Aero No. 1.

In artistic photography out-of-doors it is often desirable to work with a high aperture lens having a small depth of focus in order to obtain a particular image quality. The use of Supersensitive Panchromatic Film, however, requires that shorter exposures be used than those necessary with the older type of panchromatic emulsion. If it is not desired to cut down the lens aperture, the alternatives are to reduce exposure time or use a neutral density in the lens. In some cameras, such as those used in cinematography, the exposure time cannot be shortened except by reduction of the angular aperture of the shutter, which is undesirable, and a neutral density must be used. To provide for cases such as this, two new filters, Wratten filters 3N5 and 5N5, have been introduced. They are combinations of a yellow filter with a neutral density. The factors with Supersensitive Panchromatic Film in sunlight are 3N5, factor of 4, 5N5, factor of 5.

CHAPTER VIII

THE PHOTOGRAPHY OF COLORED OBJECTS FOR REPRODUCTION

THE maker of photographs for reproduction will have many objects to photograph similar to those which have previously been dealt with, and the procedure will, in the main, be similar. It is desirable to consider for what process the negative is required before deciding on its character. If it is to be merely an ordinary photographic copy in monochrome of a colored object, then the usual rules apply. If the negative is required for mechanical printing, then we must know the process, *i.e.*, whether for a surface process, such as lithography and collotype; intaglio, such as photogravure; or relief, such as half-tone, in order to develop to a suitable contrast.

Photography is sometimes brought to the aid of pure chromolithography, when the reproduction is to be of a different size from the original, or if it is framed and cannot be removed from the frame. The first thing necessary in the process is to make a key tracing, which is an outline made on transparent transfer paper, of every patch of color showing variation from the next patch. This has to be transferred to all the stones used to build up the colored picture in order that the lithographic draughtsman may know exactly where to put his work, so that in the end the "register" or fit of the various colors is perfect.

If now a photograph must be used instead of the original itself, it is obvious that a negative must be made which best distinguishes the variations of color, and that the correctness or otherwise of their translation into monochrome is of no importance whatever. The film or plate used and filter chosen must therefore depend entirely on the character of the subject, having this end in view. Viewing the original through a number of differently colored filters will frequently be of assistance. It will sometimes be found that ordinary material, without any filter at all, will distinguish the patches of color better than any other procedure. With regard to collotype and photogravure, which require ordinary negatives, color sensitive materials with contrast or compensating filters should be used, as the particular subject requires.

With regard to photo-lithography and relief processes, such as ordinary half-tone, in which the final result is to be a surface broken up into grain, the grain is nearly always required in the negative from which the copying on to the printing surface is done. Consequently it is an economy if the negative, which gives us the color record, can also be split up into grain at the same time. To work in this manner is called the "direct method," and the Wratten Process Panchromatic plates are specially designed for the purpose. Whether it is possible to work "direct" or not depends on the amount of contrast contained in the original.

In a grained negative the illusion of tone is secured, not by varying density (*i.e.*, thickness of deposit of silver) as in an ordinary continuous tone negative, but by deposits of silver in the form of spots of very great opacity, but of varying size. Places where the spots are very small and there is much clear glass will represent shadow, those where the spots are very large and there is little clear glass will represent the high lights, and proportionately for other tones; the size of the dots everywhere corresponding with the amount of light reflected from the original.

Except in certain cases, when the so-called "highlight" negatives are required, any given area in the highlights must contain some transparent spaces, and in the shadows must contain some points of dense silver. But it is obvious that, if there is a considerable amount of contrast, it will be impossible to fulfill the necessary conditions, because before any points of silver have impressed themselves in the shadows of the negative, the dots in the highlights will have received so much exposure as to make them completely cover up all the transparent spaces, and that part will no longer serve as a grained negative. So that only certain objects or originals are suitable for reproduction by the "direct" manner, which consists in placing the object in front of the camera, illuminating it, and photographing with the half-tone cross line or irregular grain screen in front of the plate. The actual details of this work would be out of place here; further details can be obtained from our booklet on "Reproduction Work with Dry Plates and Films."

It may, however, be well to point out that originals with heavier contrasts than about sixteen to one should not be attempted by the "direct" process; that is, if the light reflected from the shadows is taken as one, then that reflected from the highlights should not be more than sixteen times as much. It is true that heavier contrasts are often done, and made to pass by the waving of white paper in front of the original during the exposure, a practice known technically as "flashing," but, beyond a small amount, this practice is very strongly to be deprecated, as it is ruinous to detail and gradation, and plates and filters must not be blamed if the results appear flat when this is done.

With subjects of heavy contrast, resort must be had to the "indirect" process. In this a negative is made in the ordinary way, but the exposure and development are so arranged that, while all the detail is secured, the density of silver deposit is restricted, so that the negative does not exceed a certain range of contrast. From the negative a positive is made, either on paper or, preferably, on a slow dry plate (*i.e.*, a transparency). This, while having all the details of the original, will have the contrasts compressed so that they are within the limits possible to the half-tone process, and a grained negative can now easily be made in the usual manner, either on wet collodion or on another dry plate.

As examples of common subjects having heavy contrasts, we may take most solid objects such as articles of furniture, carpets, etc.; though some articles for catalogue illustration, such, for instance, as candy or various packet goods, may very well be done direct. Many oil paintings, especially old ones, are better reproduced by the indirect process.

The next thing to be considered is the style of reproduction. If for monochrome printing, then the principles already outlined in previous chapters must be applied. If color contrast is required, then a filter must be used absorbing that color, which it is appropriate to render darkest, and a material sensitive to the colors that are not required to print. If, on the other hand, correct luminosity values are wanted, then a K2 filter should be used with a Wratten Panchromatic Plate. In general it will be found that, for color work in a reproduction studio, the panchromatic plate will be most suitable; for "direct" grain negatives, the Wratten Process Panchromatic.

In the case of an original, such as a brown or sepia print, that by reason of its color is difficult or impossible to do on an ordinary or wet collodion plate, it is generally sufficient to use a panchromatic film or plate or process panchromatic plate without any filter; though to secure the utmost possible detail it may sometimes be necessary to use a K1 filter.

The simplest cases of color reproduction are presented by stained MSS., typewriting, checks, maps, and so forth. These nearly all require the use of contrast filters. A full discussion on the correct procedure will be found in Chapter V.

Next come subjects to be reproduced in two colors. Sometimes these are drawn in two colors, sometimes in more; in either case it is desirable to know what colored inks are to be used in the reproduction. Filters are then selected so that the light reflected from the parts of the original, which it is desired to print in one of the inks, shall be absorbed and the negative be transparent there. Thus, supposing, we have a crayon drawing of a lady's head in pink and yellow, we want a green filter to absorb the pink and allow the yellow to pass, and a blue-violet to pass the pink and absorb the yellow. Many good color-effects may be obtained in two printings when the two inks together make a black. Any two inks of color complementary to each other will give a black and a scale of grays, as well as the two colors separately. Thus, an orange-red and a greenish-blue will give those two colors and black; a green and pink, the same; an ultramarine blue and yellow, the same. This method can be applied, also, when we only have one color and black; for example, a red and black. The use of the red filter, "A," and a panchromatic plate will permit only the black to be photographed; the second negative is made with the blue filter, and will give us both the red and black. Now if this be printed in an ink imitating the red of the drawing, the black can be printed in black, or in an ink which on the top of the red will make a black.

Another method is to make a positive from the negative taken through the red filter; now register upon this the negative taken through the blue filter. This latter negative records both blacks and reds as clear spaces, while the positive records only reds as clear spaces, so that the two together are equivalent to a negative, in which the red of the subject is represented by clear spaces. The black negative is, of course, taken through the red filter. If we have several colors and black, the procedure is more difficult, and it is sometimes troublesome to extract the black if the colors are at all dark. A filter should be selected that does not completely cut out any color present, but that transmits most freely the deepest color. Sometimes it is most convenient to expose the same plate for a portion of the time through each of the filters of a tricolor set, but the filters have to be made of the best optical glass, as otherwise the resulting image will appear doubled. Sometimes, on the other hand, no filter at all is necessary, or at most a light yellow filter, and a sufficiently long exposure will give the black alone on the negative.

The three-color process is treated in a separate chapter. The methods are exactly the same in a reproduction studio, except that arc lamps are generally substituted for daylight. The only adjustments are corrections in the exposure ratio of the filters, which may not be the same as for daylight.

CHAPTER IX

THREE-COLOR PHOTOGRAPHY

Color Analysis and Synthesis

THREE-COLOR photography is based upon the fact that all colors distinguished by the human eye may be matched by mixing, in various proportions, light of three primary colors. This fact was first stated as a theory by Wünsch, and later by Young, but was established experimentally by Clerk Maxwell in 1860. Maxwell selected, as the primaries, three colors which are not capable of being produced by the mixture of any other colors. These were a pure red, pure green, and pure blue. Their exact positions in the spectrum were chosen empirically. By taking monochromatic light of these colors, he was able to determine the proportions in which they must be mixed in order to produce, for each point in the spectrum, the same color sensation as produced by the spectrum itself. The results are expressed

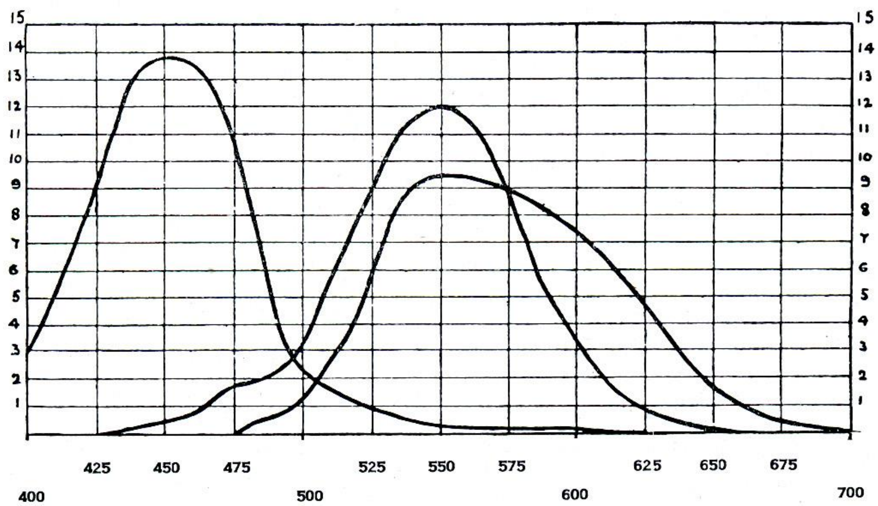


FIG. 46. TRICOLOR SENSATION CURVES

in three overlapping curves (fig. 46), one for each primary, the heights of which, at each wave length, show the proportions of the primaries which must be mixed to produce the color sensation corresponding to that wave length in the spectrum.

Principles of Additive and Subtractive Reproduction

That a process of color photography could be carried out on the basis of color synthesis by means of three primaries was first demonstrated by Maxwell in 1861. According to this process, three photographs are taken of the subject, one through a red filter, one through a green filter, and one through a blue filter. A positive print of each of these negatives is projected onto a screen through a filter of the same color as used for the corresponding negative. When the three images are brought into registry on the screen, a picture in natural colors is produced.

This process forms the basis of the so-called additive processes of color photography. These are distinguished by the fact that all colors and the sensation of white are reproduced by the admixture of light of three primary colors in different proportions. These proportions are controlled by means of three black and white photographic images, one for each primary color.

Another means of producing color photographs was pointed out by Louis Ducos du Hauron in 1869. This investigator showed that, instead of projecting the three black and white images by lights of the three primary colors, each image may be converted into a stain image complementary to the color of the corresponding taking filter. When the three images are superimposed, a color picture is produced which does not require projection with colored lights, but which is visible directly by either transmitted or reflected light.

This procedure forms the basis of the so-called subtractive processes. These are distinguished by the fact that all colors and black are produced by superimposed or mixed dyes or pigments in varying proportions, each dye or pigment absorbing light of one of the primary colors.

Theoretical and Practical Taking Filters

Various inventors have proposed to design taking filters for three-color photography with transmission curves approximating the tricolor sensation curves of Maxwell. They reason that if a set of three filters, when used with suitable photographic materials, will give these curves, there can be obtained in the spectrograph a set of negatives in which the opacities at every point in the spectrum are proportional to the light intensities for each primary. If, from these negatives, positive transparencies are made and projected in registry upon a screen by means of monochromatic lights exactly corresponding with the primaries, the spectrum will be reproduced. This result, however, can be obtained only if the correct exposure is given to the spectrum. If a number of different exposures be given, it will be found that the reproduction will vary, not in intensity only, but also in color. The reason can be seen by referring to the curves (fig. 46). Take, for instance, a red in the general region of 610, which should be recorded to a certain extent through the red filter and to about one-third of this extent through the green filter, and should therefore be reproduced by monochromatic red and green lights in the same proportions, giving the sensation of orange. With a sufficiently low exposure, however, this red will record only through the red filter and not at all through the green; that is, it will be reproduced as a dim but pure red. On the other hand, with great exposure, the plates will be quite opaque in both the red and the green filter negatives, and, in reproduction, we shall have a bright yellow caused by the mixture of all the red and all the green light. Similar conditions hold for nearly all points in the spectrum. With over-exposure, the region about 520, for instance, which should be a pure green, will be recorded to some extent in all three filters and will be reproduced as a greenish white or even a pure white.

