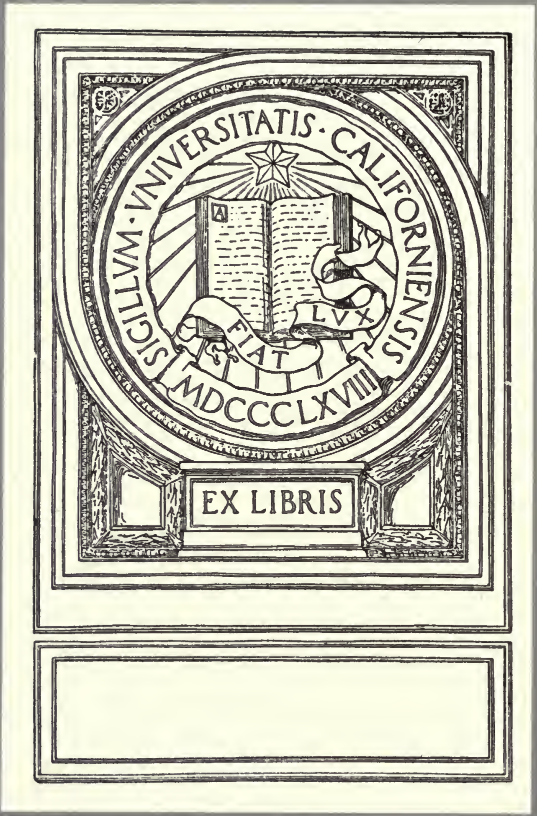
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THREE-COLOUR PHOTOGRAPHY.

Three-Colour Photography:

THREE-COLOUR PRINTING AND THE PRODUCTION OF PHOTOGRAPHIC PIGMENT PICTURES IN NATURAL COLOURS

BY

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CONTENTS.

PART I.

LIGHT AND COLOUR.

PART II.

THEORY AND PRACTICE OF THREE-COLOUR PRINTING.

A.—THE THEORETICAL BASIS OF THREE-COLOUR PRINTING.

B.—SENSITIZING OF PLATES AND THE LIGHT FILTERS.

PREFACE OF THE AUTHOR.

A GERMAN Edition of this book was published in 1897, and it represented the first work which entered into all details concerning Three-Colour Photography. Based upon the laws of colour mixtures, general rules of colour decomposition by photographic means have been discussed and the composition of printing inks ascertained enabling a satisfactory recomposition of the colours to be effected. The very pleasing reception of the book necessitated a second edition last year. The work was then completely revised and brought up to date. Special attention was given to the practical part, especially to the photographic colour decomposition. As light filters must be adjusted to suit the sensitiveness of each particular plate, and as the numerous commercially obtainable dry plates show great variations in their colour sensitiveness, the filter recipes given would be of little value. The colour scale which is attached to this book should, however, enable everyone to adjust his own filters.

I have been guided by the conviction that a simple and easily workable process serves the practical man better than a complicated and perhaps theoretically more correct process. Simplification has been my aim throughout the work.

A wish for an English translation of the book has often been expressed, and Mr. Henry O. Klein has undertaken the difficult task of preparing one. This fact is not only flattering to me because Mr. Klein has mastered the theory and practice of three-colour photography in al its details, but also by reason of his being intimately acquainted with its literature, and his name therefore offers a guarantee for a perfect and faithful translation.

A. VON HÜBL.

TRANSLATOR'S PREFACE.

ALTHOUGH excellent handbooks on Colour Photography have been written in English, they hardly touch the limits of that important branch of indirect colour photography—three-colour printing.

The often-expressed wish for an English translation of Baron von Hübl's excellent work, *Die Dreifarben Photographie*, which has been a valuable guide to many who had to find their way in a process which was surrounded with mysteries and secrets, has been the chief inducement which has led me to undertake the laborious but highly interesting task of translation.

I wish to express my deep gratitude to Baron von Hübl, who has greatly assisted me in the preparation of the supplements, which were printed under his personal supervision, and to Mr. William Gamble, Editor of the "Process Year Book," who kindly undertook the revision of the translation.

HENRY O. KLEIN.

London, January, 1904.

INTRODUCTION.

EVERY pictorial representation endeavours to secure the nearest possible approach to nature, for the absence of which it is supposed to compensate.

Rarely is it possible to give an idea of the nature of an object by simple outline drawing; we therefore shade it to give the impression of body; we further introduce colour to lend life and truth to our representation.

To appreciate the beauty of an outline drawing or even of a shaded monochrome, a certain artistic perception or a well-trained eye is required, whereas even those who have no artistic knowledge can appreciate the charm of a harmonious colour scheme. The great bulk of the public therefore is always influenced by colour, preferring the worst colour print to the best photogravure, and it has often been found necessary to colour wood engravings or photogravures to secure their approval.

Colour intensifies the illusion just as a plastic representation does, and who is there more ready to regret its absence than the photographer, who daily has the opportunity to compare the magnificently coloured picture on the focussing screen with his monochrome copy?

It is certain that the first photographic picture created a desire for photographs in natural colours, and to fix the colours of the camera picture has always been a problem, on the solution of which men have laboured since the earliest days of Photography. We can divide all experiments in this direction into two groups: we prepare light-sensitive surfaces which retain the colour of the light under which they are exposed, or we produce photographic pictures which we colour and superpose to obtain the desired result. The first method we term the direct, the second the indirect method of producing photochromes.

The earliest experiments in direct colour photography were originated by Becquerel, Seebeck and Poitevin. The basis of their experiments is the property which silver subchloride possesses to reflect light similar in composition to that which caused its formation.

Zenker, in 1868, explained the production of these colours by his theory of stationary light waves, which Prof. Lippmann proved by his subsequent experiments in 1891.

Lippmann's experiments created immense enthusiasm throughout the scientific world, although later it was found that this process was devoid of practical importance owing to the great difficulty of procuring perfect results, but it must be acknowledged that his researches indicate an important advance in the solution of this difficult problem.

E. Valenta, Lumière, Krone, and especially Neuhauss, deserve praise for their labours in perfecting this method, but useful practical results have not been obtained yet.

Of the highest importance for the future of direct colour photography are the investigations of Wiener, who studied the theoretical part of important questions on Heliochromy in a most exhaustive manner.

According to Wiener, the colours of direct photochromes are neither caused by interference nor real (pigmentary) colours. The first are produced by stationary light waves and are found in Becquerel's silver chloride plates; also in the Lippmann plates, where the silver bromide is in close contact with the mercury surface, whereas, in the case of paper coated with silver chloride, which Seebeck and Poitevin used, the formation of body-colours is propagated. The formation of body-colours is explained by Wiener in the following :—A light-sensitive substance can only be altered by those coloured rays which this substance absorbs; red light will therefore have no influence on a red body, or yellow or green rays will produce no effect on a green-coloured substance. If, therefore, a light-sensitive substance is discoloured through the influence of light, this substance will, when exposed to red, yellow or blue light, continue to alter until it is of a red, yellow or blue colour, which colour remains after subsequent exposure to light. We observe this phenomenon by experimenting with silver sub-chloride—the so-called photochloride—and we can therefore explain the presence of colour in pictures made on papers coated with this substance.

Papers which are coated with fugitive red, yellow and blue dyes of the coal-tar group give, after exposure under a coloured transparency, correspondingly coloured prints. Wiener's theory prepared for us a new and precise method for the production of photochromes, and although up to the present useful practical results have not been obtained, it is very probable that this method will lead to a satisfactory solution of the problem of colour photography.*

The second indirect method is also more than 30 years old. It consists of the superposition of coloured photographic images.

The ordinary negative and positive methods are employed, and ordinary pigments are used for the colouring of the transparencies. The number of these pigments for constituting coloured pictures is generally limited to three, because we suppose that all colour sensations can be reproduced by combination of the three colours, yellow, red and blue.

The three transparencies are printed from negatives which are made on plates of different colour sensitiveness: on one of these plates the yellow portion of the picture will not have acted, we have a negative for the yellow transparency, on the second and third plate the red and the blue part of the original has not acted, and we obtain in this way the negatives from which the red and blue transparencies will be made.

If the three transparencies are combined we get a combination picture which should be a reproduction of the original in its true colours.

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*Since the above was written considerable progress has been made in this method of Heliochromy by Worel, Neuhauss, Szczepanik and others.—*Trans.*

This principle of indirect Photochromy or of the photographic three-colour picture can be used in various practical ways. We can make the three pictures by means of the carbon process on glass or any other transparent medium which serves as support until we combine them or we print the three pictures with printing ink on paper one over the other in the printing press, and produce a colour print.

The first experiments in three-colour work were done with the carbon process, as the photo-mechanical printing processes were not then known. The process has latterly been greatly modified, and that excellent results can be obtained by this method is sufficiently proved by the well-known magnificent colour lantern slides or stereographs made by Lumière.

In the second method, the photographic three-colour printing, the first stages dating back to 1865, have been chiefly perfected by Dr. H. W. Vogel and Dr. E. Albert, who introduced it to the commercial world.

This process is much used now, and owing to the recent improvements of the half-tone process is rapidly increasing.

In this process photography is not absolutely necessary, and theoretically it is quite unimportant whether the plates for the yellow, red and blue printing are of manual or photographic origin.

In practical work, however, the making of these three plates by hand is beset with the greatest difficulties, as the most experienced chromo-litho artist cannot judge the effect of mixing three so very different colours, and can never obtain a passable result. A three-colour print, the plates of which are produced by an artist, is theoretically quite feasible, but practically it is out of question.

Instead of superposing pictures composed of pigments, we can also compose our picture by optical means, which idea is the basis of polychrome projections, and the photochromoscope. Ducos du Hauron referred to the possibility of these colour projections, and Vidal, Ives and Scott have made practical use of the idea.

The three negatives are printed on ordinary chloride or bromide silver plates, and the resultant respective positives backed with a yellow, a red, and a blue glass, and projected on a white wall or screen on which they are superposed by means of a triunial lantern. If the colours of the glasses are well selected, the three coloured lights, if overlapping on the screen, will recompose to form white light. If the three positives are introduced, we obtain a projection in the colours of the original.

In the Ives' Photochromoscope the three positives are also illuminated through coloured glasses; they are not, however, projected, but reflected into the eye by means of a system of mirrors.

The three illuminating glasses remain here, as well as in polychrome projection, unaltered, which circumstance greatly facilitates the correct reproduction of the colours, whereas, in the previously mentioned methods the colouring of the transparencies has to be varied according to the colours of the corresponding positives, the Photochromoscope and the projection methods only require once the careful adjustment of the colours of the three glasses, which afterwards will always remain the same, whatever positive may be used.

Only this condition gives the Photochromoscope a superior position, compared with the coloured transparency, otherwise the principle underlying both methods is the same, and equally good results can be obtained with both.

The Photochromoscope, however, does not furnish us with a material picture, and for this reason must be of minor practical importance.

A very original idea has been followed by Joly, of Dublin. He uses glass plates with a ruling of very thin transparent parallel lines about 10 per mm. These lines are red, green, and blue in colour, which order is repeated and the whole plate appears in transmitted light of a light grey colour.

If such a glass plate is pressed into contact with a photographic dry plate during exposure, the plate being one which is equally sensitive to all parts of the spectrum, the red rays reflected by the original can only pass through the red lines and affect the plate, which will reduce the silver in development wherever light impressed the plate.

The green parts of the original will be only imprinted under the green, the blue under the blue lines, whereas the white will act through all lines. If a positive is made from this negative and viewed in contact with a similar screen, we obtain, when the two plates are in perfectly correct register, a picture of the object in almost natural colours. The process is difficult, it reproduces the colours in a very degraded manner, and is not likely to become of practical value.

As the foregoing indicates, only the indirect methods of Photochromy give up to now satisfactory results. The three-colour printing methods especially deserve to be commercially considered with the greatest attention.

The practical part of this process consists of :—

The decomposition of the original colours and the printing.

The problem of colour decomposition by photographic means can be considered as solved, as by employing different sensitizers and light-filters the conditions of sensitiveness can easily be regulated, but the recomposition of the three-colour pictures by means of printing leaves much to be desired. Especially the production of the photo-mechanical printing surfaces is uncertain if a very accurate reproduction of all the delicate gradation of the negative is wanted, and also the printing process itself lacks that uniformity which three-colour printing requires.

PART I.

LIGHT AND COLOUR.

A. THE UNDULATORY THEORY OF LIGHT.

NUMEROUS phenomena lead us to believe that the phenomena which we term light is produced by the vibrations of the ether, an extremely thin, elastic, and homogeneous medium which pervades all space.

If this ether is left undisturbed, we have absence of light—darkness. A luminous body, however, the smallest particles of which are in a state of violent vibration, will excite the ether. Vibrations of high frequency in all directions will take place, and the retina of our eye will receive the sensation of light.

The vibrations of a luminous body are imparted to the ether in a very similar way to the propagation of sound waves in air. If the vibrating air particles reach our ear we are aware of the sensation of sound; if those of ether reach our eye, we receive the impression of light.

The wave motion of light, however, consists of stationary undulations, and the ether particles oscillate, pendulum-like, perpendicularly to the direction in which the light travels.

The motion is imparted from particle to particle, resulting in the wave-like motion of the mass of ether.

Bodies show a very different behaviour towards the impinging ether waves; some offer no resistance to its motion—they are transparent, others cause an elastic repelling motion—they reflect the light, and finally most bodies offer more or less resistance to the advance of ether waves, which cannot penetrate or can only partly penetrate the body—they are opaque or translucent—they absorb light entirely or partially.

If a body in motion comes into contact with another one, the action of the first one ceases, heat is created, as the example of hammer and anvil teaches us. If one of the two bodies does not possess sufficient resisting power, a deformation or total breaking up will be the result. Something similar happens to the undulating ether which meets the bodies, completely repelling the same, heat will be generated, and perhaps a deformation of the ether-struck substance may take place. This deformation, however, solely confines itself to the composition of the molecules, to a shifting of atoms, a chemical decomposition of the substance: such bodies are termed " light-sensitive."

In ether waves we have two characteristic elements: the way which the moving particle undulates—the amplitude; and the time which is required for one undulation—the undulation period.

The undulation period can be expressed by the number of undulations per second. The distance from wave crest to wave crest is termed the wave length, and theory teaches us, that with an increase of the undulations per second, a decrease of the wave length takes place. The greater the distance of the hammer from the anvil, the more powerful its effect; accordingly the greater the stroke of the ether particles, the greater its amplitude; the more powerful its effect on the retina, the brighter the sensation of light and the more efficient its chemical action. The intensity and power of light therefore depends on the amplitute of the ether waves.

The slight tap of a hammer, although sufficient to deform a piece of lead, makes no impression upon a plate of steel, even if we repeat the blow for several times.

The vibrating ether waves of small amplitude may be able to decompose the bromide of silver of the gelatine dry plate, but have no effect upon the iodide of silver of the wet plate, even with continued action, which explains the well-known fact that a slow plate cannot be fully exposed when the illumination is bad. The number of vibrations and the wave lengths determine in the case of sound, the keynote, and in light, the colour.

Ingenious experiments have made it possible to ascertain the numbers of vibrations of coloured light, and it has been found that 400 billion impingements per second create the sensation of red, and that by increasing this number, we obtain the yellow, green, blue, and finally violet sensation which corresponds to 750 billion undulations per second.

The wave lengths are inversely proportional to the number of undulations, and vary between 750 to 400 million parts of a millimeter.

The most important source of light is the sun, and we term its light "white," whilst every other quantitatively different sensation of light is termed "coloured."

When sunlight passes through a prism it is dispersed, and on a suitably placed white screen a coloured band will be visible, this being the familar spectrum. In the spectrum all variations from red to yellow, green and blue to violet are represented, and the question as to the number of colours in the spectrum, and the division of the spectrum into six or seven colour bands is quite arbitrary.

We find the sensation of "white" is caused by the simultaneous action of ether waves of different wave lengths upon our retina, and further, that white light is composed of all the coloured rays visible in the spectrum. If any component is removed, the rest, although composed of different coloured lights, will only impress our eye with a single colour sensation. If we abstract, for instance, the green rays from white light, the remaining red, yellow, blue and violet parts will combine to form the sensation of red light. If light strikes a body it can be absorbed or reflected, or it can pass through. In most cases all three phenomena can be observed. It can, for instance, occur that the absorption is solely confined to certain wave lengths, whereas, the rest can pass or be reflected.

If the reflected rays reach our eye, they will give rise to the sensation of colour; the body in question cannot appear white, because one of the components of white light is absent, it will therefore appear coloured. If, for instance, a glass plate absorbs all green rays, the penetrating rays will make us perceive "red." This glass we will call red, because it has absorbed the green rays. Paper coated with Eosine will appear red, because the light reflected from its surface is devoid of green rays.

If rays of light are absorbed, *i.e.*, ether motion annihilated, heat must be generated, and under certain conditions an alteration in the chemical composition of the compound will follow. A compound which absorbs the green rays, permitting, however, all others to penetrate or reflect, if at all light-sensitive can be only decomposed or chemically altered by green light; every other species of rays will leave this body unimpressed. If we expose paper dyed with Eosine to the light it will be bleached; the structure of the Eosine molecules will be destroyed by the impinging ether waves—we therefore call it light-sensitive. The decomposition has only been caused by the green part of the white light, and we term such a compound green-sensitive. If we cover the Eosine paper with a green, a red, or a blue glass plate, and expose to strong sunlight, the paper will only bleach under the first glass, and will retain its colour under the other two.

Cyanin is orange-sensitive, it bleaches only under the influence of orange rays, because it absorbs the same; chloride, iodide and bromide of silver are blue-sensitive, because they retain the blue rays and appear in transmitted light of an orange colour. A body equally sensitive to all rays, a "white sensitive" compound, should therefore be black; dealing however with photographic preparations, the action of white light is always due to a certain component of it.

The vibration theory of light has given us the following principles, which are photographically of the highest importance.

(1) A substance can only be chemically altered by rays which it absorbs.

(2) Not necessarily every coloured body must be chemically altered by these rays, because they may only generate heat, without causing chemical change,

(3) Every light-sensitive substance requires a certain intensity of light for its decomposition, light of minor intensity produces no effect.

B. COLOURED LIGHT.

In classifying light we have to distinguish between homogeneous and mixed light, the former representing light of one wave length only, the latter light of different wave lengths. White light as well as most light reflected from coloured bodies consists of light of different wave lengths. We can produce monochromatic light by decomposing white light, as by passing the same through a prism, and if we are to use monochromatic light we can only make use of the spectrum colours. It is only possible to approximately judge the composition of a light by ocular tests, and the use of a prism, which enables us to decompose the light, is of the highest importance in the study of colour sensations. White light will give us a continuous spectrum when passing through a prism; coloured lights, however, will show certain gaps indicating the absence of light of certain wave lengths. Although white light is not perfectly free from those bands, as proved by the Frauenhofer lines which are visible in the solar spectrum in great numbers, they are, however, so fine as to in no way interfere with the sensation of light we receive.

The most important of the Frauenhofer lines have been given letters, and it is customary and convenient to denote a certain part of the spectrum or light of a certain wave length by quoting the lines.

Fig. 1 shows the most important lines in the spectrum and their relative position to the colours of the spectrum. The bottom scale indicates the wave length in $\frac{1}{10000000}$ of a millimeter. This unit is called the "Angström unit," and has been given the sign μ.

Towards the red end of the spectrum the intervals are small and increase towards the violet. We conclude, therefore, that the red rays in the spectrum are confined to a limited area, whereas the blue and violet are extended. It is, however, noteworthy that the extension of the colours and also the form of the wave length scale is dependent on the material of which the prism is made, and differs with different samples of glass.

The red extends from the extreme beginning of the spectrum to the line C; it is red of a yellowish hue, approximately the colour of vermillion. From C to the line D the red becomes orange, which melts into a pure yellow quite close to D.

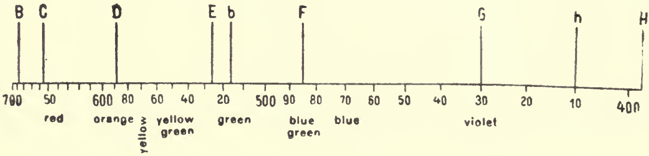

Fig. 1.

The orange near the D line can be represented by the colour of amber. The pure yellow is represented by a very narrow band, which becomes yellow-green, and between E and b is of a yellow-green, not unlike the pigment called emerald green. After b begins pure green, and near F is a small band of blue-green which Helmholtz called cyan blue. This green blue is equivalent to that seen in mountain lakes and glaciers. Behind F the blue loses the greenish hue and gradually develops into a violet near the line G. The reddish blue is generally called indigo, but it is actually more like ultramarine. From G to the end of the spectrum we notice a violet of a more bluish colour rather like methyl violet.

König and Dieterici (Helmholtz' "Physiological Optics," page 320) state that the red end of the spectrum up to line C presents only different luminosity and not different hues, which is also noticeable in the violet end starting from line G. An actual range of colour in the spectrum is only to be found between the lines C to G.

The distribution of colour in the spectrum is very irregular, the red, orange, green and blue-violet occupying large zones in the spectrum, whereas the yellow and blue-green are confined to narrow bands. Red-violet represented in dyestuffs by certain compounds of the eosine order is completely missing, but can be formed by overlapping the red and the violet end. A perfectly closed repeating colour scale is the result of the introduction of this red violet.

There is another method of producing the spectrum, which offers the possibility of decomposing light, and this by means of diffraction gratings.

A diffraction grating consists of a glass plate which is engraved with extremely fine parallel lines. The spectrum produced by these gratings shows the same order of spectrum colours but with a loss of brilliancy and an extension of the band.

The scale of wave lengths is also different, as shown in fig. 2.

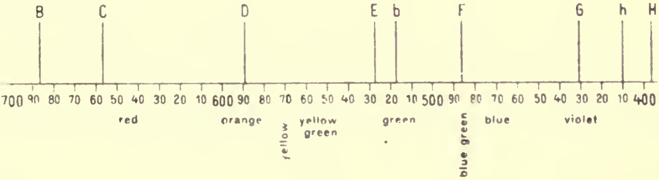

Fig. 2.

We further notice that differences in the wave lengths correspond to equal divisions of the scale. This feature makes the diffraction spectrum for many purposes extremely valuable, and as the material on which the grating is engraved does not influence the distribution of the spectrum colours, the diffraction spectrum is generally considered the "normal spectrum" for scientific research.

The red is the most extended, the green occupies about the same space as in the prismatic spectrum, and the blue-violet the smallest space. Yellow is in the centre and is, like blue-green, confined to a narrow band.

For practical work, however, the prism is generally in use, because the grating which must have about 5000 lines per inch is expensive, easily destroyed, and of considerably less luminosity than the prismatic spectrum.

As mentioned before, the colours of the spectrum are equivalent to from 400 to 750 billion ether undulations per second.

Experiments, however, have shown that there are ether waves in sunlight with considerably greater and smaller undulation periods, which proves that there are portions of the spectrum not visible to our eye. These spectral zones beyond the violet and red end of the visible spectrum, although not causing the sensation of light, are extremely active chemically, and are known by the names of infra red and ultra violet. By taking a negative of the solar spectrum we obtain a band which extends over the visible ends of the spectrum, and which shows in the ultra violet as well as in the infra red part numerous dark lines. The reason why the infra red remains invisible is that the light is absorbed by watery substances, and cannot reach our retina; the ultra violet light is also invisible on account of our defective vision, which is not sufficiently sensitive to such high ether vibrations.

To observe the spectrum we use instruments called spectroscopes.

To be independent of solar illumination, and as artificial sources of light are deficient of the Frauenhofer lines, which are necessary for the registration of the spectral zones, we attach a scale in front of our sensitive plate and so photograph the scale with the spectrum. After we have ascertained the position of a certain line on the scale we can readily read from the scale the spectral zone.

We observe that in coloured light certain parts of the complete spectrum are missing, and they are marked by black bands, the edges of which are unsharp. If we look with the spectroscope against a source of white light, which furnishes a continuous spectrum, and if we intercept the light by placing a glass plate coated with eosine in its path, we notice that the green part of the spectrum disappears, because the red dye absorbs the green rays.

To avoid elaborate description of such "absorption spectra," it is usual to express the same in a graphic form, which shows all the peculiarities of the absorption.

Fig. 1 or 2 shows a horizontal line marked with Frauenhofer lines. On such a scale a curve is created showing by its increase an increase in the absorption. Such a curve not only shows us the absorption and its position, but also the intensity of the absorption.

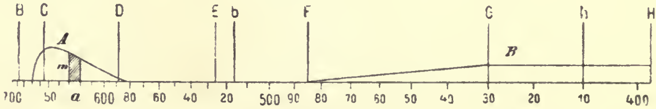

Fig. 3.

Fig. 3 tells us that the light which passes after the absorption took place consists chiefly of green rays, because over the orange and blue part of the spectrum two curves, A and B, are constructed. We notice further the abrupt termination of the absorption band in the red and its gradual diminution in the orange. The curve B, however, shows equal absorption in the violet and graduated intensity between F and G.

Comparing the prismatic and the diffraction spectra of this source of light we notice equal quantity of the constituents of both spectra, but a difference in their distribution and, therefore, also in their intensity, and the form of the absorption of the curves is in both cases a different one.

It is easy to transfer results achieved with the prism to the normal spectrum by means of the wave length scale, because colours located between the same parts of the scale are identical, and their intensity is inversely proportional to the space they occupy.

If we wish to represent the absorption (fig. 3) on a normal spectrum (fig. 4) we must note that, for instance, the rays between 630 and 640 have an extension a, and that they are covered by the shadow of an intensity m. In the normal spectrum this kind of rays takes up space b, and, therefore, the intensity of the shadow n must be lower, $a\,m = b\,n$, and it is easy to calculate $n = \frac{a}{b}\,m$.

We can definitely ascertain the proportions $\frac{a}{b}$ for certain wave lengths of two spectra of a given length, and there is no reason why we should not transfer the absorption curves of one spectrum to another.

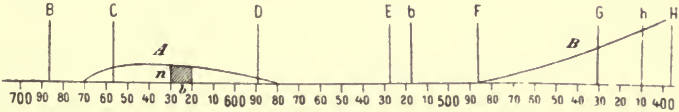

Fig. 4.

In the present case we find the following :—

For wave lengths ...... 700 $\frac{a}{b}$ = 6·0
" " ...... 650 " = 2·2
" " ...... 600 " = 1·6
" " ...... 550 " = 1·2
" " ...... 500 " = 0·9
" " ...... 450 " = 0·6
" " ...... 400 " = 0·3

If we translate in this way the absorption represented in fig. 3 we obtain the curves A and B for the normal spectrum (fig. 4), and they represent the form of the absorption bands which we should obtain with a diffraction grating. As the illustration shows, the abrupt termination of curve A towards the red end is missing. This abrupt ending of the band in the prismatic spectrum is governed by the concentration of rays in parts of the spectrum with longer wave lengths. Curve B rises from F towards the violet. We notice further a considerable intensity of the absorption bands A and B, whereas the prismatic spectrum shows equally intense absorption in the blue as in the red.

In observing colour we encounter certain peculiarities, which can be classified in two sections. We differentiate the tone of colour, *i.e.*, the qualitatively different sensation from black and white, and finally the purity of colour governed by the absence of the black and white sensation. All mixtures of pure colour with black, grey, and white we term shades.

From a physical standpoint we consider three different colour sensations: (1) the tone of colour (hue), governed by the wave length of the light; (2) luminosity or intensity dependent on the amplitude of the light waves and (3) the saturation dependent on the different degrees of unity in the admixture of the light waves. If light of only one wave length is present, we feel the sensation of complete saturation, but if there are present the other wave lengths which go towards the composition of white light, the saturation will be greatly diminished.

Referring to luminosity again we may further mention that different colours cause by themselves different impressions of luminosity, yellow light appears of greater luminosity than blue light. This "specific" luminosity must not be taken for the luminosity we are dealing with. The former is a brightness of colour often caused by admixture with white.

MIXED LIGHT.

Of the greatest importance for a proper understanding of the theory of colour is the effect of a mixture of coloured light. If the retina is struck by light of different wave lengths, we no longer distinguish the different components, but receive a uniform impression of coloured light.

Experiments show that by mixing different monochromatic lights we do not necessarily obtain coloured light again, but we can also receive a sensation of pure white.

White therefore is not only formed by recomposing all spectral colours, but suitable choice of two is sufficient to give this impression. Two colours which, if mixed in definite proportions give white, are called complementary colours, and the spectrum can supply us with a never ending number of such colour pairs.

Complementary colours are:—

Red and blue-green.
Orange and cyan blue.
Yellow and reddish blue.
Yellow-green and violet.

We further find the complementary to every colour from yellow-green to red, in the range of colours between blue-green and violet. There is no single colour complementary to the spectral green but a mixture of red and violet called purple. On the basis of this experimental result we can form the following conclusion. Every colour has a complementary colour, and by mixing the two we get colourless light. It has been possible to ascertain the exact wave length of complementary rays, and we give the following instances:—

Red of a wave length of 640 is complementary to green wave length 500.

Orange, wave length 590 to blue, wave length 487.

Golden yellow, wave length 573 to blue, wave length 475, etc.

Such measurements are, however, closely connected with the individual constitution of the eye, and differ very considerably, especially in the end colours of the spectrum.

Two colours, closer to each other than the complementary colours, result, when mixed, in a spectral colour found between the two and mixed with a small proportion of white.

The amount of white affecting the saturation of a colour will be increased in the same proportion as we remove the two colours from the complementaries. If we mix the two ends of the spectrum we obtain a purple which, however, does not show the full saturation of the spectral colours.

