March 12, 1940. A. C. HARDY 2,193,722

METHOD OF COLOR REPRODUCTION

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Fig. 3.

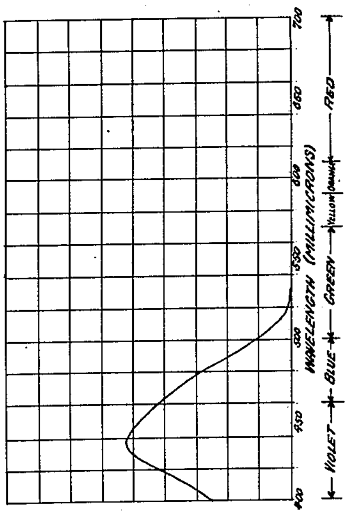


Fig. 2.

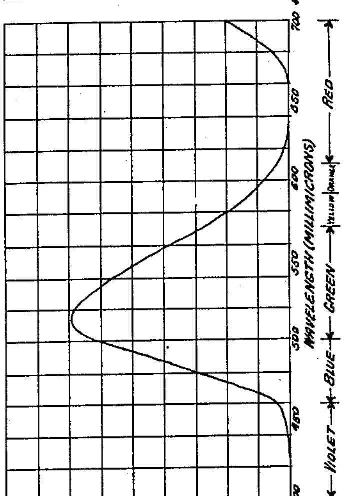


Fig. 1.

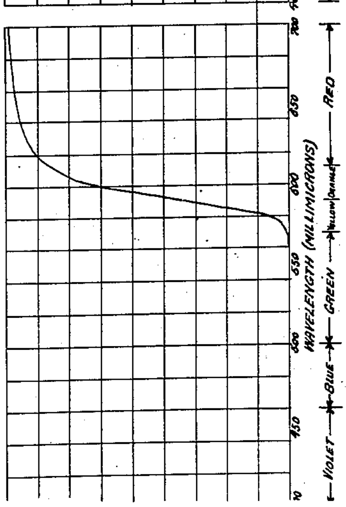
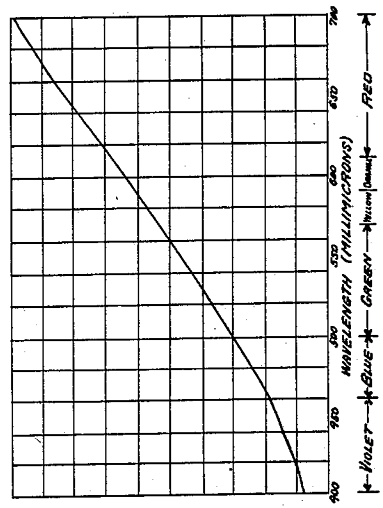


Fig. 4.



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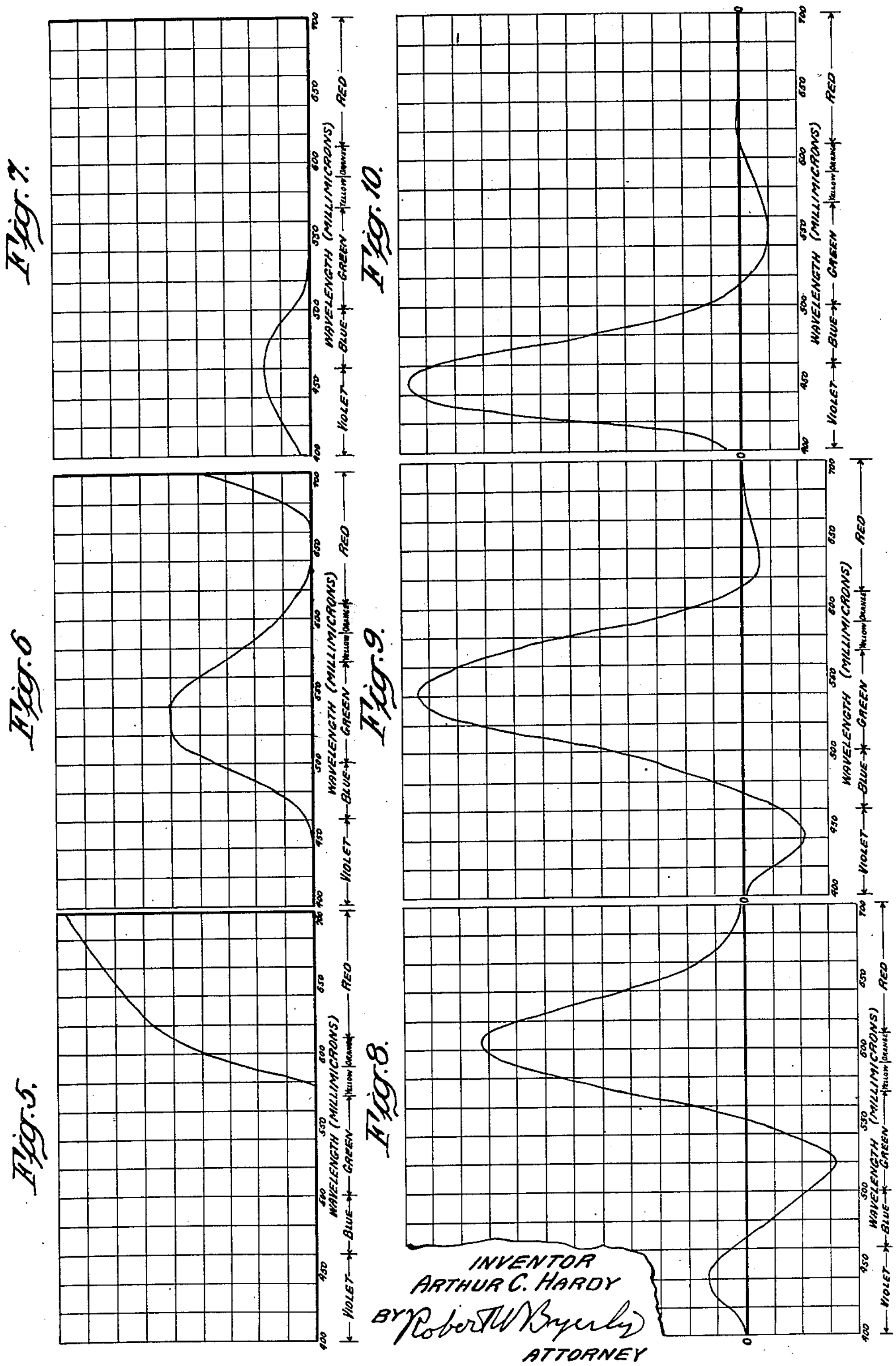

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Fig. 13.