This variation of color with exposure is of great importance in practical photography, since we wish to reproduce from nature not only variations in hue, but a considerable range of intensities for every hue. It is necessary that whatever variation there is in intensity, the true hue shall always be rendered.

Another very important reason that the tricolor sensation curves cannot be used for practical taking filters is that the sensation curves were derived by mixing monochromatic lights. Now, in order to provide sufficient luminosity with available light sources, all projection or viewing filters for additive reproduction must transmit light over a considerable range of the spectrum. For the same reason, and also that they may not extinguish each other when mixed or superimposed, the dyes or pigments for subtractive reproduction must transmit or reflect light over considerable regions. Hence, attempts to use the sensation curves as a basis for designing taking-filters for practical color processes result only in considerable degradation of color.

From these considerations, it may be seen that it is necessary that the absorption curves of the taking-filters should be as abrupt as possible and that they should overlap to a slight extent only. The ideal taking-filters would then be somewhat as shown in fig. 47.

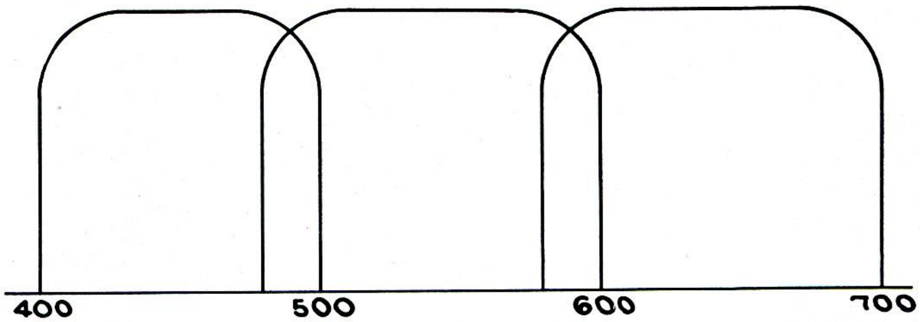
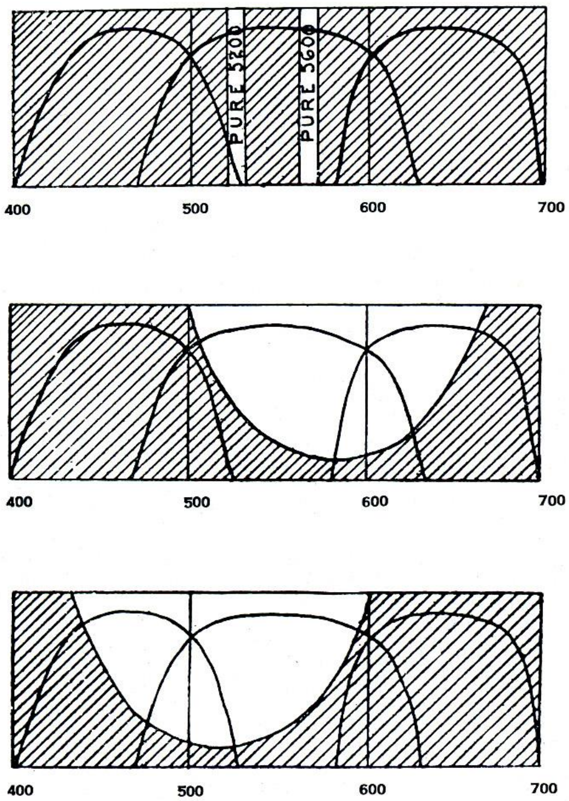


FIG. 47. IDEAL TAKING FILTERS

Such filters cannot give a literal reproduction of the spectrum. They will divide it into five distinct regions, each of a practically uniform hue. The first is the region extending to 600, which has been recorded in the red filter only and which is therefore reproduced as pure red. The second is the narrow region between 580 and 600, recorded through both the red and green filters, and therefore reproduced as pure yellow. The third is the region between 500 and 580, recorded only in the green filter and reproduced as pure green. The fourth is the region between 480 and 500, recorded in both the green and the blue filters and reproduced as blue-green. The fifth is the region between 400 and 480, recorded only in the blue filter, and reproduced as blue.

It will be seen that although the ideal taking-filters give a fair reproduction of the spectrum, they fail to distinguish between monochromatic hues lying within any one of the five regions described. For example, a monochromatic yellowish green of wave length 560 and a monochromatic bluish green of wave length 520 are reproduced alike with sharply cutting filters, since each of them is recorded through the green filter only.

For actual colored objects, however, the reproduction becomes greatly superior. This is because no naturally occurring colors or artificial dyes, paints, or pigments reflect monochromatic light. The illustrations in fig. 48 show typical absorption curves of dyes that match visually the pure spectral colors corresponding to wave lengths 560 and 520. Thus, the yellowish green of any object will be recorded rather fully through the green filter, to a less extent through the red filter, and only very slightly through the blue filter. It will, therefore, be reproduced as a yellowish green. A natural bluish green, on the other hand, will be recorded only very slightly through the red filter, to a greater extent through the



SPECTRUM SHOWING PURE COLORS WITH TRACE OF FILTER CURVES.

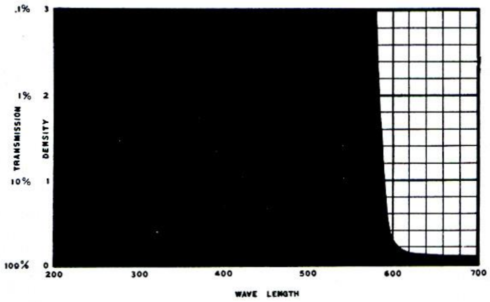
CURVE OF NATURAL YELLOW-GREEN MATCHING PURE LIGHT OF W. L. 560

CURVE OF NATURAL BLUE-GREEN MATCHING PURE LIGHT OF W.L. 520

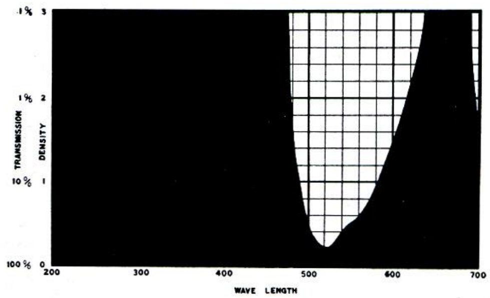
FIG. 48

blue filter, and rather fully through the green filter, so that it will be reproduced as a blue-green. By similar reasoning, it may be seen that all naturally occurring colors can be reproduced satisfactorily by sharply cutting taking-filters.

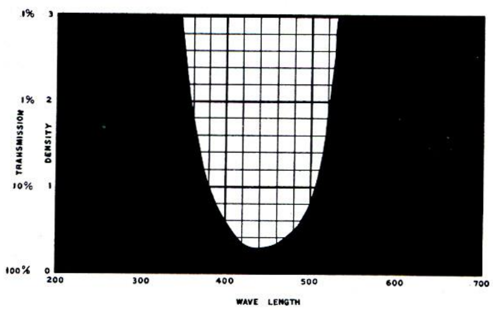
In the making of actual tricolor taking-filters, it is not possible to adhere strictly to the ideal filters without great losses in efficiency, particularly in the green and blue filters. This is due to the fact that we have to accept the spectral cuts of the best dyes and combinations of dyes available. Now it happens that for almost all known dyes, the edges of their absorption bands which lie toward the short wave lengths are less abrupt than the edges toward the longer wave lengths. Thus, the red filter can be made practically as abrupt as theory indicates, since the long wave edge of an absorption band determines the cut between the red and green regions. The cut between the red and invisible regions is determined by the limit of the sensitivity of the photographic emulsion. In the green filter, there must be an absorption band in the red region. Since one of the green filter cuts is determined by the short wave edge of this band,



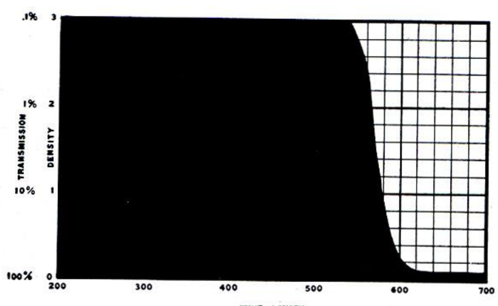
WRATTEN FILTER NO. 25 (A)



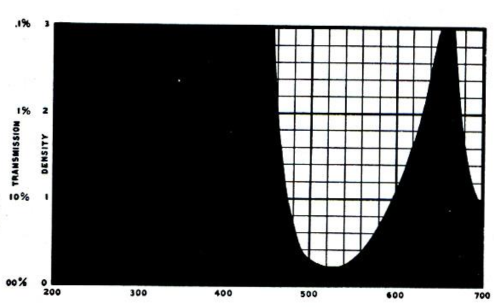
WRATTEN FILTER NO. 58 (B)



WRATTEN FILTER NO. 47 (C5)



WRATTEN FILTER NO. 28



WRATTEN FILTER NO. 40A

FIG. 49

this cut is necessarily less abrupt than indicated by the ideal filter. This condition could be overcome by increasing the concentration of the red absorbing component of the green filter were it not for the fact that the green absorption of the green filter would be increased, necessitating unduly great exposure in the camera, and the cut would be shifted too far into the green region.

The green filter cut between the green and blue regions presents no difficulty. The blue filter cut between the green and blue regions must be somewhat less abrupt than the ideal filters would indicate for the same reasons as the green filter cut between the red and green regions.

Much experimental work and long practical experience have shown that the Wratten Tricolor Filters, Nos. 25 (A), 58 (B), and 47 (C5) are highly suitable taking-filters for use with Eastman orthopanchromatic and hyperpanchromatic materials. Formerly, filter No. 49 (C4) was used as the blue taking-filter, but the increase in the red and green sensitivity of panchromatic materials, achieved in 1931, makes the use of the more transparent blue filter No. 47 (C5) of advantage. Those who wish to experiment will find that excellent results can also be obtained with Nos. 28, 40A, and 47. Curves of these two sets of taking filters are reproduced in fig. 49. That these filters are a very near approach indeed to the ideal is shown by the fact that pictures made through them and properly projected in the additive manner by means of a triple lantern are practically above criticism.

Making Three-Color Negatives

Cameras

The object of a three-color camera should be the making of three negatives, taken through the proper filters, that will exactly superimpose. This implies that the three negatives should be of identical size, of equal sharpness and apparently from the same point of view. Also, the subject must not appear differently in the three negatives as the result of its motion. The necessary conditions by which this object is achieved depend somewhat on the nature of the subject to be photographed.

The simplest subjects to photograph are still subjects. For these, an ordinary camera may be used. Three separate exposures are made on three separate plates or films, one through each of the tricolor filters. The timing of these exposures is done according to the filter ratio, as is described in a later section. Care must be taken that the lighting does not change during the time the three exposures are being made. A rigid tripod is indispensable.

An improvement over the ordinary camera with separate plate or film holders is provided in the repeating back. The plate holder of the repeating back takes a plate long enough so that three exposures can be made on the one plate, one above another or side by side. One of the tricolor filters covers the space for each exposure. The repeating back may be operated by the same mechanism that operates the shutter, so that after the first exposure is made, the holder automatically drops to the next position, and likewise after the second exposure. Certain automatic repeating cameras use roll film instead of plates and carry the filters on a revolving shutter behind the lens.

For general work, however, some form of single exposure camera is necessary. These cameras have the advantage that if the subject moves during the exposure, at least the movement is the same in all three negatives and no color fringes are introduced. In such cameras, except, under certain conditions, for negatives of motion picture size, some form of optical light-dividing device is necessary in order that all three negatives may be made from the same point of view.

Such a light-dividing device is called a "beam-splitter." It usually consists of one or more partly transparent reflectors placed in the path of the rays so as to bring about the formation of three identical optical images in place of one. It may be placed between the subject and the camera lens, making necessary the use of three objectives of identical focal length. More often, however, it is placed between the lens and the photographic plates, making necessary the use of only one objective.

Sometimes the surfaces of the reflectors are coated with an extremely thin, semi-transparent layer of silver, platinum, or gold to increase their reflecting power. If so, silver is to be preferred, on account of its high efficiency, wherever it can be protected from the tarnishing action of the air by cementing between glasses. The combined reflection and transmission of an electrically "spluttered" silvered reflector may, under favorable conditions, amount to 85-90% of the incident light. Platinum and gold have the advantage of resistance to tarnish, but the disadvantage of possessing lower efficiency than silver. These semi-transparent metal-coated reflectors, however, are difficult to prepare satisfactorily and are expensive. Many cameras have been designed, therefore, to utilize only the surface reflection of optical plate glass. For a complete description of one-exposure cameras employing both coated and uncoated reflectors, the reader is referred to *The History of Three-Color Photography* by E. J. Wall (American Photographic Publishing Company, Boston, 1925).