The following table taken from Helmholtz's "Physiological Optics" shows the result of a combination of two spectral colours in a very intelligible form. At the head of the horizontal and vertical columns are placed the simple colours, where the columns cross the result of the combination of the two colours is given.

	Violet.	Indigo.	Cyan-blue.	Blue-Green.	Green.	Greenish Blue.	Yellow.
Red.	Purple.	D. Pink.	W. Pink.	White.	W. Yellow	Golden Yellow	Orange
Orange.	D. Pink.	W. Pink.	White.	W. Yellow	Yellow.	Yellow.	
Yellow.	W. Pink.	White.	W.Green	W.Green	Greenish Yellow		
Yellow-Green.	White.	W.Green	W.Green	Green			
Green.	W. Blue.	Water-Blue.	Blue-Green.				
Blue-Green	Water-Blue.	Water-Blue.					
Cyan Blue.	Indigo.						

D—Dark. W—Whitish or light.

This table shows in how many different ways the same mixed colour can be obtained, for instance, yellow and violet give the same results as red and cyan blue, *i.e.*, purple, called pink.

As in the colours of the spectrum and in this purple all possible colour tones find a representation, no new colour sensation can be created by admixture of more than two colours, but the larger the number of components in a colour mixture, the more white will predominate and the less saturated will be a mixed colour. If rays of any part of the spectrum therefore reach our retina, we can only feel the sensation of one spectral colour or purple. The resulting mixed colours must be complementary to the remaining part of the spectrum.

The mixing experiments with coloured lights have further shown that their composition does not affect the result of mixing, that colours which look similar also give similarly mixed colours. Red and yellow-green give yellow, and this yellow, when mixed with other colours, shows no different from spectral yellow or a yellow which is the result of the addition of rays of a whole spectral zone. Based upon this principle we can use the law laid down for spectral colour, for polychromatic lights, as given by coloured media.

If white light passes a coloured glass or a dye solution, etc., a certain kind of rays, mostly belonging to a whole spectral zone, will be lost through absorption, and this is the cause of the unabsorbed light which passes, appearing coloured. The coloured glass acts similarly to a paper filter, the one separates undissolved particles from a solution, the other absorbs certain light rays.

The unabsorbed rays belong to a fraction of the spectrum, are equal in their composition to a single whitish colour tone, and behave in mixture similarly to simple spectral colours. The spectral orange and green result in yellow, and the same colour of less purity will be formed by a composition of similarly coloured media. Such a mixing or addition of light can be performed in many ways, but we must make a difference between the superposition of coloured media and that of light passing through it. We can use three lanterns and place the coloured glasses in front of the objectives.

If we project red light with one lantern and throw a disc of green light overlapping the red, we obtain a mixed light of a whitish yellow. If the luminosity of the lights be altered by interposing transparent colourless plates, we get a variety from red to yellow, and finally green. If we project a blue disc on the mixture of the two lights, we obtain by proper adjustment pure white, and again by reducing their luminosity all possible colours, but always of a whitish hue, can be obtained. This method is made use of in polychromatic projections.

But also with the help of mirrors a mixing of coloured light is possible, and is made use of in the Photochromoscope.

The principle of this apparatus can be seen in the adjustment of mirrors and in an instrument by C. Zinck. A closed wooden box of the shape shown in Fig. 5 has openings R, Y and B, which are covered with their respective coloured glasses. The interior shows three adjustable mirrors S_1 S_2 S_3 which reflect the light coming from the coloured glass towards the opening O.

The mirrors S_1 and S_2 are uncoated thin glass plates, but S_3 has the usual silver deposit.

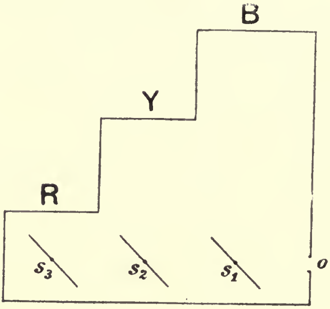

Fig 5.

The light passing through the red glass and reflected by mirror S_3 passes through the two transparent mirrors S_2 and S_1 and reaches the eye at O. The light which passes through the green and blue glasses will be reflected by the surface of the mirror glasses S_1 and S_2 towards O, and the eye of the observer will receive one impression of the three colours superposed. By adjusting the luminosities of the coloured plates, which must be carefully selected, we obtain "white," and if we place on the coloured glasses the respective photographic positives made of three colour negatives, a coloured picture will result at O.

THE THEORY OF COLOUR SENSATION.

As shown above, lights of physically different composition can excite similar colour sensation. Our eye cannot decide whether the impression "white" is caused by the action of all spectral colours or whether, for instance, only blue, green and red are present, and a mixture of red and blue excites exactly the same sensation as violet and green.

In this respect our eye differs greatly from our organs of hearing, which, when struck by sound waves of different length, combine all into a chord, whilst we are capable of distinguishing the different sounds constituting the chord. Two chords which are composed of different sounds are never identical to our ear in the same way as colours, however differently constituted they may be, to our eye.

We can only find an explanation for this strange phenomena if we suppose that our eye is only susceptible to a limited number of elementary sensations. This supposition is the basis of several hypothetical theories of colour vision, and the most important ones may be mentioned here.

The Theory of Young-Helmholtz.—Young's (1807) theory accepted by Helmholtz and Maxwell is known as the Young-Helmholtz theory, and finds great and undivided favour with all physicists. This theory assumes the presence of only three kinds of light sensitive nerve fibrils in our eye, serving as the means of communication for the three primary sensations. When excited they convey to our brain the sensation of red, green and violet respectively. According to this theory we may take it that all colours consist of the fundamental colours: red, green and violet.

If all the three nerve fibrils are excited simultaneously and in the same degree, the sensation of white results, whilst at rest the sensation is black. Homogeneous light of any colour always excites all three nerve fibrils, but in different intensity, and we conclude therefore that every spectral colour is composed of all three fundamental colours.

The intensity of action caused by homogeneous colours of the spectrum is to be seen in Fig. 6. The curve R represents the intensity of the red nerve, curve Y and V with which the green and violet nerve fibrils were excited, and this is in all parts of the spectrum.

If we take it that all homogenous colours are composed of the three fundamental colours, the curves represent the necessary proportion in which they are to be mixed, if we wish to excite the sensation of the spectrum colours. The spectral red excites, as already mentioned, strongly the red sensitive and only slightly the other two fibrils, and our retina conveys the sensation of red.

We can imagine the spectral red to consist chiefly of fundamental red and a small proportion of fundamental green and fundamental violet. This mixture slightly weakens the saturation of the spectral red, which if compared with the fundamental red is supposed to be of a whitish hue.

The spectral yellow excites all red and green, but in a small degree the violet sensitive fibrils; we therefore think of it as composed of equal quantities of fundamental red and fundamental green with a little fundamental violet.

In a similar manner it is possible to explain the sensations of green, blue and violet; they are always to be considered of less saturation than the fundamental colour, which only causes the reaction of a single order of nerve fibrils.

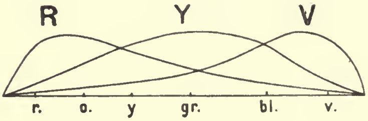

Fig. 6.

The curves in the illustration are very different from those which have been found by actual colour mixing experiments, and according to Helmholtz the three fundamental colours are to be found in almost equal proportions in all spectral colours, whilst they must be considered as extremely pure if compared with them.

Only by mixing of these pure fundamental colours can, according to the Young-Helmholtz theory, spectral colours and their components be developed, and it is absolutely false to take the three spectral colours, red, green and violet, as the foundation colours. If we tried to imitate the different colour sensations and mixed the spectral primaries in the same proportion as the Helmholtz curves show, an almost colourless sensation would result.

The choice of the foundation colours is rather arbitrary as any three colours could be chosen to compose white. Young's choice fell on three apparently excellent points of the spectrum, the two ends and the colour of the centre, but we could just as well take middle colours, such as yellow and blue-green and purple* as the three fundamental colours.

The Young-Helmholtz theory of colour vision has often formed the basis of a theory of trichromatic pictures, and

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*Purple is a verbal translation of the German word "purpur," but means a colour of the shade of Rhodamine R.—*Trans.*

has therefore been given a more detailed description here. Young's three fundamental colours were considered as the only correct ones for the colouring of the three pictures, and the curves showing the sensitiveness of the three species of nerve fibrils were accepted as the correct curves of sensitiveness of our photographic plates. But as shown above, the choice of Young's colours is arbitrary, and we cannot therefore see the reason why red, green and violet are the most suitable colours for polychrome projection or the Photochromoscope.

It is further impossible to comply with the fundamental principles of this theory, because we are not in possession of coloured light of the purity of the spectral colours, not to speak of that of the fundamental colours. Helmholtz's mixing curves are, therefore, of no importance in trichromatic work, because the result we should obtain in the Photochromoscope would be an almost colourless picture.

If we wish to obtain the colours which are to be found between the primaries by mixing, for instance, yellow, red and blue, the curves would look very different. To obtain the spectral green and orange, however, we have to introduce "negative" red and blue values, because the mixture of these colours would be too white. Maxwell took this precaution, and his curves certainly form an approximately correct basis for three-colour photography, provided the three fundamental colours are correctly chosen.

Colour Theory of Hering.—While the Young-Helmholtz theory premises only one excitement of the retina, Hering knows of two synonymous processes. According to Young-Helmholtz only the antithesis "activity and rest" exists, and in this latter condition the nerve remains unaltered for a longer period. Hering, however, states a chemical change in the substance of our organs of vision, known as dissimilation, and in the state of rest the opposite chemical reaction assimilation establishes the equilibrium. These alterations of substance form the sensation of light and colour. According to Hering's theory there are four primaries—red, green, yellow and blue. They actually make the impression of primary colours, and they can be found without the addition of other colours. All other colours are complex, because we can easily distinguish in them two of the primaries, for instance, in the violet, the red and the blue.

Red and green, as well as blue and yellow, exclude each other, because they are never to be found in a colour simultaneously. Hering further considers black and white as primary sensations, and so distinguishes three pairs of primary sensations, red and green, blue and yellow, and black and white. These three sensations are caused by the chemical changes which are supposed to take place in the three components of our substance of vision. Dissimilation of one, called black and white sensitiveness, causes the sensation of white, assimilation of this substance, however, causes the sensation of black. The second component of this substance is red-green sensitiveness, the third yellow-blue. Dissimilation of these substances is the cause respectively of red and yellow colour sensations, whereas assimilation corresponds to the green and blue. All colours of the spectrum act in a dissimilating way on the black and white substance, and mixed light appears colourless if it has equal dissimilating and assimilating power on the red-green or yellow-blue sensitive substances. No alteration of matter is then traceable and "white" is the result. The spectral yellow acts in a dissimilating way on the black and white and blue-yellow substance, as also does the spectral blue towards the first; towards the latter, however, it acts in an assimilating way. A mixture of yellow and blue cancels the effect on the blue-yellow substance, causing, however, dissimilation of the black and white, i.e., the sensation of white.

Two species of rays producing white are, therefore, not "complementary," but "antagonistic," lights, and, according to Hering, we cannot speak of "complementary colours" but of "contra colours."

This theory enables us to explain certain subjective light and colour sensation more easily than the Young-Helmholtz hypothesis, and physiologists are the warmest supporters of this theory.

We detailed this theory to show that the acceptance of Young's primaries does not form a scientific axiom, which serves to support the theory of trichromatic pictures and, further, to explain the choice of four primary colours, because further explanations of three-colour systems will necessitate the employment of these theories.

C. Body Colours and Dyes.

If a body absorbs all white light, it will appear black; if it reflects all rays, white; if it absorbs only a part and reflects another part which is complementary with respect to white, we term it grey; and, finally, if the body reflects rays combining with each other in a colour mixture, we receive the sensation of colour.

The bodies showing in powder form or in solution high absorptive powers for certain species of rays, or bodies which show characteristic colouration after considerable dilution we term pigments or dyes.

In everyday life we call such dyestuffs "colours," a description to be avoided as much as possible, because colour signifies a quality of a body, but "dyestuff" is a coloured substance used for colouring other bodies.

As with coloured lights, we distinguish in body colours colour-tone and its variations, but the terms "purity" and "saturation" convey slightly different meanings. By purity we understand the absence of "black;" "saturation," however, depends in this case on the amount of admixture with white. The expression "intensity" can also be used.

The more or less bright the impression which a coloured body conveys—its "luminosity"—is conditional on the specific luminosity mentioned on page 28. If we coat a piece of white paper (fig. 7) with a dye E E, e.g. dissolved Eosine, we notice that a white ray of light S loses the green ray constituent after passing through the Eosine surface; this red coloured ray meets the paper surface, which is a white irregularly reflecting body, and which causes a diffusion of the ray in all directions. From this point, therefore, coloured light rays (s) proceed and meet our eye after penetrating the Eosine surface and again gaining a colouration.

A part, however, of the white light will be dispersed from the surface of the dye coating and will be reflected toward S 1 striking our eye uncoloured and weakening, therefore, the depth of the coloured surface. If the dyestuff consists of powdered transparent particles, the colouring of the light is performed in a similar way, but if the particles are devoid of the necessary transparency, we shall find that the ray of light cannot penetrate towards the white surface; the surfaces of the dye particles will already reflect the light, and it will reach our eye in a very weakly coloured condition. This is the reason why body colours appear whiter than transparent colours. The characteristic colouration of a powdered pigment is only noticeable after mixture with a liquid body, because the light cannot penetrate sufficiently into the dry, pure pigment powder, and will be reflected in a slightly altered condition. If we combine these particles with a transparent liquid medium we obtain an almost homogenous substance in which light can penetrate, and from which light will be reflected in an intensely coloured condition. In this way water acts when making up a colour, and the gum and varnish in water and oil colours. The nearer the relation of the pigment and the medium as regards dispersing powers, the more homogenous will be this mixture in optical respects, and the more saturated will the colour appear. This explains the saturated colour magnificence of oil painting as compared with the whitish colouring of water-colour painting.

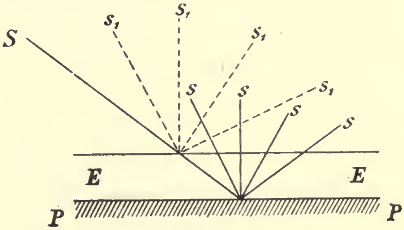

Fig. 7.

The pigment, so to speak, splits the white light into two parts, the absorbed and the reflected; its colour is, therefore, always complementary to the absorbed part of the light. What is the composition of each only the spectroscope can tell. For such analytical research the spectroscopes of Schmidt & Haensch or Penrose & Company, in

London, are to be recommended.* If the surface which you wish to analyse is placed so as to receive full illumination, and is viewed with the spectroscope, we only perceive those colours which are reflected, whilst those which are absorbed form a shadow band, called the absorption band. It is, however, considerably easier to ascertain absorptions if we compare the partial spectrum with the complete one, for which purpose special comparison spectroscopes are made.

Excellent forms of comparison spectroscopes and spectroscopic cameras are put on the market by Zeiss in Jena and Penrose and Company in London. In these instruments we notice two spectral bands close to each other, enabling us to ascertain the weakest absorptions. For all examinations of coloured liquids we use special glass tubes enabling us to view different densities of the liquid. The comparison spectroscope of Zeiss in Jena has a wave length scale, which makes it possible for us to measure exactly the absorptions. Experiments conducted in this way show that the absorptions of dyestuffs do not consist of rays of one wave length, but of rays occupying more or less broader spectral zones.

The situation of the absorption band is characteristic of the colour tone of the pigment, whilst the shape, and especially the width of the band, determines the shade of the colour.

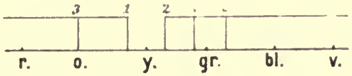

Fig. 8.

Disregarding the specific luminosity of a colour and taking equal intensity of the incident white light, the pigment will be the darker as the absorption band is broader. A dyestuff reflecting only the narrow zone of the yellow rays (fig. 8) appears yellow brown, because a yellow of minor luminosity conveys this impression. If the reflected part of the spectrum enlarges, reaching, for instance, from

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*A very useful instrument for ocular and photographic tests is Tallent's Spectroscopic Camera, sold by Penrose & Co.—*Trans.*

3 to 4, we obtain a purer colour because the reflected orange and yellow-green combine to form yellow and intensify the yellow.

If the red and green are also reflected, leaving only an absorption band up to 5, a further increase of yellow takes place; all species of rays which by combination form yellow are now actively engaged in the formation of colour.

If the reflected spectral zone further enlarges, reflecting also blue-green, we find that the latter will combine with red to form white, and the intensity of the yellow only increases on account of this mixture with white light. It therefore follows:—

(1) The relatively purest colour is due to a pigment of which the reflected spectral zone is narrower than the distance of two complementary colours; and

(2) If the reflected zone is smaller, blackish tints will predominate; if it is wider, the colour will show a whitish hue.

The one-sided absorption of dyes is generally caused by a more or less broad band, which begins in the visible spectrum and terminates in the ultra-red, or ultra-violet. The absorption band of a yellow pigment therefore starts in green or blue, extends over the violet, does not absorb the entire ultra-violet, but ends near line H.

Red dyestuffs reflect most of the visible violet, orange pigments only up to line H, whereas yellow dyes with greenish hue, such as picric acid, begin the absorption in the blue but extend far into the ultra-violet.

This phenomenon explains the remarkable behaviour of red and yellow dyes towards ordinary photographic plate. Red, as well as orange pigments, appear in photography fairly light, whereas yellow dyes are devoid of photographic activity, and appear black.

But the other parts of the spectrum not affected by the absorption band also show a limited extension.

In the case of yellow pigment this zone extends up to blue, but does not embrace the whole spectral red, though a part of it will be shadowed by a second absorption band situated in the ultra-red and ending in the visible red. As soon as the colour tone of the pigment extends over the green towards blue, a shifting of the zone of reflected rays from red towards violet takes place. Green dyes absorb, therefore, the visible violet, but blue dyes the ultra-violet. Nearly every dyestuff shows two or sometimes more absorption bands partly situated in the invisible spectrum.

If we compare dyes in such concentration that they appear to be equally saturated, we find that the width of the absorption band is governed by the nature of the dye. We distinguish dyes with very narrow but intense absorption bands, as chiefly dyes of organic origin, and dyes with broad but weak absorption bands, as belonging to the mineral and earthy order. In the section of organic dyes we have to place those of animal and vegetable origin, and a good number of the coal tar or aniline dyes. Whereas these dyes show in high concentration unaffected clear parts of the spectrum, the mineral dyes show a general absorption.

This feature explains the brilliancy of the aniline dyes as compared with the dull and impure looking appearance of the dyes of the mineral order.

Fig. 9 shows the absorption of two red dyes. (I.) is Eosine on paper; (II.) rose madder. The colour tone of both appears the same, but their purity differs, and the rose madder looks almost brown beside the Eosine.

A distinct limit between both does not however exist, and just as there are many coal-tar dyes showing broad absorption bands, so there are also a few mineral dyes, for instance, chrome-yellow, which leave nothing to be desired as regards purity of colour.

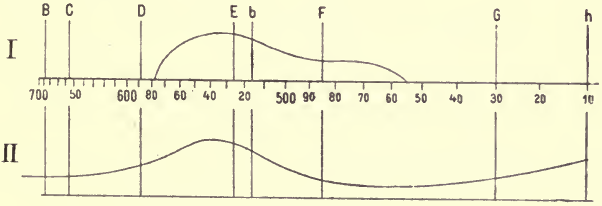


Fig. 9.

Most aniline dyes cannot resist the action of light; they bleach under its influence and we call them fugitive. The reason of this quality, which greatly reduces the practical value of these dyes, may partly be found in their complicated chemical composition, but may also be explained by the very narrow absorption bands of these dyes. We find, for instance, that aniline dyes with broad absorption bands are fairly permanent, although lacking in brilliancy. The light attacks the fugitive dye at a single part of its spectrum, but those showing broad absorption are attacked by many species of rays, though none of them are acting with full force—just as the strokes of a wedge-shaped hammer are more telling than those of a round-shaped one.

The absorption band terminates in the prismatic spectrum more abruptly towards the red end than towards the blue, and as concentration of the dye increases, the band begins to widen towards the blue, but very little towards the red. The extreme end of the spectrum seems nearly always to escape absorption, which is the reason why highly concentrated solutions always appear red. This red end can, however, be completely absorbed by many inorganic substances, as, for instance, a weak solution of copper sulphate, which absorbs the whole of the spectral red.

Those rays belonging to a spectral zone of minor luminosity, do not influence the appearance of a pigment considerably, so long as rays of great luminosity escape absorption. A solution of Acid Green passes nearly the whole red up to the line C, but if we add a weak copper sulphate solution, we do not alter the colour of the solution, though very greatly altering its absorption.

Therefore the spectral violet seems to play no part in the world of the pigment colours.

According to Vogel, Methyl Violet owes its colour only to the spectral red and blue, because if viewed through a tank filled with copper oxide-ammonia solution, which absorbs the entire red, its colour is blue.

Only occasionally do rays belonging to the end portions of the spectrum influence the appearance of a dye. However, dispersion and density of medium which keeps the dye in solution, considerably affects it.

A solution of Eosine in water is of a more bluish hue than that in alcohol, and a solution in Chinoline is of a decided violet colour. If we let a dye solution dry on paper, or if we mix the same with gelatine or collodion (according to the nature of the dye) we notice a shifting of the absorption band towards the red if compared with the absorption of the liquid dye; the colour of blue and violet dyes will therefore appear of a more bluish hue, whereas blue-green and green dyes will appear more yellow green.

The absorption band will be broader in each case, but not so intense, they will be also less abrupt and often entirely altered. The dispersive powers of the colourless bodies begin to assert their influence, but the differences between coloured collodion and gelatine surfaces is very slight. If the differences are very marked, they are caused by secondary phenomena. Collodion has often an acid reaction and affects certain acid sensitive dyes, as, for instance, Methyl-violet. Dyes, however, which are insoluble in either alcohol or water, show very marked differences. Cyanine gives, for instance, pure blue collodion films, but gelatine films are of a reddish colour, due to a precipitation of the dye.

Analogous to gelatine and collodion are other bodies, which take hold of the dye molecules in a purely physical molecular combination. Animal fibres, paper, kaolin, bromide of silver, flaky precipitates, the latter especially at the moment of formation, show this peculiarity known as substantive colouration. If we add to a red diluted aqueous Rhodamine solution, kaolin, the latter will assume the intense violet colouration which dry Rhodamine surfaces show; the dye stuff has been precipitated by the kaolin in a dry powdery state.

If we form with the dye a new chemical combination we again alter the tone of the colour. If a gelatine film stained with Eosine be treated with silver nitrate the colour will change towards a bluish tint, because eosine-silver has been formed, for the same reason bromide of silver, if bathed in Eosine, takes a similar colour and shows a very different absorption than, for instance, kaolin coloured with Eosine.

The Middle Absorption of Dyes.

Having to differentiate in every sensation of colour between the tone of colour and its purity, we can therefore imitate the colour of a body, with one spectral colour (or purple) and addition of white and black.

The spectral colour determines not only the colour tone, but the amount of white and black in its tint.

The colour tone can be characteristically represented by a narrow absorption band in the spectrum, situated over the part of the spectrum which is complementary to its body colour. Dealing therefore with the tone of a pigment, we can substitute for its absorption band a narrow absorption eliminating only one species of rays, and only for the characterization of pale green and yellow green are two narrow bands required.

The middle absorption does not form an equivalent for the geometrical mean of the absorption band, because the latter does not give us a band of even density, and the band visible in the spectroscope is imperfect in its shape and extension.

A fairly diluted alcoholic Cyanine solution shows for instance on the D line and in advance of it a narrow band; by increasing the density of the dye we notice a rapid increase towards the blue, but only one fourth of it towards the red, giving an absorption band from C to F. We might conclude that the colour of this solution changes with increasing concentration from greenish blue to violet, but this is by no means the case. The diluted solution is of a slightly bluish green hue, but the colour of both must be termed "blue." This difference between colour and its absorption can be explained by our imperfect spectroscopic observations. Viewing diluted solutions, we only observe the maximum absorption situated in the orange, whereas we do not observe a very weak absorption in the green. The absorption band of the saturated solution appears as a black band of even density from C to F, the solution should therefore look violet. But it is actually blue, and evidently so because we do not observe the maximum in the orange. Only by extreme concentration does Cyanine absorb all green, and appears really violet.

Fig. 10 shows the construction of those absorption bands.

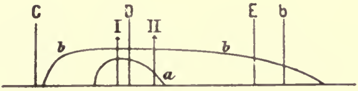


Fig. 10.

a showing diluted *bb* concentrated solution of cyanine.

According to previous explanations a middle absorption near *I* would correspond to *A*, near *II* to *bb*; as however both solutions have the same blue tone of colour, the same middle absorption must be corresponding, and will lie between *I* and *II*.

To get approximate results it is admissible to examine solutions of different concentration, and establish a middle value.

The middle absorption of Cyanine is behind *D*, being equivalent to wave length 570. This absorption does not coincide with the absorption maximum (wave length 590) which is to be found in the orange. A second method of ascertaining the absorption of a colour tone is to compare it with the colours of the spectrum, and to find an equivalent. If we now find the complementary colour we can consider its position in the spectrum equivalent to the middle absorption of the dye which we are testing.

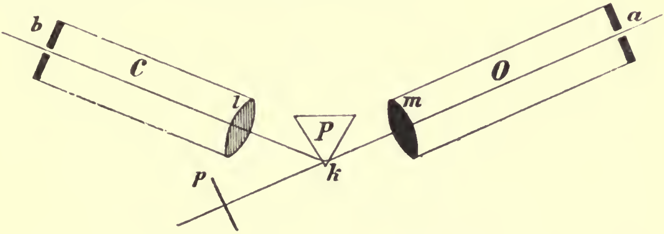


Fig. 11.

To be able to compare with spectral colours, we must be able to view the same isolated and in greater extension, and the instrument fig. 11 has been specially recommended for this purpose by Helmholtz. Remove the eye-piece of the telescope of a spectroscope, and replace it with a tube having a narrow slit *a*, through which we look towards the prism.

The prism has to be placed in such a way that *k* lies in the axis of the tube *O*, carrying the objective lens *m*. *C* is the collimator tube with lens *l* and slit *b* facing the source of light.

Looking through slit *a* we observe the surface of the prism illuminated with one colour only which can be changed by shifting the tube *O*.

As the prism only covers one half of the field of view, we can place in the other a coloured glass plate *p*, which is illuminated from behind.

By accurate adjustment of tube *C* we are enabled to obtain even illumination of the field, and to match the colour with a spectrum colour. The necessary adjustment of tube *(O)* will give us also the wave length of the colour.

The table shows a number of absorptions of dry gelatine films coloured with aniline dye, and for the sake of comparison absorption maxima are added.

DYE.	ABSORPTIONS.		
	Middle.	Maximum.	
Naphthol Yellow ...	455	from	455
Benzopurpurine ...	490	,,	485
Erythrosine ...	532	,,	539
Rose Bengal ...	542	,,	563
Diamine Blue ...	580	,,	650
Fast Green ...	594	,,	625

These statements cannot be considered absolutely correct, due to the method by which they were arrived at, but are for practical purposes accurate enough.

DYESTUFFS IN THEIR MIXTURES.

If we coat a surface with a dyestuff, we prevent this surface from reflecting a certain kind of rays, and the surface will appear coloured. If we coat this surface a second time with another layer of transparent colour, the second will absorb some of the rays which the first reflected, and the luminosity of this surface will be decreased.

If we coat white paper with Eosine, which absorbs the green rays, the paper will appear red, because

white – green = red.

If we coat this red paper with a yellow dye, which absorbs the blue rays, the paper will appear orange, because

white – green – blue = orange.

Every subsequent addition of colour will absorb certain rays of light and will alter the colour and its luminosity, until no more light is reflected, and then the surface will appear black. We can compare this procedure with the operation of subtraction. If we mix the dyestuffs they will act in an analogous manner, the different particles of the colour absorb certain amounts of light, and only those are reflected which are not absorbed by the colour particles.

We notice the same phenomena when coloured liquids are mixed, and coloured glasses superposed. Although we can combine mixtures of rays by addition, we have to adopt different methods to perform it. For experimental purposes the use of the colour top is the most convenient. We put the different colours on a circular cardboard disc 20 c.m. dia. in the form of segments, and on rotating it the colours will blend into one uniform colour impression. The segments can be measured, and they will give the quantities required for a special colour mixture. For rotating the discs a small electro motor or clockwork, or hand-turning apparatus can be employed. The rapidity required is $\frac{1}{20}$ to $\frac{1}{50}$ of a second for the passing of each colour.

For comparing colour mixtures it is usual to cut paper segments corresponding to these colours, which are rotated by means of a colour top. Fig. 12 shows such an arrangement. Supposing it has to be found whether a certain chrome yellow and ultramarine reflect complementary rays. *a* is the chrome yellow, *b* the ultramarine, and to exclude false calculations as to the resulting grey, two smaller segments, *w* and *s*, made of black and white paper, are inserted. The four segments were, after rotation, shifted towards each other until an even grey tone was obtained. Measurements of the periphery sectors resulted in 137° chrome yellow, 223° ultramarine, 147° white, and 213° black; a combination of rays of

0·38 chrome yellow, and 0·62 ultramarine result in a grey

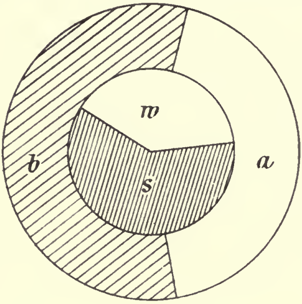


Fig. 12.

which is composed of 0·41 parts of white and 0·59 parts of black.