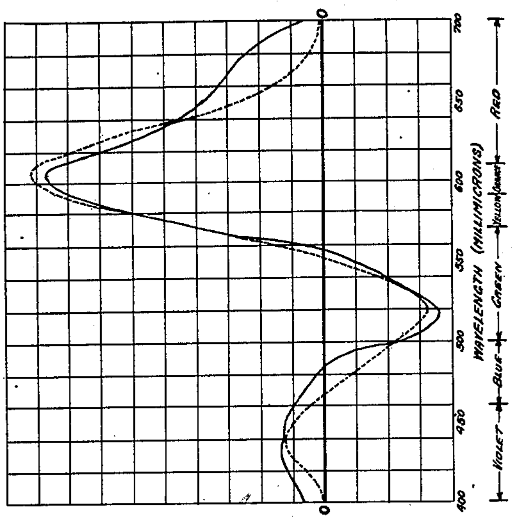


Fig. 11.

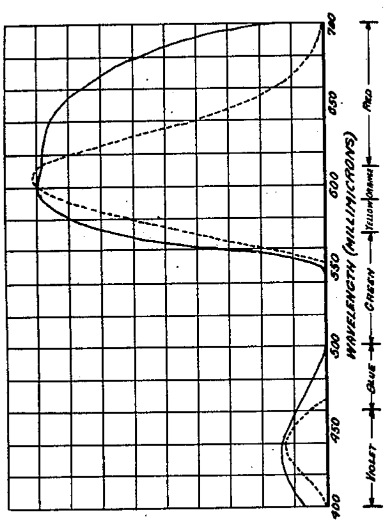
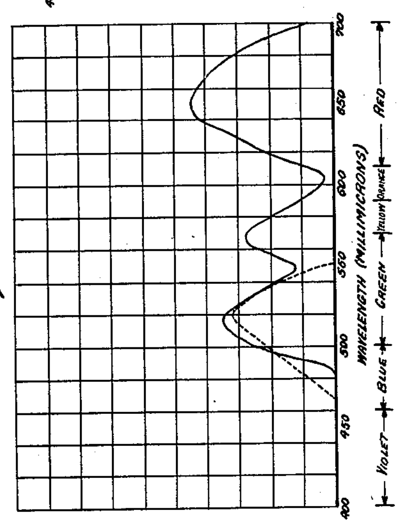


Fig. 12.



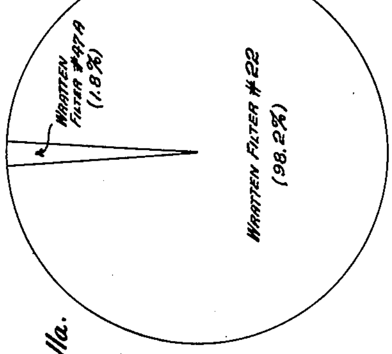


Fig. 11a.

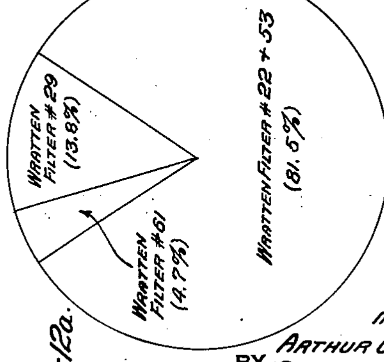


Fig. 12a.

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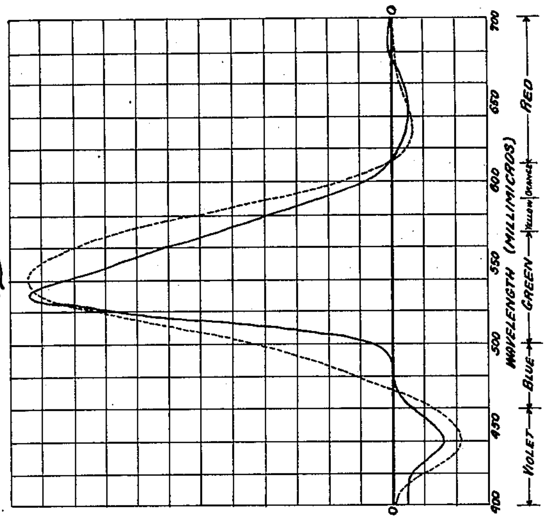
Fig. 16.



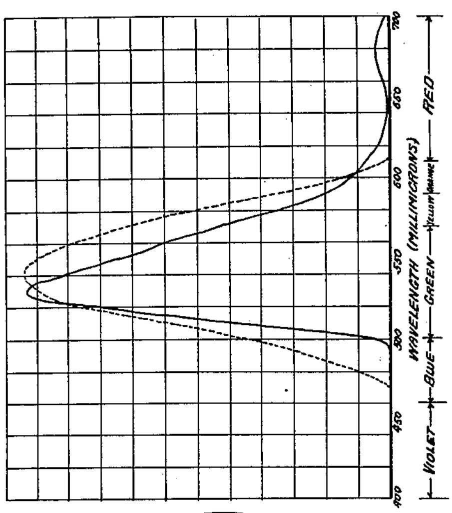


Fig. 14.

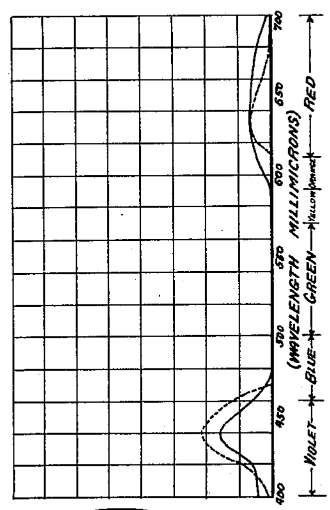


Fig. 15.

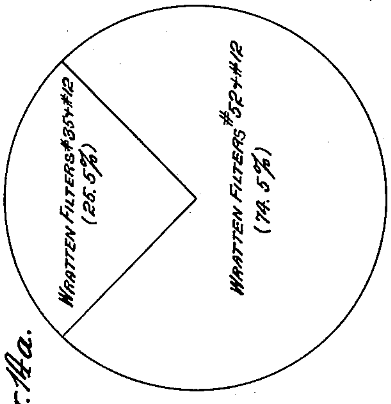


Fig. 14a.

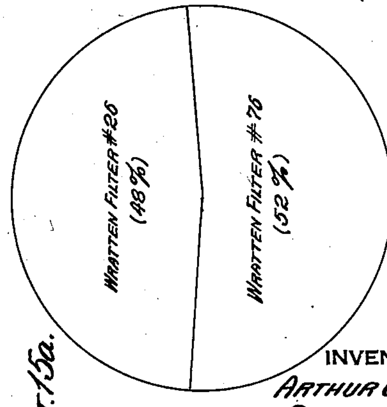


Fig. 15a.

