

July 7, 1964

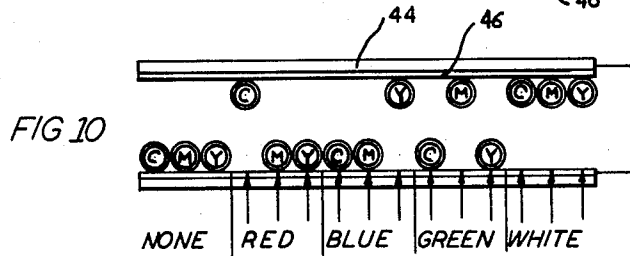
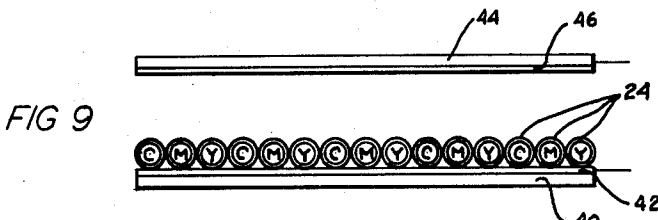
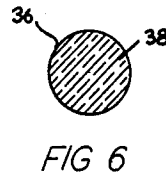
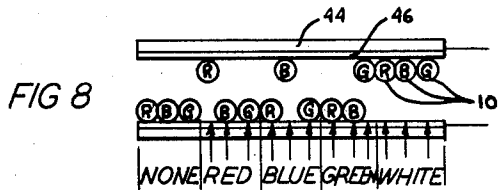
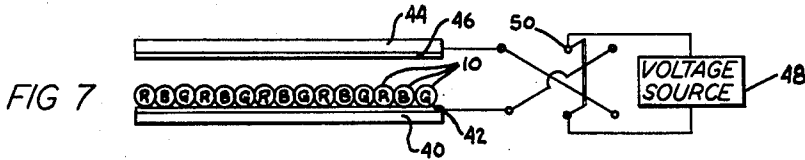
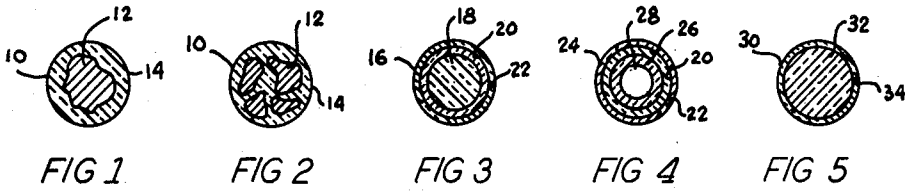
E. K. KAPRELIAN

3,140,175

COLOR ELECTROPHOTOGRAPHY

Original Filed July 3, 1957

2 Sheets-Sheet 1



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INVENTOR.