0·36 chrome yellow + 0·62 ultramarine = 0·41 white + 0·59 black.

Such colour mixtures cannot produce the sensation of white, but only of grey, because each colour reflects only part of all components of white light. We find that such colour mixtures are different from the mixture of coloured lights, page 31, because the luminosity of such coloured light mixtures is equal to the sum of all luminosities of the single components. For the shade of colour the following rule is in both cases applicable: "Similar looking colours give similar looking mixtures." In both cases colour is lost, and an admixture with white takes place.

Very different results are obtained if the actual pigments are mixed, because the luminosity of a pigment is always decreased by the addition of another colour. Although such mixtures also result in loss of colour, blackish tints will be obtained, and the shade of a colour mixture is not only governed by the tint of the single components, but also by the absorption bands of such pigments.

To ascertain the result of an actual pigment mixture, we have to remove all rays from the absorption spectrum of the one which the other absorbs; the remaining rays now govern the colour tone and the shade of the mixture.

It therefore follows that;

The absorption band which is characteristic of the colour tone and shade of a mixture, can be obtained by superposing their absorption bands. The absorption bands may be found beside each other, or they may clash. This difference is of the greatest importance for the result of the colour mixture.

1. *The absorption bands do not clash.*

Fig. 13 shows such a case.

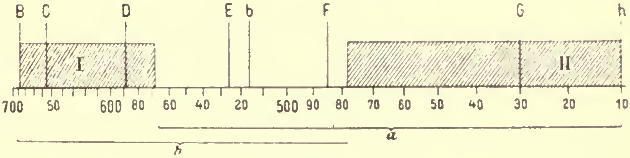


Fig. 13.

I corresponds to the absorption spectrum of a blue, *II* to that of a yellow pigment. A combination of both shows the absorption band of the pigment mixture.

A mixture of the reflected rays *a* and *b* evidently results in a whitish green, but if such colours are mixed by means of a colour top, a green is obtained which is mixed with a whitish grey, because the resulting white is of minor luminosity, and produces the sensation of grey.

If the pigments are bodily mixed, we obtain again the same green, but without admixture of that white, which has been the result of *a* and *b*, and if the reflected rays only correspond in a narrow part of the spectrum, we obtain a green of a blackish shade. (Page 40).

If the absorption bands of two pigments do not clash, we note that the colour of their mixture corresponds to that of a mixture of similar coloured lights.

2. *The absorption bands clash.*

If we prolong the absorption band *I* in fig. 11 until it reaches the band *II*, we obtain white by mixing the coloured rays. On the colour top we obtain a grey, and by mixing pigments a black. If, however, the band *I* extends over *II*, we obtain on the colour top and by mixing the coloured rays violet tints, whereas the pigment mixture results in black, provided both absorption bands have sufficient intensity. As soon as the absorption bands of pigmentary mixtures clash, we notice considerable differences when compared with the mixture of coloured rays.

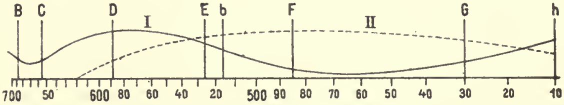


Fig. 14.

The spectra of dyes are by no means as primitive as our example shows, and the visible band in the spectrum does not give a true reading of absorptive conditions of a dye, as made clear on page 45. These are the reasons why it is generally useless to ascertain the result of the mixture of broad banded pigments beforehand.

Fig. 14 illustrates such a case. *I* represents ultramarine; *II* vermillion. As ultramarine is of a blue, and vermillion of a red colour, we do not doubt that by mixing on the colour top we shall obtain violet. By mixing of the pigments, however, the two absorption bands will clash, and as the experiment shows, a brown colour will result.

These facts lead us to the differences between narrow and broad absorption pigments, and between aniline and mineral dyes, which are of the greatest importance in practical work. The former act similarly to coloured lights, giving most extraordinary and not anticipated mixing results, as for instance, blue-green and red-violet give a beautiful blue, purple and yellow a pure red, blue-green and orange a pure green, somewhat similar to a mixture of the mineral pigments, chrome yellow and Prussian blue.

There is, however, a method by which broad absorption pigments can be made to mix like coloured lights, and this is by placing the different colours which we want to mix side by side, in small lines or dots. At a certain distance the colours will blend and produce a uniform tint, which is precisely the same as the mixture on the colour top. Several industries make practical use of these methods, as for instance in tapestry manufacture and in several of the painting and printing arts. The water-colour painter applies his colour to coarse paper in such a manner that the crest of the grain is of a different colour from the lower parts of the paper, and the oil painter mixes his colour particles in a similar way. Vermillion and ultramarine act in this case as violet, and red and green as yellow. This method of mixing colours is of highest importance, however, to the art of colour printing. By placing coloured lines on dots beside each other, an evenly coloured surface can be produced, and the colours mix similarly to coloured light, as blue and vermillion will give us violet.

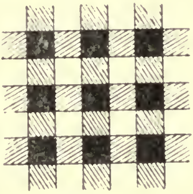


Fig. 15.

If these lines, however, cross as in fig. 15, the luminosity of the colour will be decreased, and its colour will be the more degraded the more the space is occupied by the actual overlapping of the coloured lines. If we produce two half-tone scales from white to black, and print the two over each other in different colours, we shall find that the colour of this scale is by no means uniform if broad absorption colours were used, because the darkest tint shows the mixture of the substance; the lightest, however, shows the mixture of coloured rays. If we use narrow band dyes, the mixture of the substance is also similar to the mixture of the coloured lights, and the above-mentioned difficulties are not noticeable.

THE OVERLAPPING DEFECT.

It has generally been regarded as immaterial whether two colours were mixed on the paper or superimposed, but this view is only correct if we are working with perfectly transparent and not too intense surfaces. In practical work this latter condition cannot be observed, and the last printed colour will always predominate over those which form the base.

A paper printed in yellow and then in red colour should give a yellow orange, but we obtain a red orange, due to a defect by which the yellow dye cannot act sufficiently. We term this phenomena the "overlapping defect." As is well known, printers' and painters' colours vary greatly in this respect, but even the most transparent colours prevent, if used in more saturated condition, the full effect of the underlying colour.

The following experiment will prove this statement.

Coat half of a piece of paper with an even coat of chrome yellow, and overlap with an even coating of Rose Bengal, which is a very transparent colour.

Cut a large disc of the superimposed coloured paper, and smaller ones of the red and yellow respectively, for experiments with the colour top.

To match the colour of the large disc, the sizes of the yellow and red sectors must be equivalent to the acting quantities of the yellow and red in superposition.

To arrive at similarity of colour it will be found necessary to complement the large disc with white, and the following equation will express this:

0.34 chrome yellow, 0.66 Rose Bengal =
0.3 white, 0.7 mixed colour.

The colour of the large disc equals a mixture of one part of chrome yellow and two parts of rose bengal, instead of equal proportions of the two dyes, according to theory.

The transparency of a colour surface greatly depends on its density, and the saturation of the surface reflecting the colour will determine the amount of "overlapping defect." A red coloured surface of deep saturation will already reflect the impinging rays of light before they reach the yellow underneath, whereas a light red coloured surface permits nearly all the yellow to be also reflected. If a yellow scale is printed over a red one, the deep tints will be red orange, but the light tints will be yellow orange.

Of course this overlapping defect is very marked in three printings, and the first layer of colours can scarcely act whenever the other two are saturated colours.

This imperfect mixing of superimposed colour surfaces forms one of the most important difficulties in trichromatic work; it is the cause of insufficient blending of the colours and of a sensation of poverty of colour which we generally perceive when viewing a three-colour print. Three-colour transparencies are, however, perfectly free from this defect, and nothing reminds us of their trichromatic composition.

Relation between the Shape of the Absorption Band and the Hue of Colour.

If a coloured mixture reflects complementary rays, we receive an impression of whitish colour, if such rays are absorbed the impression of a darkened colour will predominate. Different shapes of absorption bands are therefore the cause of whitish and blackish shades.

If a mixture of colours only reflects complementary colours, we get a sensation of a pure, but more or less dark grey.

For the shade of the mixture it is of no importance whether the absorption is a general or a partial one, whether certain rays are completely absorbed and the rest recombine to make white, or not.

Fig. 16 shows the absorption spectrum of two grey pigments. In *I* all rays of the spectrum show an even but not too intense absorption; *II*, however, shows a grey produced by a mixture of three narrow absorption band colours, and its neutral colour is only due to the reflected yellow and blue rays.

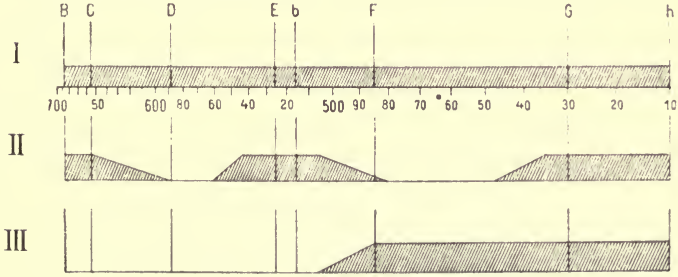


Fig. 16.

Both greys can cause precisely the same sensation, but show entirely different qualities in their mixture with other pigments. The grey *I* will give a yellowish grey, if mixed with a yellow pigment the absorption of the latter is visible in *III*. Grey *II*, however, loses its character in such a mixture altogether, and becomes a blackish orange-red.

Blackish red or orange, being colours of poor luminosity, are termed brown.

This sensation takes place whenever the pigment mixture reflects the narrow zone of those spectral rays, or when in the case of a red colour the reflected rays are subdued by an even complete absorption band.

The latter case corresponds to a mixture of a red pigment with a pure grey.

The blackish green, known to us as "olive," can be produced by the mixture of a green dye with a pure grey, or its origin is due to a complete, but not too dense, absorption of all parts of the spectrum except the green, but can also be produced by mixing several narrow-banded absorption pigments. The whitish shades are denoted by placing the word "light" in front of the colour name.

For the blackish shades the word "dark" is used, as for instance dark-blue, dark-violet. In many cases the shades have their own names, corresponding as a rule to objects of a similar colour.

TINT OF COLOUR.	NAME OF MIXTURE WITH WHITE.	GREY.	BLACK.
Purple.	Pink.	Wine-red.	Brown.
Red.	Light-Red.	Copper-Red.	Brown.
Orange.	Flesh-Red.	Chamois.	Yellow-Brown.
Yellow.	Straw-Yellow	Greyish-Yellow	Yellow-Grey.
Yellow-Green	Light-Green.	Grey-Green.	Olive.
Green.	Light-Green.	Grey-Green.	Tea-Green.
Blue-Green.	Water-Blue.	Sage-Green.	Tea-Green.
Blue.	Sky-Blue.	Blue-Grey.	Steel-Blue.
Violet.	Lilac.	Violet-Grey.	Dark-Violet.

The same alteration, due to overlapping of colour, takes place also if we cover the coloured surface with a coloured glass, and it is immaterial whether the glass is in close contact or not. A blue dye viewed through a yellow glass will appear green, precisely as the mixture of the colour with yellow does.

Illumination with coloured light will give analogous effects.

Artificial illuminants, especially candle, gas and electric incandescent light are yellowish if we take daylight as white, and their spectrum terminates before blue-violet is reached. In such light, coloured bodies appear as if coated with a yellow film, and we cannot distinguish between light-yellow and white, or between blue and blue-green or purple and red.

Impure greys, if viewed by this artificial light, appear of a yellow-brown colour, whereas pure grey remains of a neutral tint. This explains the phenomena, that three-colour transparencies containing impure greys greatly change their character if viewed in artificial light. Even the electric arc light must, if compared with daylight, be considered as a yellowish illumination. The light of an artificial source can be made white by depriving the same of all rays complementary to blue violet, or by filtering the same through a suitably coloured medium.

D. GEOMETRICAL REPRESENTATION OF COLOUR MIXTURE.

If we imagine at the points *A* and *B* (fig. 17) two colours, and on the line all successive mixtures of two colours, we can term the line *A B* as the mixing line of the colours *A* and *B*.

Fig. 17.

We take *A* as yellow, and *B* as red, and we place on the mixing line all tints obtainable with this yellow and red. One point in this line will show the more yellow, the nearer this point is to *A*; a point semi-distant from *A* and *B* equals a mixture of equal proportions of yellow and red at the point *a*. A mixture of one part of yellow and three parts of red is represented at *C*.

If we imagine *A* and *B* the quantities of the mixing colours as weights, we find that the quantity of a mixed colour at a certain point equals the sum of the quantity of colour we assumed at *A* and *B*, equal to the sum of the weights we imagine there. This goemetrical representation of colour mixtures is equally applicable to the mixture of coloured lights, but of course the standard by which to measure the quantities of the composing colours will be a different one. By the mixture of pigments their weight can be taken as measure for quantities on the colour top; we measure the quantities by the sectors which go to compose the colour, but when mixing spectral colours, their luminosity corresponds to the quantity, and as the latter is in direct relation to the width of the slit, we measure therefore the quantity of colour to be mixed, by the width of the slit. In the case of light mixture by means of mirrors, as for instance in the photo-chromoscope, the luminosity of the colours will also be considered when measuring quantities, and if we vary the luminosity by interposition of transparent media (photographic diapositive) we shall find again that the transmitted quality of the positions corresponds to the quantity of the light to be mixed.

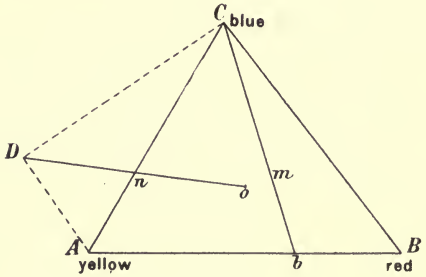


Fig. 18.

The mixing line of dyes will show blackish shades, whereas that of coloured lights will show the whitish ones. If the opposite colours on the mixing line are complementary ones, at one point of the line we shall obtain a pure black, and in the case of mixed lights a pure white.

If we wish to combine the colours *A* and *B* with a third *C*, we can take any point outside the mixing line for the third colour (fig. 18), and consider every line drawn from *C* to any point of line *A B* as the mixing line of the respective colours.

According to this theory, all colours obtainable by mixing *A B* and *C* are to be found within the triangle *A B C*.

If we take *C* as the blue colour, we find in *A B* all orange, in *A C* the green, in *C B* the violet colours, and the triangle is filled with continuous colour gradations obtained by a gradual shading of the two colours towards the third. Such a surface will be termed the mixing surface.

Corresponding to the origin of the mixing surface we are enabled to find a point which is characteristic for a certain mixed colour in the following way. Imagine at the points where the colours are situated which we want to mix, weights equivalent to their quantity, and let us ascertain the centre of gravity of such a system. The position of this centre will give us the geometrical position of the mixed colours. If, for instance, one part of yellow is to be mixed with two parts of red, and 1·5 parts of blue, we imagine in *A B* and *C* weights corresponding to the quantity of the surface. If we consider first the weights in *A* and *B* the centre of gravity will be at *b*, and we have to imagine at this point a mixed colour corresponding to one yellow + two red = a weight of three units, viz., three parts of orange. The line *b C* has only three units in *b*, in *C* 1·5 units, and the centre of gravity of this line is to be found in *m*, because $C\,m = 2\,b\,m$. Point *m* is therefore the centre of gravity of this weight system, and its position corresponds to three parts of orange + 1·5 blue, and also to one part of yellow + two parts of red + 1·5 parts of blue.

Colours placed in any of three mixing lines are less pure than those in the extreme corners, and colours in the triangle itself must therefore show considerable loss of purity, and considerable admixture with white or black. If one of the corner colours is complementary to a mixed colour in one of the mixing lines, we must in the case of coloured light obtain a point of pure white, in the case of pigments a pure neutral grey or black within the mixing surface.

If we want, for instance, to construct such a triangle for the colours chrome yellow, Eosine, and Methylene blue lake, we must proceed in the following manner.

We take any shade of triangle and place in the corners the three colours; mix carefully weighed quantities of these colours in various proportions; ascertain their geometrical position as explained above, and insert the mixed colours in their respective places. Of the highest importance is it to find the position of the neutral point in the triangle surface corresponding to neutral grey or black.

We mixed a neutral black and ascertained point *o* with the help of the centre of gravity construction, using the quantities required for the mixture.

Colours which cannot be imitated by mixing of the three colours are outside the triangle, and we can also ascertain their position by mixing experiments.

In the example given, we miss for instance, a pure green, because the chosen blue and yellow give a green of a blackish shade.

It will, however, be possible to produce two similar looking colour mixtures by either mixing a pure green with black, or chrome yellow with Methyl-blue. If two parts of yellow and one part of blue, or one part of green and one part of black were required to produce the colour, the position of the new green is as follows: the green produced by mixing yellow and blue is situated on the line $A\ C$ at the point n, because $C\,n = 2\ A\,n$; the pure green mixed with black gives the same colour, the green must therefore lie within the mixing line $o\ n$ if o is the neutral point, and as this colour, mixed with equal proportions of black, gives colour n, it follows that the position of n is in D ($o\,n = D\,n$).

All colours which can be produced by mixing this green or the blue and yellow, are situated in the triangle $A\ D\ C$; and if we add this green to the former colour system, yellow, blue, red, we obtain a further increase of green colour mixtures, and the possible colours which can be produced by mixing the four, are to be found within the quadrangle $A\ B\ C\ D$.

We can ascertain the positions of any number of colours, and construct a polygon which facilitates many problems of the mixing of colours.

A very convenient method of constructing a colour chart is by means of the colour top, as described page 47, but we must not forget that the colour obtained on the top is only equal to the substance mixture in the tone of colour, and not in its shade.

The colour chart is also only applicable to narrow-banded pigments, because we assume that the mixing result is governed by the colour of the components, which is not the case with pigments showing broad absorption bands. A mixing line between vermillion and ultramarine would not represent a purple, but a brown colour mixture. If we therefore insert such pigments in our colour chart, we must bear in mind that their position only represents their colour, and not their substance mixtures. The periphery of the polygon contains only the purest colours; in the centre we find black, and every line between the black and any colour in the periphery represents a mixing line between the respective colour and black.

Taking the neutral point as the centre of a circle, we can supplement the pure colours and produce a colour circle.

The distribution of these colours is governed by the chosen form of the mixing triangle, which served us in constructing the circle.

Suitable choice of the colour triangles may result in a position of colours having equal extension in the circle in which each colour appears to differ from the other in the same degree. The colour difference of two points can be measured by the angle, enclosed by the radii which we can draw towards these points.

In this construction we find Hering's four primary colours distanced from each other by 90°.

Such a circular colour chart is represented in Supplement I, but a slightly different method has been made use of in its construction.

Four pigments representing the fundamental colours have been selected and placed on two lines, crossing each other at an angle of 90°. The crossing point represents black and the centre of the colour circle.

For the yellow fundamental colour, chrome yellow of a neutral tint has been chosen, and for the green primary Acid Green. The latter colour has been dissolved in a warm solution of gelatine, and corresponds to a spectral zone near *b* towards *F*, and being neither of a yellow nor a blue shade.

The two other fundamental colours must be complementary, and are respectively ultramarine and a colour made up of Eosine and Erythrosine.

A great number of colour mixtures have been produced, and those necessary to fill up a continuous colour scheme have been selected, and introduced in the circle.

To give an idea of their relative position a few have been printed in colour in Supplement I, but we must imagine the space enclosed by the circle to be filled with corresponding colour gradations.

We find, for instance, in the middle between red and yellow an orange, and the radius between orange and the centre is to be covered with mixtures of the two pigments, *i.e.*, an impure orange, gradually melting into brown and brown black.

The intensity of the colours in the circle is to be taken as such that a mixture of equal proportions of diametrically opposed colours furnishes a neutral grey or black, and that two pigments mixed in equal proportions result in a colour situated in the centre between the two components.

Pigments of equal purity stand semi-distant from black, and are to be found in a circle of corresponding diameter. Permanent artists' and printing colours shew a relatively black appearance, and must therefore stand nearer to the centre black. In this group we find the different yellow and blue shaded madder lakes, the Prussian blue, samples of which are given in Supplement I. More pronounced black shades nearer to the centre of the colour scheme, are represented by brown and green.

The largest circle represents the colour circle of aniline dyes in transparent gelatine films, which show in transmitted light greater purity, and are most removed from the centre black. By comparing such coloured films with the colours of the spectrum it has been possible to ascertain their wave length, which is also marked on the circle. On the basis of these points, and from the conclusion that complementary wave lengths are diametrically disposed towards each other, it has been possible to obtain a full wave length scale on the periphery of the circle, commencing from 640 and terminating at 440μ (shorter wave lengths do not produce new colour sensations). The characterization of the colour of every pigment can therefore be calculated. We note that for instance ultramarine has a wave length of 463, vermillion 600, etc., which tells us that the light reflected from these pigments produces a similar sensation as spectral light of 463μ and 600μ. With the help of this colour table we are enabled to solve the following problems:

(1) As every line within the mixing surface represents a mixing of the colours situated at both ends of the line, we can in one case ascertain the result of a mixture of two pigments, and in the other we can find the necessary constituents of a mixed colour. The mixture of two pigments is the blacker the further the pigments are removed from each other within the colour circle.

We notice that Prussian blue and chrome yellow produce a green mixture called sage green, which consists of 75° of black, because the two colours are removed from each other by an angle of about 150°.

We can further produce this green by mixing one part of pure green with three parts of black. The composition is shown in Supplement I in a graphic form, and the size of the colour discs represents the quantities of the colour components. If the distance apart of two pigments amounts to 180°, or if the colours are diametrically situated, they will each be complementary to a black, or in minor intensities to a grey, because two colours diametrically opposed must be complementary. An enormous number of complementary colour shades can be constructed from the peripheral colours. Blue-green will be found to be complementary to red, but also to brown, yellow to steel-blue, violet to olive-green. The definition of a complementary is therefore quite arbitrary whenever colour shades are also to be considered.

We further find that the colour of Prussian blue can be produced by mixing Brilliant Green with Methyl Violet, because it lies on the mixing line of these pigments, but according to its position we also find that equal quantities of the pigments are required.

The same colour can also be obtained by mixing about three parts of Rhodamine and five parts of Viridine lake, or one-fifth part of Indian yellow to one part of Methyl-blue lake. The brown in the table is the result of a mixture of violet lake with chrome yellow, or yellowish red with black, or Fluorescein with Methyl-blue lake, or by superposition of films stained with Methyl-violet and picric acid, etc.

We can also choose three or more pigments, and ascertain the proportions necessary for the production of a colour mixture of a certain shade.

Prussian blue can be produced by mixing seven parts of peacock blue, one part of chrome yellow, and 1·8 parts of Rhodamine lake. Sage green, by mixing one part of chrome yellow, one part of blue green, and half part of Nachtrosa (a colour very much like Rose Bengal). It follows that all colours within the colour circle can be produced in an endless variety of ways.

(2) If we connect three points representing colours, we find that this triangle encloses all possible colour mixtures, but that colours situated outside the triangle are not obtainable. The larger therefore the triangular surface the larger the number of possible colour mixtures.

If three colours connected by lines result in an obtuse angled triangle, a black or grey colour mixture is impossible, etc. If we connect a colour in the circle by means of a straight line with the neutral point, we find the middle absorption of the pigment. We take, for instance, for the dye called "Nachtrosa," the middle absorption corresponding to point D 4/5 E in the spectrum.

The high importance of such a geometric representation of these colour and pigment mixing laws is apparent. Neither the artist, nor the technical man who has great experience in the mixing of colours, is in a position to solve problems as stated above, by practice or speculation. A look, however, at the colour table shows us the result of the most complicated mixtures, and makes the solution of the most difficult problems in reference to colour mixtures possible. Such a problem is three-colour printing, and only by the aid of this colour scheme is a rational treatment of this process feasible.

The Spectral Mixing Line.

By stretching the colour circle into a straight line we obtain a colour band, which—not considering the presence of the purple tints—differs from the spectrum, inasmuch as every colour fills equal spaces and shows equal intensity. The part of the spectrum represented by this band is illustrated in fig. 19. We must not mistake this as a spectrum, and Frauenhofer lines and the wave length scale characterize only the colour shade at this particular point. Taking shorter parts of this band into consideration, we term the same the "spectral mixing line," because they correspond to the characteristics of a mixing line.

This line is in a certain way related to the normal spectrum. If we assume that in white light equal proportions of rays of different wave lengths are present, representing equal numbers of ether waves of every undulation, the diffraction grating will represent a line equally balanced with different rays of light similar to the mixing line, provided we further assume that to compose white from complementary coloured rays, equal intensities of light are required.

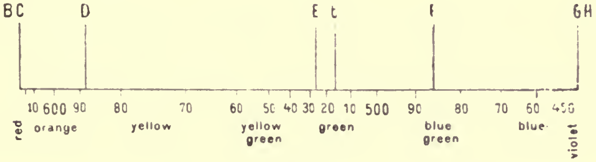


Fig. 19.

The intensity of the colour would be in both cases the same, but their extension or their quantity will differ. In the spectrum, excess of green and blue, but especially of red, is noticeable, or by recomposition white would not be obtainable in the mixing line, however the excess is compensated for by purple.

This view, which may not be perfectly correct, has the advantage that aided by it we are in a position to develop, in a very simple manner, the theory of the photographic colour decomposition, and to answer with the greater facility, every question concerning the same.

Exceptions to the Rule of Pigment Mixtures.

Actual mixing of pigments shows sometimes exceptions to the rules laid down in Supplement I, and it will be necessary to consider the same.

As stated before, the rule of ray mixtures in pigments only holds good if their absorption bands do not collide. If we use green pigments for mixtures with yellow or blue, this condition cannot be fulfilled, because the first always show absorption bands situated in the spectral blue and yellow. The absorption band of the yellow and blue pigment overlap another band, which is already present, and its effect is greatly diminished. This explains the fact that a green of fair intensity does not alter when mixed with yellow or blue pigments in accordance with the mixing rules. Another irregularity is noticeable whenever we wish to produce yellow or blue-green by pigmentary mixtures. White light, as the spectrum shows, contains only small amounts of yellow constituents, and a body of yellow colour does not only owe its colouration to these yellow rays, but chiefly to the reflected green and red. An orange pigment does not reflect green rays, nor a green pigment red rays, a mixture of both being therefore devoid of either, cannot result in a yellow. The absorption band of the mixtures lies over the complementary colours red and blue-green, and only an impure yellow or brown can be the mixing result (page 38).

The same phenomenon is noticeable by mixing green and blue colours to make blue-green.

Pure blue-green is a colour with which we rarely meet ; the magnificence of the peacock's feather is due to this colour, and the extraordinary charm of the colour of a clear mountain stream or a glacier is mostly due to the pure blue-green. This colour must not be mistaken for a blue-green mixture, and it is as much different from it as the pure yellow from the yellow brown, which is the result of a mixture of orange and yellow-green. We can only receive a sensation of pure blue-green if a body reflects, in addition to blue-green, also the whole of the blue and green rays, and this is in a mixture with a green pigment, impossible. The colour chart becomes therefore incorrect as soon as green forms one of the mixing components.

Pigments can, however, be formed for all other parts of the colour circle following the rules laid down, but we also meet a strange phenomenon, which makes the correctness of the geometrical representation questionable. If we mix, for instance, equal proportions of dyes, which are represented in *a* and *c*, fig. 20, and which are 120° apart, we obtain an impure green *d*, which we can, however, also obtain by mixing the pure colour *g* with black. Angle α is 60°, and we conclude that the colour *d* is composed of equal parts of pure green and black.

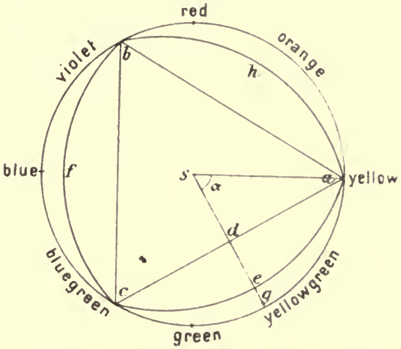


Fig. 20.

This theoretical conclusion is, however, not confirmed in practice, because it is quite possible to mix a very pure green with a yellow and blue-green. This contradiction can, however, be explained by the fact that an addition of black is not felt in the same degree as the mixing proportions. A similar phenomenon is noticeable if white and black are mixed. An addition of 10° to 20° of black causes inconsiderable change of colour, except if compared with pure white; a colour top mixture of equal black and white appears as light grey, and by no means as a colour situated midway on the mixing line, which can only be represented by twenty parts of white and eighty parts of black.

A white surface, ruled with fine black lines, shows very different results. Such a surface appears to our eye in the luminosity governed by the proportion "white : black," and black lines of the same thickness as the white spaces produce a middle grey.

Evidently we are facing a difference between objective luminosity and subjective sensation.

Fechner demonstrated the well-known laws of a connection between the objective luminosity and the subjective sensation. A comparison between the tone of a ruled screen and the homogeneous grey of a colour top mixture, directly confirmed the "Fechner law." For this purpose a paper has been ruled with black lines of different thickness representing five different luminosities. The width of lines varied between 0·05 and 0·40 mm. and measurement of the width of the black lines and the white spaces made it possible to ascertain the luminosity of this screen, which has been imitated on the colour top with the help of black and white sectors, the angle of which has been measured to ascertain the luminosity of the homogeneous grey.