Photographic Materials

For color separation negative making, either plates or films may be used. For the larger sizes of negatives, plates are preferred. Nevertheless, satisfactory negatives of considerable size may be made on films if the three negatives are treated exactly alike in development, fixing, and washing and are dried slowly and uniformly without the use of undue heat so as to avoid unequal shrinkage of the support.

Formerly, it was often suggested that greater speed might be attained if, instead of using a panchromatic material for all three negatives, materials specifically sensitized for different regions of the spectrum were employed. For example, it has been recommended that a special green sensitive emulsion with a yellow filter be used for the green record instead of a panchromatic emulsion with a green filter. However, in view of the new panchromatic emulsions with increased speed to green and red light, the advantages of using two or three different kinds of plates specifically sensitized for different regions are materially lessened if they are not altogether eliminated. For example, the present day emulsions of highest green speeds are emulsions which are sensitive to red also. Furthermore, the use of different emulsions has the disadvantage that the speeds to red, green and blue light may change considerably and independently on keeping. With panchromatic plates, if the speeds change, speeds to the three colors usually change in about the same ratio. Also, the contrasts or gammas of three different plates are apt to differ considerably, necessitating a different degree of development for each plate. Therefore, wherever possible, it is recommended that the same panchromatic emulsion be used for all three color records.

For color separation negatives not made through a halftone screen, the following panchromatic materials are especially recommended:

Wratten Panchromatic Plates
Wratten Hypersensitive Panchromatic Plates
Eastman Portrait Panchromatic Film

Eastman Supersensitive Panchromatic Film
Eastman Supersensitive Panchromatic Motion Picture Negative Film.

For color separation negatives made through a half-tone screen, Wratten Process Panchromatic Plates are recommended.

The Determination of Tricolor Filter Ratios

In making tricolor negatives, a rule of general application is that, for a scale of grays, the densities of the images obtained through the three filters should be identical. If this condition is not observed, errors in color rendering may be introduced which cannot be corrected by after-treatment. The observance of this rule necessitates adjustment either of the time of exposures or of the intensity of light through the three filters in exposing the negatives. The balance of exposures will vary for the same filters when different kinds of panchromatic materials, or even different batches of the same kind of materials, are used. It will also vary with the spectral composition of the exposing light.

As a guide for three-color workers in determining the exposure ratios, the Eastman Kodak Company supplies, packed in each box of panchromatic plates or cut films intended for three-color photography, a card bearing the filter factors for the Wratten Filters Nos. 25 (A), 58 (B), and 47 (C5) for sunlight, white flame arcs and incandescent tungsten lamps. These factors are based upon careful laboratory tests and are valid for standard light sources of the type indicated. However, the light from different sources, even of the same type, varies somewhat in composition. For example, the composition of the light from a tungsten lamp varies widely with the temperature of the filament, which, in turn, depends upon the current. Different lamps are made to operate at different filament temperatures. Also, the composition of "daylight" varies with the location of the studio, the condition of the atmosphere, etc. Furthermore, the exposure ratio depends somewhat on the way the filters are used and upon the nature of the color process. In assigning the filter factors printed on the cards furnished with Eastman materials, consideration is given to the manner in which the material is intended to be used. Allowance cannot be made for all conditions, however. Therefore, it is strongly recommended that the careful color worker determine or verify the filter ratios under the actual conditions of practice.

Certain conditions may make it obligatory for the photographer to determine his own ratios. Among these are the use of a filter not belonging to the standard tri color set, or the use of a color camera with some sort of optical device which divides the beam of light into three parts, one for each filter, in proportions not accurately known.

For purposes of convenience, we may distinguish between filter factors and filter ratios in the following way. The filter factor is a definite number by which the exposure through the filter must be multiplied in order to obtain the same densities, for a scale of grays, as if the filter had not been used. The filter ratio may be defined as a set of numbers, one for each filter, which are equal to the filter factors or proportional to them, but which show only the relative exposures which must be given through the three filters in order to obtain the same densities for a scale of grays.

For example, the filter factors by standard daylight for a batch of panchromatic plates may be as follows:

Filter	Red	Green	Blue
Factor	9	5	6

Now these numbers, 9 : 5 : 6, give the filter ratio directly, but any multiple of these numbers gives the ratio equally well, as, for example, 18 : 10 : 12 or 4½ : 2½ : 3. This distinction is made because, for three-color photography, it is usually simpler and entirely adequate to determine the filter ratio rather than the filter factors.

The laboratory method of determining filter ratios requires giving the specified photographic material an exposure to either an intensity scale or a time scale through each of the three filters. The specified light source is, of course, employed. For the sake of simplicity, we shall assume the intensity scale has been used. The negatives of the three sets of exposures are usually developed for the same time, which is approximately the same as used in practice. The densities on the three negatives are then measured and plotted against the logarithms of the corresponding intensities. For this purpose, only the relative intensities need be known, the absolute values being unnecessary. Three curves are thus obtained, somewhat as shown in fig. 50, which are the characteristic curves of the tone reproduction through the three filters.

Now for correct color reproduction, the three curves should superimpose. This we could bring about by altering the exposures so as to move two of the curves to the left

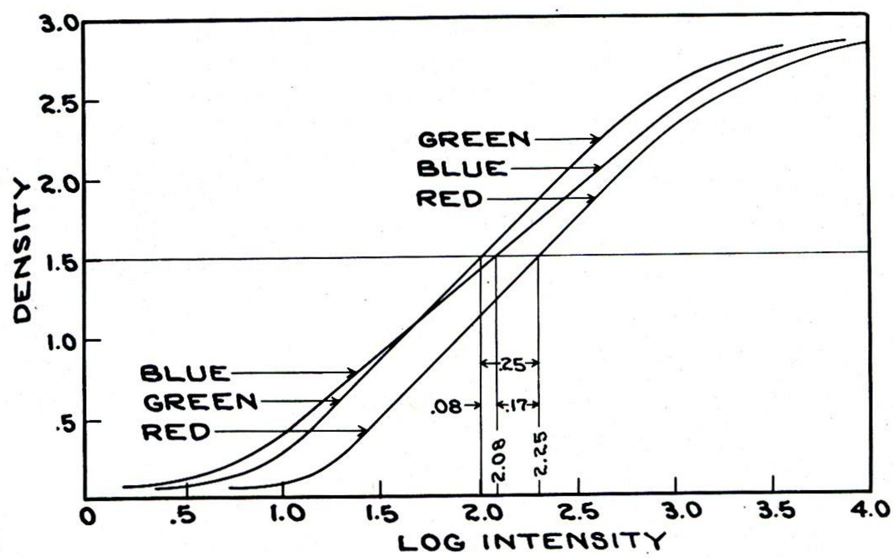


FIG. 50. CHARACTERISTIC CURVES THROUGH TRICOLOR FILTERS

or to the right, parallel to their original positions, were it not for the fact that frequently all three do not have the identical slope or "gamma." In particular, the slope of the curve through the blue filter is usually slightly lower than that through the other two.

This difference in gamma is due to the fact that a silver bromide emulsion is more opaque to blue and violet light than to other colors. It can sometimes be corrected in the development of the negatives or at a later stage in the color process. The difference is usually small, however, and the correction is seldom made.

What is done is to match the curves at the density for which it is most important to obtain accurate color balance. The particular density selected depends somewhat upon the nature of the subject to be photographed, upon the camera exposure, and upon the nature of the color process. In portraiture, it is very important that the color rendering be correct in the lighter tones corresponding to the flesh tints and whites. Also, in general, the eye is more sensitive to variations in hue in the highlight portions of the picture than in the darker portions. Therefore, the negative curves are usually matched at the density corresponding to a highlight in the picture. This should correspond to a matte white object, not to the specular reflection from a polished surface. The point usually lies well up on the negative curve.

For example, we shall assume that it corresponds to a density of 1.5. If it is desired to match the negatives at some other portion of the curve, the changes in procedure will be obvious.

We now draw a horizontal line through our curves corresponding to the selected density, which, in this example, is 1.5. Now it will be seen that this line crosses the curve of the blue filter 0.08 to the right of the green filter curve and that it crosses the red filter curve 0.25 to the right of the green filter curve. This means that to make all of the curves coincide at a density of 1.5, we must multiply the exposures given through the blue and red filters by numbers corresponding to the logarithms 0.08 and 0.25, while still plotting the original values of the relative intensities. These numbers are approximately 1.2 and 1.8. In practice, the intensity scale represents the luminosities in the subject we wish to photograph, and the numbers by which we multiply the intensities through the different filters to get the curves to superimpose represent the ratios of the camera exposures through the three filters in order to get approximately the same densities on the three negatives for a scale of grays. Therefore, the ratio 1.8 : 1.0 : 1.2 or 9 : 5 : 6 is the filter ratio for the red, green, and blue filters.

The determination of filter ratios in the studio is partly a matter of trial and error. However, with a ratio card or some previous experience as a guide, one or two trials are usually sufficient. The method used depends upon the type of camera employed.

For cameras in which three successive exposures are made, the Eastman Ratiometer provides a convenient means of determining the ratio on a single plate. This device is shown in fig. 51. It consists of a cardboard box, lined with black

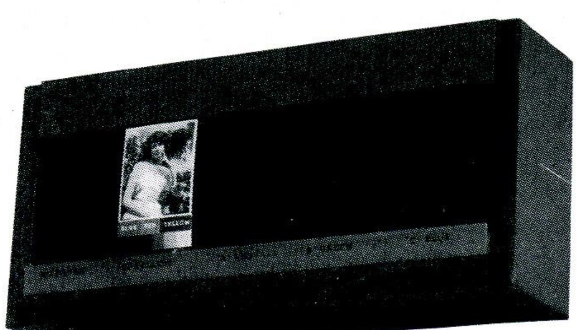


Fig. 51. Eastman Ratiometer

velvet, on top of which slides a black and white print with a scale of grays at the bottom. With the same light that is to be used for taking the color picture, an exposure is made on the ratiometer through the red filter with the print in the position marked "A" Red. Then, with the shutter closed, the print is pushed into the next position and an exposure is made through the green filter. Similarly, a third exposure is made through the blue filter. The three exposures are given according to the ratio indicated on the card packed with the plates or according to an estimate based on previous experience. The plate is now developed and the three negative images examined. If the three images match, at least in the highlight portions or whatever portion is most important, the correct exposure ratio was given. If they do not match, another set of exposures must be tried. The small graded strip at the bottom makes it possible to estimate how much the exposures need to be changed, because each patch requires 50% more exposure than the preceding one to give the same density in the negative. Usually, a second trial, based upon the first, is the most that is necessary to determine the ratio with sufficient accuracy. Assuming that the same material, filters and light source were used as in the laboratory test previously described, the required exposures would be 9 sec., 5 sec. and 6 sec. or 4½ sec., 2½ sec. and 3 sec. or some other set of values standing in the same ratio, the actual time depending upon the intensity of illumination and the diaphragm setting of the lens. It is advisable to stop down the lens to make the exposures long enough so that they can be conveniently timed.

With cameras designed to make the three exposures simultaneously, a black and white print, such as is used on the Eastman Ratiometer, need be photographed only once for each trial. The three negatives are examined as before and the exposures adjusted, if necessary, to obtain a match.

With such cameras, it is usually impossible to make this adjustment by giving the three separate exposures different times. Even where this is possible, as, for example, in a camera with three focal plane shutters, it is inadvisable to alter the times of the separate exposures except for still objects. On moving objects, colored fringes will be introduced into the picture unless the three exposures coincide exactly in time.

Neither is it advisable, on a three lens camera, to adjust the exposures by using different diaphragm settings on the three lenses, except for flat subjects which lie in one plane at right angles to the camera axis. With subjects having depth, the use of different diaphragm settings for the three negatives gives rise to different depths of focus and, consequently, to color fringes on objects which lie out of the plane of sharp focus.

It is very detrimental to color rendering to attempt to balance the exposures by using filters known as "open-cut" filters which have a considerably higher transmission than the standard. For example, let us suppose the ratio test shows that the exposure through the green filter must be greatly increased to equal that obtained through the red and blue. We may therefore be tempted to substitute for the 58 filter a much more open filter having an absorption curve such as that shown in fig. 52. While it is true that this filter would

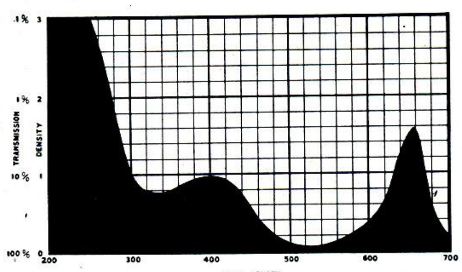


FIG. 52. OPEN-CUT GREEN FILTER

have a somewhat increased transmission for green light compared with the 58, this is achieved only at the expense of a very much greater increase in the transmission of red and blue light. Therefore, although we might be able to balance our exposures for a scale of grays, we should increase the exposure to green light through the green filter very much less than if we retained the standard 58 filter and gave more exposure by some other means. Also, we should increase the amount of red and blue light recorded through the green filter. The result, as seen in the finished color picture, would be that the greens would appear darker and less luminous in comparison with the other colors and that the blues, reds and magentas would contain too much green. The blues would therefore appear greenish and the reds orange, and the magentas would be diluted with white. By similar reasoning, we can show the harmful effects of substituting more "open-cut" filters for any of the three standard filters.