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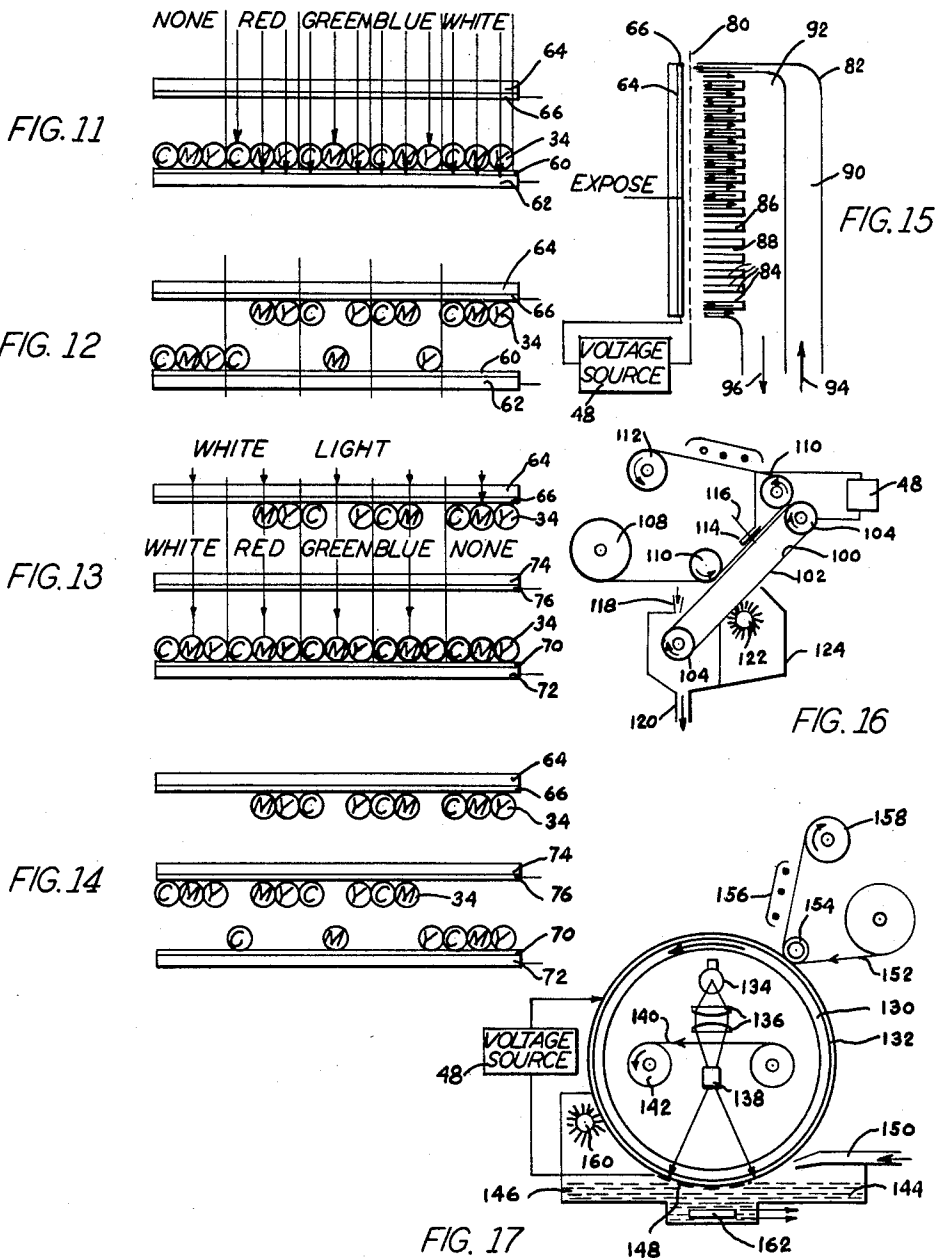
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1

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## COLOR ELECTROPHOTOGRAPHY

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Original application July 3, 1957, Ser. No. 669,866, now Patent No. 2,940,847, dated June 14, 1960. Divided and this application Mar. 14, 1960, Ser. No. 14,778  
12 Claims. (Cl. 96—1)

This application is a division of application Ser. No. 669,866, filed July 3, 1957, now Patent No. 2,940,847.

This invention relates to improved methods and means for electrostatic color photography or color printing.

In ordinary electrostatic photography or printing there is formed on an insulating surface an intermediate electrostatic image, corresponding in potentials to the light values of the original object, and this electrostatic image is rendered visible by dusting with a suitable powder which adheres selectively to the surface in a pattern corresponding to the electrostatic image. A description of this process may be found in U.S. Patent 2,297,691, issued Oct. 6, 1942, to C. F. Carlson.

It is also possible to practice electrostatic photography by illuminating a layer of normally insulating photoconductive powder which is located in an electrical field. In this case powder lying in an illuminated area becomes charged and is attracted away to a region of opposite polarity. A description of this process may be found in U.S. Patent 2,758,939, issued Aug. 14, 1956, to M. L. Sugarman.

In the electrophotographic processes of these and other patents of the prior art the action is essentially that of an ordinary monochromatic or black-and-white system. The basic image is one rendered in monochrome, and it is possible, by utilizing color separation techniques, to produce color prints or photographs by superimposing in proper registry separation images employing properly chosen dyes or pigments.

In contrast with previously known systems the present invention produces the color image directly in a single step without the use of separation images. In the practice of this invention the color image is produced by the selective migration of charged color particles in an electrical field according to the color or wavelength of the light.