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Fig. 19.

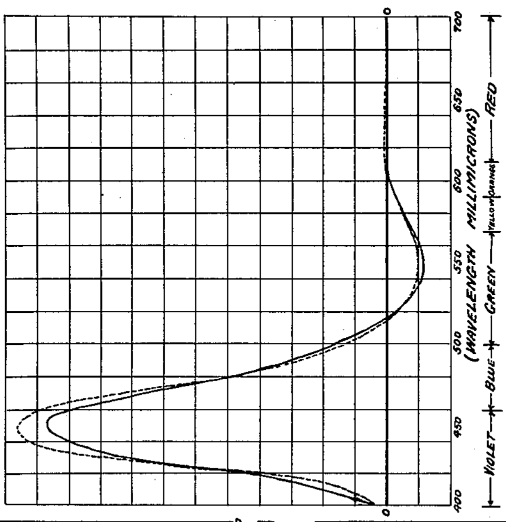


Fig. 17.

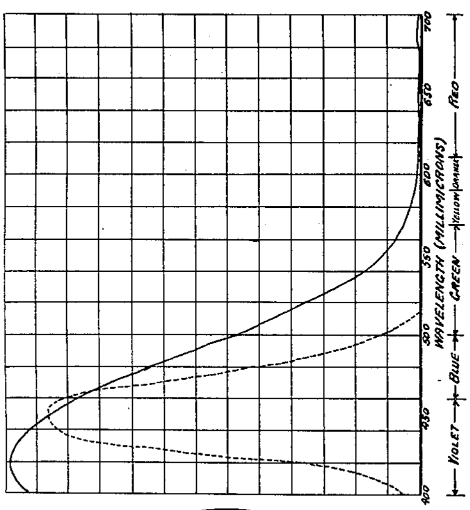
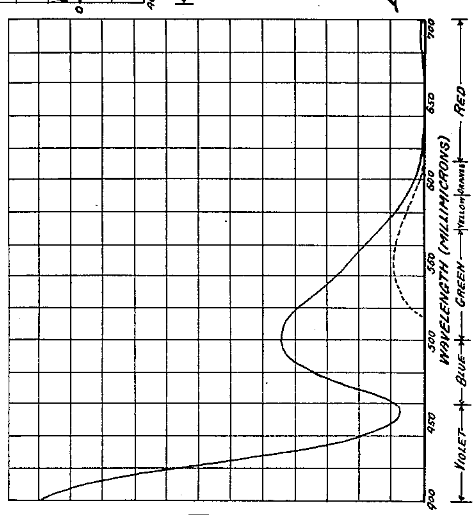


Fig. 18.



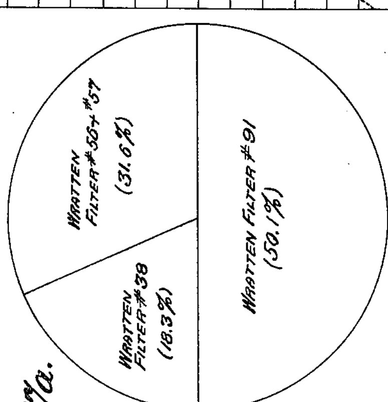


Fig. 17a.

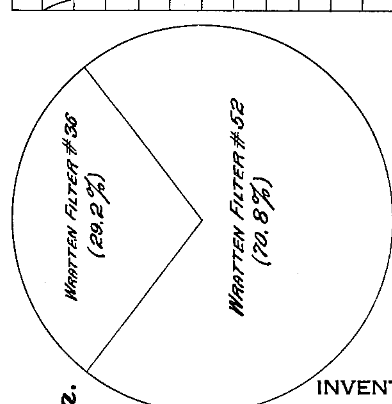


Fig. 18a.

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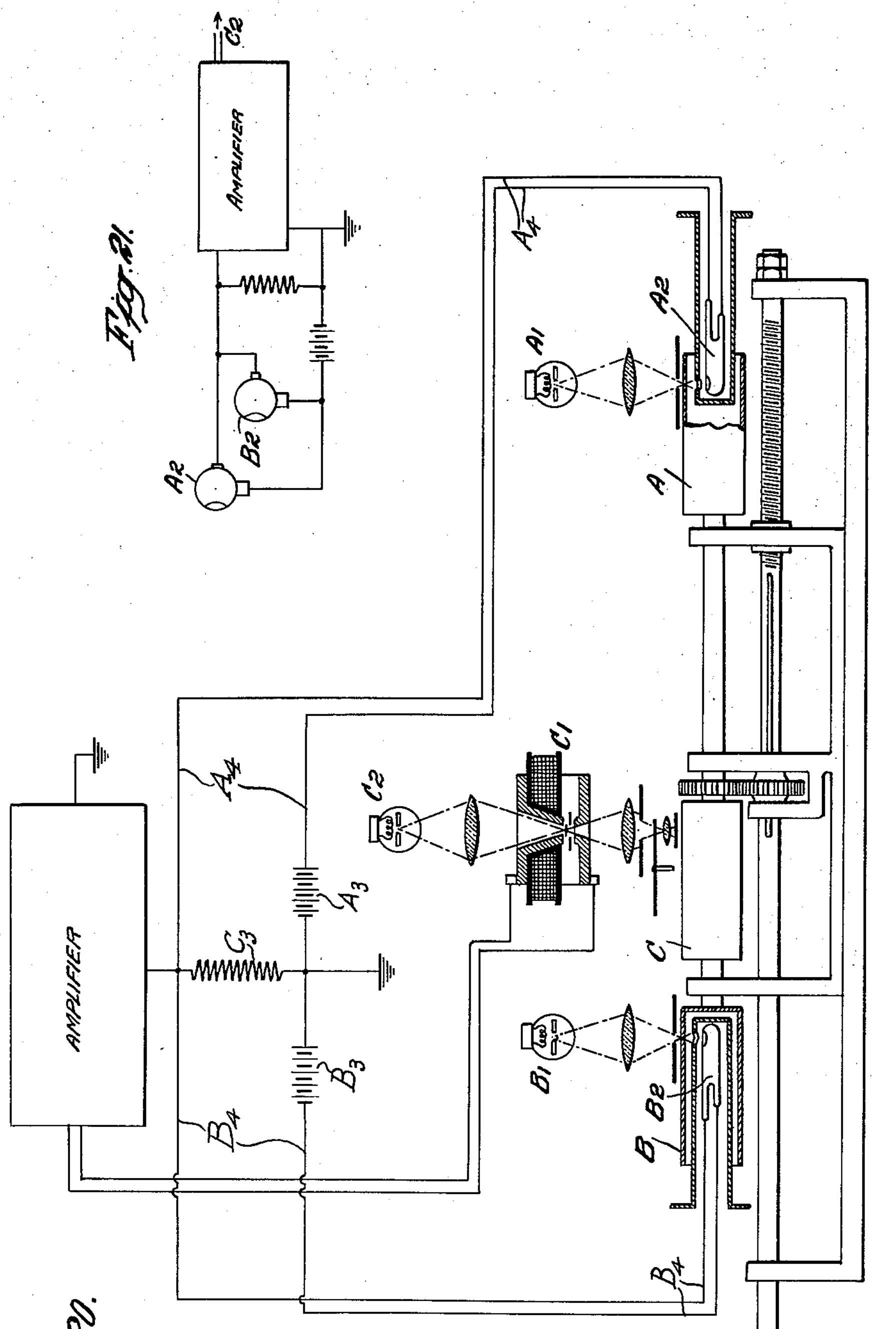