This detriment is due to the fact that when the concentration of a dye in a filter is decreased, the transmission is increased at a very much greater rate in the region of the maximum absorption of the dye than in the region of minimum absorption. This behavior is a fundamental property of all dyes.

Since the methods indicated have been shown to be unsuitable for adjusting exposure ratios in one-exposure cameras, the only methods left are the use of correcting filters and the use of neutral densities.

The function of correcting filters is to alter the spectral composition of the light reaching the camera lens so that equal exposures will be obtained for a scale of grays behind the three filters. For example, if the exposure to blue light is excessive, a yellow or pale orange filter may be used over the camera lens. However, correcting filters are not available ready-made for all the various combinations of light sources, photographic materials and optical light-dividing devices found in color cameras. Consequently, the use of correcting filters has a limited application.

Neutral densities form the most efficient and generally applicable method of adjusting exposure ratios in one exposure cameras. These are supplied by the Eastman Kodak Company in the form of sheets of filter film, known as Wratten Filter No. 96, which comes in a number of different densities. A neutral density is inserted in the path of the light going to each filter for which it is necessary to decrease the exposure in order to obtain a match.

The values of the neutral densities required are very easily determined if the filter ratio is determined by the laboratory method. It is necessary only to read directly from the curves the amounts on the log exposure axis by which two of the curves must be moved to make them coincide with the curve for the filter through which the least exposure was obtained. In the example shown in fig. 50, the beam through the green filter requires a neutral density of 0.25, while the beam through the blue filter requires a density of 0.17.

The values of the neutral densities may also be determined from the filter ratio. Take, for example, the ratio 9 : 5 : 6 for the red, green and blue filters. Now the neutral densities, instead of adjusting the exposures through the three filters by altering the *time*, make the adjustment by altering the *intensity*. Thus, the intensities must be in this same ratio, 9 : 5 : 6. This means that a density transmitting $\frac{6}{9}$ of the light must be placed in the blue filter beam, a density transmitting $\frac{5}{9}$ of the light must be placed in the green filter beam, and no density at all must be placed in the red filter beam. Now a density is the logarithm of the transmission *inverted*. Thus, the densities required are the logarithms of $\frac{9}{6}$ and $\frac{9}{5}$, which are approximately 0.17 and 0.25.

In practice, for the most exacting work, as in motion pictures, where succeeding scenes taken in different cameras must match, it has not been found necessary to select the neutral densities with a precision greater than $\pm$ 0.025. Thus, if we have a series of densities of the values 0.05, 0.10, 0.15, 0.20, etc., (the absence of a density corresponds to 0) it will be sufficiently accurate to select the density of this series coming nearest to the required value. By doing so we cannot be in error more than 0.025.

With regard to the positions of the neutral densities, the only fixed rule that can be laid down is that they should be placed so that each affects the light beam through the desired filter, and through that filter only. They should be kept flat in order not to disturb the definition of the lens. It is of the utmost importance that, like filters and lenses, they should be kept perfectly clean and free from marks or scratches.

The Exposure and Development of Three-Color Negatives

The filter ratio having been determined and the corresponding adjustments having been made in the camera by means of neutral densities, there still remains the necessity of giving the correct amount of exposure in the camera. The object is to expose so that all of the tones will lie within the essentially straight line portion of the characteristic curve of the emulsion with the possible exception of the deepest shadows and the highest catch lights. Good color rendering can be obtained only over that range for which the tone reproduction is correct. For this reason, it is advisable to keep the lighting soft in subjects for three-color photography. If the range of tones in the subject is excessive, the best that can be done is to expose so that the highlights fall slightly short of the over-exposure region and allow the shadows to fall where they may. Incorrect exposure introduces serious errors in color rendering which cannot be corrected by altering the development of the negatives, by intensification or reduction, or by any other means. Consequently, correct exposure in the camera is one of the essentials in obtaining a good color picture.

Another requisite is that each of the color separation negatives be developed essentially to the same gamma. As already pointed out, developing the three negatives for the same time usually results in a slightly lower contrast or gamma for the blue filter image than for the other two. However, since it is inconvenient to determine the exact degree of development required to correct the slight error and since it is sometimes impossible to give different development to the three records, it is best to select a good panchromatic material on which the gamma difference is slight and to develop all three negatives for the same time.

The gamma to which the negative should be developed depends upon the method of printing the positives. The object is to obtain a finished color picture in which the gradation of tones is the same as in the subject. More precisely stated, the gamma of the entire process should equal unity. The gamma of the entire process is the product of the gammas of the separate steps. Therefore, if the gamma of the printing process is greater than unity, the gamma of the negatives must be less than unity and *vice versa*. That is to say, if the printing process increases the contrast of the negative, the contrast of the negative must be correspondingly lower than that of the subject. In practice, for either additive or subtractive prints intended to be viewed by projection, it is advisable to make the gamma of the print (referred to the original subject) a little greater than unity, say about 1.2. This is done because the contrast of the print is lowered by projection onto a screen, on account of lens flare, room lighting, etc.

It is sometimes supposed that increasing the contrast of a color picture affects the intensity scale of the picture and gives more saturated colors without affecting the hues. This, however, is a mistake. It can readily be shown, by means of the characteristic curves or by actual trial, that the contrast has an effect on hue also. In particular, if the contrast is too great, all mixed colors, such as yellows, blue-greens and magentas, which are mixtures of two or three primaries in any but equal proportions, will have their dominant hues displaced toward the color of the primary which is present in the larger proportion. For example, while a pure yellow, consisting of equal amounts of red and green, would suffer no change in hue, an orange or reddish yellow would become redder and a greenish yellow would become greener. This result holds for both additive and subtractive processes. For this reason, correct contrast is necessary for correct rendering of hue.

Additive Processes

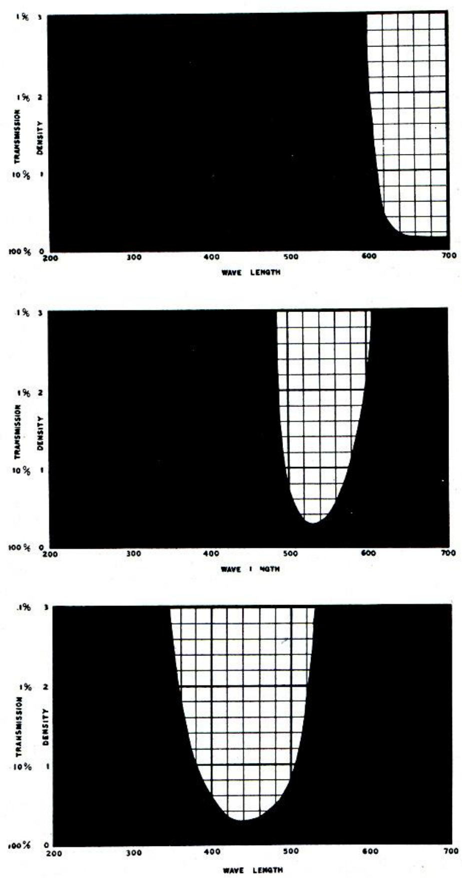
The additive processes of three-color reproduction are the easiest processes to work and give the most accurate reproduction of colored objects.

In additive projection, as with the triple lantern, the great difficulty is to obtain sufficient light. As previously stated, this difficulty prohibits a close approach to monochromatic lights for illuminating the three positive prints. In order to obtain saturated colors, however, it is necessary that the transmission bands of the projection filters should be abrupt and that they should not overlap one another appreciably. Inasmuch as the taking-filters do overlap, it is better to use a different set for projection. The red projection filter should be of a pure red, not an orange color. It should not pass light of shorter wave length than 600 mμ. The green should be a pure green, not transmitting any red or blue and extending from 500 to 600 mμ. The blue filter should transmit as little green light as possible, but it should also be as transparent to blue light as possible. Since it is difficult to find stable dyes that absorb the green light completely without also absorbing a considerable proportion of the blue light, a compromise must be made and a small amount of bluish green light must be allowed to pass the blue filter. The transmission of a small amount of the ultra-violet by a blue projection filter would not, of course, do any harm since it is invisible anyway.

Suitable filters for three-color additive projection are Wratten Filters Nos. 29 (red), 61 (green) and 47 (blue). The absorption curves for these filters are reproduced in fig. 53.

For proper color rendering by means of three-color additive synthesis, it is necessary that the relative amounts of light through the three filters be so adjusted that the field or screen appears white when there are no positive transparencies in place. Then, if the negatives have been properly exposed and developed, and the positive transparencies have been printed and developed alike, a scale of grays will be satisfactorily rendered when the positives are placed in the proper beams. Also, all colors will be properly rendered.

Naturally, the adjustment of the three beams will be different for tungsten light and for arcs. If tungsten lamps are used, these should be of the heavy filament type, especially designed for projection purposes, and they should be operated on as high a current as is consistent with a reason-



WRATTEN FILTER NO. 29

WRATTEN FILTER NO. 61

WRATTEN FILTER NO. 47

FIG. 53. FILTERS FOR THREE-COLOR ADDITIVE PROJECTION

able life of the lamp in order to obtain sufficient illumination through the green and blue filters.

A widely used modification of the additive method is the screen plate process of three-color photography. In this process, suggested by Ducos du Hauron and first carried out by Joly, a glass plate is covered with an immense number of transparent colored elements, so small that they are indistinguishable to the eye. Each third of these elements is colored with one of the primary colors, red, green and blue. A panchromatic emulsion is put into contact with the elements on this plate and the camera exposure made through the elements. Either the sensitiveness of the panchromatic emulsion and the transmission of the color elements must be mutually adjusted in manufacture so that equal exposures are obtained for white light through the three kinds of elements, or a correcting filter must be used on the camera to attain the same end.

Screen plates are of two kinds. In the one kind, represented by the original Joly plates and by the Finlay plates of today, the screen elements are of a definite size and arranged in a regular pattern. In the other kind, represented by the Autochrome plate, the particles vary somewhat in size and have no definite arrangement.

In the regular screen plate process, the panchromatic emulsion is usually carried on a separate glass plate from the screen elements. For exposure, the emulsion of the panchromatic plate is pressed into contact with the elements of the screen plate in the plate holder. The negative is developed and a positive print made from this onto a lantern plate. The lantern plate is then registered with a viewing screen with the same size and arrangement of elements as the taking screen, and the two bound together. Thus, a color picture is obtained by additive synthesis. As many positives as desired are made from each negative by this process.

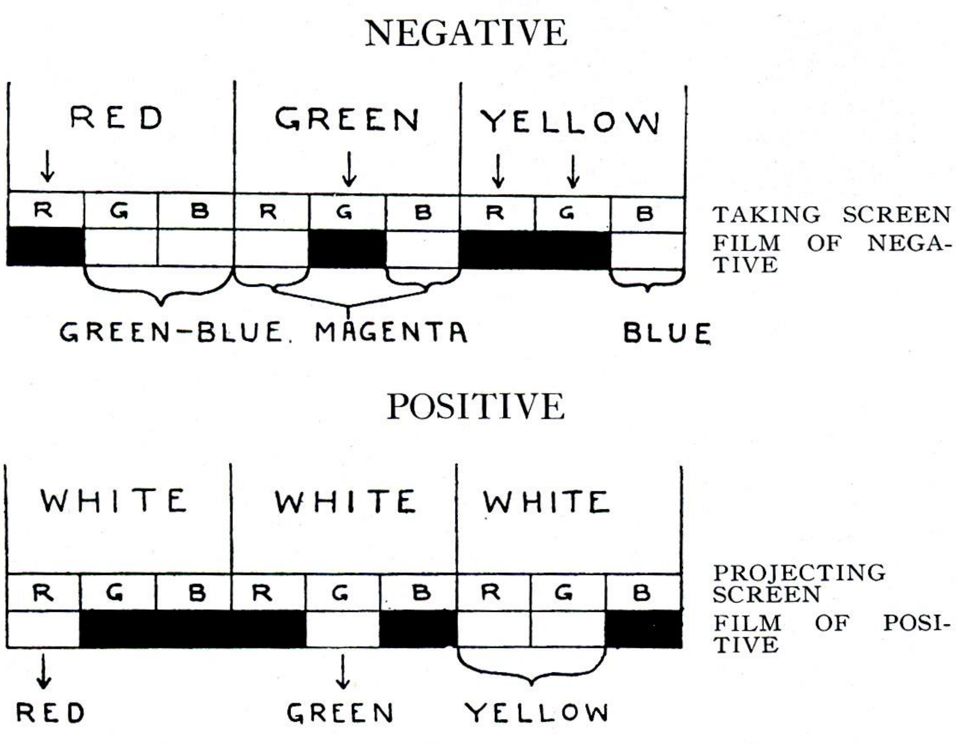


FIG. 54

The process is illustrated by the diagram (fig. 54). Here we have three patches of colored light, red, green and yellow, falling upon the screen, which is represented by three groups of the primary elements. The red light penetrates the red elements, producing blackness in the negative film beneath them. The green light penetrates the green elements, producing blackness in the film beneath them. The yellow light, composed of a mixture of red and green light, penetrates both of these elements leaving the negative film transparent under the blue elements only.