One of the objects of this invention is to employ the principles of electrostatic electrophotography in the production of color prints.

Another object is to provide a relatively simple, direct and low cost arrangement for the production of color photographs, prints, posters and signs.

Still another object is the provision of a method and means for the continuous production of color prints.

These and other objects will become apparent from the specification and drawings in which:

FIG. 1 shows in cross section one form of photoconductive color particle.

FIG. 2 shows in cross section another form of photoconductive color particle.

FIG. 3 shows in cross section still another form of photoconductive color particle.

FIG. 4 shows in cross section still another form of photoconductive color particle.

FIG. 5 shows in cross section one form of a non-photoconductive color particle.

FIG. 6 shows in cross section another form of non-photoconductive particle.

FIG. 7 shows diagrammatically the arrangement of photoconductive color particles prior to exposure in one method of the invention.

FIG. 8 shows diagrammatically the arrangement of the color particles of FIG. 7 after exposure.

2

FIG. 9 shows diagrammatically the arrangement of photoconductive color particles prior to exposure in another method of the invention.

FIG. 10 shows diagrammatically the arrangement of the color particles of FIG. 9 after exposure.

FIG. 11 shows diagrammatically the arrangement of non photoconductive color particles prior to exposure in still another method of the invention.

FIG. 12 shows diagrammatically the arrangement of the color particles of FIG. 11 after exposure.

FIG. 13 shows diagrammatically the relationship of elements for printing from the color image resulting in FIG. 12.

FIG. 14 shows diagrammatically the final arrangement of the color particles in FIG. 13 after exposure.

FIG. 15 shows one means employing color particles for producing an image.

FIG. 16 shows another means employing color particles for producing an image.

FIG. 17 shows still another means employing color particles for producing an image.

The color particles shown in FIGS. 1 to 6 are typical of the image forming elements which can be utilized with the method of photography described herein. In the use of any of these particles the essential action is that in a layer of mixed color particles, those particles of a given color will migrate or, if desirable, react oppositely by remaining unmoved when subjected to light of the given color.

The color particle 10 of FIGS. 1 and 2 comprises one or more bits 12 of a suitable photoconductor surrounded by a layer or coating 14 of dyed gelatin or similar material. Typical photoconductive materials include selenium, zinc oxide, cadmium sulfide, cadmium telluride, anthracene, and sulfur. Actually any photoconductive powder may be used, and it is preferred that the particle sizes fall in the range of 2 to 30 microns. The dyed layer may consist of any suitable dye in gelatin, wax, vinyl or silicone resin, cellulose ester or similar material in a thickness of from 4 to 25 microns. The powdered photoconductor may be mixed with the dyed layer material together with a solvent and then dried while being agitated, as by a warm air blast. Spraying of the photoconductor-solvent-dye layer mixture into a heated chamber will also yield suitable particles. In order to increase the photographic speed of these particles it may be necessary to add to the dye layer a small amount of a suitable salt to reduce the electrical resistance of the layer and thereby permit more rapid charging of the particle.

FIG. 3 shows a particle 16 comprising a central core 18 which may consist of a clear, transparent glass or plastic bead carrying a transparent photoconductive layer 20 and an outer, dyed, transparent layer or coating 22. The multiple layers may be formed in the manner described in connection with particle 10, or the photoconductor layer may be evaporated onto the glass bead. A bead diameter of 3 to 30 microns, a photoconductive layer of 5 to 60 microns thickness and a dyed layer of 4 to 25 microns thickness will yield satisfactory particles in the 21 to 250 micron diameter range.

FIG. 4 shows a particle 24 comprising an inner capsule 26 containing a liquid dye 28, a photoconductor layer 20 and a dye layer 22. The dye filled capsule 26 preferably in the diameter range of 3 to 20 microns, may be produced in the manner described in U.S. Patents 2,730,456, 2,730,457 and 2,714,074, issued by B. Green. The photoconductor layer may be added by evaporation and the dye layer applied as described in connection with FIGS. 1 and 2.