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Patented Mar. 12, 1940

2,193,722

UNITED STATES PATENT OFFICE

2,193,722

METHOD OF COLOR REPRODUCTION

Arthur C. Hardy, Wellesley, Mass., assignor to Interchemical Corporation, New York, N. Y., a corporation of Ohio

Application September 4, 1936, Serial No. 99,415

17 Claims. (Cl. 178—5.2)

This invention relates to a method of color reproduction and aims to provide a more exact reproduction by the three-color method than has heretofore been obtained.

As the terminology of colorimetry and color reproduction is not fixed, I will first define the sense in which various terms will be used in this application.

"Color" will be used in the abstract or optical sense and as so used should be understood to exclude pigments and other colored materials as well as the physiological sensation produced by color. A color has intensity and a spectral quality. The spectral quality of a color may be defined by its spectral energy distribution, that is, by the proportionate strength of radiations of different wave lengths which constitute the color. The spectral energy distribution of a color may be plotted as a curve whose abscissae represent different wave lengths and whose ordinates indicate the relative strength of radiation at each wave length. The spectral quality of a color determines the stimulus required to produce the same color sensation. The stimulus may be defined by two factors, dominant wave length and purity, or by factors termed trichromatic coefficients.

The "primaries" of a color reproduction system are the colors of the colored lights which are mixed to give the observer a color sensation intended to duplicate the sensation which he would receive from colored light from the original subject.

A "color-separation image" is an image of the subject which is used to control one of the primaries in making a reproduction. It is a monochrome, usually black-and-white, image of a colored subject recording the effect of a spectral component of the light emitted by a colored subject, that is to say, it is a record of the part or component of the light emitted by the colored subject in some particular spectral region; or, more specifically, it is an image whose point-to-point variation in tone corresponds to the point-to-point variation in the intensity of a spectral component of the light emitted by the subject, so that the tone of each point of the image is a record of the intensity of a spectral component of the light emitted at the corresponding point of the subject. In projection systems of color reproduction, the color-separation image may be a transparent positive which directly controls a colored light constituting one of the primaries. In systems of color reproduction used in the graphic arts, the color-separation images are formed upon or transferred to printing members, so that they control the primaries represented by the colored inks applied. Although color-separation images are not in themselves colored, they are frequently identified by the names of the colors of the primaries which they control. Thus the expression "red color-separation image" means a color-separation image to be used for controlling a primary whose dominant wave length is in the red part of the spectrum.

A "receptor" is a material or device which undergoes some change when subjected to radiant energy in the form of light and thus may serve to make a record of the amount of light which it receives. The spectral sensitivity of a receptor is its relative response to light of different wave lengths and may be indicated by a curve in which the abscissae represent different wave lengths and the ordinates represent the relative extent to which the receptor is modified by radiation at each wave length. The response of a receptor to light of mixed wave lengths is measured by the integral with respect to wave length of the product of the strength of the radiation at each wave length and the sensitivity of the receptor at each corresponding wave length. If the receptor has a non-uniform spectral sensitivity, this integral is also a measure of the intensity or brightness of the spectral component of such light to which the receptor is sensitive.

To further clarify the meaning of these terms, I will describe the simplest form of three-color reproduction—the three-lantern method. The first step consists in making color-separation images by photographing a colored subject three times, once through a red filter, once through a green filter and once through a blue filter. In the taking of each photograph, the filter and the photographic plate combined constitute a receptor; and the spectral sensitivity of this receptor is determined by the spectral transmission characteristics of the filter and the spectral sensitivity of the photographic emulsion on the plate. When the color-separation photographs are taken, the colored subject is ordinarily illuminated by white light unless it is self-luminous. If the colored subject is transparent, white light to illuminate it may be passed through it. If it is non-transparent, the light is reflected by the subject. In any case, colored light is emitted by the colored subject and the three color-separation images record the effects of the components of this emitted light in the spectral regions in which the three receptors are sensitive. The same effect may be obtained by taking each photograph with the filter placed between a white light and the subject instead of between the subject and the photographic plate; but this arrangement, while equivalent, is usually less convenient. The next step is to use the three color-separation images in making a colored reproduction of the subject. The three separation images, which in this instance are photographic positives, are placed in three separate projection lanterns each containing a white light shining through a red, green or blue filter. The three images are superimposed on the same screen. The lights and the projection filters determine the primaries of the systems. Thus, for example, the colored light coming through the red projection filter constitutes the red primary of the system. The spectral energy distribution of each primary is determined by the spectral energy distribution of the lamp in the lantern and the spectral transmission characteristic of the filter used with the lamp. In making the reproduction on the screen, the primaries are controlled by the color-separation images, that is to say, the three color-separation positives determine the proportions of the mixture of the three primaries at each point of the reproduction on the screen.

It has been customary to assume that, in a reproduction system such as that which has been described, the color filters used in making the three color-separation images should be the same as the color filters used in making the reproduction. Departures from this assumption in practice have, for the most part, been based on empirical attempts to improve color reproduction. A notable exception to these empirical attempts is the method described by F. E. Ives, U. S. Patent No. 432,530, where it is proposed to base the color-separation filters on Maxwell's curves for the primary color sensations and to use as the reproduction primaries lights each of which excites only a single sensation. This suggestion proved to be abortive when it was subsequently discovered that Maxwell's curves were not color sensation curves at all but merely color mixture curves on a purely arbitrary basis.