The screen tone has been viewed at such a distance, that the lines were distinctly visible; and although the surface does not appear homogenous, with a little practice and repeating of the experiment, a comparison between the two tones is quite possible. The objective luminosity of the grey on the colour top is known to us by its composition, and the screen surface of the same luminosity represents the subjective colour sensations.

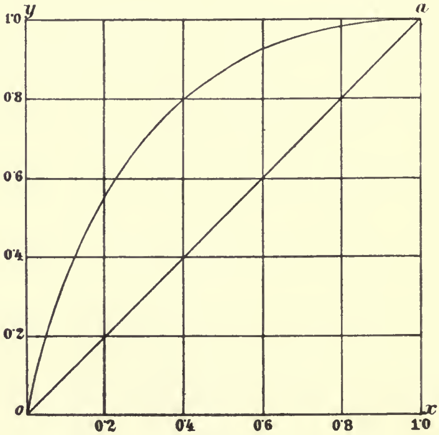


Fig. 21.

The result is graphically demonstrated in fig. 21. If subjective and objective luminosity would be equal, the straight line, *o a*, would be the result, because a screen luminosity of equal parts of black and white would correspond to the colour top luminosity 0.5.

The curve in fig. 21 shows a logarithmic line, in which the subjective luminosity increases in logarithmic progression with the increasing objective luminosity.

A grey, for instance, composed of 3·5 parts of white, and 6·5 parts of black, appears to our eye twice as bright as it ought to appear, and we are only impressed by one-fourth of the amount of black if this is present in equal quantities in a black and white mixture.

It is possible that similar phenomena are noticeable in mixtures of black with other colours, but it must then also be ascertained how much the rule is influenced by the luminosity of the colour.

These conditions are, however, of the greatest importance for all colour mixtures, because only a part of the black in the colour impresses our retina, and colours must therefore appear purer than they actually are.

A green made of equal parts of Prussian blue and chrome yellow contains, according to page 61, $\frac{3}{4}$-parts black. If our sensation of colour would follow the mixing laws, we could only perceive a grey of a greenish tint, but as the presence of 75% of black yields a luminosity of 0·64, and not the subjective luminosity of 0·25, the black sensation is so very much weakened that the green appears sufficiently pure.

For colours distancing each other by 120° in the colour circle, the conditions are still more favourable.

The amount of black in the middle colour mixture amounts, as already stated, to 52%, and should cause a colour sensation of a pigment semi-distant between the colour and black. But that is by no means the case, because a mixture with 52% of black shows a subjective luminosity of nearly 0·9, and the colour appears to us as if mixed with 10% of black only. We obtain a green shade, not situated in point *d* of our colour chart (fig. 20), but in *e*, which point is considerably removed from black.

Ascertaining in a similar way the subjective purity of all colours in the mixing line *a c*, we can construct the curve *a e c*, in which they should be placed according to their appearance.

Colours produced by pigment mixtures appear to us purer than they actually are, and with colours placed in the points *a b* and *c*, we can obtain, apart from the colours situated within *a b c*, all other shades enclosed by the curves *e f* and *h*.

Without this peculiarity of our colour vision, the technique of painting as well as the production of a colour print would be an impossibility.

PART II.

THEORY AND PRACTICE OF THREE-COLOUR PRINTING.

IF we wish to reproduce a coloured object with three colours only, we must select pigments of special qualities. They must be chosen so as to enable us to produce the greatest number of mixed colours.

Only after this condition has been fulfilled can we proceed to decompose the original colours by photographic means.

The choice of colours is quite independent of the photographic process, but the latter is governed by the former, because the photographic process is called upon to decompose the original in three monochrome images of the colours of the chosen pigments.

A. THE THEORETICAL BASIS OF THREE-COLOUR PRINTING.

The theory of three-colour printing may be divided into two parts. The first deals with the choice of a suitable colour system, the second with the production of the negatives.

a. CHOICE OF THE COLOURS.

To obtain the greatest possible number of colour mixtures with the three colours, it will be necessary to select a mixing triangle of the largest possible dimensions. We must therefore select colours far removed from black, and if connected, forming an equilateral triangle.

The first condition indicates the selection of the pure, brilliant pigments of the aniline order, and the second compels us to select colours semi-distant in the periphery of the circle.

The choice of narrow-banded dyes is also preferable, because they follow the laws of colour mixture and are free from the irregularities to which colours with broad absorption bands are liable.

If the mixture of a red and blue dye results in a brown instead of a violet, as for instance, in the case of vermilion + ultramarine, we know that such colours are not suitable for our purpose.

Three narrow-banded colours, situated in the colour circle at 120° from each other, form a suitable colour system for trichromatic printing, and a great number of such theroretically possible systems can be ascertained.

As, however, yellow cannot be produced by pigment mixtures, as shown on page 64, this colour must form one of the fundamental colours.

This condition decides the only theoretically correct colour system, because the other two being 120° away from the yellow are the blue-green and the pink.

The triangle which corresponds to these requirements is shown in Supplement I, giving cadmium yellow, a colour between Rose Bengal and Erythrosine, and another between peacock blue and Viridin green, as fundamental colours.

Slight differences in these colours are, however, of no importance, but the yellow must be absolutely correct, and must not be of a reddish tint, because a neutral pure yellow cannot be produced by colour mixture, and would therefore be missing.

How far we can succeed in reproducing all hues of colour which are to be found in a painting by using three colours our colour chart will show us. Neither in nature nor in a painting are those pure colours to be found which are at our disposal when using aniline dyes. The painter rarely uses pure colours, he generally works with mixed impure colours, and the colour magnificence of a painting is not due to the use of brilliant pigments, but to the effects of colour contrast. The usual artists' and printers' colours are to be found within the smaller circle where Prussian blue and madder lake are to be found, and as the colours placed within the circle are almost in the proposed correct colour triangle, it follows that the reproduction of all colours of a painting is possible, because the mixed colours appear to be brighter than they really are.

The conditions for three-colour transparencies are more favourable because the colours of the films correspond to those of the largest circle (page 61). If we choose for the transparencies the colours, Naphthol Yellow, Erythrosine and Fast Green, we find this triangle to enclose all colours of nature and the artist's palette.

At present aniline dyes are not used for three-colour printing, but the more permanent printing inks, chrome yellow, madder lake, and Prussian blue. This combination corresponds to the smaller triangle, which shows a very favourable construction for the mixing of green or violet colours. Every artist would repudiate the idea of painting a picture with these three colours, knowing that by mixing them he could only obtain impure tints; and yet after all we insist upon a true colour rendering with these pigments in trichromatic work.

In working this process we constantly meet a number of difficulties which only lead us to wrong conclusions, unless we strictly separate the different phases of the process. How often is the photographic part condemned when the printing inks are wrongly chosen, and we follow illusions which can never be realised.

In three-colour printing it is of importance that the intensities of the three monochrome prints correspond to the units which we described in page 61. The colours must be equivalent, and neither must suffer at the expense of the other. Full red and yellow hues must result in a middle orange; full red and blue, or blue and yellow, in a middle violet; whilst green, when mixed, and all three superposed, should be complementary to a neutral black.

Only three pigments, symmetrically placed in the colour circle, conform to these requirements, because the centre of gravity of such a system lies in the neutral point of the colour circle.

If we choose, as in fig. 22, three pigments which are not semi-distant *B R Y*, and if *S* forms the centre of the colour circle, corresponding to the position of black, we obtain by mixing equal quantities of the fundamental colours a red brown of the colour *a*, but not a black, because the centre of gravity of the system *B R Y*, lies in this point. If these colours are to compose a black, we have to restrict the red to about half. We must therefore mix $1B + 1Y + 4/7R$. The three colours *B R Y*, do not conform to the conditions which are required for trichromatic work, because, although a reduced intensity of the red results in a black, or a grey, the colour print will be deficient in red, and if we preserve the equilibrium of the colour system, we have to meet another defect in the black shades. Instead of neutral grey we get a brownish grey, and a neutral grey where green grey is required.

Such phenomena must be noticeable when using chrome yellow, madder lake, and Prussian blue as printing inks, and unretouched three-colour prints always show a distinct brown in the place of the grey.

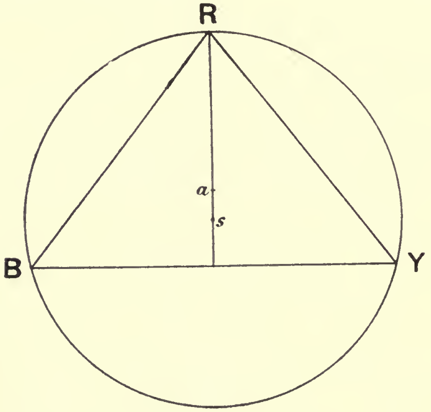


Fig. 22.

As by means of retouching, and the use of the overlapping defect, this deficiency can be corrected, we cannot condemn the permanent colour system entirely, because the importance of permanent, good workable printing inks is apparent.

But we must acquaint ourselves with the disadvantages of such a colour choice, and if the excess of red ruins a green or blue, or if instead of red only orange is present, and we cannot get a black or grey without disturbing the equilibrium of all the other colours, whilst negatives made with the most excellent filters do not show the correct colour rendering, we should seek the cause there, where it will be found, and not dream of impossible photographic colour selection.

We can use at the present, two fundamental colour systems, forming the basis for further detailed explanations.

(*a*) The theoretically correct colour system, yellow pink and blue green, to which the printing inks, cadmium—or light chrome yellow—rose lake, and a greenish peacock blue correspond, and

(*b*) The permanent colour system represented by yellow, madder lake, and Prussian blue.

Supplement I. shows the two colour systems, and the mixing results.

The first system does not find practical application, because permanent colours of this particular hue have not been found, but it is employed in the making of three-colour transparencies.

The yellow and the red in Supplement I comply in every respect with the necessary conditions, but the blue green is deficient for securing the full purity, which is essential for the formation of a perfect green, as theory requires it.

The second colour system shows the colours which are to be used if permanency of the print is required, but they give an impure green and orange, exhibit all defects which have been already mentioned, and require extensive retouching, especially of the red printing plate.

Of course we must not conclude that the employment of correct colours makes retouching necessary, because the overlapping defect and defects closely connected with the photo-mechanical printing process have to be considered.

Much confusion was caused some time ago by the term "impurity" of our pigment colours. It has been asserted that a correct rendering of colour is not possible in trichromatic work because the pigments are "impure." Sometimes this term was used to express "blackish hues," at other times, to represent the presence of different coloured rays in reflected light. The blackish appearance of our pigments, can only cause a darker representation of one object, but is without influence on the colour tone. The fact, however, that chrome yellow reflects red and green rays besides the yellow, is without consequence upon the theoretical possibilities of trichromatic work. Even coloured glass passes different coloured light, and still it corresponds exactly in admixtures to the spectral rays; the red, yellow and green which pass a yellow glass show in colour mixture the same result as spectral yellow.

Finally a few words referring to the choice of colours for the Photochromoscope and polychromatic projection may be welcome.

In this process the pictures are the result of a mixture of coloured light, and the colour system must be constructed with the aid of a colour chart prepared for such mixtures.

Such a colour chart only differs in one point, *i.e.*, the centre is represented by white, and the circle is filled with whitish hues of the periphery colours. Again, the fundamental colours are to be 120° distant, and an infinite number of such theoretically correct colour systems can be found. If we use the trio, yellow, pink, and blue green, we should only obtain a whitish blue. Blue is, however, the specific darkest colour and must be as intense as possible; blue must therefore be one of the three fundamental colours, and red and green must follow. According to the hue of the chosen blue, we get the following systems: ultramarine, spectral red, yellow green, or violet, red orange, and pure green. These are the colour systems made use of by Ives and Vidal.

B. THE PHOTOGRAPHIC PROCESS.

The choice of the three colours, which are to be used as printing inks in trichromatic printing, is governed by the laws of colour mixtures, and photography is to produce negatives to correspond to the chosen pigments. If we encounter insurmountable difficulties in adjusting the photographic process to suit our printing inks, we should have considered such possibilities when choosing the colours.

The intimate relation between printing ink and production of colour negative must be theoretically considered, and must never be lost sight of, because the aimless experimenting leads very rarely, particularly in three-colour photography, to the desired end.

Photography is to produce three negatives of such a character that prints made with the chosen colours and superimposed result in a faithful reproduction of the colours of the original. Such negatives are to be produced by allowing certain coloured rays to act upon our photographic plate, whilst excluding others.

The negative required for the production of the red print termed the "red negative" must show no action of light in all those parts where the colour of the original corresponds to the printing ink, and all those colours which result from mixing with the other two colours must be represented in the negative by gradations, governed by the amount of red present in the colour. We must therefore exclude light rays of this particular colour, and only permit those rays to act on our plate, which are absent in the reflected light of this pigment. We find that the green rays are missing in this reflected light, and we must therefore make use of the green rays for the production of our negative. The photographic plate must therefore be green sensitive.

Considering these facts we are led to the conclusion that for the production of the yellow and blue printing negative, plates are required which are sensitive to their complementary rays.

However correct this view may appear, it does not furnish us with a precise description of the production of the negative, because it is questionable whether the picture forming rays are to consist of a monochromatic green, or a mixture of different rays, as in both cases the green may be complementary to the chosen printing ink. If we ascertain the absorption band of the red ink, and determine a necessary sensitizing of the plates, we meet the question whether the photographic plate is to be sensitized for the whole, or only a part of this particular band, because, in both cases, we should comply with the condition of the plate being insensitive to the reflected rays of this band.

We see that such considerations do not lead to satisfactory answers, and the question of sensitizing plates is a complicated problem which has scarcely been answered in a way which may not be theoretically attacked.

The following explanations endeavour to solve this question with sufficient accuracy for practical work. They show the relation between printing ink and the sensitizing of plates, and give a generally useful receipt for the photographic decomposition of colours.

Every colour of the original which we want to produce has a definite absorption band, which governs the peculiarities of the colour sensation. In three-colour printing it is required to compensate for this band, by means of three absorption bands corresponding to the fundamental colours, but varying in intensity to such a degree that a similar colour sensation is the result. This problem is easily solved with the help of our rules of colour mixtures.

Fig. 23.—I represents the absorption band of a colour in an original, of a distribution of colour on the spectral mixing line as discussed on page 63. *B R Y* corresponds to the middle absorption of the chosen fundamental colours, blue, red, and yellow. We shall in future use these short terms, so that it will be necessary to remember that blue, for instance, represents blue green, red, pink, etc.

It must further be remarked that the spectral portions in front of *C* and after *G* need not be considered, because the absorption of such weak light does not influence the colour of a body materially (page 63), and further, that the middle absorption in our illustration does not correspond to the theoretically correct fundamental colour system, but has been assumed so as to make further explanations as simple as possible.

Pigments, absorbing the middle and the limits of the spectrum, would show the colours: purple, greenish yellow, and green, which is a useless colour system for three-colour printing.

The reproduction of the colours of the original by mixing the three fundamental colours corresponds to a distribution of its absorption band over the parts *B*, *R* and *Y* of the spectrum. To solve this problem, we must imagine this band to consist of several elementary bands, and the action of each of them to be represented in *B*, *R* and *Y*.

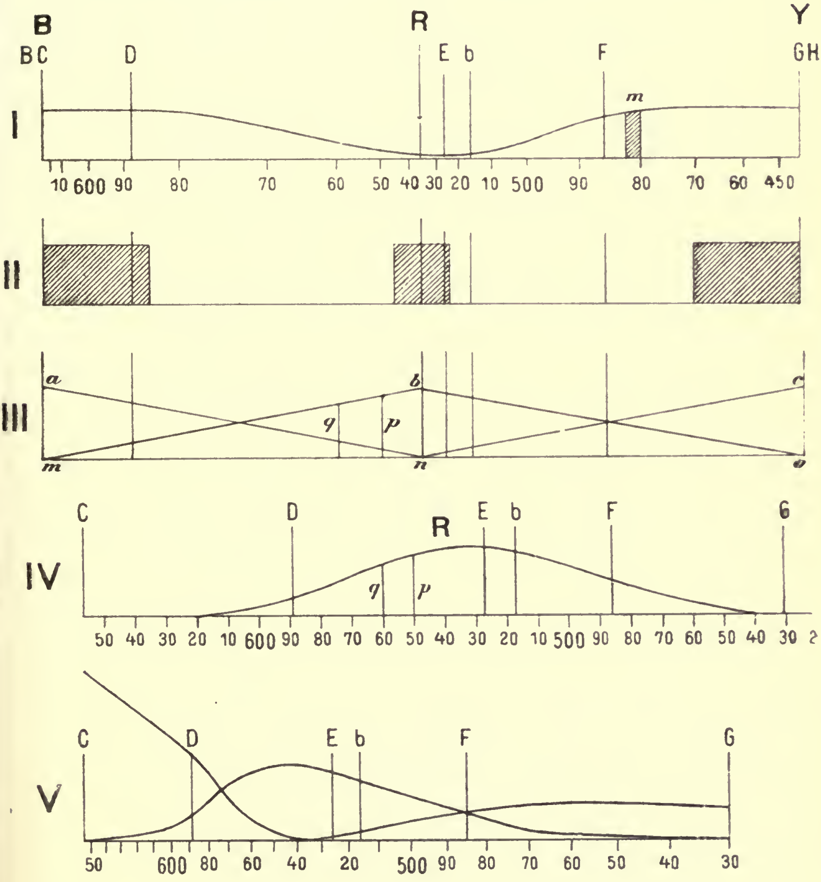


Fig. 23.

Element *m* can be replaced by absorption band on *R* and *Y*, and as the distance between *R* and *Y* can be considered as a mixing line, it follows that the intensities of these bands are inversely proportional to the distance of point *m* from *R* and *Y*. In this way we are enabled to decompose every band element between *R* and *Y*, and we can further distribute the absorption band between *B* and *R* over those two points. The result of such a decomposition is illustrated in II. The intensity of *R* is governed by the whole absorption band of the original colour, but for the intensities placed in *Y* and *B* we are only to consider the spaces *Y R* and *B R*.

The pigment characterised by the absorption spectrum II is due to a mixture of the three fundamental colours, and will produce the same colour sensation to our eye as the original colour I, although they are spectroscopically entirely different.

Absorption band I corresponds to a pigment called "sage green," which is produced by a mixture of Prussian blue and chrome yellow, and has been discussed at pages 61 and 62.

As II shows, two parts of *B* + two parts of *Y* + one part of *R* constitute this colour. If we assume the absorption in *B R* and *Y* to correspond to blue green, pink and yellow, we can illustrate the decomposition of this pigment in Supplement I. The discs show the tint of the colours and its purity, whilst their size indicates the quantity of the components.

This distribution of the absorption band over three definite points in the spectrum must be photographically accomplished, and the necessity of sensitizing the photographic plates for these particular regions is obvious.

The plates for the red printing negative must be sensitive from *B* to *Y*, the plate for the yellow or blue negative from *R* to *Y*, and *R* to *B*. If this condition is not followed, and the plate is very sensitive for smaller portions of the spectrum, we should obtain incorrect colour rendering.

If the plates, for instance, are only sensitized for the nearest surroundings of points *B R Y*, we should not observe the absorption band of Methyl violet, situated between

R and *B*, because they are, so to say, blind for these particular rays.

The consequence would be a total absence of the narrow banded violet in our reproduction. These considerations determine the necessary extension of the sensitizing curves, and we only want to ascertain the form of the curve or the measure of sensitiveness for the different rays.

As the assumed colour distribution corresponds to a mixing line, it is easy to answer this question. The sensitiveness of a plate for the production of the red negative must evidently gradually decrease from point *R* towards *B* and *Y*, and the other two plates from *B* respectively, *Y* towards *R*.

The necessary conditions of sensitiveness of the three plates are given in three straight lines in III, *m b o*, corresponds to the green sensitive *a n* to the red, and *n c* to the blue sensitive plates. We are to sensitize our three plates according to the required colour sensitiveness. The connection sought for between the chosen fundamental colours, and the sensitiveness of the plates is not described, and can be expressed in the following :—

The photographic plates which are required for the production of the three negatives must be sensitized in such a manner, that their maximum on the spectral mixing line corresponds to the middle absorption of the chosen fundamental colours, and their sensitiveness has to reach the middle absorption of the next fundamental colour ; the sensitizing curves form straight lines. To ascertain the curves for the normal spectrum, we have to insert the colour sensitiveness required for the different wave lengths into the scale of the normal spectrum IV.

The intensities *b n*, *p q*, are to be inserted on the corresponding scale portions, and we arrive at the curve *R* representing the normal spectrum. The sensitizing curve for the prismatic spectrum is illustrated in diagram V, and has been obtained by methods described on page 27.

Based upon these generalities, we can proceed to determine the sensitizing curves for the colour systems explained on page 73.

1.—Sensitizing Curves for theoretically correct Colour System:—Yellow, Blue Green and Pink.

As the colour table shows, these colours have the following middle absorptions:—

Yellow 455μ *F* ½ *G* in the prismatic spectrum.

Blue green 595μ yellowish red in front of D line, and pink 530μ close before *E* line.

The plates are therefore to be sensitized, so that those regions of the spectrum named in Fig. 24, I with *b*, *r* and *g* represent the maxima of sensitiveness.

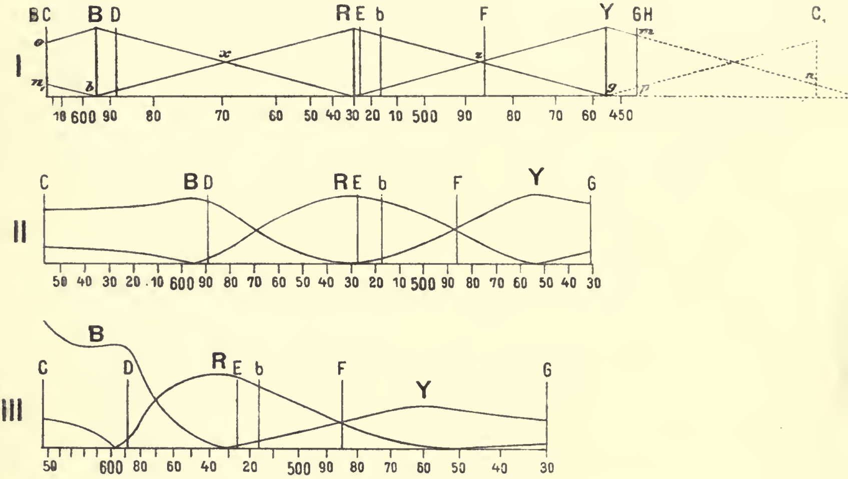


Fig. 24.

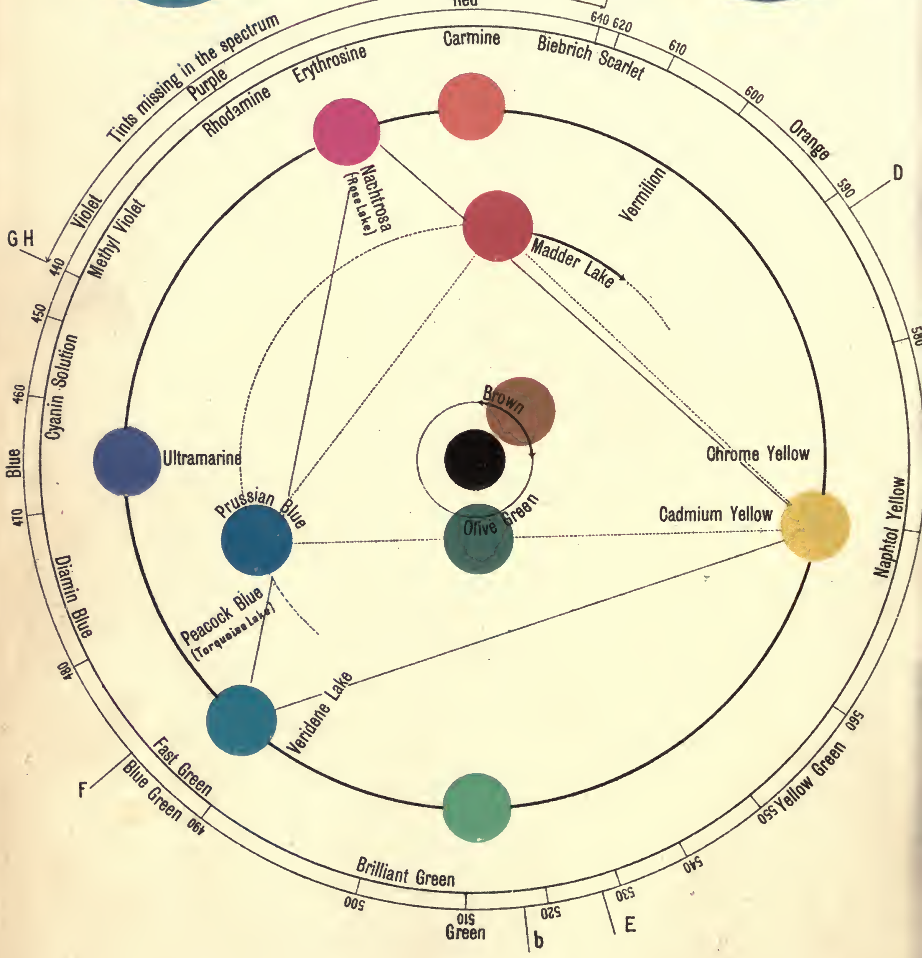
We find *r* to be in the centre of the spectral mixing line between *b* and *g*, because the colours belong to an equilateral mixing triangle.

The plate for the production of the red negative is to be sensitized for *b g*, the sensitiveness to decrease towards *b* and *g*, corresponding to the progress of the straight lines *R b* and *R g*.

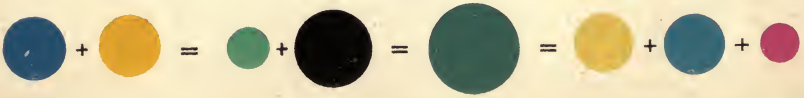
To obtain the necessary curves for the sensitizing of the yellow plate, we must insert the maximum of sensitiveness *g Y* in *g*, and the point *Y* is to be connected with the middle absorption of the two other colours with *r* and *b*.

Theoretically correct Colour-System.

Permanent printing inks.



Composition and analysis of sage green.



In this way we obtain the decreasing sensitiveness towards green—the straight line *Y r*—and to arrive at the line towards *b* we must continue the mixing line over violet, towards red, until we reach the colour *b*. In the diagram this continuation over the *G* line is marked with dotted line, and *C C*, or *b b*, corresponds to the whole colour circle, represented in a straight line.

The straight line *Y b*, represents the second part of the curve which illustrates the sensitiveness of the plate, which is to serve for the yellow negative.

Before this line is *Y m* the blue violet part of the spectrum, the piece *n b*, belongs to the spectral red, and *m n* is missing in the spectrum. The plate must therefore be sensitized, not only for blue green but also, although in a minor degree, for red orange, the sensitiveness being illustrated by the straight lines *r Y m* and n_1 *b*.

In precisely the same way, the straight lines *r B o*, and *g p* for the blue printing negative are to be found, and we notice that this plate must show a trace of blue violet sensitiveness.

As *b* b_1 is formed by the three sides of a regular mixing triangle point *x* represents the yellow, point *z* the blue printing colour.

If the progress of the sensitizing line is transferred on the normal spectrum, in the way already described, we obtain the curves *B R* and *Y*, illustrated in Fig. 24, II, which after transformation for the prismatic spectrum represent the curves III, and our plates must correspond to these curves if spectroscopically tested.

2.—CURVES OF SENSITIVENESS FOR THE PERMANENT COLOUR SYSTEM:—YELLOW, MADDER LAKE, AND PRUSSIAN BLUE.

The middle absorption of these colours is according to the colour table:—

For Prussian blue about 580μ quite close to the *D* line;
Madder lake 505μ i.e. *E* ½ *F*, and
Yellow 455μ i.e. *F* ½ *G*.

The points *b r* and *g*, Fig. 25, on the spectral mixing line, govern the maxima of sensitiveness of the three plates, and the sensitiveness must conform to the straight lines in the figure. Transferred on to the normal and then on to the prismatic spectrum we obtain the curves *II* and *III*, which are to be strictly observed when sensitizing the plates, and testing same spectroscopically.

The zone of sensitiveness of the photographic plates for three-colour work extends over a large area in the spectrum. The sensitizing of every one of the three plates is influenced by all three pigments, and is to correspond to the whole colour system, and not to a single colour. If one of the colours is altered, a change in the sensitizing of our three plates is required. If the sensitizing only depended on the one colour for which the negative is required, we should find, for instance, that madder lake and chrome yellow always require a constant condition of sensitiveness, and if we choose Prussian blue or blue green for the third, the same mixing colour would have to result, which is evidently impossible.

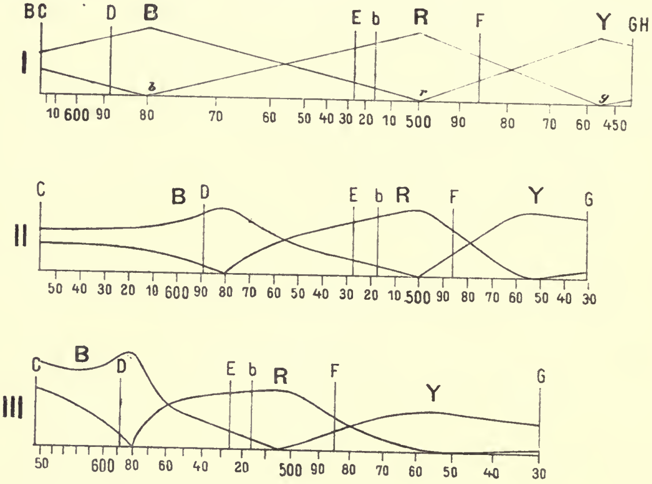


Fig. 25.