When the positive is registered upon the viewing screen, the red light is represented by the clear red elements, the green and blue ones being obstructed. In the same way, the green is represented by clear green elements, the red and blue being obstructed, and the yellow is represented by the light transmitted by the red and green elements, the blue only being obstructed. It will be seen that if the negative instead of the positive be registered upon the screen, the complementaries to the original colors will be obtained; the red will be represented by a mixture of green and blue, the green by the magenta color resulting from the mixture of red and blue, and the yellow by blue.

Professor Joly, who used exactly the method described, made his taking screen of colors with wide transmission bands somewhat resembling the color mixture curves, while the viewing screen on which the positive was registered had deep colors with narrow transmission bands.

In the Autochrome Plate, the color elements are composed of dyed and flattened starch grains and the panchromatic emulsion is coated on the same plate, separated from the colored elements only by an extremely thin layer of water proof varnish. After exposure and development, the image is reversed by removing the negative silver image with a permanganate or bichromate solution and blackening the residual silver bromide in the developer. Thus, a positive is obtained in which the colors are immediately visible. The reversal process is necessary because of the impossibility of registering a print with an irregular screen.

The use of the same colored elements for both taking and viewing in the Autochrome screen plate makes it necessary to adjust the colors so that the screen itself appears neutral to the eye. Therefore, in order that these same particles shall give equal exposures on the panchromatic emulsions used, a correcting filter is necessary in taking. The Autochrome filter for daylight is of an orange color to compensate for the excess of blue and green sensitivity in the panchromatic emulsions.

Subtractive Processes

Although the additive methods of color photography are capable of giving results of great accuracy and are comparatively simple to work, they have several disadvantages. The chief of these are the difficulty of obtaining bright pictures on projection and the impossibility of making prints on paper to be viewed by reflected light. For these reasons, the subtractive process is preferred for many purposes and the fact that the commercial three-color half-tone process is subtractive makes the subtractive method by far the most widely used.

In subtractive processes, the three negatives through the red, green and blue filters are taken as in the additive process, but, as previously indicated, they are printed, not as transparencies to be projected by colored light, but as three superimposed prints, each in a color complementary to one of the taking filters.

Thus, if we divide the spectrum so that we consider white light to be made up of red, green, and blue, then the negative taken by red light is printed in a color which transmits or reflects all the green and all the blue, simply absorbing the red. In the same way, the negative taken by green light is printed in a magenta color, which transmits all the red and all the blue, absorbing the green. The negative taken by blue light is printed in yellow, which transmits all the red and all the green, but absorbs the blue. Let us turn now to fig. 55. At the bottom of this is a test object produced by the super-position of the three single color prints shown above it. This test object shows six patches of color; at the bottom, the single ink colors, and at the top, three patches, each of which is formed by the superposition of two of the inks—a red formed by the superposition of magenta and yellow, green formed by the superposition of blue-green and yellow, and blue-violet formed by the superposition of blue-green and magenta. Thus, the test object has at the top the three primary colors, red, green, and blue, and at the bottom their complementaries, blue-green, magenta, and yellow. In the red negative, the red patch is recorded as black and also the magenta and yellow patches, by virtue of the red light reflected from them. If we print this in blue-green ink, we shall print blue-green wherever there was no red in the original; that is to say, in the position of the green patch, the violet-blue patch, and the blue-green or minus red patch.

The green negative will record as black, the green patch, and the blue-green and yellow patches by virtue of the green light reflected from them. Making from it a positive print in magenta, we shall print magenta ink in the positions of the red patch, the violet-blue patch, and the magenta patch, these being the patches from which no green light was reflected. In the same way, the blue filter negative will record as black, those patches from which blue light is reflected; that is, the violet-blue patch, and the magenta and blue-green patches. This is printed in yellow ink, so that we print yellow in the places where no blue is reflected; that is, in the positions of the red patch, the green patch, and the yellow patch. Superposing these three printings, as is done in the original figure, we obtain red by the printing of magenta ink upon yellow ink, green by the printing of the blue-green ink on the yellow ink, and violet-blue by the printing of the blue-green ink upon the magenta ink, the other three patches being produced by the printing of the three inks separately. If we print all three inks on the top of one another, we shall get a black, or if they are only partially printed, a scale of grays.

Of the various methods for actually preparing photographic lantern slides or prints in the three-color process, it is not intended to speak in this book; for that purpose, reference should be made to a book on three-color photography, such as E. J. Wall's "*Practical Color Photography*," but it is necessary to devote some attention to the selection of the printing colors.

These printing colors, by whatever method they are to be applied, whether as stained gelatin in the stripping film or other carbon processes, as dyes in the pinatype process, or as printing inks, must be, as nearly as possible, complementary to the taking filters. This is necessary because we start with the assumption that the paper on which we print (or the viewing surface, if transparencies are in question) is reflecting blue, green, and red, comprising all colors, which, when blended together, look white. Now, as already stated above, if we print from the red record negative, we are printing from the shadow portions of the negative, that is, where there was an absence of red in the original, and therefore no record, so that we must print in a color that completely absorbs all red. At the same time, there may have been some other color in this portion of the original, so that not only must the red be absorbed, but the green and blue must be completely reflected. Therefore this color will be a minus-red (blue-green). In the same way, the material in which the shadows of the green record negative should be printed will be a minus-green (magenta), which entirely absorbs the green and reflects all the blue and red, and the blue record negative must be printed in a minus-blue (yellow), which entirely absorbs the blue, and, at the same time, completely reflects the red and green.

All actual printing colors, and especially inks and pigments, as distinguished from pure dyes, depart more or less from the requirements that we have arrived at for the ideal printing colors. In short, printing inks do not sufficiently absorb the colors they should absorb and do not reflect sufficiently the colors they should reflect.

Further consideration will show what effect these deficiencies in the inks will have on the color rendering.

A red must be reproduced by printing full strength yellow and full strength magenta. Now the yellow allows some of the blue to be reflected, and the magenta allows so much of the yellow and yellow-green to be reflected that the result will be a grayish orange rather than a true red.

Yellow will be reproduced by yellow alone. This will be fairly satisfactory, except that there is some degradation due to the absorption of red and yellow and the reflection of some blue, these defects making the color somewhat grayer than it should be.

Green will be reproduced by printing full strength yellow and full strength blue. But some of the green is absorbed by the yellow ink and a much larger amount by the blue ink; therefore, the green will look a dark yellowish-green, rather than a bright pure green.

A blue-green will be matched by the printing color itself, but this will be darker than it ought to be, because it absorbs over half of its own color instead of reflecting all.

A pure blue will be reproduced by full strength blue and full strength magenta, but this is degraded, because neither pigment reflects all the blue as it should.

Black will not be a dense neutral black, but either greenish black or reddish black according to whether the red has absorbed the green insufficiently or the blue has absorbed the red insufficiently.

Thus, we must expect to find a degradation in the colors of a subtractive print, when printing inks are used, even when the filters and films or plates are satisfactory, and exposure, development and printing have been carried out correctly.

Three- and Two-Color Motion Picture Processes

A motion picture process that was adapted to show the accurate and beautiful results that can be obtained by the three-color additive method was the Gaumont process. By this process, three-color separation negatives were taken simultaneously, one above another, in the space of two standard frames on panchromatic motion picture negative film. Three lenses were required in the camera, each covered by one of the tricolor filters. The positive prints were projected onto the screen by means of three lenses. Partly on account of the constant necessity for registering the three images on the screen, this process has not found any considerable commercial application.

An interesting three-color motion picture process is the Kodacolor process of the Eastman Kodak Company. This is an additive process, somewhat related to the screen plate processes, based upon an ingenious invention made by R. Berthon in 1909. According to this invention, the color elements are, in effect, formed on the panchromatic emulsion by optical means. A cross-sectional diagram of the optical system used in the Kodacolor camera (fig. 56) shows how this end is accomplished.

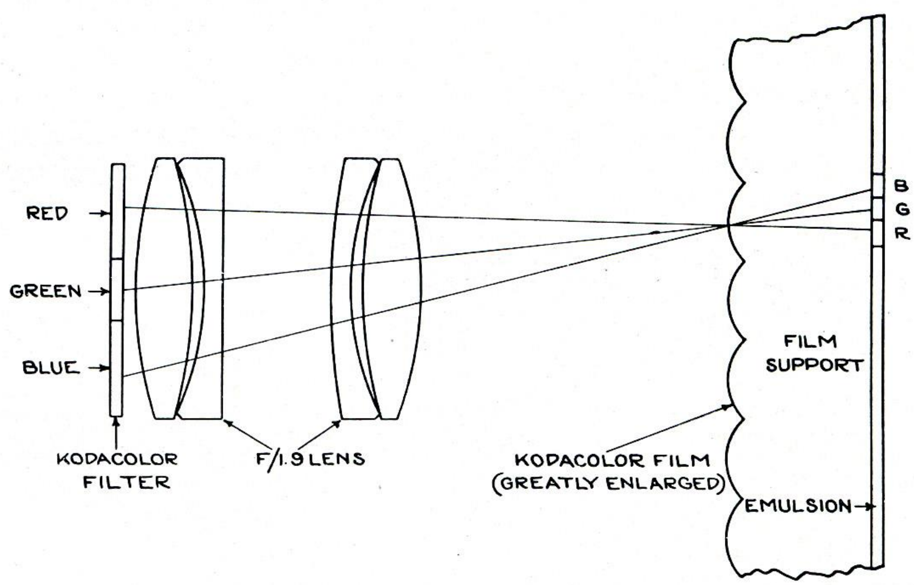


Fig. 56. Diagram of Kodacolor Process

A color filter, made up of bands of the three primary colors, red, green, and blue, is placed immediately in front of the camera lens. The film is placed in the camera with its support side facing the lens. The film support has been embossed with an enormous number—22 to the millimeter—of minute lenses. These lenses are of such a focal length and aperture that they form adjoining images of the banded filter on the panchromatic emulsion on the back of the film. Since the lenses are of the cylindrical type, there are formed, behind each lens, a red, green, and blue stripe running across the picture. Therefore, when the exposure is made, the film acts like a screen plate. After exposure, the film is developed and put through a reversal process so that a positive is obtained. As seen in the hand, this positive looks like an ordinary black and white film. If viewed from the support side, however, it may be noticed that the tones of those portions of the picture representing colored objects will change when the film is held at different angles to the eye. This change is due to the minute lenses and filter records on the film, which cause different amounts of light to be transmitted in different directions. When the positive is placed in a projector, with a lens and filter similar to the camera lens, and illuminated from the emulsion side, all of the filter records on the film are projected upon the proper color bands in the filter by the embossed lens elements. Thus, from those portions of the film that were exposed to red light, white light is projected onto the red filter, while shadows corresponding to the blue and green filter images, which were unexposed, are projected onto the blue and green filters. Similarly, from each part of the film the light is projected through the proper bands of the filter so that a picture in natural colors is produced on the screen.

The two-color motion picture processes give only approximations to three-color rendering. They are employed to simplify the construction of cameras for separation negatives and to facilitate the making of subtractive prints.

In making two-color negatives, exposures are made through red and green filters only. The red and green filter images may be recorded in alternate frames on the motion picture negative stock, making a two-color negative twice as long as a black and white negative of the same scene. Another method of obtaining the color separation negatives is to use a "bipack" made by placing a green sensitive film and a panchromatic film in contact in an ordinary motion picture camera. The exposure is made through the support of the green sensitive film. On account of the green and blue sensitivity of the panchromatic film, a thin layer of red dye is coated onto the surface of the green sensitive film to absorb light of these colors. A red dyed, green sensitive film made in this way by the Eastman Kodak Company is known as "Zelcras." If the additive method of reproduction is used, a black and white print from the two-color negatives is projected through red and bluish green filters, the two pictures of each pair being registered on the screen. The colors of these filters are so chosen that a white screen is obtained with the projection light when no film is in the gate. The filters must therefore be complementary to each other. If the subtractive method is used, the separation negatives are printed in two colors in register, sometimes on opposite sides of double coated positive stock, and sometimes in superposition in a single gelatin layer. The red filter negative is, of course, printed in a bluish green dye image and the green filter negative in a red dye image, the dyes being chosen so that they give a good gray when mixed in proper proportions. In other words, the colors of the dyes should be complementary to each other.