As the result of a mathematical investigation, I have ascertained that the common assumption that the color-separation filters and the color projection filters should be the same is completely erroneous, and I have devised a method by which the spectral sensitivity characteristics of the receptors which should be used to make the color-separation images may be computed from either the spectral quality or the equivalent stimulus of each of the three primaries to be used in the reproduction.

This method consists in first determining either from the spectrophotometric characteristics of the three primaries, or from the equivalent stimulus of each primary, the trichromatic coefficients of the primaries which may be represented as $x_R y_R z_R$, $x_G y_G z_G$, and $x_B y_B z_B$ (Handbook of Colorimetry, Massachusetts Institute of Technology, 1936, pp. 9–13). I have found mathematically that the spectral sensitivity characteristics of the three receptors required to produce correct color-separation images for the control of primaries having the trichromatic coefficients above stated are determined from the following set of linear equations:

$$x_R S_R + x_G S_G + x_B S_B = \bar{x}$$
$$z_R S_R + z_G S_G + z_B S_B = \bar{z}$$
$$y_R S_R + y_G S_G + y_B S_B = \bar{y}$$

wherein S_R, S_G and S_B are the desired spectral sensitivities of the receptors, and $\bar{x}$, $\bar{y}$ and $\bar{z}$ are the basic data concerning the chromatic properties of the human eye, such as those published by the International Commission on Illumination.

By computations based on the above equations, I have ascertained that, in all cases where the primaries are real colors, the required spectral sensitivities of at least one of the receptors for making the separation images contains negative values. My invention gives physical effect to these negative values.

The method of color reproduction which I have invented consists in controlling at least one of the primaries used in making the reproduction by means of a color-separation image in which the light emitted by a colored subject in one spectral region has had an effect opposite to that of the light emitted by the same colored subject in another spectral region. In such an image, the point-to-point variation in tone corresponds to the difference between the corresponding point-to-point variations in the intensities of two spectral components of the light emitted by the colored subject, so that each point of the image is a record of the difference between the intensities of two different spectral components of the light emitted at the corresponding point of the subject. My invention includes also the method of making such a color-separation image by subtracting the effect of light on one receptor from the effect of the same light on another receptor. The invention includes photographic and electrical methods of effecting this subtraction.

To clarify the nature of my invention, I will give a specific example of the use of the invention in the simplest method of color reproduction, that is, by three-lantern projection. In this example, I shall refer to the accompanying diagrams which are graphs of spectral energy distribution and spectral sensitivity characteristics plotted over the extent of the visible spectrum. In the diagrams,

Figs. 1, 2 and 3 show the spectral transmission characteristics of a red, a green and a blue projection filter;

Fig. 4 shows the spectral energy distribution of a lamp used in each projection lantern;

Figs. 5, 6 and 7 show the spectral energy distribution of the primaries of the system;

Figs. 8, 9 and 10 show the spectral sensitivities of the ideal or theoretical receptors required for making red, green and blue color-separation images to control the primaries whose spectral energy distributions are shown in Figs. 5, 6 and 7;

Figs. 11 and 12 show the sensitivities of two practical receptors used in making the red color-separation image and Figs. 11*a* and 12*a* show the filters forming part of these receptors;

Fig. 13 shows the result of subtracting the effect of light on the receptor whose sensitivity is shown in Fig. 12 from the effect of the same light on the receptor whose sensitivity is shown in Fig. 11;

Figs. 14, 14*a*, 15, 15*a* and 16 correspond to Figs. 11, 11*a*, 12, 12*a* and 13 and relate to the green color-separation image;

Figs. 17, 17*a*, 18, 18*a* and 19 correspond to Figs. 11, 11*a*, 12, 12*a* and 13 and relate to the blue color-separation image; and

Fig. 20 is a diagrammatic view of an electrical apparatus for picture reproduction by scanning, which is used in one modification of my invention, and Fig. 21 shows a different electric connection which may be used with said scanning apparatus.

In the specific example which I shall describe, the reproduction is to be made by three images superimposed on a screen and projected from three lanterns provided with projection filters whose spectral transmission characteristics are shown in Figs. 1, 2 and 3. The three filters are the red, green and blue filters sold by the Eastman Kodak Company and identified as Wratten Filters, Nos. 24, 59 and 47. The spectral transmission characteristics of these three filters shown in Figs. 1, 2 and 3 are taken from "Wratten Light Filters", 13th edition, revised 1934, published by the Eastman Kodak Company. The light used in each lantern is a tungsten lamp operated at a temperature of 2848° K. The spectral energy distribution of this lamp is shown in Fig. 4, which is based on data published by the International Commission on Illumination (Handbook of Colorimetry, Massachusetts Institute of Technology, 1936, p. 16).

The first step in the use of my invention is to determine the spectral qualities of the primaries of the reproduction. In the present instance, the primaries are the colored lights emitted from the three projection lanterns. Their spectral energy distribution may be obtained by multiplying the spectral energy distribution of the lamp by the spectral transmission characteristics of the projection filters. The spectral energy distributions of the three primaries, obtained in this way, are shown in Figs. 5, 6 and 7.

The spectral energy distributions of the primaries shown in Figs. 5, 6 and 7 provide data for computing the spectral sensitivities of the receptors required for making correct color-separation images for use in controlling these three primaries. From these curves, the trichromatic coefficients of the primaries are found to be as follows:

Red primary	Green primary	Blue primary
$x=0.6749$ $y=0.3248$ $z=0.0002$	$x=0.2944$ $y=0.6059$ $z=0.0977$	$x=0.1369$ $y=0.0710$ $z=0.7921$

(id. pp. 8, 32, 33, 49, 50). By substituting these values and the values of $\bar{x}$, $\bar{y}$, $\bar{z}$, published by the International Commission on Illumination (id. p. 7, p. 35, Table XII) in the equations above given, the spectral sensitivities of the three receptors required to produce correct color-separation images for these three primaries have been computed and the results are plotted in Figs. 8, 9 and 10. From these figures, it is evident that the required spectral sensitivities of the three receptors differ widely from the transmission characteristics of the projection filters shown in Figs. 1, 2 and 3, and from the spectral energy distribution of the primaries shown in Figs. 5, 6 and 7, and that the required spectral sensitivity of each receptor is negative in a part of the spectrum.