To obtain the required broad bands of sensitiveness, it will be necessary to use mixed colour sensitizers, and their activity will have to be controlled and corrected by suitable light filters. Only by means of spectrographic experiments is it possible to find a suitable plate preparation. We must choose mixtures of suitable colour sensitizers, and we have to vary the proportions until spectrographs show a band of sensitiveness, which corresponds to the above curves. This procedure is by no means simple and sure, because the effect of a sensitizer and the action of a filter chiefly depends from the length of exposure.

Short exposures give a shorter band than long exposures, and as the conditions of light are very different in the spectrograph from those in the camera, it is hardly possible to state the full suitability of a plate from the spectrographic tests.

It is, therefore, advisable to use a monochrome reproduction of certain colours for controlling the light filter and the sensitiveness of the plates. If we photograph the three colours chosen as fundamentals, we should expect to obtain in each plate two colours rendered white and one black. Such a result can only be obtained if the three colours are of equal and absolute purity, a condition which the blue colour scarcely fulfils.

For this purpose it is better to use the complementary colours of the fundamentals, which should show half of the action of the primaries on the three plates. Such colours can be taken from the colour chart, or can be ascertained by means of colour top experiments.

For the yellow printing colour, for instance, we find a reddish blue complementary, a blue which corresponds to a not too diluted Cyanine solution, and this blue must show in the red and blue negative equal and half the density of pure white.

Yellowish vermilion, the complementary colour to blue green, is to act on the red and yellow printing negatives equally, and half as intense as white.

The green which we chose as the complementary to the red printing colour, will act similarly in the case of the yellow and blue negative.

Although the action of the control pigments which are used for ascertaining the sensitizing curves of the plates is partly governed by their purity and intensity, these conditions are of no influence in their action on two different plates.

Every blue of this particular shade, whether mixed with white or black, must appear in the red and blue negative of equal intensity, because in the final print it must be composed of equal quantities of the two fundamental colours, and a blackish shade is only caused by the addition of the complementary yellow. It is immaterial whether permanent printing colours or aniline dyes are used for the control, so long as they have the required shade. Their action does not so much control the maxima, but the branches of the sensitizing curves, a feature which is very valuable, because the latter can be easily ascertained by making spectrographic tests.

In a similar way the control colours for the other printing principle, prussian blue, rose madder, and yellow are to be found.

Other colours, as for instance shown in the colour chart Supplement I., can be used. Their action will give us valuable hints as to correcting our colour filters, and we shall in another chapter deal with this colour scale in detail.

c. Theory of Ives.

Ives' theory is embodied in a patent of February 7th, 1890, and is based upon the Young-Helmholtz hypothesis (page 33).

Ives intends to give to the three pictures in the Photochromoscope colours which have been assumed as primary colour sensations, and chooses for the photographic process plates the sensitiveness of which corresponds to the curves of the above-mentioned diagrams. If the negatives are to serve for three-colour printing, Ives makes the condition that each of the printing inks used excludes one of the three fundamental sensations, which are therefore complementary to the assumed fundamental sensation.

The red printing negative has therefore to be made on a photographic plate the sensitiveness of which corresponds to the green curve of the diagram, and must be printed with a colour absorbing only the primary green. The photographic plate has to be sensitive for all parts of the spectrum, especially for the green, and the dyestuff is a narrow-banded pigment, absorbing only the green rays.

We arrive here again at the relation between printing ink and sensitiveness of plates, and if Ives denies such a relation we can only explain it according to his belief in a one colour system, and the principle of Young's choice of colours. If we accept this standpoint, we need not respect the fundamental colours when making our negatives, because Young has already chosen the same, and their corresponding mixing curves have been constructed by Maxwell and Helmholtz.

Young's colours, however, do not belong to a theoretically correct fundamental system of three-colour photography (page 78), and Ives' chosen pigments for trichromatic printing, Prussian blue, Eosine or Rhodamine red and yellow, are in no way connected with Young's colours (*vide* colour Supplement I).

Green, greenish yellow, and bluish red would have to be chosen, and the diagrams in question would form a correct base, but such a fundamental colour system cannot be made use of for obvious reasons.

Ives' curves, mentioned in the patent specification, are based upon the mixing experiments of Maxwell, where three spectral colours have been assumed as fundamentals. They are entirely different from those which Helmholtz's theory advances, and which are based on his mixing experiments with spectral lights.

Helmholtz's colours are ideal, non-existing, fundamental colours of extreme saturation, and if we followed his diagram we should have to add, for instance, a very considerable amount of red and blue to the green in the photochromoscope, and the yellow in three-colour printing would not only consist of the yellow pigment, but of a mixture of red and blue. The Photochromoscope would only yield very whitish colour shades, and the three-colour print only impure blackish colour shades.

To obtain a certain wealth of colour in the Photochromoscope, and sufficient purity in the trichromatic print, we have to make use of every colour enclosed in the triangle, a condition which is possible with Maxwell's diagrams. Although it cannot be disputed that sensitizing curves are best arrived at by mixing experiments with spectral lights, the practical man will find it easier to quickly answer questions concerning three-colour printing by methods described in these pages.

D. DR. H. W. VOGEL'S SENSITIZING THEORY.

Dr. H. W. Vogel, the discoverer of colour sensitizers, made three-colour photography possible, and has been the first to recognise the relation between colour sensitiveness of plate and printing colour in the following principle made known in 1885. The dyestuff used as colour sensitizer must be used as the printing colour, and if the dye should not be suitable for this purpose, an equivalent pigment of the same spectroscopic qualities must be found. No mention is made as to the choice of the fundamental colours, which ought to be chosen as described previously. If Dr. H. W. Vogel propounds the dyes Cyanine, Eosine, and a yellow pigment, it is not said that they also form a practical fundamental colour system, because Cyanine and yellow would never form a green. Still Vogel's theory has often been misrepresented in this way. Only after the choice of colours has been made can we make use of it, and this law is—with approximate supplementary clauses—extremely valuable to the beginner in trichromatic difficulties, on account of its precise and easily understood form.

We arrived at the conclusion that the maximum of the sensitiveness of the plate has to correspond to the middle absorption of the printing colour, and as a dyestuff only sensitizes for the spectral colours which it absorbs, it follows that the appearance of the two colours would be the same if the sensitizing maxima would also be characteristic for the shade of colour. As this, however, is not the case, and as further the photographic band of action suffers a shifting of the absorption maxima for the reason stated further on, we have to expect certain differences in the shade of the colours. We must further make it a condition that the band of sensitiveness shows a distinct shape, and covers a certain broad region of the spectrum, which necessitates the use of mixed sensitizers and corrections by means of light filters.

The Vogel theory is therefore neither theoretically correct nor of practical value, but states, however, in a very comprehensible form the relation between printing ink and sensitiveness of plates.

E. Relation between Printing Colour and Light Filter.

The seemingly intimate connection between the printing colour and light filter has often been made a leading principle in trichromatic printing, and Cros and Ducos du Hauron based their experiments on this principle. A green (respectively a blue and yellow light filter) has been used for the taking of the negatives, and the latter were printed in their complementary colours, red, yellow and blue.

Until recently the principle has found much favour, and Hazura and Hruza made numerous experiments to find complementary light filters to given printing colours.

The term "complementary" refers as a rule to the colour tone of two pigments; for the spectral composition of their reflected lights the term "complementary" furnishes only very general information.

By means of colour top experiments we can find several greens of different spectral behaviour to match a given red; for instance, a green pigment only absorbing red rays, and another only reflecting the green region of the spectrum. Both pigments show the same colour tone, they are both complementary to red, but used as light filters, entirely different results would be arrived at.

The tone of colour plays no part with the complementary colour; a certain green is not only complementary to a certain red, but also to its mixtures with black—also the brown — and red gives with olive colourless colour top mixtures, as well as with pure green (*vide* page 61).

The condition that the light filter should be complementary to the printing ink may at one time be possibly correct, whilst at another time entirely wrong.

This is however, different, if we add another condition to that of a colourless colour top mixture, *i.e.*, a complementary feature in their spectral behaviour. To a given red pigment which only absorbs the green region of the spectrum, every green would be complementary which absorbs all spectral rays, with exception of these particular green ones.

Such pigments could be termed "spectroscopic contra colours." To the absorption band of the printing ink, the gap in the band of the filter would have to correspond. Such contra colours could only be ascertained spectroscopically, a method adapted by Hazura and Hruza. The difficulties which are met when such filters are to be made, are almost insurmountable.

It is clear that the chosen fundamental colour must belong to a practical colour system, and that the photographic plates must show equal sensitiveness for all regions of the spectrum. The latter condition is only possible exceptionally for one part of the spectrum.

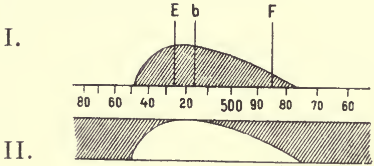


Fig. 26.

If I (fig. 26) represents the absorption band of the printing colour *II* shows the light filter and the plate must be made equally sensitive from D$\frac{1}{2}$ *E* to over *F*. The effect is the same as if the plate had been sensitized according to absorption curve I, and would have been exposed without a single filter.

The principle that the light filter should be complementary to the printing ink is therefore equal to Vogel's principle, printing ink and sensitizing dye should be spectroscopically the same.

Both conditions are relatively correct, but as the former cannot be made practical use of, Dr. H. W. Vogel offered a seemingly easier condition.

B. THE SENSITIZING OF PLATES AND LIGHT FILTERS.

Having chosen a fundamental colour system, and constructed the corresponding curves of sensitiveness, we can proceed with the sensitizing of the plates. Of suitable dyestuffs we select the most probable sensitizers, test the same spectroscopically, and make the necessary corrections by means of suitable light filters. Before entering into details referring to the actual preparation of plates, it is advisable to discuss the action of the suitable colour sensitizers, and the features of dyes used in the preparation of light filters.

A. THE SENSITIZING OF PHOTOGRAPHIC PLATES FOR COLOURED RAYS OF LIGHT.

The ordinary photographic plate is generally called blue sensitive, because a moderate exposure shows after development only a visible action of the blue and violet spectral rays on the photographic plate. If this exposure is prolonged, the green, then the yellow, and finally also the red rays exert a chemical action. A photograph of the spectrum extends by short exposure to line *F*; prolonged exposure widens the band towards the red, especially in gelatine dry plates.

The conditions of sensitiveness of the photographic bromide of silver in the prismatic spectrum are represented in curves I and II (fig. 27). I represents the gelatine, II the collodion plate, and we notice that the first is mainly sensitive for blue rays between *G* and *H*, whereas the latter shows greatest sensitiveness for violet rays. If these curves are transformed for the normal spectrum, we obtain the sensitiveness shown in fig. 28.

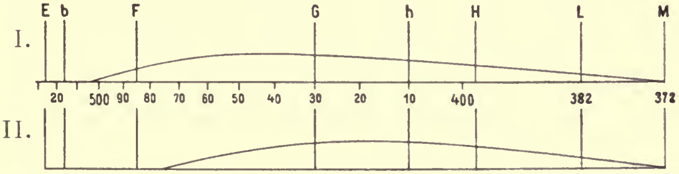


Fig. 27.

The most powerful action on both plates is due to the spectral violet, but the gelatine plate is of greater blue sensitiveness than the collodion emulsion. A short exposure scarcely shows this difference in practical work, but prolonged exposure widens the band of the gelatine plate towards *E*, and we obtain a distinct green sensitiveness.

Both plates give, therefore, somewhat different results in the case of oil paintings, where long exposures are needed.

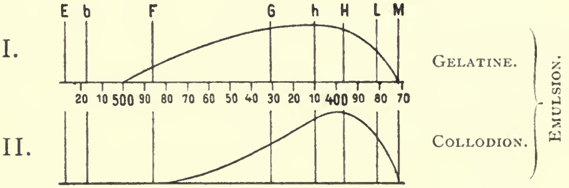


Fig. 28.

Photographic plates are further sensitive for the invisible part of the spectrum, situate near *H*, the ultra violet rays, and it is certainly of practical interest to acquaint ourselves with the influence of this species of rays during a photographic exposure of pigments. According to the experimental results of Dr. J. M. Eder, these rays play an unimportant part in the composition of the photographic image, and their influence seems to have been exaggerated on many occasions.

Daylight contains only a small amount of ultra violet rays; the glass of the lens or the filter absorbs a great deal, and the high sensitiveness of the bromide of silver does not extend very far into the ultra violet. On the photographic action of the pigments these rays are, therefore, without influence.

The addition of suitable dyes to the bromide of silver can greatly increase the sensitiveness for the less refrangible part of the spectrum, and spectrographs show, besides the characteristic band in the blue violet, another band of sensitiveness in a part of the spectrum nearer towards the red.

The bromide of silver plate can be sensitized for green, yellow and red in such a high degree that pigments reflecting such rays will be rendered in the photographic print more or less light with even exposures of short duration.

Not every dye, however, acts as a sensitizer, and amongst a great number which have been tested spectroscopically, many show a band of sensitiveness, but in only a few cases is the band sufficiently pronounced to be of practical photographic use. The sensitizing by means of a dye can only take place if the dye itself, or in combination with the bromide of silver, is light sensitive, and if the dye combines with the bromide of silver particle and colours the same.

The photographic film will then be made sensitive for light rays of a certain colour, and according to Dr. H. W. Vogel's law of absorption, for those rays which the coloured bromide of silver absorbs.

We have already pointed out on page 41 that the colour of a coloured solid body is very different from that of the dye solution ; the band of sensitiveness of the coloured bromide of silver can, therefore, not clash with the absorption band of the dye solution, but is, compared with the latter, shifted towards the red end of the spectrum.

The colour of the bromide of silver may not differ essentially from that of the particles of a dry collodion film stained with the same dye, and we may, therefore, state that the band of sensitiveness of a stained plate corresponds to the absorption band of a dry collodion film to which the same dye has been added. The region of sensitiveness created by a dyestuff is not of abrupt termination, but spreads with increasing exposure towards both ends.

Short exposures show the maximum, long exposures the whole extension of the absorption band. The tendency to spreading depends on the quantity and activity of the dyestuff and the sensitiveness of the plate itself. When the film is not sufficiently covered we obtain, even in prolonged exposures, only narrow bands of sensitiveness, and the same feature is noticeable when dyes of minor activity or bromide of silver of low speed is used.

The above mentioned sensitizing phenomena are only very marked if the particles of bromide of silver are embedded in colourless media. Generally this is not the case. When colouring the liquid emulsion, as well as when bathing dry plates in a dye solution, not only the bromide of silver particles, but also the gelatine or the collodion will be coloured. Such media act then as screens, as light filters for certain rays, and are the cause of a weakening, shifting and deformation of the band of sensitiveness.

The region of sensitiveness exceeds always in width this screening effect, because the former assumes even in short exposures greater extensions than the absorption band of a considerably coloured film shows. The screening defect, however, influences rays corresponding to the absorption maxima of the dye and causes the formation of more or less deep, and often very sharply, terminating gaps in the sensitizing curves.

The screening defect is more noticeable with gelatine plates than with collodion emulsions, because gelatine quickly absorbs dye solutions and can be deeply stained by weak solutions. It follows that the curves of sensitiveness of a colour sensitized plate show rarely, if ever, any conformity with the actual colour sensitizing of the dye; they are, however, curves representing the photographic action, influenced by the screening defect of a dye. We further find that the maximum of sensitiveness which a dye can produce is not a constant, but depends on the plate itself, and on the way in which the plate has been sensitized.

A collodion emulsion plate will, when sensitized with erythrosine, show the greatest sensitiveness at $D\frac{1}{2}E$, i.e., for rays of wave length 557, whereas a gelatine plate, if bathed in a very weak solution, shows a maximum near 560; if bathed, however, in a strong solution it shows the maximum of sensitiveness near the *D* line at 585. Erythrosine can, therefore, sensitize for yellow-green, for yellow, and also for orange, according to the way in which we sensitized the plate.

It is certain that, due to the screening defect, the band will be decreased; it will be seemingly compressed, and this is the reason why gelatine plates show sometimes a narrower band of sensitiveness than collodion plates.

This shifting and alteration of the sensitiveness due to screening defects has been discovered by the author and Dr. G. Eberhard, who restudied this question and confirmed same. This fact is of importance in the preparation of plates for trichromatic work, because the exact position of the region of sensitiveness is of great importance.

(1) *Sensitizing for Blue-Green.*—A dye showing a distinct maxima of sensitiveness in the blue-green of the spectrum between line *b* and *F* is not known at present, but Acridine, recommended by Dr. J. M. Eder, is an excellent dye for the sensitizing of a plate for rays from *E* to *H*.

In Supplement II, Fig. 1 shows the band of sensitiveness of a photographic plate sensitized with Acridine N.O. of A. Leonhard, in Mühlhausen; it joins the active region of the pure bromide of silver and shows at *E b* a little maxima, which is probably due to the screening defect of this dye. This dye can be used for gelatine plates as well as for collodion emulsion, and acts equally well, but the first-mentioned maxima is more pronounced in the gelatine plate.

Of different behaviour are the Acridines of a red shade, as Acridine orange, Acridine 3B, Acridine scarlet, etc. They only sensitize for a part of the spectral region between *D* and *E*, and are therefore of no practical value because better green sensitizers are at our disposal.

(2) *Sensitizing for Green.*—An excellent sensitizer for the pure green spectral rays is Uranine, the sodium derivative of Fluorescein. It is always used as a silver compound, and its action in collodion emulsion is demonstrated in Fig. 2, and on gelatine plates in Fig. 3, Supplement II. Uranine or Uranine-silver both colour bromide of silver red, and to this colour corresponds its sensitiveness chiefly for green rays from $D\frac{1}{2}$ *E* to *F*. Collodion emulsion actually shows this wide band, but gelatine plates do not show the same sensitiveness on account of the screening defect of the dye, the absorption maxima of which is situated between *b* and *F*.

In collodion plates the action of the Uranine joins the region of the sensitiveness of the bromide of silver, but gelatine plates show a distinct maximum between the two, which intense colouration and the use of dry plates can shift into the yellow-green.

(3) *Sensitizing for Yellow-Green and Yellow.*—Especially in the presence of silver compounds, which increase the sensitiveness, the Eosines form excellent sensitizers for this part of the spectrum. Exactly as in the case of Uranine the region of sensitiveness of the gelatine plate is smaller than in collodion plates, and is isolated towards the blue end of the spectrum. Eosine yellow shade shows in collodion emulsion plates a maximum near $D\frac{3}{4} E$, as Fig. 4 shows. Fig. 5 shows the action of Erythrosine with maximum $D\frac{2}{3}E$, and Rose Bengal shows a maximum which is situated in the pure yellow.

Fig. 6 is the curve of sensitiveness of Erythrosine on gelatine plates (*a*) represents a weak, (*b*) an intensely stained plate.

Of a still more bluish shade than Rose Bengal is the Thiodichlortetrajodfluorescein, Alpen Rosa of L. Durand Huguenin & Co. in Hüningen, showing a maximum in the reddish yellow of line *D*, as curve 7 demonstrates. Similar features are exhibited by Cyklamine, which is a powerful sensitizer, especially in the form of a silver compound.

In the place of the Eosines for the sensitizing of *D* to *E* we can also use the Rhodamines, which are of a more bluish shade, and their sensitizing power is between the pure Eosine and their silver compounds. For ordinary Rhodamine curve 8 acts analogous to Rose Bengal, and the blue shaded Rhodamine 3B corresponds in its action to the "Alpenrosa" (Alpen rose) mentioned above.

All Rhodamines show characteristic narrow, intense absorption bands, but as they also colour very strongly, a deformation of the band of sensitiveness may also take place. 8*b* shows this phenomena.

Band *a* breaks in two parts if the films are deeply stained, and the maximum corresponds to the absorption maximum of the wet collodion films stained with Rhodamine.

A very suitable sensitizer for yellow-green and pure yellow is the Chinolin red. It does not act as powerfully as the Eosine silver compounds, but is very suitable for mixed sensitizers for gelatine plates.

(4) *Sensitizers for Orange and Red.*—A good yellow orange sensitizer is that recommended by Eder and Valenta, viz., blue shade Rhodamine 3B, the Tetraäthyl-Rhodaminaethylester curve 9.

To sensitize a photographic plate for the orange rays of the spectrum we use Cyanine, a dye which shows remarkable sensitizing action on account of its instability and sensitiveness to light, but which also for this very reason often causes a great deal of trouble in photographic processes. Whereas the Eosine and Acridines improve foggy emulsion, and work extremely clear, the Cyanine requires perfectly clear and brilliant working emulsions. To avoid failures with this sensitizer special attention must be paid to this peculiarity.

If we take a gelatine film in an alcoholic Cyanine solution, we obtain a blue film similar to collodion, but if treated in an aqueous solution or if subsequently immersed in water, the colour of the film will be violet.

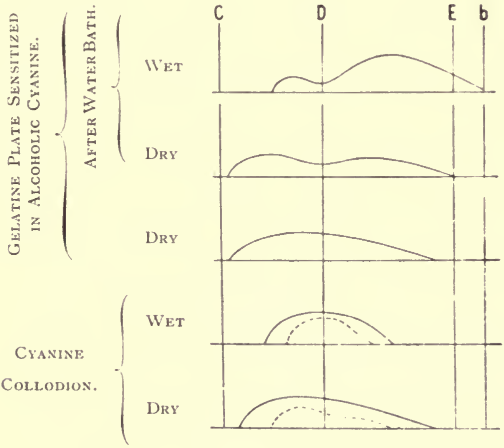


Fig. 29.

Fig. 29 demonstrates the absorption of wet and dry films.

It appears also that the bromide of silver according to the treatment of the photographic plate, can be stained either blue or violet by Cyanine solutions and show accordingly different sensitiveness.

Collodion emulsion sensitized with Cyanine should contain blue bromide of silver, and we actually obtain a band of sensitiveness corresponding to the absorption bands of the blue collodion film.

Supplement II, curve 10, shows the band of collodion emulsion only slightly stained with Cyanine; if more Cyanine is added we obtain a minimum on line *D* which corresponds to the absorption spectrum of the alcoholic dye solution, and forms two bands divided by a narrow band.

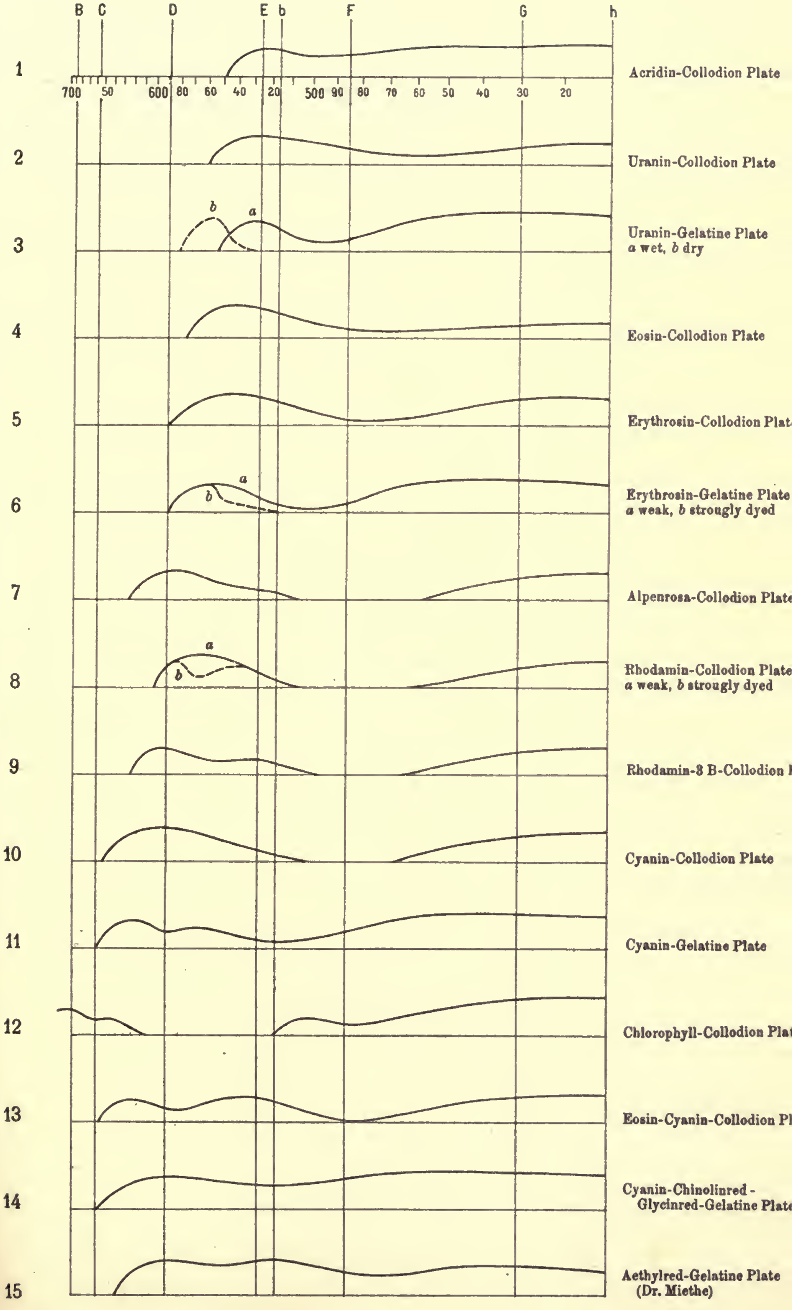
A gelatine plate sensitized in an aqueous Cyanine solution shows a band represented in curve 11, the form of which comes very near to the absorption band of the violet dry gelatine film.

Deeply coloured plates show a gap between the two maxima, due to the screening defect of the dye, and in wet exposed plates we find the maximum between *D* and *E* less pronounced than in dry films. As a sensitizer for the spectral red, we must mention the Nigrosine and Alizarine blue bisulphite. Both were recommended by Dr. Eberhard, and Nigrosine is often used for the sensitizing of gelatine plates. For collodion emulsion its action is insufficient for practical purposes, and Ethyl Violet recommended by E. Valenta, or Chlorophyll, curve 12, should be used. Freshly prepared extracts of ivy leaves are used in the emulsion and the plate receives a weak borax bath before exposure.

If broad bands of sensitiveness are required we are bound to mix several sensitizers.

If a plate is sensitized with two dyes, the action of the one nearly always weakens or totally destroys the action of the other. A plate sensitized with Cyanine and Eosine does not show the same high sensitiveness for orange and green, which these dyes singly produce, and the intensity and extension of the band fig. 13 is reduced to one-half. We are inclined to explain this phenomenon by a limited power of combination of the bromide of silver particles with

Supplement II.



Hübl, Three-colour-photography.

dyes, and that in the presence of different sensitizers only smaller quantities of the dyes are combined with the bromide of silver. It is, however, remarkable that the proportions of the two dyes can be greatly changed without disturbing their relative action.

The second phenomenon, the total destruction of the action of the second sensitizer, always takes place when the preparation or composition of the plate does not comply with conditions necessary for the sensitizing with the particular dye.

Silver nitrate destroys, for instance, the colour of Cyanine, and a collodion plate stained with Eosine and Cyanine, but subsequently immersed in silver nitrate only shows the sensitiveness produced by the Eosine.

Even if conditions are suitable for the action of both dyes, the band of sensitiveness of one dye can be destroyed, and the chemical character of the dyes appears to play then an important rôle. Dyes of the same chemical group act generally beside each other, but dyes of very different chemical composition often influence each other to disadvantage. Very powerful sensitizers often prevent the action of weak ones, and the screening defect of a dye has great influence upon the band of sensitiveness of the other.

If a mixed colour sensitizer should fully exert its action in every part, we must use dyes of the nearest possible chemical composition acting with equal intensity, requiring not too large quantities, and not showing too intense absorption bands.

The silver compounds of the Eosine, although they do not interfere with the action of the Rhodamine, prevent the sensitizing action of Acridine, Nigrosine, Chinolin red, etc.

It will be necessary therefore to make use of the Eosine silver compounds or silver free dyes have to be used for mixing.

To obtain a band of almost even density from *C* to *H* we can use for collodion emulsion the combination, Uranine-Eosine-Alpine Rose (or Cyklamine) as silver compounds, or for gelatine plates the mixture of Acridine, Chinolin red and Cyanine.

An excellent dissertation dealing with dye mixtures as sensitizers for bromide of silver gelatine plates has been written by Dr. G. Eberhard.

An almost panchromatic plate of good keeping qualities and well suitable for trichromatic work can be prepared, according to Dr. Miethe, in the following way.

Cyanine, Chinolin red and Glycin red are used, which have to be separately dissolved, 1 gr. in 500 ccm. alcohol. To the Cyanine solution a few drops of ammonia are added.

For the sensitizing solution we mix:—

Glycin red 1 : 500	20	ccm.
Chinolin red 1 : 500	20	,,
Alcohol	50	,,
Water	100	,,

This solution should stand for several hours, after which time 1 ccm. Cyanine solution 1 : 500 is added and the whole filtered.

The clear violet solution is further diluted with 100 ccm. alcohol, 200 ccm. water, and 1 ccm. cyanine solution and 5 ccm. ammonia are added.

This solution keeps in the dark for several weeks.

The gelatine plates are bathed for $1\frac{1}{2}$—2 minutes, rinsed under the tap for two minutes, rinsed with distilled water, and finally dried.