In a two-color process, all colors are reproduced as pure red, pure bluish green or as various mixtures of either of these colors with white or grey. Thus, if we arrange certain actual colors in the order in which they occur in the spectrum, as we pass from red to blue, the colors in a reproduction with a full exposure will pass by gradations from red through pink to light gray and then through pale bluish green to pure bluish green. The particular place in our imitation of the spectrum at which the gray occurs in the reproduction is of considerable importance. For example, it must not occur in the yellows, since many shades of yellow are of extreme importance, particularly in the photography of faces and figures, which make up most of motion picture drama. For example, flesh tones and the color of blond hair are really shades of yellow. These must not be reproduced as gray. It is better to reproduce these colors as shades of pink, that is, as reds diluted with various amounts of white or gray. Therefore, we shall allow the gray to represent a yellowish green. The color represented by gray must not be too far into the green from the yellow, however, or foliage will be rendered as gray and blond hair will be rendered as light auburn. The correct green to be rendered as gray corresponds to a spectral hue at about 575 $m\mu$.

This result is achieved by an adjustment of the spectral cut of the green taking filter. The two-color green taking filter is made to transmit a little farther into the blue region of the spectrum than the three-color filter. Accordingly, light yellows are recorded to a slightly less extent through the green filter than are whites. Thus, by balancing the exposures through the red and green filters for white light, yellows are reproduced as pale pinks.

Wratten Filters Nos. 28 (red) and 40 (green) are especially designed as two-color motion picture taking filters for high intensity tungsten light, and Nos. 28 and 40A are especially designed for daylight and white flame arcs. Filters Nos. 28 and 60 are also fairly satisfactory for a tungsten light source. For two-color projection, filters Nos. 23B and 69 are recommended.

The manner in which various colors are rendered by a two-color process, adjusted in accord with the considerations we have made, is summarized in the table below.

Color of Original	*Color as Reproduced by a Two-Color Process*
White	White
Gray	Gray
Black	Black
Red	Red
Orange	Light red
Yellow	Pink (pale red)
Yellowish green	Gray
Bright green	Light bluish green
Bluish green	Bluish green
Blue	Deep bluish green
Spectral violet	Black
Purple	Dark reddish gray
Rose	Red

It is probable that much of the success of two-color photography is due to psychological processes, since, for example, the rendering of yellows as pinks and of blond hair as a pinkish gray appears much more natural on the screen than would be anticipated on a strictly physical basis. A direct comparison of a two-color rendering with a three-color rendering shows at once the deficiencies of the two-color process in the rendering of many colors, however.

Frequently, it has been attempted to increase the number of hues which can be reproduced from two separation negatives by choosing projection filters or printing dyes which are not strictly complementary to each other. Although the number of hues which can be imitated with such filters or dyes may apparently be slightly greater than with complementaries, any gain is necessarily offset by the loss in saturation of other colors and by the impossibility of obtaining a true white or gray. Therefore, the use of such filters and dye combinations is not to be recommended.

CHAPTER X

THE OPTICAL PROPERTIES OF FILTERS

IT is curious to note that in books dealing with photographic optics, and indeed in practically all photographic literature, the optical properties of filters are ignored. In spite of the immense amount of attention which has been devoted to attaining the wonderful definition given by the modern anastigmatic lens, we know of no mention of the fairly obvious fact that the definition of any lens can be completely ruined by a bad filter, and that a considerable number of filters do actually degrade the definition of the lenses with which they are used.

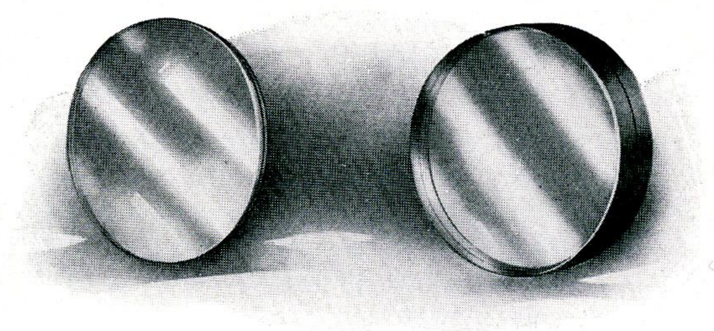
It is frequently stated in photographic periodicals that a simple and cheap way of preparing a filter is to dye a fixed out lantern plate, and, after drying, use it as a filter on a portrait lens. While this process is simple and cheap, the loss of definition is so serious, that probably few careful workers would be satisfied with such a makeshift.

In order to investigate the optical properties of filters, we designed a large testing instrument, consisting of a lens of great focal length forming an image of a distant object, which image can be examined by means of an eye-piece sliding upon an optical bench. The filter to be tested is placed upon the front of the lens and the aberrations which it introduces in the image are determined. The aberrations introduced by a filter will vary as the square of the focal length of the lens, so that as the focal length of the lens is about five feet, and the magnifying power of the eye-piece is fourteen, the linear size of the aberrations is 1,000 times as great as those which the filter would produce upon a lens of six inch focus.

The errors introduced by any filter can thus be rigidly determined, and, provided that the lens with which it is to be used is known, it is possible to insure that the filter is quite suitable for its purpose.

Errors in filters tending to produce aberrations and imperfect definition are of two kinds; those inherent in the glass, and those produced by strains induced in manufacture or mounting.

The first class of errors can only be avoided by careful selection of the glass, though, unfortunately in this, as in all other optical work, accuracy involves expense. Crystal plate is not good enough in surface for the preparation of filters, and even filters for small lenses must be made from glass of considerably higher quality. If filters of the highest possible accuracy are to be obtained, then the glasses into which they are cemented should be optically surfaced and tested in the same way as lenses. When filters are intended for microscopic work, or for other purposes where they are not to be used upon a lens, as, for instance, in spectroscopy, it is not necessary for the figure of the glass to be perfect, provided that the



In "B" Glass In "A" Glass (Flats)

FIG. 57. CEMENTED "K" FILTERS

glass is free from surface imperfections, reasonably flat, as flat as a good patent plate, for instance, and preferably white optical glass, not green glass.

The Eastman Kodak Company prepares filters in glass of two qualities:

A. Optical Flats, accurately surfaced by the finest optical glass workers and which necessarily makes this glass much more expensive.

B. Picked optical glass for use on lenses, and not recommended for use on lenses of longer than ten inches focal length.

The second class of error is produced by strains to which the glass is subjected. Many filters are made by coating dyed gelatin upon glass, but this method has the disadvantage that the drying of the gelatin bends the glass into a saucer shape. If then the second coated glass is cemented to the first by Canada balsam, a lens is produced, which may seriously alter the focus of the lens (this is shown with the effect exaggerated in fig. 58,) while any greater bending in one direction than in the other will destroy the definition by introducing astigmatism. In order to avoid this defect filters may be made by coating dyed gelatin upon prepared plate glass, and then, after drying, stripping the gelatin from the glass. These gelatin films can be sold at low prices as "film filters," and when handled with care they are perfectly satisfactory. While it is to be recommended that for permanent use cemented filters should be employed, because the film filters deteriorate, yet the latter are convenient for experimental work, and give results equal as far as color correction goes to the cemented filters. No attempt should be made, for photographic work, to protect the films by binding them between cover glasses, because, even if the cover glasses themselves are quite free from any tendency to introduce aberrations, the uncemented films thus bound up introduce complex reflection effects which greatly affect the definition.

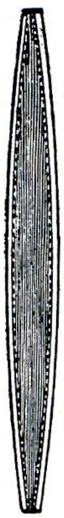
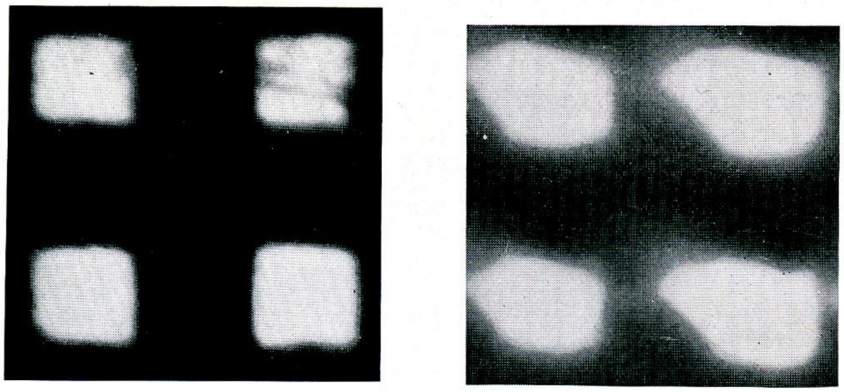


FIG. 58
LENS-SHAPED FILTERS, PRODUCED BY COATED GLASS

A very important point in the preparation of color filters is to insure that all the filters of a special kind which are prepared are accurately of the same depth of color. The Wratten film filters are tested in the following manner: after a quantity of film has been coated and stripped, specimens are selected at random and are compared with a standard piece of film upon a very accurate measuring instrument called a spectrophotometer. This instrument indicates whether the tint of the batch is identical with that of the standard, and whether the depth of the tint is also normal. Every sheet of film is then compared visually in four positions with a sheet of standard film in a specially designed comparator instrument, and any sheet which departs by more than a given amount (usually 2 per cent.) from the standard is rejected. The rejections are very considerable, because even with the greatest care variations in the gelatin or in the rate of drying will produce alterations in the color of the resultant filters, and often batches are rejected altogether, while even of a first-rate batch, many sheets will depart too widely from the standard; but the method insures that all the films actually passed are of the same color.

After cementing the films into selected glass by means of Canada balsam the filters are dried for from three to six weeks according to size at a constant temperature in a special drying cupboard. This slow drying is necessary to prevent strains in the glass being produced by unequal contraction of the balsam. Such strains are very likely to occur if the filters are dried too quickly or at unequal temperatures.

The danger of strain is much lessened by using glass of considerable thickness, and for this reason the larger filters are usually made in thick glass, while filters made from optical



(*a*) Original definition (*b*) Definition after screwing up tightly in cell

FIG. 59. THE EFFECT OF STRAINING A FILTER

flats are no less than half an inch in thickness, so that no danger of strain remains.

After drying and cleaning, the filters are carefully tested for freedom from aberration, and are then ready for mounting in the fitting which is to carry them for use.

Here, also, care must be taken that pressure, and especially uneven pressure, is not put upon the filter in mounting. Filters are frequently fastened into cells by means of a screw clamping ring, and, if this ring has not a shoulder upon it, it is sometimes screwed tight down on to the filter in order to hold it tightly. Such a procedure is almost certain to distort a thin filter and spoil the definition, as is shown in fig. 59, where (*a*) shows the original definition given by the filter and (*b*) that obtained after screwing the filter up in its cell.

The same defect may be induced by binding up the filters at the edge with strips of gum paper such as lantern binding strip. Even a label which extends over both glasses of a thin filter may cause sufficient distortion to make the filter very inferior.

The tests through which filters pass for optical definition are graduated according to the class of filter.

The Wratten test for Class A filters, cemented in optical flats, requires that the finished filter shall in no way degrade the definition of the test lens (of five feet focal length) when used at full aperture. Now this lens is specially designed to give the best possible definition, and the test object for flats contains a number of fine lines which are separated from each other only $\frac{1}{2000}$ inch. So that the test requires that a flat filter when used on a lens of sixty inches focal length at full aperture (about $2\frac{1}{2}$ inches) shall clearly separate lines only $\frac{1}{2000}$ inch apart.

This test may seem more accurate than is necessary, but by it one can guarantee flat filters to give perfect definition under any circumstances, even in high power telephoto work, or when used upon large lenses covering big plates for severely critical work.

Ordinary filters cemented in optical glass of good quality, but not in specially surfaced flats, are tested in a less severe manner. The test object for such filters is shown in fig. 60, this being a photograph of the image enlarged about 17 diameters. This test object consists of a number of opaque lines crossing each other so as to leave transparent squares. In the instrument the image which is produced has lines $\frac{1}{60}$ inch across.

Fig. 61 shows the effect on the image produced by a filter showing slight astigmatism. In fig. 62 (*a*) and (*b*) a filter has been used in which the astigmatism is very severe.