The next step is to produce a red color-separation image of a colored subject in which light in the spectral region including wave lengths from 470 to 550 (in which the curve shown in Fig. 8 is negative) has had an effect opposite to that of light from the rest of the visible spectrum. This step may be carried out as follows:

A practical receptor having a spectral sensitivity corresponding to the positive part of the required sensitivity curve shown in Fig. 8 is provided. Such a receptor is made by the use of a panchromatic photographic plate, such as that described by L. A. Jones and Otto Sandvik in the April, 1926, issue of the Journal of the Optical Society of America and Review of Scientific Instruments, with the filter shown in Fig. 11*a*, which consists of a 98.2% sector of Wratten Filter No. 22 and 1.8% sector of Wratten Filter No. 47A. (A similar result can, of course, be obtained by making successive exposures of the plate through Wratten Filters Nos. 22 and 47A, the relative length of the exposures corresponding to the relative size of the sectors shown in Fig. 11*a*.) The spectral sensitivity of this practical receptor is indicated in a full line in Fig. 11. It will be seen that the spectral sensitivity of this practical receptor approximates the positive part of the theoretically correct red receptor which is shown in Fig. 8 and in a dotted line in Fig. 11 for the purpose of comparison.

A practical receptor having a spectral sensitivity approximating that of a mirror image of the negative part of the spectral sensitivity curve of the theoretical red receptor shown in Fig. 8 is provided. This practical receptor is made by combining the panchromatic plate above referred to with the filter shown in Fig. 12*a*, which consists of a 4.7% sector of Wratten Filter No. 61, a 13.8% sector of Wratten Filter No. 29, and an 81.5% sector of Wratten Filters Nos. 22 and 53 superposed. The spectral sensitivity of this practical receptor is shown in Fig. 12. It will be observed that, in a part of the spectrum, the sensitivity of this practical receptor approximates a mirror image of the negative part of the spectral sensitivity curve of the theoretical red receptor which is shown in Fig. 8 and shown in a dotted line in Fig. 12 for the purpose of comparison. It will be noted also that the sensitivity of the practical receptor is greater than that of the negative part of the curve for the theoretical receptor between the wave lengths 550 and 700, and that, in the same region, the curve of the practical receptor shown in Fig. 11 exceeds the sensitivity curve of the theoretical receptor.

The effect of light from the subject on the practical receptor of Fig. 12 is subtracted from the effect of light from the subject on the practical receptor of Fig. 11. This is accomplished in the following manner: A colored subject is photographed with each receptor to make records of different spectral components of the light which the colored subject emits. A negative image is made with the receptor of Fig. 11 using short exposures, so that the chemical effect on the plate as measured by the transparency of the developed plate bears a linear relation to the amount of light received. In a similar manner, a negative is made with the receptor of Fig. 12. From this negative a positive is made by contact printing. A third plate is then exposed successively through the negative made on the receptor of Fig. 11, and the positive made from the receptor of Fig. 12. In this instance also, the exposures are short, so that the chemical effect bears approximately a straight line relation to the amount of light received. The resulting composite image on the third plate is a positive at each point of which the effect of the spectral component of the light emitted by the colored subject which is recorded on the receptor of Fig. 12 is subtracted from the effect of the different spectral component of the same light from the same part of the subject which is recorded on the receptor shown in Fig. 11.

The result of subtracting the effect of light on the receptor of Fig. 12 from the effect of light on the receptor of Fig. 11 is indicated by a full line in Fig. 13. The separation image made in the manner described is, therefore, identical with the separation image which would be made by a theoretical receptor having the spectral sensitivity indicated by the full line in Fig. 13.

It will be observed that the curve showing the effect of the subtraction in Fig. 13 closely approximates the theoretical sensitivity curve desired, which is shown in Fig. 8 and indicated by a dotted line in Fig. 13 for the purpose of comparison. The approximation is much closer than the approximations of the practical receptors shown in Figs. 11 and 12 to the positive and negative parts of the theoretical curve also shown in those figures. This indicates another advantage of my method, since, as indicated in Figs. 11, 12 and 13, the departures of the practical receptors from the theoretical sensitivity required can be made to balance off so that the subtraction not only gives effect to the negative part of the theoretical curve but also eliminates a large part of the departure of the sensitivities of the practical receptors from the sensitivity theoretically required.

The next step is to prepare a green color-separation image of the same colored subject in which light in the spectral regions between wave lengths of 400 and 470 and between 612 and 700 (the regions in which the spectral sensitivity curve shown in Fig. 9 is negative) has produced an effect opposite from that of light in the region between wave lengths of 470 and 612 (the region in which the sensitivity curve shown in Fig. 9 is positive). This is accomplished in the manner already described, by subtracting the effect of light on a practical receptor whose spectral sensitivity is shown in Fig. 15 from the effect of light on a practical receptor whose spectral sensitivity is shown in Fig. 14. The result of the subtraction, indicated in Fig. 16, closely approximates the required spectral sensitivity curve shown in Fig. 9. The practical receptors whose spectral sensitivities are shown in Figs. 14 and 15 consist of panchromatic photographic plates such as that already specified used with the filters shown in Figs. 14*a* and 15*a*.

The next step is to prepare a blue color-separation image of the same colored subject in which light in the spectral region between wave lengths of 512 and 610 (the region in which the sensitivity curve shown in Fig. 10 is negative) has had an effect opposite from light in the spectral region between wave lengths of 400 and 512 (the region in which the sensitivity curve shown in Fig. 10 is positive). This is accomplished in the manner already described, by subtracting the effect of light on a practical receptor whose spectral sensitivity is shown in Fig. 18 from the effect of light on a practical receptor whose spectral sensitivity is shown in Fig. 17. The result of the subtraction, indicated in Fig. 19, closely approximates the required spectral sensitivity curve shown in Fig. 9. The practical receptors whose spectral sensitivities are shown in Figs. 17 and 18 consist of panchromatic photographic plates such as that already specified used with the filters shown in Figs. 17*a* and 18*a*.

The next step consists in using the red, green and blue color-separation images prepared in the manner above described to control the three primaries in making a colored reproduction of the colored subject. In the three-lantern method of color reproduction, this is accomplished by placing the red color-separation image upon which light from the subject has had the effect indicated in Fig. 13 in the lantern emitting the red light whose spectral energy distribution is shown in Fig. 5, placing the green color-separation image on which light from the subject has had the effect indicated in Fig. 16 in the lantern emitting the green light whose spectral energy distribution is indicated in Fig. 6, and placing the blue color-separation image upon which light from the subject has had the effect indicated in Fig. 19 in the lantern emitting the blue light whose spectral energy distribution is shown in Fig. 7. It is to be noted that, in the specific example given, each of the three color-separation images is a photographic positive image adapted for use in the projector.