Recently Dr. Miethe has been successful in preparing an almost panchromatic plate with the help of a new dye, called "Aethyl red." This plate shows further remarkable rapidity, and may play an important part in the practice of three-colour photography.*

The firm of O. Perutz has been entrusted with the manufacture of this plate, of which curve 15 supplement II shows the band of sensitiveness. If the curve of sensitiveness is to indicate the character of a plate for the reproduction of coloured objects, we must bear in mind that in the prismatic spectrum the red and yellow rays are confined to a small region and are in their action of greater intensity than the blue rays.

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* An almost panchromatic Collodion Emulsion can be prepared with Diamant black P.V. (of Messrs. The Bayer Co.,) Uranine and Erythrosine.—Transl.

Dr. Neuhaus pointed this fact out several years ago, and recommended for the experiments with colour sensitive plates the diffraction spectrum. We obtain with a diffraction grating a correct statement as to the colour sensitiveness of a plate, but such spectra are of poor luminosity, and the minor actions of the less refrangible rays, which are the most interesting to us, may be completely overlooked.

If we expose, for instance, the red sensitive plate of commerce to the diffraction spectrum, we miss the red sensitiveness entirely, leading us almost to believe that the plate is not orthochromatized, and still this plate may, if light filters are used and sufficiently long exposures are given, render red pigments sufficiently light.

For this reason it is better to employ the prismatic spectrum, and to correct the results for the normal spectrum. (Page 27).

To obtain accurate results we must further measure the densities of the band on different plates, and the Martens polarisation photometer of the firm of Schmidt and Haensch is a very convenient instrument for this purpose.

How very different are the results if the prismatic or the diffraction spectrum is used, we shall demonstrate in a few examples.

Curve *a* (fig. 30) represents a gelatine plate sensitized with Erythrosine. According to the prismatic spectrum we expect same sensitiveness for yellow, green and blue, whereas the normal spectrum shows a curve of very limited sensitiveness for yellow green rays.

Curve *b* shows a gelatine plate of apparent greater red sensitiveness if exposed to the prismatic spectrum. The normal spectrum shows a very small sensitiveness for red, and this plate if used without a filter on a coloured original will actually exhibit no red sensitiveness.

The Eosine silver collodion plate *c*, if judged by results obtained with the prismatic spectrum shows only sensitiveness for yellow green, whereas this plate does not render yellow green pigments lighter than the blue, which corresponds to its behaviour towards the normal spectrum.

A plate *d* showing in the prismatic spectrum equal sensitiveness for all rays, would be according to the curve of the normal spectrum so little sensitive for the less refrangible rays, that red objects would be rendered black.

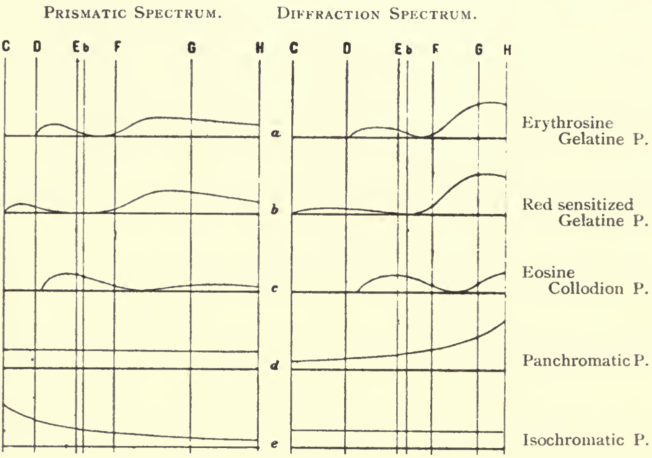

Fig. 30.

If all equally pure and saturated colours are to be rendered equally light, the normal spectrogram must correspond to a curve which is practically a straight line. In the prismatic spectrum the plates would have to show a sensitiveness represented in curve *e*.

Finally, a few remarks referring to the description of colour sensitive plates may be inserted here. The term "orthochromatic" can be applied to plates, which enable us to photograph a coloured original in such a way as to give gradation of tone corresponding to the luminosities of the colours. They are only sensitive for yellow, green and blue, and they do not represent red tints sufficiently red. "Panchromatic" plates are those plates which are sensitive for all colours, but this sensitiveness may be of very different proportions from the different rays. By means of light filters, their band of sensitiveness can be varied to requirement.

The term "isochromatic" has often been made an equivalent for orthochromatic, but it would be advisable to use the term only in the sense as C. Bonacini recommends for plates of equal sensitiveness to all parts of the normal spectrum. They would have to be sensitized, so as to give a band of even intensity of the normal spectrum as shown in curve *e*. Such plates can not be made at present, but the isochromatic effect can be obtained by using panchromatic plates and suitable light filters.

B.—THE LIGHT FILTERS.

To exclude the action of certain rays upon the photographic plate we insert in front or behind the lens, or in front of the light sensitive surface, a transparent coloured medium—a coloured glass plate, a collodion or gelatine film, or a tank filled with coloured liquid—and we term such bodies light or ray filters. The rays absorbed by the filter do not reach the photographic film, which causes the same effect as if the plate were insensitive to these particular rays. If we insert, for instance, a yellow glass in front of the lens, which absorbs all blue and violet rays, it will be impossible to obtain a photographic action on a wet collodion plate, because the plate is practically deprived of its blue violet sensitiveness.

If on the other hand filters are used, which absorb rays to which the photographic film is insensitive, no effect can be produced. If we expose, for instance, a bromide of silver collodion plate behind a Methyl-blue filter, the result will in no way differ from the exposures without a filter, because it is immaterial whether the yellow rays reach our plate or not. The efficacy of a filter is only governed by its absorption band, and not by its colour. Two filters of precisely the same colour may act very differently if their absorption spectra are not the same. Increased saturation of the filter colour widens the absorption band, and prevents the passing of rays, which less intense filters permit.

A diluted solution of Eosine only absorbs the green rays, and does not influence an ordinary plate as a light filter, but a more concentrated solution, showing an absorption band over blue and violet, will act like a yellow filter.

It is therefore not sufficient to name a dye solutiou as a filter, but the concentration and thickness of film must also be quoted if they are to produce certain actions.

If we were to use plates equally sensitive to all parts of the spectrum, every filter would come to its full action, but using plates only sensitive to certain parts of the spectrum, rays passing through a filter can only act in conformity with the sensitiveness of the plate. The same filter, if used with different plates, will give entirely different results, and to allow rays of a certain spectral region to act upon a plate, the light filter must be adjusted to suit the sensitiveness of the plate, and rays to which the plate is insensitive can freely pass the filter.

To make use of a certain species of rays for the production of a photographic negative, we have to sensitize the plate for the desired part, and to choose a filter which will suitably limit the region of sensitiveness. Such filters can only be used with plates of very decided conditions of colour sensitiveness, and are termed " correction filters."

If we only wish the green rays for instance to act, we should sensitize the plate with Fluorescein silver, retaining in this way the greatest part of the blue violet sensitiveness of the plate. To exclude the latter it will suffice to use a yellow medium as a correction filter, which will act like a complete filter of a green colour.

For the testing of a filter, a spectroscope is used, but we must remember that the extension of the spectrum band depends on the intensity of the light passing the slit (page 45). The same has to be considered in spectrograms, where the intensity of the source of light influences the result, and as during the exposure the light impressions are added on the plate, the extension of the absorption band of the filter will largely depend on the length of exposure.

The spectrogram must not necessarily be uniform with the spectroscopic test of a filter, and very considerable differences may be noticed if highly sensitive plates are used, which have a tendency to spread in their region of sensitiveness. A green filter, for instance, showing in the spectroscope a small opening near *E b*, may pass rays to *D* and *F*, perhaps so weak that the eye may not perceive the same, but they may be very active on a strong green sensitive plate, and the spectrogram will show, if sufficiently exposed, a broad band shaded off towards *D* and *F*. The spectroscopic tests are therefore insufficient if a light filter which is to be tested on the exposure of the spectrum furnishes correct results, which, however, are only partly uniform with the conditions of the camera (*vide* page 83).

In practice, filters made of coloured glass are rarely met with, because such glasses are very difficult to produce if certain absorptions are required, and we use therefore aniline dyes in solution, or coloured collodion, gelatine, or varnish. It must be noted that the shape and position of the absorption band may greatly differ if dyes are used in dry or in liquid form.

(1) *Yellow Filter.*—Yellow filters always absorb the entire violet, and according to the tint, also more or less blue or blue-green.

The absorption band of a greenish-yellow extends to F, of a yellow medium to $E \frac{1}{2} F$; further dilution retains these points of absorption, but flattens the curve in its progress towards the violet.

A typical greenish-yellow filter is picric acid, the absorption band of which is given in 1 (fig. 31). 1 represents concentrated, and 2 and 3 the band of more diluted solutions. The absorption spectrum of a diluted solution would make us conclude that the absorption band only includes the violet, and ends near G; the spectrogram, however, proves the band to be almost independent of the concentration of the solution.

Picric acid does not entirely absorb the whole of the ultra-violet, but its absorption band gradually decreases behind line M.

As, however, the sensitiveness of a bromide of silver plate is very limited near M (*vide* page 89). We may take picric acid to afford a complete protection against the action of the ultra-violet rays.

Picric acid filters of small concentration are without influence upon the ordinary gelatine plate, they slightly increase exposure and hardly influence the photographic action of the pigment colours.

Collodion plates require with these filters considerably longer exposures, and their maxima of sensitiveness will be

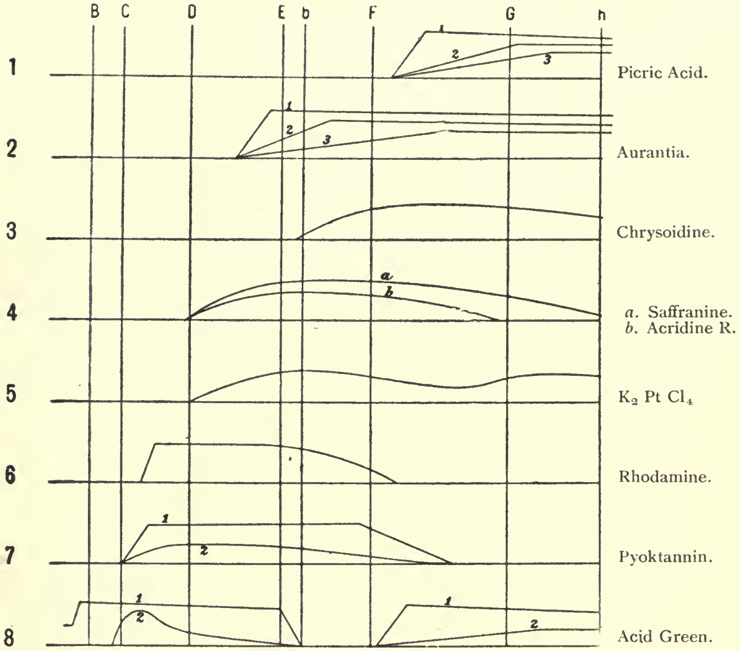

Fig. 31.

shifted towards *G*, showing a curve similar to that of the gelatine plate. The photographic activity of the pigment colours, however, is also in this case only slightly stimulated.

For a pure yellow light filter the behaviour of Naphthol yellow is characteristic. The absorption band extends over *F* and shows otherwise the peculiarities of the picric acid band. A solution of chromate of potassium acts in an analogous way.

Wet plates cannot be exposed behind these filters, but gelatine plates give a complete picture if the exposure is long enough, without showing much different colour rendering, if compared with filterless exposures. Blue and green pigments are rendered lighter, yellow and red have scarcely acted. This phenomenon is explained by the shifting of the photographic band of action caused by such filters. Fig. 32

will explain this, the maximum remains between *F* and *G*, and the space between *F* and *D* is covered by a slight shadow band.

(2) *Orange Filters.*—Transparent bodies of this colour can either absorb the whole of the violet, blue and green, or they show a relatively strong absorption between *F* and *G*, decreasing slowly towards *E* and *H*. Orange filters of the first description are made with Aurantia and Methyl orange in solution or in collodion films, and with bichromate of potassium solutions. The second quality of orange filters are represented by Chrysoidine. The absorption band of Aurantia is shown in 2 (fig. 31) in three concentrations 1, 2, 3. According to O. Buss, the band terminates in the ultra-violet, and does not extend far over the visible violet. The Aurantia filter protects, therefore, a photographic plate very insufficiently against the action of the ultra-violet rays, but the latter can only act in the case of very prolonged exposures.

The absorption band of Chrysoidine is shown in 3; it not only passes the ultra-violet, but also the visible violet rays—although only much weakened—and corresponds in its progress almost entirely to the curve of sensitiveness of the gelatine plate. The maximum of sensitiveness is shifted by this filter in an entirely different way from Naphthol yellow and Aurantia.

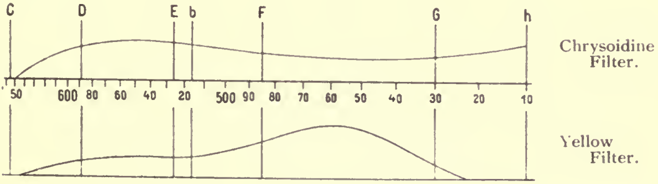

Fig. 32.

Fig. 32 shows a spectrogram on an ordinary bromide of silver gelatine plate with a Chrysoidine filter. The maximum of sensitiveness is shifted towards the yellow green, and if the blue and violet rays are absorbed by means of a Naphthol yellow filter, the plate will behave as if sensitized for the spectral zone *D E*. Ives used this filter for orthochromatic work without colour sensitizing the gelatine plates. It is feasible but enormously long exposures (200-600) are required.

The Acridine of Leonhard in Mühlhausen acts similarly to Chrysoidine; its absorption band is narrower, and ends abruptly near line *G*. Acridine solutions therefore pass the entire visible violet.

(3) *Red Filters.*—The absorption band of substances suitable for red filters is situated either between *D* and *F*, or covers the whole spectrum from *H* to *E*, and gradually decreases towards *D*.

Most aniline dyes belong to the former group. If an abrupt ending towards the red end is desired, we find Eosines or Rhodamines in solutions very suitable; if, however, a gradual shading of the absorption ends is wanted, dyes from the group of the Azo order are well suited. Curve 4 (fig. 31) shows the absorption of Biebrich scarlet or collodion stained with Safranine.

If blue and violet rays are to be excluded, we must combine these filters with yellow or orange films. With the broad banded filters of the second order this is not needed, and as representative potassium chloro-platinite, curve 5, may be mentioned. The very small amount of blue rays passing this solution is only traceable with the help of the spectroscope, and can only come into action in the case of very long exposures.

By combining several dyes the opening of the filter can be restricted according to the requirements. If, for instance, a filter is wanted, passing only spectral red, we can combine a collodion film stained with blue shaded Rhodamine (0·5g. Rhodamine 3 B. and Tetra-Aethyl-Rhodamine aethylester to 100 ccm. collodion) with a Naphthol yellow and Aurantia varnish film. The band of the Rhodamine film is shown in 6. The said combination passes only rays from *A* to *C*.

(4) *Violet and Blue Filters.*—To protect the photographic plate against the action of the yellow green and yellow rays, we can use a solution of Methyl-violet, or

better the acid violet or Pyoktannin which is insensitive against acids.

The dry collodion film is of a blue colour, and shows a broad band, the intensity of which gradually decreases towards *C* and *F*, curve 7 (fig. 31).

Very suitable for collodion dry filters is the Victoria blue, on account of its great solubility in alcohol-ether. The absorption bands of blue aniline dyes do not commence in the extreme red, but leave a gap between *A* and *C*; but solutions of copper salts, as copper sulphate or ammonia copper oxide for instance, also Prussian blue in oxalic acid, show complete end absorption.

A concentrated solution of ammonia copper oxide absorbs all rays from the red and over *F* passes the blue, absorbs the greater part of the visible violet and the ultra-violet completely.

(5) *Green Filters.*—Very diluted solutions of green aniline dyes show in the spectroscope a narrow band near line *C*, but spectrographic experiments teach us that such pigments not only absorb the ultra-violet, but also the visible violet and blue, and act very similarly to a picric acid filter. Increasing concentration makes this end absorption also visible in the spectroscope, and intensely coloured films cover the whole spectrum, with the exception of a narrow gap in the green and blue-green.

Absorption spectrum 8 corresponds to a solution of Acid Green, and we note that the concentrated solution only permits rays between *b* and *F* to pass.

If this dye is mixed with picric acid, or with a solution of chromate of potassium, we obtain filters, the opening of which corresponds to a distinct kind of green rays.

A mixture of 20 ccm. of a saturated solution of chromate of potassium and 5 ccm. Acid Green 1 : 1000 does not completely absorb the red end, and this gap can be closed by adding copper sulphate solution.

Coloured films used as light filters can be used in front or behind the lens, or in front of the sensitive plate. To avoid distortion of the picture, especially if the filter is used close to the lens, parallelism of the surfaces is essential. The focus of the lens is, however, an important factor. Short-focus lenses may not show differences if plate glass is used for the filter, but long-focus lenses require optically-worked glass, and even then show occasionally slight unsharpness.

Formerly, glass plates coated with collodion or varnish were used near the lens, but as the sharpness of the picture is unfavourably influenced, glass plates coated with coloured gelatine are now used in front of the plate.

Optically-worked glass is not required in this case, and ordinary plate glass answers well. Such filters are easily made by coating these glass plates with gelatine and staining the same afterwards with suitable dyes. Plate glass is used, levelled and, after slight heating, coated with a 5 per cent. well-filtered gelatine solution and dried free from dust. Sometimes an ordinary gelatine dry plate can be fixed, washed and used for this purpose. To protect the filter from injury another plate glass can be sealed to it with Canada balsam. The staining of the plates is always done in aqueous solutions which have been made slightly alkaline or acid with acetic acid or borax.

Very suitable for such filters are the following dyes.

Naphthol yellow S and Chinolin yellow give, with short immersions and if in slightly acid condition, a yellow similar to the colour of picric acid; if the immersion is prolonged a rich pure yellow is obtained.

Chrysophenine gives with short immersions pure yellow, with long reddish yellow films. Acid Green and a little acetic acid or Malachite green and borax colour green.

Fast Green bluish gives a blue-green colour to the gelatine.

Diamine and Methyl-blue colour similar to Prussian blue.

New Blue gives a pure blue, and acid violet a reddish blue colouration. The last-named four dyes are to be used in acid solutions.

Methyl violet in alcoholic solutions gives a blue violet; dyes of the Eosine group, especially Erythrosine and Rose Bengal, used neutral, give bluish-red tints.

Biebrich scarlet, Saffranine, Xylidin, Ponceau give, in acid solutions, colours not unlike spectral red, whereas Benzo-Purpurine colours a yellow red.

Methyl orange and acetic acid give a pure orange.

By mixing two or more of these dyes all imaginable absorptions may be arrived at.

To facilitate a slow and even colouring of the gelatine a weak solution with 20 per cent. of alcohol is used. The colour bath consists of:—

Water	100 ccm.
Alcohol	20 ccm.
Aqueous dye solution 1 : 150	10-20 ccm.
Acetic acid	5 drops.
or cold saturated borax solution	3 ccm.

The plate is laid in a dish, the filtered dye solution poured over, and the dish kept rocking until the desired intensity is arrived at, the plate drained and rinsed in a similar bath as above, but without colour solution being added, and dried.

If the colour is to be reduced a water bath, which in the case of acid colour bath has been made alkaline with borax, in the case of alkaline colour bath has been made acid with a few drops of acetic acid, is employed.

C. THE PRACTICE OF THREE-COLOUR PRINTING.

(A) THE PRODUCTION OF THE PHOTOGRAPHIC NEGATIVES.

The Apparatus.—For three-colour work every camera can be used which possesses sufficient stability to avoid shifting during the changing of the plates and filter. The slightest movement of the camera may influence the dimensions of the negatives, and proper registration is impossible. For sizes up to 8 × 10″ gelatine dry filters can be used in front of the sensitive plate. They may be fastened in the dark slide or can be used similarly to ruled screens in the screen adjustment frame.* All filters, wherever employed, must be of equal thickness, because the introduction of a glass plate in the path of the rays emerging from the lens alters the size of the image.

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* This method has been adopted by Sanger Shepherd in his sliding dark slides for trichromatic work.—Transl.

For large sizes it is advisable to use tanks, which are manufactured in excellent quality by Carl Zeiss, in Jena, Penrose & Co., in London, etc.

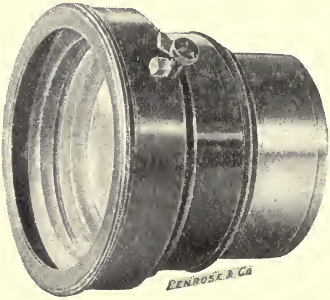

Fig. 33.

The tanks are formed by a circular glass ring closed hermetically with two optically-worked glass discs, and are enclosed in a brass mount which fits on to the front ring of the lens. The width of the tank, which is governed by the glass ring, is generally 5 mm. All following recipes for filter solutions refer to a 5 mm. tank opening, and if different widths are used the filter solution must be treated accordingly. If, for instance, a tank of 10 mm. width is in use the given filter solution is to be diluted with equal quantities of water. If one of the negatives does not require a filter, the tank filled with water only must be used.

To enable very rapid change of plates in the case of portrait or landscape exposures, sliding triple dark slides have been constructed in which the plates covered by the filters are placed beside each other. (Sanger, Shepherd & Co., London, are makers of these slides).

Cameras have been built to enable the simultaneous exposure of all three negatives by means of a mirror system which reflects the picture in three directions upon sensitive plates protected by light filters.

Three-colour photography requires powerful lenses, because intensity of light is needed to produce powerful negatives on our plates which are of minor red sensitiveness. The lens must further give same sized images after being once focussed. Ordinary lenses have different foci for the blue and red rays. If we focus the brightest and most visible picture of the yellow rays, the red, the focus of which lies behind the blue and yellow, will not be considered. The conditions of three-colour photography, however, demand the participation of the red rays in the formation of the picture.

The ordinary lens corrected only for blue and yellow, shows, if used with a red light filter, a peculiarity called "focus difference," the negative lacks sharpness and the dimensions do not correspond with the focussed dimensions.

With lenses of short focus and whenever limited use is made of the angle of the lens this feature is not so much noticeable, but large process lenses showing same would be rendered useless for our purpose.

To avoid these difficulties, Carl Zeiss, Jena, constructed the Apochromat Planar, Voigtlander & Son the Apochromat Collinear, and Taylor, Taylor & Hobson, Leicester, the Cooke Process lens. These lenses give, independent of the colour of the filters, sharp and same sized pictures.*

The Photographic Process.

Because the wet process with iodized and bromized collodion permits sensitizing with dyes only exceptionally, we have to make use of the two other emulsion processes for trichromatic work.

Working conditions will have to decide for us in the choice between gelatine dry plates and collodion emulsions. Collodion emulsion gives the broad sensitizing bands which are in no way affected by screening defects, and which are so very desirable for our purpose. And again, if the less refrangible rays are to act on our plate, collodion emulsion may be. superior to dry plates in point of length of exposure Further, the working with collodion emulsion is simpler and more convenient, especially in the case of large sizes.

Plates up to any size can be made immediately, and all operations of washing, developing, etc., can be performed

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* Amongst lenses for trichromatic work must be mentioned the excellent "Homocentric," of Messrs. Ross, in London.—Transl.

without dishes. However the impervious surface of the dry plate, the greater rapidity, the well-known ways of treatment speak in favour of dry plates wherever the collodion practice is not practised. At present excellent collodion emulsion (Dr. E. Albert's, sold by Penrose & Co., London) is on the market, and the manufacture of same is possible without great difficulties. The emulsion is mixed with silver containing colour sensitizers, or the dye is added to the emulsion, and the plates immersed in a weak silver bath before exposure. In the case of dyes which are not suitable for the silver bath, a borax bath with an addition of glycerine is used if necessary to prevent too quick drying of the plate.

Emulsion sensitized with silver containing dyes requires very careful treatment, whereas the bathing process requires less care, but is inferior in point of sensitiveness.

If gelatine plates are chosen, the commercial colour sensitive plates can be used or plates can be sensitized whenever wanted.

In several cases the employment of the colour sensitized plate in its moist condition after bathing is recommended, and although such plates have often been blamed for unsharp negatives, this objection is only partly justified. Gelatine plates, even if used dry, do not give that keen sharpness which collodion plates exhibit, but although in the wet condition negatives are softer, this difference is not much noticeable in continuous tone negatives. For three-colour work moist plates can be well employed, and we gain the additional advantage of being able to prepare a plate immediately before use according to requirements. Gelatine plates exposed wet give clean and clear negatives of excellent colour rendering. The so-called orthochromatic plates sensitized with Eosine commercially obtainable are not perfect for the production of the red printing negative, but with suitable light filters give fairly satisfactory results.

The red sensitive plates, which are on the market, give perfect negatives for the production of the blue picture.

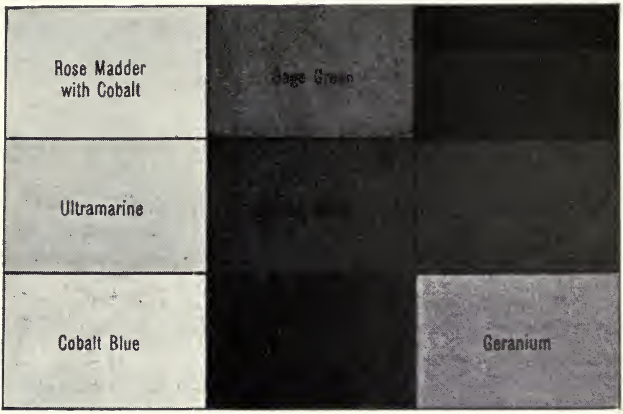
The plates which are called "panchromatic" are red and green sensitive, and are suitable for all three exposures; they offer in small sizes the advantage of being able to use

Colour Chart.

To serve as a test object for ascertaining the correct filters and plate sensitiveness for the two fundamental colour systems. (See page 114)

Yellow Picture.

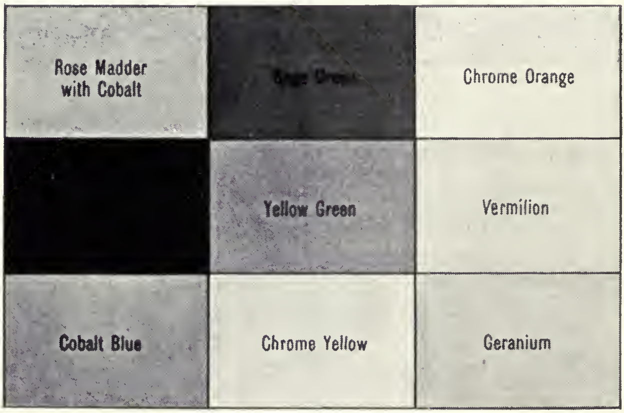
Printing Ink: Cadmium or Chrome Yellow.
Dye for Lantern Slides: Naphthol Yellow S.



Rose Madder with Cobalt	Sage Green	
Ultramarine		
Cobalt Blue		Geranium

Blue Picture.

Printing Ink: Peacock Blue and Viridin Lake.
Dye for Lantern Slides: Fast Green Bluish.



Rose Madder with Cobalt	Sage Green	Chrome Orange
	Yellow Green	Vermilion
Cobalt Blue	Chrome Yellow	Geranium

the Colour Chart.

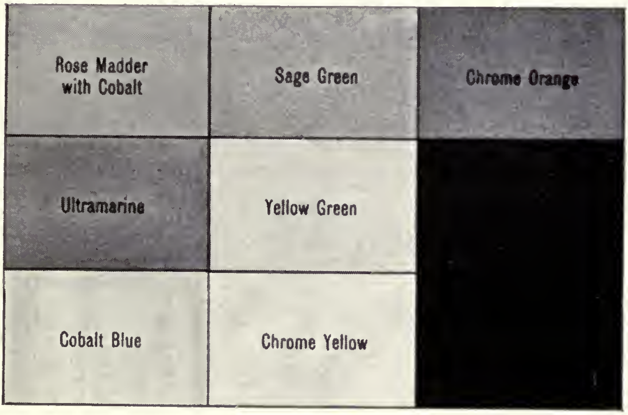
Red Picture.

Printing Ink: Nachtrosa.
Dye for Lantern Slides: Erythrosin.

Rose Madder with Cobalt	Sage Green	Chrome Orange
Ultramarine	Yellow Green	
Cobalt Blue	Chrome Yellow	

Red Picture.

Printing Ink: Madder Lake Bluish.



Rose Madder with Cobalt	Sage Green	Chrome Orange
Ultramarine	Yellow Green	
Cobalt Blue	Chrome Yellow	

one plate in a sliding dark slide for all exposures, which can be developed simultaneously. The difficulties which have to be overcome in the production of trichromatic negatives not only consist in the correcting of the colour of the plates, but in the absolutely necessary similarity in character of the three negatives.

To obtain a true reproduction of the original colours, which only definite mixing proportions of the three fundamental colours can achieve, we must insist upon similarity in the gradation of the negatives. It is by no means advisable to use, for instance, for one negative, a wet plate; for the second, a collodion emulsion plate; and for the third, a gelatine dry plate, because each gives a negative of different gradation. The whole series of negatives must be made in the same process, the same conditions of light, and the same development, obtain the same clearness of the shadows, the same density in the high-lights, and the same gradation in the half-tones.

One plate, therefore, sensitized for red and green, and used for all three negatives, offers certain advantages.

To facilitate the judging of the similarity of the negatives, it is advisable to use a grey scale, consisting of little strips of neutral grey paper of different intensities. As a neutral grey reflects all rays of white light, the photographic reproduction of grey tints does not depend on the colour sensitiveness of the plate or of the filter, but is only governed by the gradation peculiar to a photographic film.