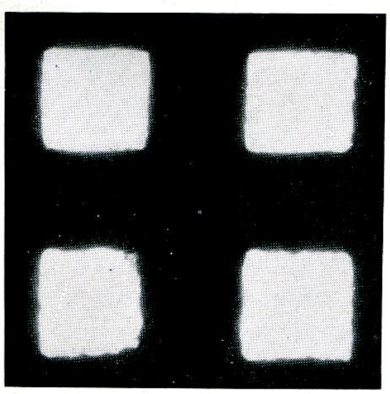


FIG. 60. FILTER-TEST OBJECT

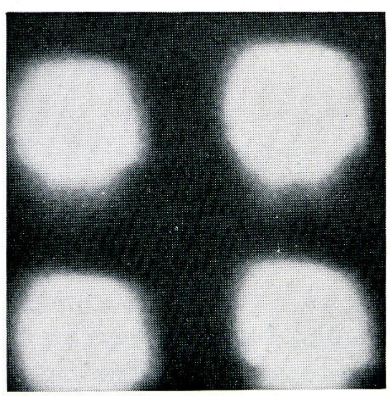
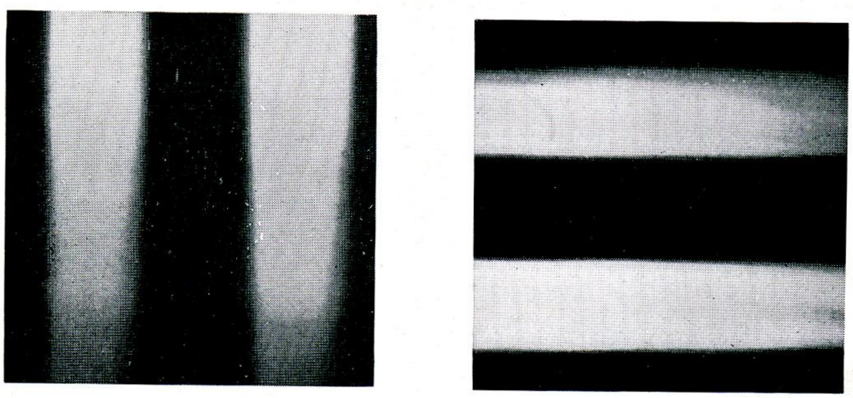


FIG. 61. TEST OBJECT THROUGH ASTIGMATIC FILTER

If a filter shows astigmatism the set of black lines running in one direction will have a focus in a different plane to the set of lines running at right angles to them, so that one set must always be out of focus; in the case of bad astigmatism it is possible that one set of lines will disappear entirely when the other set is focused sharply; in fig. 62 (*a*) shows one set of lines in focus, and (*b*) those at right angles to them.

We require of filters in B glass that at full aperture the image shall be free from astigmatism, and that the definition shall be such that filters up to two inches in diameter shall not visibly degrade the definition of a lens of six inches focus used at *f*.4.5. Filters between two inches and three inches in diameter must give good definition on a lens of ten inches focus used at *f*. 4.5, while filters above three inches in diameter must give good definition on a lens of sixteen inches focus used at *f*. 8.

For very long focus, or telephoto lenses, only flats will give satisfactory results, and for the semi-telephoto lenses, it is also desirable that filters should be cemented in glass of the highest quality.



(*a*) FIG. 62 (*b*)

On stopping down, the definition given by the filter should improve as the aperture is diminished.

In addition to giving satisfactory definition, it is necessary that a filter should not alter the focus when it is used upon a lens. A camera should always be focused with a filter in position, but the use of focusing scales upon many small cameras renders it necessary that filters for hand camera use should not affect the focal plane of the lens. A filter can alter the distance between the lens and its focal plane in two ways; it may act as a weak supplementary lens, or it may, if behind the lens, produce an effect due to its thickness.

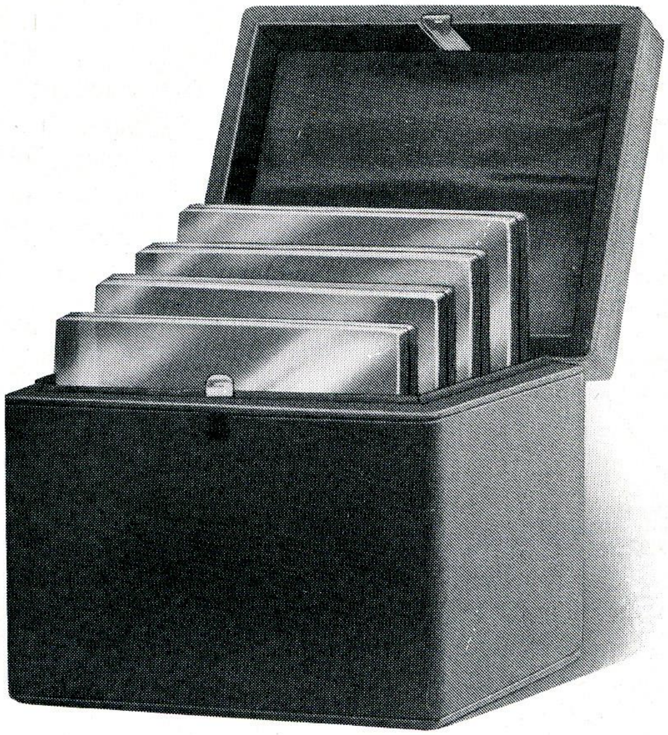


FIG. 63. SET OF TRICOLOR FILTERS WITH FOURTH PRINTER, CEMENTED IN FLATS

A "K" filter is tested not to affect the focal plane of a six inch lens by a greater amount than $\frac{1}{50}$ inch when used on the front of the lens. If a filter is used behind the lens, the lens must be moved back by an amount equal to about one-third of the thickness of the filter, but this rule assumes that the filter does not act in any way as a lens, and it is probable that some filters, which have been noted as not corresponding to the rule, really acted to some extent as lenses.

Besides the test for definition, which we have described, a set of filters, such as tricolor filters, which are to work together, must be tested for another optical requirement. They must give images of the same size, so that they will register when printed one upon another.

It is obvious, if the filters are used behind the lens, or even if they are used in front of the lens, and the object be near the lens (as in ordinary picture copying or process work), that the filters must all be of the same thickness. The shorter the focal length of the lens the greater is the error in register (for the same size of image) which a difference in thickness will introduce.

For some time it was thought that equal thickness was the main necessity for register, but with the utilization of the large filter testing instrument, it was shown that filters vary also in their effect upon the focal length of the lens. It appeared that a complete theoretical and practical investigation of the optical conditions governing register was desirable.

In order to measure the accuracy of registration, an instrument was constructed in which a lens of about ten inches focal length formed images eight inches apart of two sharply defined sets of lines, and the exact distance between these sets of lines could be measured by means of two microscopes mounted on carriages actuated by micrometer screws.

Filters can be placed in front of the lens, and the effect of these filters upon the size of the images can then be measured very accurately.

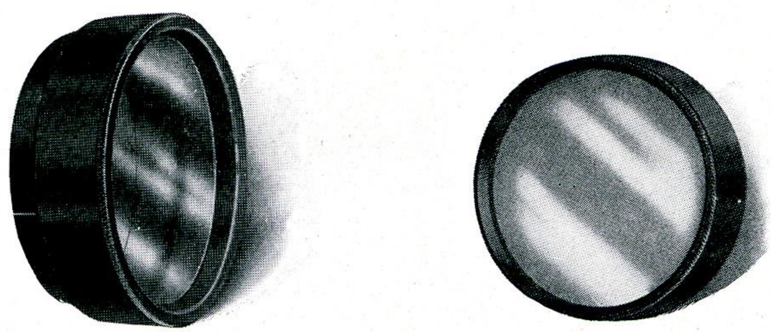
The tests upon this instrument have completely confirmed the theoretical sizes calculated from the known laws of geometrical optics, and the information which has been obtained is of considerable use in insuring that sets of tricolor filters will give satisfactory register, while tricolor filters cemented in flats ("A" glass filters) can be guaranteed to show perfect register under even the most trying conditions.

All filters issued by the Eastman Kodak Company are tested on the two instruments described for definition, accuracy of focus, and, in the case of tricolor filters, for register. Spectral transmission data for all Wratten filters are given in the booklet "Wratten Light Filters" published by the Eastman Kodak Company.

CHAPTER XI

THE FITTING OF FILTERS

FILTERS can be fitted either before or behind the lens, or just in front of the plate in a repeating back or special dark slide. This last position has the advantage that glass of lower optical quality can be used, but much larger filters are required and any speck or mark upon the filter shows in every negative, so that for orthochromatic filters a lens fitting is certainly to be preferred. Such filters should preferably be fitted in front of the lens, as in this position no appreciable



For Flats For Filters in "B" Glass

FIG. 64. SLIP-ON CELLS

shift of focus is introduced by the thickness of the glass, and the filters are also more readily accessible.

Film filters may be placed conveniently between the lens components, but this cannot be done with cemented filters, because the introduction of a piece of glass would seriously affect the corrections of many lenses; even gelatin film should not be put inside an air-space lens, which, owing to its construction, is sensitive to small alterations in the air spaces.

A filter cell should always be designed so that the filter is held securely but without pressure, and if the filter is fastened in place by a screw ring, this ring should have a shoulder and should be turned down, so that when it is screwed home, the filter can easily be turned round by holding it between the thumb and finger, but will not give any side shake.

A method of fitting is to have the filter mounted in a light metal cell, which is slipped on to the lens like a lens cap (see fig. 64). This method of fitting has the advantage that the filter can readily be removed or changed.

When ordering a filter for this form of fitting it is only necessary to send the outside measurement of the lens, but it is necessary that this measurement should be made very exactly. If a pair of sliding calipers cannot be obtained, a strip of hard writing paper should be wrapped round the lens

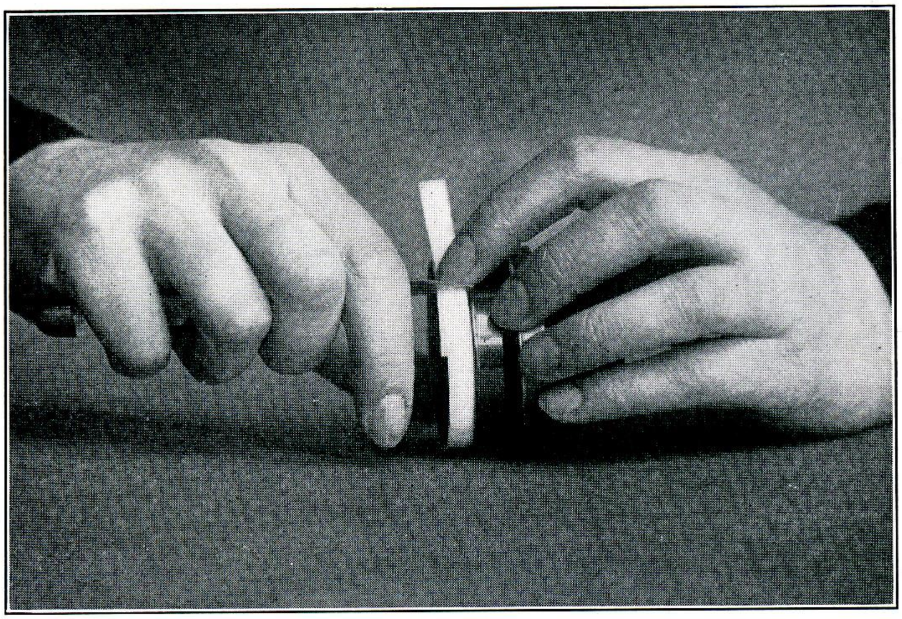


FIG. 65. CUTTING A SLIP OF PAPER TO FIT A LENS

so that the ends *overlap*, and then the two pieces of paper, where they just overlap, should be cut through in position with a sharp knife (see fig. 65). An attempt to cut a strip of paper which will just go round the lens is unlikely to result in a measurement sufficiently accurate to insure a well-fitting cell.

In order that the same filter may be used on different lenses adjustable holders are supplied as follows (fig. 66):

For 2-inch square filters, to fit lens mounts of $1\frac{1}{8}$ to $1\frac{9}{16}$-inch diameter;

For 3-inch square filters, to fit lens mounts of $1\frac{11}{16}$ to $2\frac{3}{8}$-inch diameter;

For 4-inch square filters, to fit lens mounts of $2\frac{3}{8}$ to $3\frac{7}{8}$-inch diameter.