My invention is, of course, not limited to the simple three-lantern form of color reproduction. It may be applied to the color reproduction methods used in the graphic arts including four-color methods which merely use one black print in addition to three colored prints. In order that the invention may produce accurate reproduction, the spectral sensitivities required for the theoretical receptors for the separation images must be computed from the spectral qualities of the primaries of the reproduction system. In cases where the color of the primaries is not readily apparent as in most systems used in the graphic arts, the spectral qualities of the primaries to be used in the calculation may be determined by the method described in my co-pending application, Serial No. 99,416, filed Sept. 4, 1936, which subsequently issued as Patent No. 2,165,167, July 4, 1939.

The invention is not limited to the particular photographic method of subtracting the effect of light on one receptor from the effect of light on another receptor which has been described in the specific example. A still simpler photographic method of subtraction, which may advantageously be used in forming positive color-separation images for use in the projection system, is the following: An exposure of the subject is made on the receptor of Fig. 11 and is developed as a negative. An exposure of the subject is then made on the receptor of Fig. 12. Before the plate which forms part of the receptor of Fig. 12 is developed, this plate is exposed to white light through the developed negative plate of the receptor of Fig. 11. All three of the exposures are short for the reasons above explained. The plate of the receptor of Fig. 12 is then developed and will be found to be a positive image identical with that made by the three-plate method before described. Other photographic methods of subtraction may be adopted.

My invention is not limited to photographic subtraction, as the subtraction may be accomplished in other ways. A feature of my invention consists in making the subtraction electrically. This is of particular advantage in graphic reproduction systems, as the subtraction can be accomplished at the same time that a half-tone image is made so that the color-separation image is made as a half-tone image adapted for use in engraving a half-tone plate and, in this way, controlling the amount of the primary of the system represented by the colored ink applied to this plate.

In accordance with my invention, the subtraction may be carried out by the scanning apparatus illustrated in Fig. 20. This apparatus is like the scanning apparatus for making half-tone reproductions shown in U. S. Patent No. 1,649,309 issued to H. E. Ives on November 15, 1927, except that it contains two picture drums A and B mounted on the same shaft as the film drum C, instead of only one picture drum. To make a half-tone red color-separation image for use with the primaries shown in Figs. 5, 6 and 7, positive or negative photographs of a colored subject made with the receptors of Figs. 11 and 12, and recording different spectral components of the light emitted by the colored subject, are placed on the two picture drums A and B, and are scanned by lights from two identical optical systems A1 and B1. The scanning lights modified by the two images so as to equal the two spectral components recorded by the images fall on photo-electric cells A2 and B2 which, as shown in Fig. 20, are so connected that the electric currents which they control are opposed and the resulting current is passed into an amplifier. In the connection illustrated, separate electromotive forces are impressed on the photo-electric cells A2 and B2 by batteries A3 and B3. The circuits A4, B4 containing the photo-cells and batteries are connected in opposed parallel relationship to a resistor C3 so that the two photo-cell currents are opposed in the resistor producing in it a current which is the difference between the two photo-cell currents. This current is passed into the amplifier. The output current of the amplifier is used to control a light valve apparatus C which controls the effect of a light C2 upon a film of the film drum C. The resistor C3 is thus the primary means for controlling the effect of the recording light C2. The image produced on the film on the drum C is therefore, in effect, the result of subtracting the image on the drum B from the image on the drum A, and is thus an image each point or elemental area of which is a record of the difference between the intensities or brightnesses of the two spectral components of the light emitted at the corresponding point or area of the colored subject, records of which were made by the receptors of Fig. 11 and Fig. 12.

An alternative, but less desirable, method of effecting the subtraction consists in using a negative from one of the receptors on the drum A and a positive from the other receptor on the drum B and connecting the two photo-electric cells as shown in Fig. 21 in such a way that the currents controlled by them are added.

The electrical method of making color-separation images which I have described is susceptible of general application in modifying the effect of light in one spectral region by the effect of light in another spectral region, but it is not claimed broadly herein as it forms the subject-matter of my co-pending divisional application, Serial No. 198,240, filed March 26, 1938.

In the specific examples, I have described the carrying out of my method by means of known photographic materials and filters and electrical apparatus of a known type. It will readily be understood by those skilled in the art that receptors containing photographic plates and filters especially prepared for the practice of my invention may be made on the basis of the sensitivity characteristics desired, and that, by such special means, the carrying out of the invention may be to some extent simplified. The invention is, of course, not limited to any particular means for carrying out the method.

What I claim is:

1. The method of color reproduction which consists in making a color-separation image of a colored subject, in which the light emitted by the colored subject in one spectral region has had an effect opposite from that of the light emitted by the same colored subject in another spectral region, making two other color-separation images of the same colored subject, and making a combination of three primaries by controlling the amount of each primary by one of said three color-separation images.

2. The method of color reproduction which consists in making a color-separation image each point of which is a record of the difference between the intensities of two different spectral components of the light emitted at the corresponding point of a colored subject, making two other color-separation images of the same colored subject, and making a combination of three primaries by controlling the amount of each primary by one of said three color-separation images.

3. The method of making a color-separation image for use in color reproduction, which comprises directing different spectral components of light emitted by a colored subject to separate receptors, subtracting from the response of the first receptor to the variation in intensity of a spectral component of said light from point to point of the subject the response of the second receptor to the variation in intensity of a different spectral component of said light from the same point to the same point of the subject, and making a record of the subtraction to provide an image of the subject whose point-to-point variation corresponds to the difference between the corresponding point-to-point variations in the intensities of two spectral components of the light emitted by the colored subject.

4. The method of making a color-separation image for use in color reproduction, which comprises directing different spectral components of light emitted by a colored subject to separate receptors whose response is a linear function of the amount of light received, subtracting from the linear response of the first receptor to the variation in intensity of a spectral component of said light from point to point of the subject the linear response of the second receptor to the variation in intensity of a different spectral component of said light from the same point to the same point of the subject, and making a record of the subtraction to provide an image of the subject whose point-to-point variation in tone corresponds to the difference between the corresponding point-to-point variations in intensities of two spectral components of the light emitted by the colored subject.

5. The method of making a color-separation image for use in color reproduction, which comprises passing light emitted by a colored subject to photographic receptors having different spectral sensitivity characteristics to make photographic images of the subject whose point-to-point variation in tone records the point-to-point variation in intensity of different spectral components of light from the subject, subtracting the point-to-point variation in tone of one of said images from the point-to-point variation in tone of the other of said images, and making a record of the subtraction to provide an image of the subject whose point-to-point variation corresponds to the difference between the corresponding point-to-point variations in the intensities of two spectral components of the light emitted by the colored subject.