Very suitable for this purpose are platinotype prints, obtained after exposure under a graduated scale made of writing paper. A scale with four or five gradations is quite sufficient. The three negatives are to be exposed and developed, so as to give this grey scale correctly and of same density in all three negatives.

Such a grey scale should also be used to ascertain the exposures in advance which is a necessary precaution if only one plate in a sliding dark slide is used, but such exposures are only useful if the same conditions of light are maintained, being partly governed by the intensity and the colour of the light.

If large surfaces of one colour are present in the original, it is generally found that the negative which is to be printed in this particular colour, looks under-exposed. This is slightly noticeable in the yellow printing negative, and must not mislead us. The negative must be correctly exposed if the grey scale is correctly rendered.

The appearance of the negatives does not furnish a guide as to colour separation. They often look very much the same, and always give us the impression that the colours are not sufficiently separated.

An experienced chromo-litho artist could not judge the correctness in colour separation of either negatives or print, because the mixing results of three so very heterogeneous colours are as unknown to him as the peculiar effects which mixtures of narrow-banded pigments show.

We can hardly realize that black, grey, and all shades brown can be mixed with yellow, red and blue, that the colour of ultramarine can be formed by mixing purple, red and greenish blue, that of vermillion, by mixing pink and sulphur yellow. We can only secure suitable colour sensitiveness of the plates, and prepare corresponding light filters, and to prove that these conditions are fulfilled we photograph with the original a colour chart which is composed of very different colours, and the reproduction of this chart in each negative will form a guide as to colour separation.

After ascertaining the theoretically correct colour sensitive plates and corresponding light filters, by means of spectrographic test, this colour chart is photographed in three colours, and after making a three-colour transparency to assure ourselves of the correctness of colour rendering, we consider the monochrome three negatives as standards for all future work.

Supplement III shows such a colour scheme, and Supplement IV the monochrome representations for both fundamental colour systems. This table consists of nine colour plates printed in fairly permanent colours so as not to fade too quickly when used as control object during exposures.

With the exception of the yellow and ultramarine, all other colours of the chart look more or less impure, which is generally the case with permanent colours. The sage green, consisting of Prussian blue and chrome yellow, is bluer than in the colour chart Supplement. Vermillion and chrome orange fairly correspond to the control colours (page 83).

The different, partly pure, partly impure, colours of this control table enables us to follow the decomposition and recomposition processes, and experience will finally enable us to anticipate certain final results from the appearance of the negatives and correct the colour rendering by means of retouching.

We are generally inclined to seek the cause of failures in the parts of the process which are most unfamiliar to us, as for instance in the colour of the light filters, which seems to the practical man the most important process. If blue or red predominates in the finished print, we promptly blame the incorrect colour separation caused by the filters.

We generally hear complaints about the imperfection of the red printing plate, which spoils all greens and violets, and shows a red tint predominating all over the picture.

Those who do not know the theory of three-colour photography find the cause of this trouble in the imperfections of the red printing plate.

After reducing the red print, which does not help, the negative is intensified, which only makes matters worse, and then the filter is made of a darker green colour. A new impression shows no improvement, and there is only one way left open, the retouching of the negatives.

The cause of the difficulty may however not rest in the negative at all. If the green is spoiled by the red impression, the yellow and blue is so impure that it does not stand the addition of red. If we choose in the place of the so-called "pure blue" a green blue, we find the red impression harmless, even necessary to produce certain green shades of the original.

Based upon theoretically correct fundamental colours, photography decomposes the sage green in the following way: 2 parts of blue green + 2 parts of yellow + 1 part of red (page 78), and if colours of the right shade and purity are chosen for the printing, we shall also obtain the right shade of sage green. If, however, the permanent colours are used, the red picture will be too strong and the green will appear of a very impure olive shade. In this case extensive retouching will be required.

Retouching, however, cannot be entirely dispensed with in trichromatic work on account of the faulty gradation of our printing blocks. The shortcomings of the printing press should always be remembered, and the three-colour process should not always be blamed.

In black monochrome this faulty gradation is not so very disturbing, the true outline is always retained, and if the gradation is at one time softer than at another, if the high-lights flatten, or a general tone lies over the whole picture, if the shaded details are more or less pronounced, the general impression of the monochrome does not suffer.

In three-colour printing the gradation governs the correctness of the colours, and we find a green sky, or violet tree trunks, very disturbing in our picture.

It is hardly possible to give correct recipes for the making of correct filters, because they depend on the colour sensitiveness of the plates, which require the most careful adjustment.

So also is the preparation of the filter solution, which is generally an extremely diluted solution of aniline dyes, beset with difficulties, because the staining power of the dyes is not always the same, and much apparatus is requisite, which is not generally at the disposal of the practical man.

The accompanying colour table furnishes, however, a convenient means of finding the necessary filter for a given plate.

Colour transparencies teach us that the colour decomposition is not as difficult an operation as is generally assumed. With this process very satisfactory results can often be obtained without retouching, and with filters and plates which hardly meet the theoretical requirements.

It is therefore not necessary to be too anxious about the photographic part of the process, and to believe that minute differences in the colour of the filters or the sensitizing of the plates influence the final result extensively.

SENSITIZING OF PLATES AND LIGHT FILTERS FOR THE THEORETICALLY CORRECT COLOUR SYSTEM.

(1) THE NEGATIVE FOR THE YELLOW PRINT.

The sensitiveness of this plate should be situated between *F* and *G*, and should gradually decrease towards *E* and red respectively.

These conditions are fulfilled by the ordinary gelatine dry plate, the lack of red sensitiveness of which is partly compensated by its ultra violet sensitiveness.

Red pigments will be rendered light according to page 40, whereas yellow produces no action on this plate. The yellow plate can therefore be made with an ordinary gelatine dry plate without light filter. In the case of long exposures the green sensitiveness of the plate may produce some action (page 89) and yellow will be the same. In this case it is advisable to always make use of this precaution. This filter must be employed if Lumière's panchromatic Spectrum or Perchromo plates are used.

Irrespective of the brand of plate, we use a 5 mm tank filled with a solution of Höchster New Blue 1 : 5000 or in front of the plate a dry gelatine filter coloured with the same dye (page 108). The intensity of the filter must be such, that the filter, if viewed against white paper, appears of the same depth as the ultramarine of our colour table.

Collodion emulsion is slightly different, being only sensitive for blue violet dyes. The emulsion, as well as the wet collodion plate, can be used for the production of the yellow printing negative, being hardly different from a plate of theoretically correct sensitiveness. The missing blue green sensitiveness of the collodion emulsion can easily be obtained by the addition of Acridine, which also increases the brilliancy and clearness of the plate. To 100 ccm. chloro-bromide emulsion 5 to 10 ccm Acridine NO solution 1 : 150 is added.

The sensitized emulsion will keep an unlimited time. If the exposure is long, the plate is immersed for a short time in a borax bath, consisting of 1 part of cold saturated solution diluted with 3 parts of water and exposed with a blue filter.

The following points will indicate the suitability of the plate: chrome yellow of the tabulated colour must be given as black, ultramarine as white, and all red parts, especially geranium, must show half tone.

The intensity of the filter is regulated by the green sensitiveness of the plate. If green pigments are rendered too light, the filter must be made deeper in colour, otherwise it must be diluted. The correct rendering for the yellow plate shows Supplement III.

To produce the conditions of sensitiveness which theory requires, we should have to use a sensitizer for the extreme red, for instance Chlorophyll, and absorb all violet rays with a blue green filter. This process is, however, uncertain and complicated without giving better results.

(2) The Negative for the Red Print.

Diagram of this plate on page 80, requires a plate, the sensitiveness of which lies between *D* and *F*½*G* with a prism spectra maximum in the yellow-green.

Collodion emulsion sensitized with Eosine silver is well suited for this purpose, if the blue sensitiveness is suppressed by a yellow filter and a blue-red dye is added to increase the band of sensitiveness up to *D*, which latter condition is not absolutely necessary.

Gelatine plates sensitized with Erythosine, showing a deep minimum between *E* and *F*, are less suitable.

Plates sensitized with Dr. Miethe's patented dye, "Ethyl red," giving a broad band of sensitiveness, can be well used for this purpose if the filter is suitably adjusted.

The following ways are therefore open to us:

(1) *Eosine Silver Bath Plate.*—Add to 100 ccm. emulsion 2 ccm. of the following dye mixture, and bathe the plate before exposure in ½% silver nitrate solution.

Eosine yellow, 1 : 150	30 ccm.
Rose Bengal, 1 : 150	10 ccm.

Picric acid 1 : 500 water is used as a filter in a 5 mm.

tank, or a gelatine plate coloured with Naphthol yellow G (page 108).

(2) *Collodion Emulsion with addition of Eosine Silver.*—Emulsion is mixed with a neutral solution of eosine silver in ammonia, for instance, sensitizer "A" of Dr. Albert, and exposed wet.

The commercially obtainable eosine silver solutions contain a yellow dye which acts as a light filter, but does not absorb the blue rays sufficiently, for which purpose an additional yellow filter is used.

(3) If gelatine plates are preferred, either orthochromatic or panchromatic plates can be used. For the correction of the sensitizing a green filter serves in both cases. The filter is not only to eliminate the blue and red sensitiveness of the plate, but to also decrease a too high sensitiveness in the greenish yellow.

For this purpose the following solution is used, contained in a tank of 5 mm. separation.

Acid green, 1 : 150	5 ccm.
Bichromate of potassium, 1 : 75	150 ccm.

If dry filters are preferred, they are made by bathing gelatine films in the following solution:—

Fast green, bluish, 1 : 200	15 ccm.
Naphthol yellow, S.L, 1 : 200	25 ,,
Methyl orange, 1 : 400	30 ,,
Water	100 ,,
Alcohol	20 ,,
Acetic acid	5 drops.

To facilitate the accurate adjustment of the filter, it will be advisable to use two glass plates, of which one is coloured with Fast Green, the other with Naphthol yellow and orange.

4. Sometimes it will be useful to expose the plates wet, a procedure which must be recommended in the case of large sizes. The plates are then to be bathed in the following solution for about 5 minutes:—

Water	1000 ccm.
Uranine solution, 1 : 150	25 ,,
Erythrosine solution, 1 : 150	6 ,,
Ammonia	10 ,,
Silver nitrate solution, 1 : 10	2 ,,

Then rinse under the tap and expose through a picric acid filter, 1 : 500. Such plates show a high degree of green sensitiveness, and give very clear, well-defined negatives.

To ascertain whether the filter is correct it will be necessary to photograph the colour chart. Chrome yellow is to show almost full, ultramarine and vermillion half density, and cobalt must be distinctly different from rose madder and cobalt (see Supplement III.).

If vermillion is rendered too light or too dark, the green constituent of the filter will have to be increased or reduced; if the blue shows insufficient deposit the yellow of the filter must be reduced.

3. THE NEGATIVE FOR THE BLUE PRINT.

The most suitable sensitizer for this plate is the Cyanine. The band of sensitiveness should, however, decrease from *C* towards *D* and abruptly terminate towards *E*, whereas the photographic band of sensitiveness of this dye only begins near *C*. This factor is of little importance, because the absorption of the extreme spectral red would not influence the reproduction of a colour materially (page 42).

The curve of sensitiveness of collodion emulsion sensitized with Cyanine answers theoretical requirements sufficiently, and it is only needed to suppress the blue-violet rays and to decrease the yellow-green sensitiveness. This is easily obtained by using a solution of

Potassium chloro-platinite	1 : 8 or
Aurantia	1 : 1000

Both liquids to be used in a 5 mm. tank.

Gelatine plates, coloured with Methyl orange (page 109) showing, if viewed against white paper same colour as the orange of our colour scale, serve as dry filters.

Commercially obtainable red sensitive or panchromatic dry plates can be used if exposed through a darker filter. Of the liquid filters the following must be mentioned :—

Biebrich scarlet, 1 : 1000	6 ccm.
Aurantia, 1 : 1000	10 ,,

This filter, if viewed against white paper, is to correspond with the colour of the vermillion of the colour scale.

Dry filters are prepared with the following solution :—

Biebrich scarlet, 1:200	40 ccm.
Naphthol yellow, S L 1:200	10 ,,
Methyl orange, 1:400	10 ,,
Water	200 ,,
Alcohol	40 ,,
Acetic acid	10 drops.

If we wish to sensitize our own plates Dr. Miethe's recipe, page 98, or the following sensitizing bath can be used :—

Water	1000 ccm.
Alcohol	300 ,,
Cyanine solution, 1:500	5 ,,

to which a few drops of ammonia or cold saturated borax solution is to be added. The plates are best used wet, but if required dry a 10 per cent. dextrine solution is to be added to the water. The plates will keep for about eight days, and are of far higher red sensitiveness than the plates of commerce.

Supplement III. shows the monochrome representation of the colour scale as required for the blue printing plate. If vermillion is not dense enough, the filter must be darker, but it is desirable to avoid unnecessary depth of the filter, which only causes a useless prolongation of the exposure.

THE SENSITIZING OF PLATES AND LIGHT FILTERS FOR THE FUNDAMENTAL SYSTEM: YELLOW, ROSE MADDER AND PRUSSIAN BLUE.

(1) THE NEGATIVE FOR THE YELLOW PRINT.

We find that according to the sensitizing curve (page 82) a collodion emulsion or iodide of silver plate is perfectly suitable for the production of the yellow printing plate without using a light filter. The tank is filled with water or, in the case of dry filters, a colourless glass plate is to be used (page 110).

The missing red sensitiveness of this plate is compensated by its violet sensitiveness. The sensitizing with Chlorophyll, etc., or the employment of a violet filter is not to be recommended.

If gelatine plates are used, we must decrease the blue-green sensitiveness and shift the maximum of sensitiveness towards the violet. This can be accomplished by the use of a liquid filter of Methyl violet solution 1:10,000, or a dry filter coloured with this dye (page 108). This filter, if viewed against white paper, should show a depth similar to the violet of the colour circle, Supplement I.

We find, however, that for practical requirements an ordinary plate (gelatine, collodion, wet iodide of silver plate) will answer perfectly, and there is no reason to complicate this simple process because small errors are not noticeable in this already principally incorrect colour system. We can, therefore, make the half-tone negative direct from the original in the usual way.

If, however, an isochromatic or panchromatic plate is used, the violet filter is absolutely necessary to eliminate all rays with the exception of the blue and violet. A similar filter is required if we use an Eosine silver collodion emulsion. This latter method is to be recommended, because the exposures are considerably shorter.

(2) THE NEGATIVE FOR THE RED PRINT.

The production of this negative calls for a plate showing a broad band of sensitiveness of almost equal intensity from $D\frac{1}{2}$ E to F.

(a) The most suitable plate for such requirements is a collodion emulsion plate sensitized with Eosine-Uranine-silver. To every 100 ccm. of emulsion are to be added 3 ccm. of the following solution:—

Eosine yellow, 1:150	10 ccm.
Uranine, 1:150	30 ,,

The plate is immersed in a ½ per cent. nitrate of silver solution before exposure. The light filter to be used is: Picric acid 1:10,000, or a gelatine plate coloured in an analogous intensity with Naphthol yellow S.

(b) Perfect results are also obtainable with Eosine silver solutions containing ammonia, as, for instance, Dr. E. Albert's sensitizer "A" or "P" with similar light filters.

(c) The orthochromatic gelatine plates, however, show a distinct gap between *b* and *F*, and are not well suited for the purpose. The same feature is noticeable in the different panchromatic plates on the market. All these plates can, however, be used if a deep green light filter is employed, which naturally greatly increases the exposure.

The following solution will be suitable :—

Acid green, 1 : 150	2 ccm.
Picric acid, 1 : 100	40 ,,

As usual, a 5 mm. tank is used.

Suitable dry filters are made with the following :—

Fast green; bluish, 1 : 200	30 ccm.
Naphthol yellow S L, 1 : 200	45 ,,
Alcohol	40 ,,
Water	200 ,,
Acetic acid	10 drops.

It is, however, of high importance to adjust this filter according to the colour scale and the sensitiveness of the plate.

A print of the negative should show the same colour rendering as in Supplement IV.

Chrome yellow is to act like white; ultramarine should be fairly light; and all the greens are to contain very little red.

Increased intensity of the yellow constituent of the filter increases the action of the yellow and orange colours, but decreases that of the blue. If the green is altered in the filter, the red and orange will be influenced. If the blue filter is insufficiently dense, the filter contains too much yellow; but if the chrome yellow shows this defect, the filter is not yellow enough. The yellow constituent of the filter must just accomplish sufficient density in the chrome yellow. If vermillion has too much density, the green in the filter is to be increased.

A perfect absence of the red in the space "sage green" cannot be obtained, because this green contains one part pure green and three parts of black (page 61).

Far better than all other plates mentioned is a plate sensitized with Ethyl-red, as the curve of this plate shows. Even if a green filter—which must be of a more bluish shade—is used, exposures are very short. Good results can be obtained with a wet exposed gelatine plate, sensitized with Uranine. The light filter is picric acid and Acid-green, to be adjusted by methods described above.

A simple process is also advisable in the case of the red plate, and all elaborations can be dispensed with, as the imperfections of printing plates and inks do not show slight differences.

We may finally say, that in the complaints against the red printing plate, it should not follow that red printing ink, or plate, or filter, or negative is imperfect. The chief cause is to be found in the impure and imperfect blue print, which is not of sufficient green shade.

3. The Negative for the Blue Print.

The diagram (page 80) requires a curve of sensitiveness with a maximum in yellow-orange, and shows falling-off towards the blue-green. Collodion emulsion, sensitized with Cyanine, answers this requirement if our conclusions (page 120) hold good. We only require a lighter orange filter not to disturb the curve of sensitiveness in the green.

Cyanine, which is generally avoided in practical work, can be replaced by Rose Bengal, Cyclamine, Rhodamine 3B, etc.; but a relatively darker filter is then needed (10 ccm. Aurantia 1 : 1000, and 10 ccm. Biebrich Scarlet 1 : 1000) to get greater density in the red. The green sensitiveness of the plate is, however, decreased, and such pigments are often rendered too blue in consequence. Very suitable are gelatine plates, sensitized with Cyanine (page 98 and 120), as well as all red sensitive or panchromatic plates of commerce.

After deciding the sensitizer, negatives are taken of the colour scale, and the result must show vermillion rendered white; ultramarine, black; and sage green of a fair density. Whether the latter is correctly rendered can only be ascertained experimentally. Increase of the scarlet gives more density to the red field, decrease, more to the green.

Liquid filters can be replaced by dry filters of corresponding absorptions (page 120).

A simple method of working is also in this case essential, and if a negative of excellent gradation and a fair colour rendering can be obtained, certain deficiencies in the latter may be overlooked.

B. The Production and Recomposition of the Three Pictures.

I. Three-Colour Transparencies.

Although of minor importance for practical work, because their production is connected with great loss of time, they are deserving of attention for projection purposes and the study of three-colour printing, because they are free of faults, which are all conditions in three-colour printing.

Every one of the three transparent pictures comes to full action without being influenced by the other two, and the process yields, therefore, a better guarantee for the true reproduction of the original colours, but the production of a neutral grey is very difficult; the slightest variation in the exact proportion of the three colours makes itself immediately felt, and only very brilliant surrounding colours will make the colour appear grey.

Only in certain lights do such combinations actually appear grey, and slight differences in the colour of the illuminating source are very noticeable. The colours of a transparency made for sunlight are out of balance if viewed on a grey day or in the evening. Even a yellow building is disturbing, showing a yellowish or reddish brown where a grey is obtained with sunlight.

The general admiration of these colour transparencies is not so much due to their fidelity of reproduction, but to their brilliant colouring. They remind us of stained glass, where incorrect colours, hard outlines, and missing gradation are compensated by dazzling brilliance. They often please us in a higher degree than a painting which is free from such faults. We pardon the missing greys and wrong browns in the brilliant colour transparency, but we cannot do so in three-colour printing, where such tints are of the highest importance, as they combine the colours in a homogeneous whole, and define the character and the feeling in a picture.

A suitable support for the three pictures is found in very thin mica or celluloid films. The former are considerably dearer than the latter, but they have the advantage of remaining perfectly flat. Celluloid films must be at least 0·2 mm. thick, whereas mica is only 0·05 mm. As we have to print through the support, it will be understood that mica will produce much sharper images. The pictures are produced on bichromated gelatine, supported by these films and stained with aniline dyes.

The Colourless Gelatine Pictures.

The celluloid or mica films are coated with gelatine, bichromatized, and after drying printed reversed under a negative and developed in warm water.

To control the development and to prevent a too high relief, bromide of silver is added to the gelatine.

A bromide of silver emulsion is therefore used which contains 10 to 12 grammes of silver nitrate to every 30 grammes of gelatine. The emulsion is washed with cold water and the films coated.

As the bromide of silver is not used as a light sensitive substance, but only as a pigment, all operations can be performed in daylight.

Films coated with such gelatine are now commercially obtainable.*

The films are sensitized in a solution of bichromate of ammonia 1 : 50. They are to be completely immersed in this solution for about 15 minutes. It is advisable to blot the films after sensitizing and to dry off in a few hours. The films can only be kept for one or two days. Before the printing the back of the film must be cleaned. Printing is done through the back of the film in the shade, and only if the negatives are very hard is direct sunlight used.

After printing we develop in warm water at a moderate temperature, so as to prevent deformation. After development, the films are immersed in a hypo bath to which a few drops of ferridcyanide solution has been added. The latter prevents the small amount of metallic silver from imparting to the picture a brown tint. The white bromide silver image disappears in the hypo, and we obtain a perfectly colourless gelatine picture.

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*M. Raphael, of Breslau, supplies mica films, and the firm of Sanger Shepherd & Co., of London, celluloid films, for transparency work.—Transl.

The film is now washed in cold water and can either be dried or stained immediately with the colouring solutions.

In the place of films, bromide of silver paper can be used, and the picture can be transferred similarly to a carbon print on to a transparent support. If one of the pictures is to be produced on a glass support, the latter course should be adopted.

The bromide of silver paper on the market cannot be used, because the gelatine film is too thin, but it is not difficult to prepare such paper, by coating a sheet 50 × 70 cm. with about 20 grammes of gelatine. The preparation of the emulsion and the coating of the paper can be done in daylight.

The sensitizing, printing and developing of the picture is the same as in carbon printing, but to prevent stretching of the prints they must not be soaked in cold water. They are only moistened on the gelatine side by means of a brush and quickly squeegeed on to the glass plate.

After development with warm water, the bromide of silver is dissolved in hypo and the picture washed and stained.

In the process of A. & L. Lumière, the prints are made on chromatized gelatine paper, impregnated with a shellac solution to prevent stretching during the transfer on to a collodion-coated glass plate, which serves as temporary support. The gelatine contains a small amount of cochineal red to prevent a high relief. The dye completely dissolves during the process of development and a colourless image is the result.

The gelatine image supported by the glass plate is stained, transferred and superimposed upon gummed paper, and finally transferred upon a glass plate forming the final support. The process is complicated, requires certain skill, and cannot be termed an easy one.

THE COLOURING OF THE GELATINE PICTURES.

The process of colouring is not a mechanical absorption of a dye solution, but consists of a chemical composition between the gelatine and the dye. This composition is, however, a very slight one, because prolonged washing discolours the gelatine again.

The following phenomena seem to justify the assumption of a chemical process :—

1. Very diluted dye solution can produce very intense colouration if the immersion is of sufficient duration.

2. The behaviour of aniline dyes towards gelatine is governed by their chemical character. Many do not stain in very diluted solutions, others only in the presence of acid, and again others only colour if of alkaline reaction.

The gelatine plays here the rôle of an acid or an alkali, and often combines with the acid colour, or alkali, only after liberating the acid or the alkali.

The staining can be generally more successfully performed if the bath is acid than if alkaline.

The Eosines and Rhodamines can be used in neutral solutions.

Of a great number of dyes, the following have been selected as suitable in colour for the staining of gelatine pictures :—

For the red picture :	Erythrosine in neutral solution	
,, yellow ,,	Naphthol yellow SL (1)	In acid solution.
,, blue ,,	Fast green bluish (2)	

1 gramme of the dye is dissolved in 200 ccm. of water, and kept as concentrated stock solution.

(1) Actien Gesellschaft für Anilin Fabrikation, Berlin.
(2) F. Beyer & Co., Elberfeld and London.

The baths are made as follows :—

RED :	Water	100 ccm.
	Erythrosine solution, 1 : 200	5 ,,
	Alcohol	10 ,,
BLUE :	Water	100 ccm.
	Fast green, 1 : 200	20 ,,
	Alcohol	10 ,,
	Acetic acid	10 drops.
YELLOW :	Water	100 ccm.
	Naphthol yellow SL, 1 : 200	10 ccm.
	Alcohol	10 ,,
	Acetic acid	10 drops.
	Saturated chrome alum solution	5 ccm.

If greater intensity of the yellow picture is required, an addition of 5-10 ccm. of Methyl-orange 1 : 200 is required.

The films are to be left in these solutions until perfectly saturated in colour, which often requires several hours.

More concentrated solutions flatten the picture, but act more quickly ; very diluted solutions, although more time is required, give very brilliant pictures, showing much detail in the shadows. If the picture is treated with water or a very weak borax solution, the highest lights begin to lose colour. Based upon this fact, we can alter the character of the pictures and alter their intensity until the desired result has been obtained.

The grey scale is most important in this case, but we must not forget that the colour alters after drying. The blue picture will become more green, the red more blue, only the yellow remaining unaltered. It is therefore advisable to proceed in the following way :

First stain the blue and red picture so as to obtain after drying a uniform blue colour in the grey scale, which is complementary to the chosen yellow. Such a blue corresponds to the colour of a moderately diluted alcoholic Cyanine solution (page 83). The third picture is then coloured so as to complement the blue scale to a neutral grey. After these operations are finished, the films are drained and immersed in the following solution :—

Water	1000 ccm.
Alcohol	100 ,,
Acetic acid	10 ,,

This solution frees the picture from all dye which is not bound by the gelatine, without reducing the colour of the picture. If mica films are used 50 ccm. glycerine are to be added to prevent the separating of the gelatine film from the mica whenever the latter is trimmed.*

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* The process of trichromatic colour transparencies has been brought to very high perfection by Mr. Sanger Shepherd, who, we believe, was the first to introduce the method claimed here by Dr. Hesekiel.—Transl.

Lumière gives the following recipes for the making of the dye solutions:*—

RED:	Water	1000 ccm.
	Erythrosine solution, 3:100	25 ,,
BLUE:	Water	1000 ,,
	Diamin blue, 3:100	50 ,,
	Gum arabic solution, 15:100	70 ,,
YELLOW:	Water	1000 ,,
	Chrysophenin G	4 gr.
	Alcohol	200 ,,

To decrease the colour of a picture in this process we use water for the yellow, water and ammonia for the red, and ½ to 1 per cent. gum arabic or gelatine solution for the blue.

The three component pictures can be superimposed and held in position by gummed paper or they can be sealed with Canada balsam diluted with benzole. The sealing of the transparency makes the colours appear of higher brilliancy as regards their permanency. The yellow and blue will resist the action of the light; the red, however, very quickly bleaches. It would be therefore advisable to replace the Erythrosine with a more permanent dye. The permanency of the Erythrosine picture can, however, be greatly increased by an immersion in a 5 to 10 per cent. copper sulphate solution and subsequent rinsing with water.

Dr. A. Hesekiel modified the process by using a chloride of silver positive, which is immersed in a 1:10 solution of feridcyanide until bleached, washed and treated with iron perchloride until the desired blue colour is obtained. This blue positive is then immersed in a hypo bath for 1-2 minutes. A yellow colouration can be removed with sulphuric acid 1:50.

Although the blue does not quite meet theoretical requirements, not being of a sufficient green shade, and such transparencies often lack pure greens, the results are often very satisfactory.

Dr. Selle's process has not been published in full detail. A glass plate coated with collodion forms the support of

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* All dyes and materials for this process are sold by A. & E. Lumière, Lyons, France.

bichromated gelatine, which is printed under a negative washed in cold water and coloured in dye solution, which only colours where the light has acted. The chromic oxide in this case binds the dye. After drying the collodion films supporting the coloured pictures are stripped and combined by means of adhesives.

The process is very simple and ensures the production of three same-sized images. It seems, however, that deeply stained pictures with pure lights are scarcely obtainable, because the behaviour of exposed and unexposed chrome-gelatine against dye solutions is not sufficiently different.

The possibilities of the "Selle" process are probably only to be found in the different swelling properties of exposed and unexposed gelatine.

Albert Hoffmann uses red, yellow and blue carbon tissues for the production of the three monochromes. The process is the same as carbon, and the final transfer similar to Lumière's.

To use coloured carbon tissue for the three-colour process is not a new idea, Ducos du Hauron used the same for similar purposes. The choice of colour is, however, limited to the use of powder pigments as, for instance, carmine, Prussian blue, chrome yellow, etc. Water-soluble coal-tar colours cannot be used for this purpose.

(2) The Three-Colour Printing.

The printing inks.—If the three pictures are to be combined by printing on paper, pigments have to be used which are ground in varnish. The aniline colours cannot be directly used for this purpose, because they are partly water-soluble, which must not be the case in collotype or litho printing, and they further show a dirty appearance after grinding, because the varnish does not penetrate the particles sufficiently. Another unfulfilled condition is that every pigment must have sufficient body to thicken the varnish in proportion to its colouring capacities. The aniline dyes are, therefore, converted into water-insoluble, but varnish-soluble compounds by addition of pure white powdery substances, as kaolin, zinc white, starch, etc. Such compounds are known by the name of lakes. The kaolins, for instance, greedily absorb dyes if immersed in dye solutions, and Rhodamine and Methyl violet lakes can be produced in this way.