With filters cemented in flats it is necessary that the filter should be wider than the front lens component, because otherwise the filter, being of considerable thickness, will tend to cut

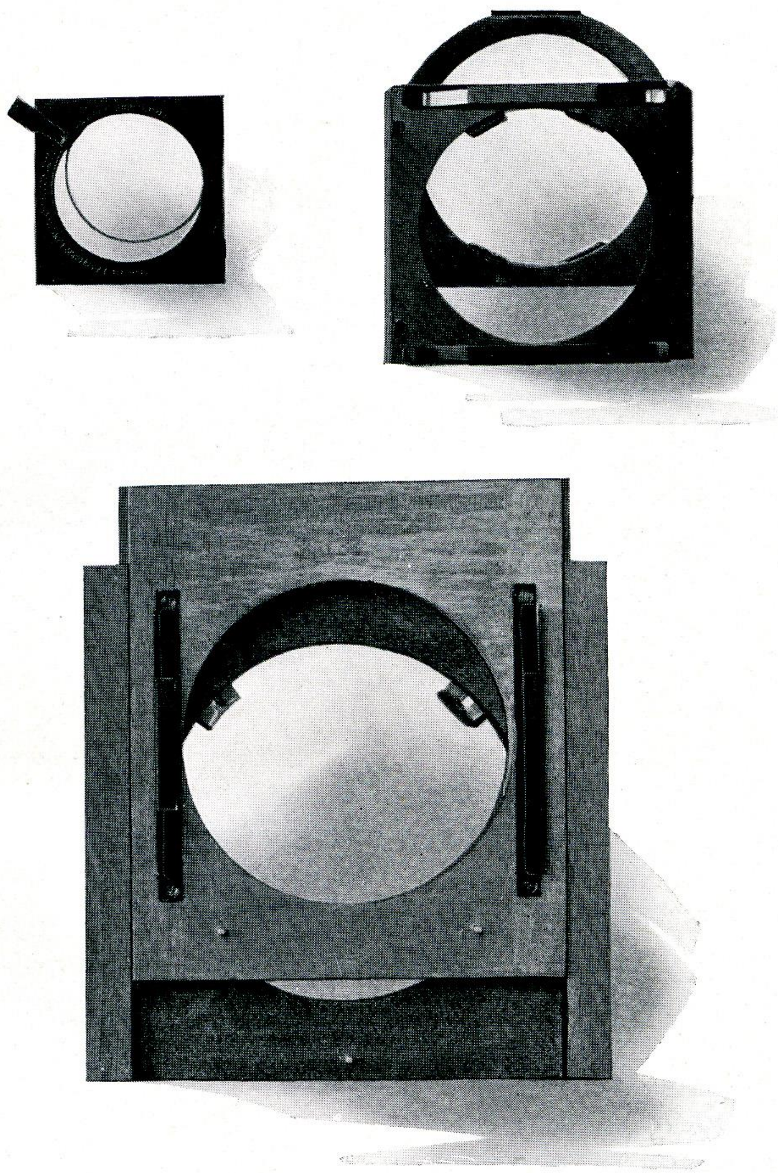


Fig. 66. Eastman Adjustable Filter Holders

down the angular aperture of the lens. The additional width necessitated can be found approximately in the following manner (see fig. 67). On a piece of paper draw a line equal to the focal length of the lens; at right angles to this draw a line equal to half the diagonal of the plate with which the lens is used.

Now extend the first line for a distance equal to the distance from the diaphragm to the edge of the hood of the lens, plus three-quarters of an inch, and at right angles to this draw another line. If now we join our starting point to the end of the line representing the diagonal of the film or plate, and produce this until it cuts the last line drawn, the length of that line which it cuts off represents half the necessary width of the filter.

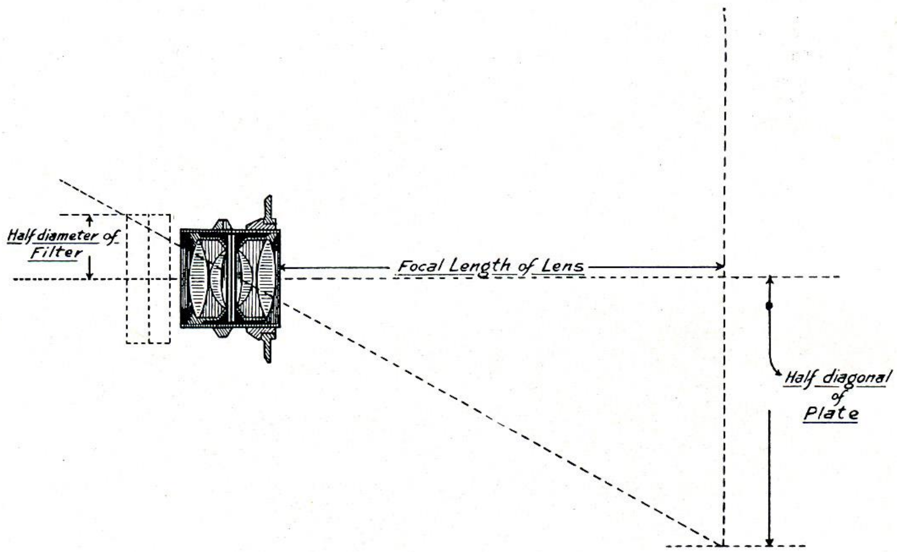


FIG. 67

Since filters in flats must be wider than the lens with which they are to be used, they should be fitted in special out-built cells which may be slipped on to the lens barrel (see fig. 64).

In order that there should be no mistake when ordering filters in "A" glass (flats) the following particulars should be given:

1. The name of the lens.
2. The focal length.
3. Maximum working aperture.
4. Length and diameter of lens barrel, over all.
5. Size of film or plate used.
6. If used for other than ordinary infinity work, give average extension of camera.

Sets of tricolor filters, if small, are best fitted in a repeating back, and used with a dark slide carrying long plates, the three negatives being taken side by side on the same plate. Where larger sizes are required, or where it is not desired to use plates of special sizes, the filters may be fitted in a frame which can slide behind the lens through an outside protecting cover screwed to the lens panel, thus changing the filters somewhat in the manner in which lantern slides are changed by a lantern slide carrier. Although this method of changing is rather slow—as the dark slide must be changed as well as the filter—it is in other respects a satisfactory fitting.

It is also possible to make a holder, either of metal or of wood, to fit on to the lens, into which the three filters can be

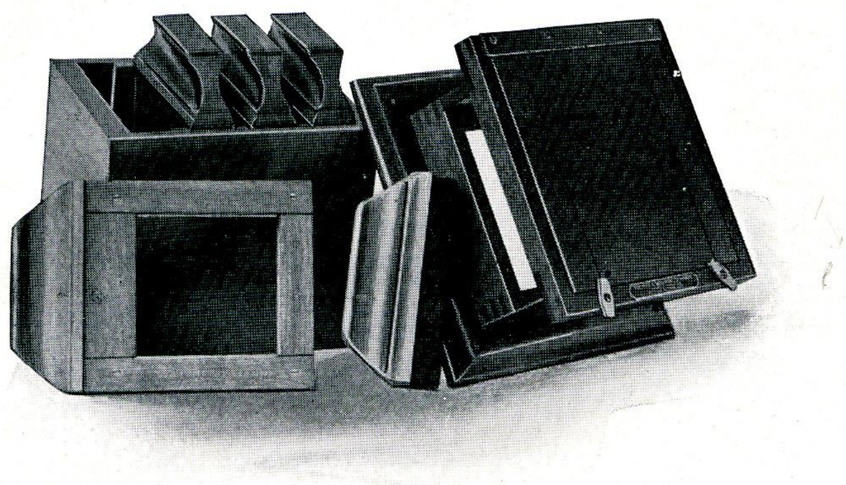


FIG. 68. STANDARD FRAMES, HOLDERS AND BOX FOR PROCESS CAMERAS

slipped in turn; this holder can also be used for any other filters in addition to the tricolor set.

For process cameras special holders for filters are advisable, and one holder in which each filter is put in place separately is probably the most satisfactory (see fig. 68). In such work great care is necessary that each filter is put in the same place, and exactly square to the lens. One way up may be better than another, and all Wratten three-color filters are marked to show the best way to insert the filter into the holder.

CHAPTER XII

THE CARE OF FILTERS

IN its simplest form (gelatin film) a filter requires a considerable amount of care in handling. The safest way is to place it between the combinations of a lens and leave it there. If it be used in front of or behind the lens in any form of carrier it should be removed after use and placed, in clean paper, between the leaves of a book, where it will keep flat and dry. Moisture tends to cloud gelatin film filters. The fingers are almost invariably moist and, to a certain extent, greasy, hence in handling gelatin films, care should be exercised to hold them by the extreme corner, if the filters be square, or, better still, by the edges only.

If it be necessary to cut the film, it should be placed between two clean pieces of fairly stiff paper, note-paper for instance, and cut with a sharp pair of scissors. A knife can also be used if the film is held firmly between two pieces of glass and trimmed round, taking care to cut and not simply to pull with the knife, as the film very easily splinters and cracks.

A film filter may be dusted with a piece of soft silk, or perhaps a better plan is to use the edge of a piece of very fine tissue paper. The latter will not scratch if used carefully, and does not leave any fluff on the film.

Cemented filters should be treated with care equal to that accorded to lenses; they should be kept in their cases and on no account allowed to get damp or dirty. Filters are clean when first sent out by the makers, and with reasonable care in handling they should never become so dirty as to require other cleaning than can be given by breathing upon them, and polishing with a piece of silk or tissue paper. A filter should never be washed with water, under any circumstances, because if water comes into contact with the gelatin at the edges of the filter, it will cause it to swell and so separate the glasses, causing air to run in between the gelatin and the glass. Even if the swelling does not cause air to run in in this manner, the filter will be strained and the definition spoiled.

If for any reason the filter gets so dirty that it cannot be cleaned by simple rubbing, after breathing on it, a piece of fine tissue paper should be dampened with denatured alcohol and gently rubbed over the surface of the filter. Care must be taken that the tissue paper is not wet enough for the alcohol to run out and spread over the edge of the filter, as it is a solvent of the balsam with which filters are cemented, and will soften it so that air may run in. Before attempting to clean a filter at all it is well to make sure that both the surface of the glass and the material are entirely free from grit, which will scratch the glass. If the glass becomes badly scratched, the only thing to do is to recement the filter with the scratch inside, which can be done in the case of flats, although this involves a considerable delay while the recemented filter is drying.

In addition to moisture, undue heat is dangerous to filters, as it softens the balsam and causes the gelatin to contract, so that filters should always be protected from heat, as far as possible.

The dyes used for most filters are quite stable to light, a table showing the stability to light of all the Wratten filters being published in "Wratten Light Filters."

The "K" filters are particularly stable, and no fear of fading need be felt. Filters, however, should always be kept in their cases when not required for use; tricolor filters, especially, should be put back into the cases as they are taken from the camera in turn. They are then quite safe and can always be found when required.

The Aesculine filters, used for the removal of ultra-violet light in photographing drawings which contain Chinese white, must be protected from light, to which they are unstable, going brown when exposed to it for any length of time.

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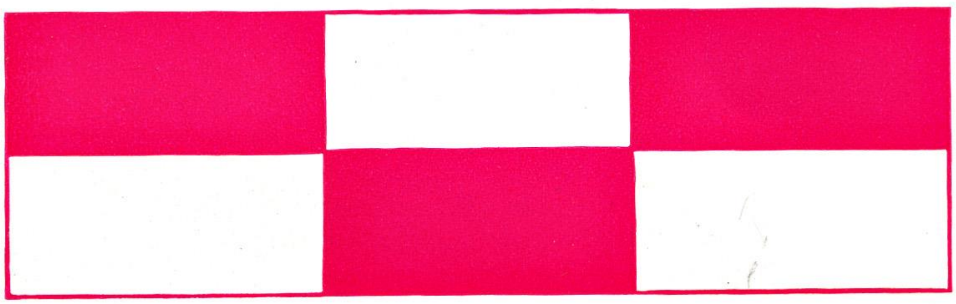
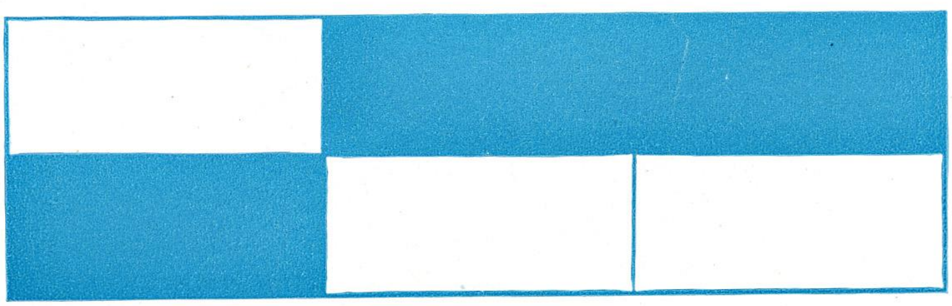
PRINT FROM BLUE FILTER NEGATIVE



PRINT FROM GREEN FILTER NEGATIVE



PRINT FROM RED FILTER NEGATIVE

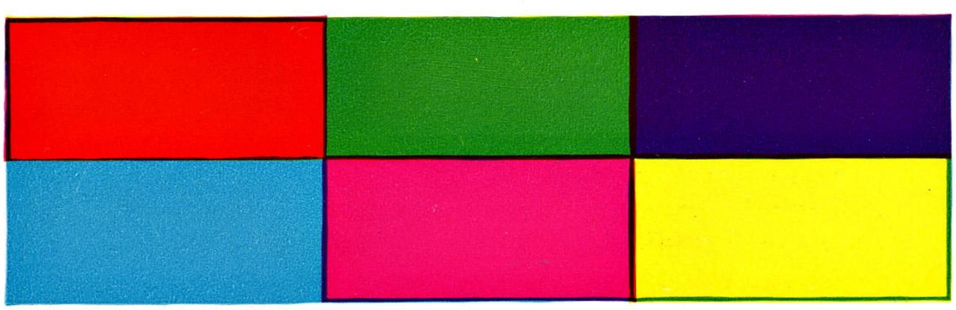


FIG. 55

Printed in U. S. A.