6. The method of making a color-separation image of a colored subject in accordance with a spectral sensitivity curve which is positive in one spectral region and negative in another spectral region, which comprises passing light from the colored subject to a receptor having a spectral

sensitivity approximating that of the positive part of said spectral sensitivity curve, passing light from the same colored subject to another receptor having a spectral sensitivity approximating a mirror image of the negative part of said spectral sensitivity curve, subtracting from the response of the first receptor to the variation in intensity of a spectral component of said light from point to point of the subject the response of the second receptor to the variation in the intensity of a different spectral component of said light from the same point to the same point of the subject, and making a record of the subtraction to provide an image of the subject whose point-to-point variation corresponds to the difference in the corresponding point-to-point variations of the intensities of two different spectral components of the light emitted by the colored subject.

7. In the method claimed in claim 6, the use of receptors whose spectral sensitivities depart respectively from the positive and negative parts of the spectral sensitivity curve by corresponding amounts, so that such departures are eliminated by the subtraction to provide an image of the subject closely approximating that which would be made by a theoretical receptor whose spectral sensitivity corresponded to that of said spectral sensitivity curve.

8. The method of making a color-separation image for use in color reproduction, which comprises directing different spectral components of light emitted by a colored subject to separate photographic receptors, subtracting from the point-to-point variation in the latent image which constitutes the response of the first receptor to the variation in intensity of a spectral component of said light from point to point of the subject the variation from corresponding point to corresponding point in the latent image which constitutes the response of the second receptor to the variation in intensity of a different spectral component of said light from the same point to the same point of the subject, and making a photographic record of the subtraction to provide an image of the subject whose point-to-point variation in tone corresponds to the difference between the corresponding point-to-point variations in the intensities of two spectral components of the light emitted by the colored subject.

9. The method of making a color-separation image for use in color reproduction which comprises exposing two photographic receptors of different spectral sensitivity characteristics to light from the same colored subject, making a negative from one receptor and a positive from the other receptor, making short, successive, registering, exposures of said positive and said negative on a photographic plate to provide an image in which the light emitted by the colored subject in one spectral region has had an effect opposite from that of the light emitted by it in another spectral region.

10. The method of making a color-separation image for use in color reproduction, which comprises exposing two photographic receptors of different spectral sensitivity characteristics to light from the same colored subject and making a negative from one receptor and a positive from the other receptor, in each of which the transparency at each point bears a linear relation to the amount of light received, making independent registering exposures of said positive and said negative on a photographic plate, said exposures being such that the transparency of the developed plate at each point bears a linear relation to the amount of light received, to provide an image in which the light emitted by the colored subject in one spectral region has had an effect opposite from that of the light emitted by it in another spectral region.

11. The method of making a color-separation image for use in color reproduction which comprises passing light from a colored subject to a photographic receptor, preparing a transparent negative from the receptor in which the transparency at each point bears a linear relation to the amount of light received, passing light from the same colored subject to another photographic receptor and then exposing the plate of the second receptor to light through the negative obtained from the first receptor and developing said plate to provide an image in which the light emitted by the colored subject in one spectral region has had an effect opposite from that of the light emitted by it in another spectral region.

12. The method of making a color-separation image for use in color reproduction, which comprises passing light from a colored subject to a photographic receptor, preparing a transparent negative from the receptor in which the transparency at each point bears a linear relation to the amount of light received, making independent registering exposures on a photographic plate, in one of which the plate is exposed to light from the colored subject in a second receptor having spectral sensitivity characteristics different from those of the first receptor, and in the other of which the plate is exposed to light through the negative obtained from the first receptor, and then developing said plate, to provide an image in which the light emitted by the colored subject in one spectral region has had an effect opposite from that of the light emitted by it in another spectral region.

13. The method of making a color-separation image for use in color reproduction, which comprises passing light emitted by a colored subject to photographic receptors having different spectral sensitivity characteristics to make photographic images of the subject whose point-to-point variation in tone records the point-to-point variation in intensity of two different spectral components of light from the subject, opposing an electric current modulated by the variation in tone from point to point of one of said images to an electric current modulated by the variation in tone from corresponding point to corresponding point of the other of said images, and making a record of the difference between the modulations of said separate currents to provide an image of the subject whose point-to-point variation corresponds to the difference between the corresponding point-to-point variations in the intensities of two spectral components of the light emitted by the colored subject.

14. The method of making a color-separation image for use in color reproduction, which comprises directing different spectral components of light emitted by a colored subject to separate photo-electric receptors, combining in opposed relation an electric current whose variations constitute the response of the first receptor to the variation in intensity of a spectral component of said light from point to point of the subject with an electric current whose variations constitute the response of the second receptor to the variation in intensity of a different spectral component of said light from the same point to the same point of the subject, and making a record

of the difference between the variations of the separate currents to provide an image of the subject whose point-to-point variation corresponds to the difference between the corresponding point-to-point variations in the intensities of two spectral components of the light emitted by the colored subject.

15. In a method of color reproduction, the steps of directing different spectral components of light emitted by a colored subject to separate photoelectric receptors, combining in opposed relation an electric current whose variations constitute the response of the first receptor to the variation in intensity of a spectral component of said light from point to point of the subject with an electric current whose variations constitute the response of the second receptor to the variation in intensity of a different spectral component of said light from the same point to the same point of the subject to modulate light in accordance with difference between the variations of the separate currents.

16. A color-separation image for use in color reproduction which consists of a monochrome image of a colored subject, whose point-to-point variation in tone corresponds to the difference between the corresponding point-to-point variations in the intensities of two spectral components of the light emitted by the colored subject so that each point of the image is a record of the difference between the intensities of two different spectral components of the light emitted at the corresponding point of the subject.

17. A color-separation image for use in color reproduction which consists of a monochrome image of a colored subject, each point of which is a record of the difference between the intensities of two spectral components of the light emitted at the corresponding point of the subject.

ARTHUR C. HARDY.

Certificate of Correction

Patent No. 2,193,722. March 12, 1940.

ARTHUR C. HARDY

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 4, for the word "systems" read *system*; lines 64 and 65, for the equations

$$“z_R S_R + z_G S_G + z_B S_B = z$$
$$y_R S_R + y_G S_G + y_B S_B = y”$$

read

$$y_R S_R + y_G S_G + y_B S_B = y$$
$$z_R S_R + z_G S_G + z_B S_B = z$$

page 5, first column, line 26, for "apparatus C" read *apparatus C1*; and second column, line 49, after "in" insert *the*; page 6, second column, line 39, claim 12, strike out "that of"; page 7, second column, line 1, claim 15, before "difference" insert *the*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 23rd day of April, A. D. 1940.

[SEAL]

HENRY VAN ARSDALE,
Acting Commissioner of Patents.