To produce lakes of high colouring qualities, the dye solution is mixed with the substance and a solution of sugar of lead added, which precipitates, for instance, the insoluble Eosine-lead on to the present kaolin. Azo colours are precipitated with alum or baryta compounds, the colours of the triphenyl methane group with tannin, etc. All colour lakes fall short of the brilliancy of the dye solution. This can be explained by the fact that the varnish is not perfectly colourless, does not entirely penetrate the colour particles, and, finally, renders the fibre of the paper partly transparent, and so reduces the luminosity of the white paper.

If the paper is coated with gelatine or collodion more brilliant results are obtained, and gelatine-coated baryta paper is most suitable for the purpose.

Printing lakes of every possible shade are now on the market, and if permanency is not of great importance, a selection for trichromatic work will be found easy. Permanent printing inks of the desired purity do not exist at present, a pure, permanent blue-green being especially missing.

To obtain permanency of the one or the other of the three printing inks is of no importance. As nearly every shade of the colours of a trichromatic print is partly composed by all three colours, the fugitive qualities of one colour, if exposed to light, would destroy the appearance of the picture in a short time. This defect will be least noticeable if all three colours are equally fugitive or permanent.

When selecting printing inks we must consider the shade of colour, the purity, and their behaviour in mixtures.

To judge the colour shade and their purity, it is advisable to compare with stained dry gelatine films, held against white paper. The films are to be stained with Naphthol yellow, Erythrosine, and Fast green respectively. Although permanent printing inks of these particular colour shades are not obtainable, the nearest permanent ones should be chosen. Many printing inks specially prepared for and used in trichromatic work show insufficient knowledge of the requirements of the process. We still find a blue which is almost ultramarine and a reddish yellow used since the beginning of trichromatic printing. No chromo-litho artist could compose a pure green with such colours, but it is expected that the three-colour process will do such miracles. We must select a yellow without a red shade, a pink like carmine, and a greenish blue, and we should not be led astray by occasional good results with other inks.

We must further mix equal proportions of colours ground in varnish, apply on paper, and judge the purity of the mixture. Blue and yellow must give a brilliant green, blue and red a fairly pure violet, and yellow and red a vermillion red.

The printing inks must also comply with the demands of a printing method as regards colouring power, body, etc.

A whitish blue is of no use, even if the colour shade is correct, because depth could not be obtained in the print.

The following inks can be recommended for trichromatic printing.

YELLOW:—Cadmium yellow, zinc yellow, and Chinese yellow, all perfectly permanent. Chrome yellow is not permanent, changing colour in sunlight.

BLUE:—Milori blue is perfectly permanent, but too much of a black shade and not green enough. It is the generally used three-colour blue. Peacock blue, No. 1305, of A. B. Fleming & Co., and Peacock blue, 00, of Kast & Ehinger; brilliant, almost correct colours, but not permanent.

RED:—Krapplack No. 1231 of A. B. Fleming & Co., permanent, but not enough of a bluish shade. The permanent colour system, Supplement I., shows the features of this printing ink. Red, No. 1611, of Kast & Ehinger; this red, specially prepared for three-colour work, is of a good bluish shade, and is shown in colour scale under the wrong name of "Geranium." It is fairly permanent, shows, after hours of exposure in direct sunlight, only slight differences, and is at present the best red which is at the disposal of the three-colour workers. Nacht Rosa of Kast & Ehinger is perfect as regards purity and shade, but very fugitive.

THE PRINTING.

Supposing we produce perfect colour negatives, and choose theoretically correct printing inks, disregarding their fugitive qualities, the final result will be so much influenced by the imperfections of the three overlapping colours that a very faithful reproduction of the colours of the original cannot be anticipated (*vide* page 52). This overlapping defect is very noticeable in the reproduction of broken tints. The pure colours, if only approximately correct, are considered satisfactory, but incorrect rendering of neutral greys or brown is a very serious defect.

Another disturbance in the balance of the three colours is caused by the imperfection of machine printing, because no process furnishes a series of prints which are perfectly alike. The intensity of the colour varies continually, because the amount of colour on the printing formes can only be regulated within certain limits. This also explains the fact that the hand-press is of very little use in three-colour work, the work being too much influenced by the printer. All these defects of three-colour printing are almost absent in chromo-lithography, where pure colours are used and where greys, browns, olives, etc., are introduced by separate plates. Ten to thirty stones are sometimes used, and defects in intensity, shade of colour, etc., are hardly noticeable.

In three-colour printing, however, every part of the picture is composed by the three colours, and if one of the components lacks intensity, the character of the whole picture is spoilt. All colours become incorrect, and greys are rendered violet or brown. To this we have to add another defect, that large grey surfaces are of mottled appearance, due to the imperfections of the printing formes, uneven distribution of the colour, etc. A grey background shows in some part a reddish and in another a greenish tint, and the effect is very displeasing.

As we are not able at present to obtain large neutral grey surfaces, it is advisable to use a fourth printing plate. All parts of the negative showing neutral grey are to be blocked out, and from a suitably retouched fourth negative a grey printing plate will have to be made. The most suitable plate for this purpose is a plate sensitized with

Eosine and Cyanine, exposed behind a suitable filter. The retouching leaves those parts which correspond to black and grey untouched, but decreases the intensity of broken tints and takes pure colours completely out. This plate, if printed in grey, increases the depth of the shadows and forms a harmonious colour effect. The process requires very skilful retouching, because if the shadows are not sufficiently eliminated, the picture is of a heavy sooty appearance.

Dr. E. Albert eliminated the grey and black in a purely mechanical way and obtains a perfectly well modelled black plate as the form-giving factor of the picture, and uses the three colours only to supply the colouring.

The process is patented, and consists in the following: Three-colour negatives and a fourth isochromatic negative are made, the latter only containing the black element of the picture. Of this negative three diapositives are made, which are laid over the colour negatives so as to register perfectly. From the negatives so composed and their positives three colour blocks are made. The diapositives serve as filters, keeping back the grey and black parts of the picture during the printing.

A similar result is attained if the three-colour monochrome positive prints are over-printed with the positive print of the black and red; from such combinations new colour negatives are made, in which the grey and black elements are missing.

Another way of producing a grey is to mix one or two of the three colours with grey. The blue can be mixed with black if pure green can be dispensed with; if the latter are required the red can be mixed with black, necessitating the loss of pure reds.

The more impure the printing inks the easier it is to obtain neutral colours, and for this reason the permanent printing inks with broad absorption bands are preferable to the fiery lakes.

For trichromatic printing collotype, litho, or letterpress can be used; intaglio photogravure cannot be considered on account of the difficulty of registering, the expense of production, and the opacity of the photogravure inks. In four-colour printing very effective results can be obtained by the addition of a photogravure key plate.

(1) Letterpress Printing.

The production of blocks from half-tone negatives has reached a very high standard, due to the introduction of perfect glass screens and the copper enamel process. Half-tone, some years ago only suitable for cheap illustration, is now suitable for art reproduction and is a serious rival to collotype, which has been lately neglected on account of half-tone. For speed of production and other qualities the latter is very suitable for trichromatic work.

The overlapping defect is not so noticeable (page 51), the colours blend better and the principle of letterpress printing furnishes the best guarantee for the evenness of a whole edition.

Another advantage is that the printing inks are not brought into contact with water; they remain pure and the paper dry, which ensures a better register. On the other hand, there is no doubt that a half-tone negative is the least suitable for the correct rendering of the gradation of an original. The shadows are either not sufficiently transparent or the lights lack detail; the gradation is limited and incorrect and over the whole picture are dots, destroying the purity of the colour. In monochrome such an even tone all over the picture is not disturbing, because a soft harmonious gradation is the result.

Three-colour half-tone not only requires considerable retouching and fine etching, but the final result depends more on the clever work of the retoucher than on the perfection of the photographic negative. The indirect process is most usual, and the glass positives are made in contact and developed with glycin.

From such diapositives the half-tone negatives are made in the camera.

If two screens are printed over each other at a very narrow angle, a pattern or moiré is obtained. According to a patent taken by Dr. E. Albert in 1891, single line screens are used crossing at an angle of 60°. If the position of the screen is not altered the original will have to be turned. Very convenient are circular screens, put on the market by Penrose & Co., for instance. The screen is mounted on a rotary carrier, and can be turned at will by means of a rack and pinion arrangement.

In place of the single line screen, cross line screens and slit diaphragms can be used. The slit diaphragm must run parallel to one of the screen lines, and its position must be changed for each negative. If the lens can be turned without altering the focus the stop can remain in the same position. There is no need to use a 60° turning of the screen, because other positions will do as well, but it is advisable to use a large angle between the red and the blue. Two negatives can be made with the slit diaphragm, the other with a round or any other shape.

In this case the screen need not be turned, as two slits, crossing at 90°, are used for red and blue, and a double circular stop, the connecting line of which crosses the screen at 45° for the yellow negative. At present this method is not much in use, but the screen is turned at 30°, and circular or square stops are employed.

Special "three-colour screens"* have been used in connection with the ordinary ruled screen, and a turning of the screen is then not required.

The ruling of the ordinary screen is diagonal, whereas that of the colour screen is 30, and 60° towards the diagonal. Two negatives are taken with the three-colour screen, turning the screen for the second, 180°. The third is made with the normal screen, and three negatives with an angular difference of 30° are obtained. Three-colour prints made with the cross-line screen are free from moiré, but they show a certain pattern which influences the beauty of the results, whereas the single line is perfectly free from this defect.

Half-tone, with grain, has been recommended for three-colour, but although grain half-tone has made considerable

---

*Made by Max Levy, and sold by Penrose & Co., London.

advances lately, there is still much to be desired as regards gradation.*

Quite recently direct half-tone and colour processes have been introduced, but found only few representations up to now.

The collodion emulsion of Dr. E. Albert, with sensitizer "A," gives excellent results for the yellow and red printing plate, but for the blue, a sensitizer is wanted which gives a good dot and sufficient red sensitiveness.†

Ordinary gelatine plates are totally unsuitable for direct work, and specially prepared ones require great skill on the part of the operator. The intensifying, reducing, etc., of the picture also results in great loss of time, and is very risky.

In favour of direct work is the possibility of manual correction of the negatives.

2. PHOTO-LITHOGRAPHY.

Photo-litho from photographic continuous tone negatives is very little practised now, as a perfectly suitable method is at present wanting. The best results are now obtained by using half-tone negatives, because the different half-tone processes, based upon grained stone, are too imperfect.

If the half-tone negative is required for transfer on stone, it must present a different character than if used for a block, because the photo-lithographic process has a spreading tendency for lines and dots. The negative must be fairly closed in the high-lights, and relatively large dots are required in the shadows. However, the process does not seem to give perfect results, as the tender tones become rough

---

*Wheeler's Metzograph Screen has been made extensive use of in three-colour work, and the very satisfactory results obtained seem to indicate a probable solution of this difficulty.—Transl.

†Since the publication of the second German edition of this work, direct colour and half-tone processes with collodion emulsion have been made known by the Royal and Imperial High School of the Graphic Arts in Vienna, and at the same time by Messrs. Penrose & Co., at whose experimental laboratory the translator of this book introduced a direct colour and half-tone process, which is based upon Baron Hübl's researches. The introduction of Klein's light filters and sensitizer "C" giving an excellent blue printing plate of high rapidity and sharp half-tone dots, has made this process commercial.—*Translator.*

and the shadows coarse, and the harmonious character of the screen picture is generally spoiled.

Better results can be obtained by printing direct on aluminium or stone. The asphalt process can be employed, or the method of A. Fritz, which is similar to the American copper-etching process. Perfect results cannot be obtained with either of these processes, as they always exhibit the imperfections of the half-tone negative.

If it should be possible to obtain a direct transfer from an ordinary tone negative, and if the printing blocks should exhibit correct gradation, a great future for trichromatic litho work for art production may be anticipated. If this process would not replace chromo-litho, it certainly would materially assist us. We do not possess another process which, especially in large sizes, can give us such quick and good work as lithography.

3. Collotype.

In the former processes a decomposition of the picture into dots or lines is required, but collotype gives perfectly photographic and almost grainless half-tones. This feature of the process should make it especially suitable for trichromatic work, but the relatively difficult treatment of the printing plate, and the irregularities of a greater number of prints greatly limit its possibilities. Collotype will therefore give a great amount of waste prints, especially as the overlapping defect is more noticeable than in half-tone.

The process is very suitable for small editions, especially where the colours of the original are of a tender nature. The reversed negatives necessary for collotype can be produced by means of a prism or mirror, or, if collodion emulsion is used, they can be exposed through the glass, but require specially designed dark slides. Stripping is not recommended on account of unequal stretching of the film.

A process worked out by the Imperial High School of the Graphic Arts in Vienna, makes use of a fourth black photogravure key plate, and faithfully reproduces the tender gradation and depth of colour of an oil painting. The process is difficult, but for fine art publications very satisfactory.

The Order of the Colours.

There is no doubt that blue should be the colour of the final print, because the last colour always predominates, and a bluish hue would be the least disturbing of the three colours.

Whether red or yellow is to be printed first chiefly depends on the character of the printing ink, because the less transparent colour must be printed first. The yellow picture is so little visible in the case of a yellow lake that it may be advisable to begin with red. If permanent inks are used, the red must be of minor intensity, because no grey could be obtained and also, in this case, it is advisable to begin with the red print.

The subsequent yellow and blue prints are to be regulated by the grey scale. If theoretically correct inks are used, the grey scale has to show after the yellow print a graduated vermillion, if permanent inks are used an evenly graduated orange.

CONCLUSION.

The foregoing treatment of the processes which attempt a photographic reproduction of natural colour in an indirect way may show that no theoretical obstacles prevent the production of pictures of very high perfection. The principle on which the Photochromoscope or colour transparencies or trichromatic printing are based is the same. All three ways are theoretically justified and equally perfect. The difficulties to be met in the practical execution of these three processes are different, and without doubt greatest in the case of trichromatic printing. They are governed by the imperfections of half-tone processes, and every improvement in this direction means progress in trichromatic printing. Absolutely correct colour-rendering can be as little obtained in this process as true monochrome reproduction by means of photography. The photographic reproduction of an engraving or a monochrome drawing leaves much to be desired.

We must not demand perfect colour reproduction of three-colour photography, and if this process produces a picture resembling the characteristic impression of the original its mission is accomplished. Such results must, however, be obtainable without retouching if the process is based on sound theoretical research, and only then is a further manual correction of the negatives justified.

APPENDIX.

Direct Three-Colour Process.—The long-desired facility of making the colour and half-tone negative at one operation is now rendered practical by a method which has been worked out in the Collodion Emulsion Laboratory of A. W. Penrose & Co., and this process is now being largely used commercially in this country.

Klein's Colour Filters are used, and these being much more transparent than those ordinarily in use, the exposures are comparatively short. The filters are used either before or behind the lens.

A pair of Levy's screens, specially ruled at suitable angles for colour work, are requisite for forming the half-tone dot effect. These screens are ruled in pairs according to one of the two following systems:—

(*a*) One screen ruled at 45°, and the other ruled at 75° to the horizontal, the latter being turned the obverse way to make 105° for the third exposure.

(*b*) One screen ruled at 90°, and the other at 60°, the latter being used the obverse way to make 120° for the third exposure.

A set of Diaphragms specially cut for three-colour work is a desirable addition to the lens. The formation of the dots with these stops is such as to neutralize the harshness of the cross-line screen effect, and the negatives hold more colour. The diaphragm should be turned until its diagonal extensions are parallel with the screen ruling. Such diaphragms are made under the Penrose Diaphragm System.

The lighting of the original must be very intense, and if electric light is used the most powerful arc lamps are required. Recently introduced improvements in arc lamps enable carbons to be used which give a violet or red illumination of great actinic intensity, greatly reducing the exposures as compared with ordinary arc lighting. The violet flame arc is used for the blue and green sensation, and the red flame arc for the red sensation.

Three negatives are made from the coloured picture, as follows :—

(*a*) Through the Blue sensation screen for the Yellow printing plate, with emulsion mixed with Sensitizer A.

(*b*) Through the Green sensation screen for the Red printing plate, with emulsion mixed with Sensitizer A.

(*c*) Through the Red sensation screen for the Blue printing plate, with emulsion mixed with Sensitizer C.

The exposures will vary with the nature of illumination, but will be approximately in the ratio of 1 : 0·5 : 1, and in the same order as above.

The sensitive plate must be handled only under a suitably safe illumination, and Rheinlander's Light Filters are recommended for the purpose. For A sensitizer the red-light glass is used in front of the dark-room lamp. For the C sensitizer the green-light glass is used.

Development is best effected with Glycin-Hydrochinon, and the negatives are "cut" and intensified according to the instructions sent out with Dr. Albert's collodion emulsion.

TESTING OF DYES, FILTERS, SENSITIVE PLATES, ETC.—For all purposes of practical and experimental testings in three-colour photography, Tallent's Spectroscopic Camera, manufactured by A. W. Penrose & Co., is to be recommended, owing to its great convenience and readiness for use. It is fitted with one of Thorp's Diffraction Prism Gratings, by which all rays of the same colour emerge parallel and, falling on the photographic lens, are brought to a focus in the plane of the ground glass or sensitive plate. The camera consists of an oblong box, to one end of which is fixed an adjustable spectroscopic slit and to the other a ground glass and dark slide, which can be shifted to different positions so as to get four or five exposures on one plate for comparison purposes. A holder for a colour cell or filter is fitted to an extension of the base in front and also a condensing lens. Incandescent gas-light or electric light can be used for the tests. A pamphlet fully describing the camera and its uses can be obtained from the makers.

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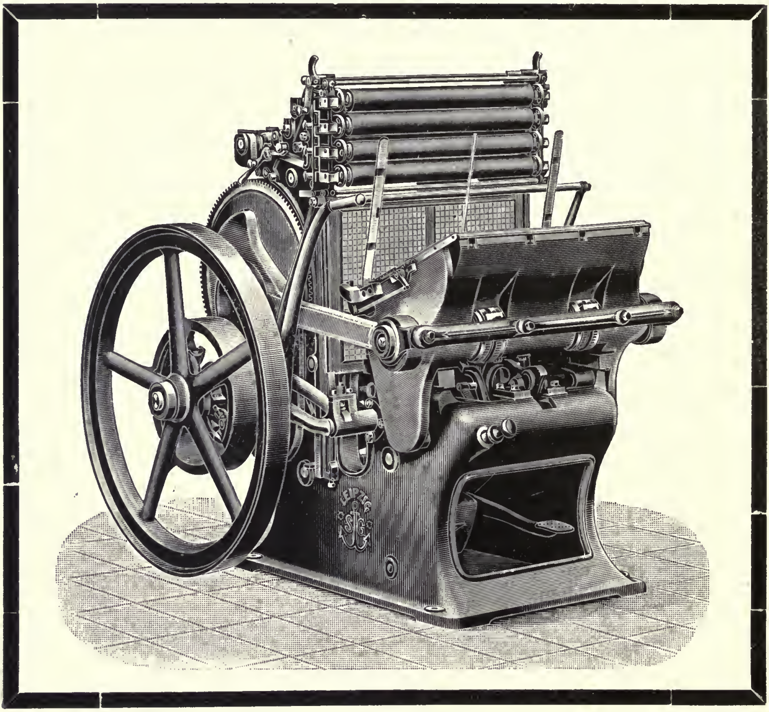

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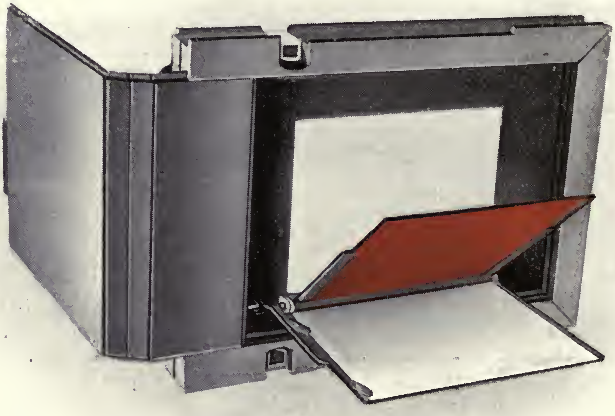

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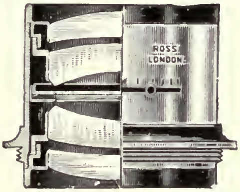

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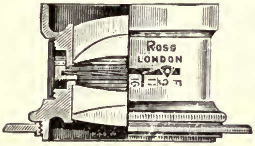

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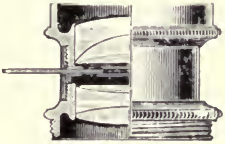

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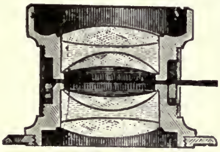

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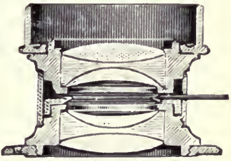

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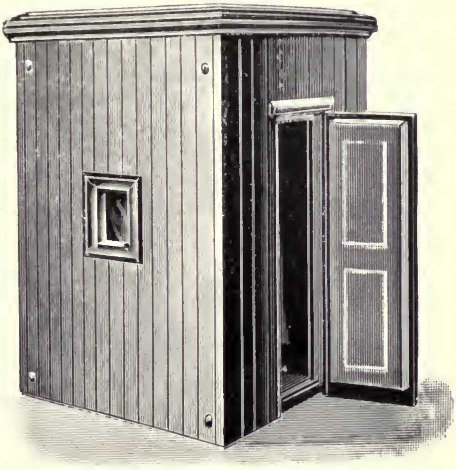

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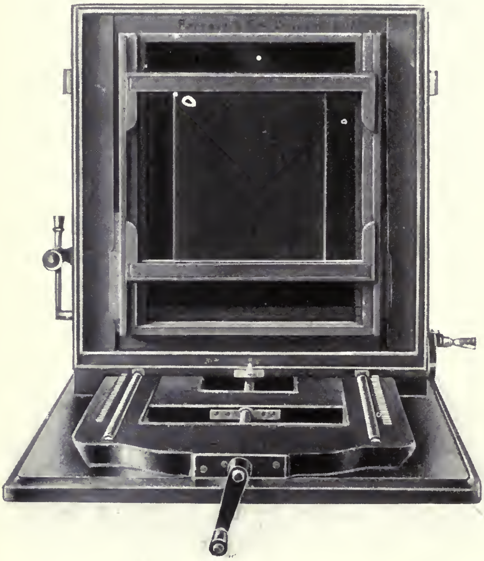

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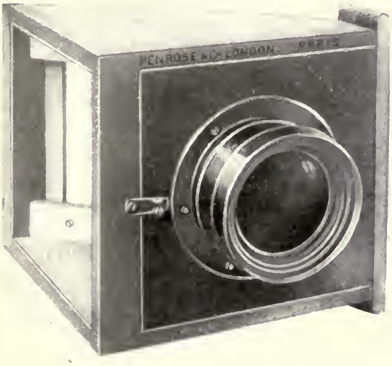
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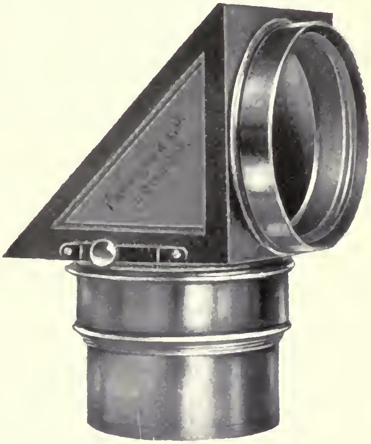

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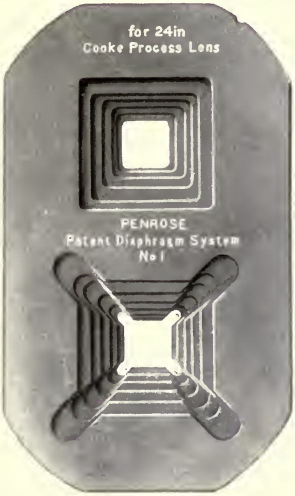
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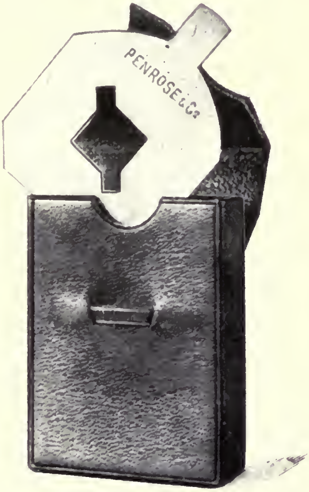
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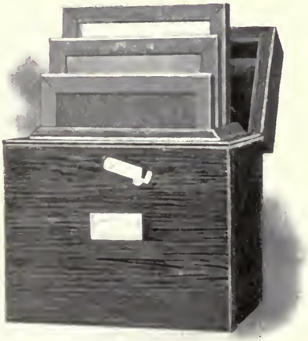

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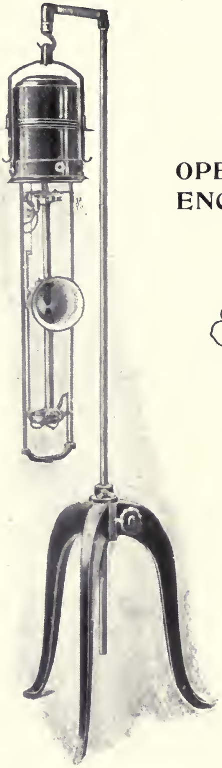

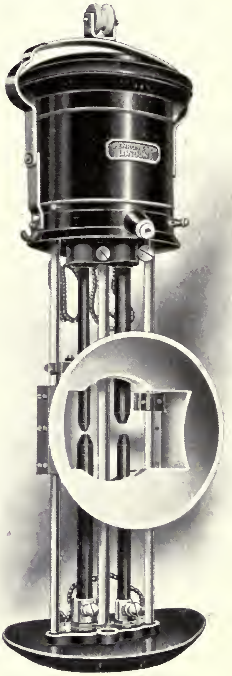

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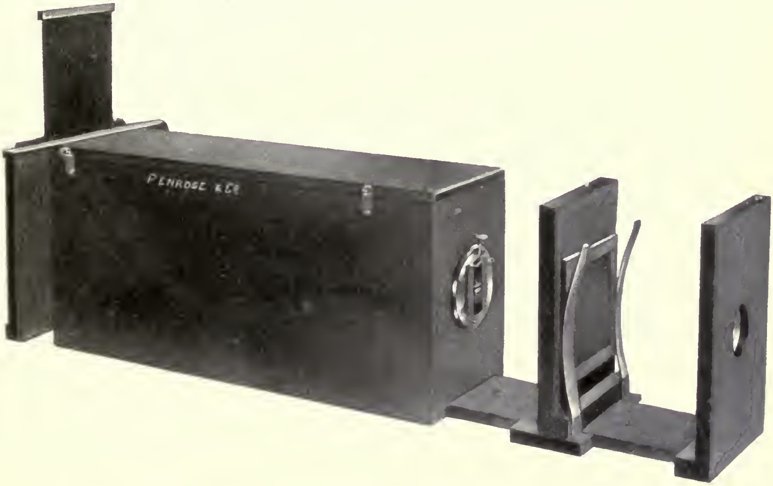

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Invaluable for all kinds of Spectroscopic Tests. Can be used for testing the colour sensitiveness of plates, adjusting liquid colour filters, testing dry filters, determining relative exposures, and generally for studying the principles of spectroscopic work.

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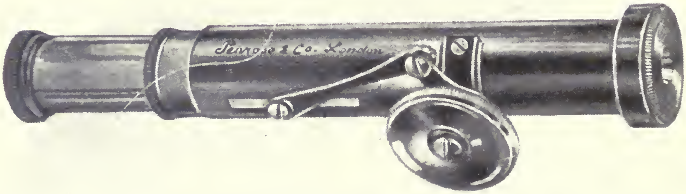

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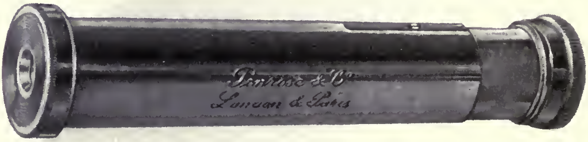

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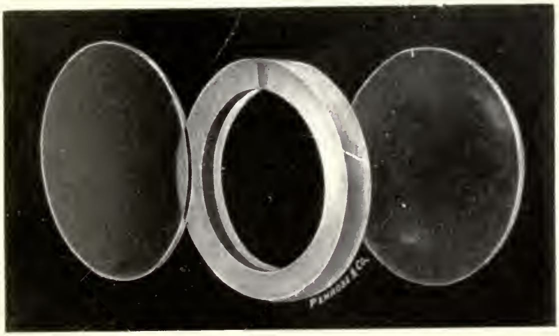
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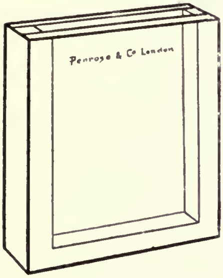
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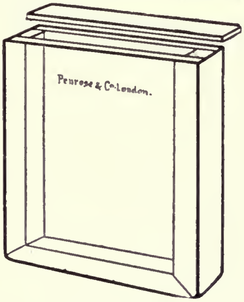
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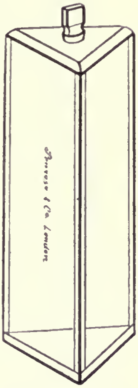
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Eosine, yellow shade
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