FIG. 5 shows a particle 30 comprising a colored glass or plastic bead 32 covered with a thin layer 34 of a conducting material. In the case of glass beads a layer of

fused transparent tin oxide is suitable. In the case of plastic beads a thin transparent layer of evaporated metal is preferred, although treatment with so called anti-static solutions is also suitable. As shown in FIG. 6, it is also possible to produce beads 36 which comprise a solid, substantially spherical body 38 of tin oxide or other transparent electrically conducting materials which are suitably colored in the mass. As in the case of other particles a diameter of between 3 and 40 microns is preferred for particles of this class, although for some applications larger particles are suitable.

In the practice of color electrophotography as set forth in the present invention the following series of steps or their equivalent must be performed in the approximate order shown:

- (1) Establishment of an electrostatic field.
- (2) Production of a light image.
- (3) Charging or discharging of colored particles, which are in the electrostatic field and on which the light image is received, in accordance with the color and pattern of the image.
- (4) Migration of either the charged or the discharged particles of step 3, corresponding to the image, to a new surface or a new location.
- (5) Fixing or receiving onto a final support surface migrated or non-migrated particles, or both, to form a final fixed color image.

It will be noted that with some arrangements to be described certain steps, particularly those enumerated 1 and 2 above, can be reversed in order.

FIGS. 7 and 8 show one arrangement whereby additive color images can be produced by the use of colored photoconductive particles. A glass or similar transparent plate 40 carries a transparent electrically conducting layer 42 of NESA glass or thin evaporated metal. An upper electrode plate 44 spaced from plate 40 by any suitable distance from 1 or 2 millimeters to several centimeters, carries at its lower surface a particle receiving layer 46 to be described below. A suitable source 48 of D.C. voltage, connected to layer 42 and electrode 44 is provided with suitable switching means 50. A negative potential of from 300 volts to 5000 volts is applied to electrode 44 depending upon its spacing from plate 40 and the characteristics of the particles employed. In this arrangement particles 10 and 16 of the type shown in FIGS. 1, 2 and 3, colored red, green and blue, are employed. A substantially uniform layer of these particles is placed on conducting glass 42. For purposes of illustration a single layer is shown in FIG. 7; the layer may be 3 or more particles deep and can be applied by simply cascading onto surface 42, or by spraying, or by applying with a roller.

After exposure to light of various colors the particles migrate to the position shown in FIG. 8. Where red, green and blue light reach surface 42, the red, green and blue particles, respectively, migrate to surface 46. Where white light reaches surface 42 particles of all three colors migrate, while at the non-illuminated areas there is no migration of particles. The image which results on surface 46 is a positive image of the additive type, which for proper viewing as a print must be transferred to a black base, for example a sheet of black surfaced paper or plastic material. The image may be transferred to such a base by the usual electrostatic means or through action of a suitable adhesive layer. Fixing of the image may be accomplished by heating the surface to cause fusion and bonding of the particle surface or the particles may be immobilized by means of a transparent adhesive overlay.

If desired, surface 46 may constitute an adhesive layer supported on a suitable base sheet in which case it becomes the image support. The image which remains on surface 42 is a negative image, also of the additive type and may be also transferred to a black base. This

may be the desired image if color reversal is a requirement of the process.

As shown in the arrangement of FIGS. 9 and 10 this method can also be adapted to subtractive color photography. Here the arrangement of electrodes is similar to that of FIGS. 7 and 8 and the parts have been numbered correspondingly. In this modification, transparent colored particles 52 of the type shown in FIG. 4 are employed, containing cyan, magenta and yellow dye at centers 28 and colored red, green and blue respectively at layers 32. Initially particles 52 are randomly distributed on surface 42 in a layer 3 to 4 particles deep, although in FIG. 9 they are shown in a single layer with regular distribution for the purpose of explanation. When subjected to a light image some of the particles will be moved upwardly depending upon the color of light. Where red strikes a red jacketed particle 24 containing cyan dye resting on surface 42 the resistance of the photoconductive layer is reduced, the particle becomes charged and migrates to surface 46. The photoconductive layer of a blue jacketed yellow containing particle struck by red light will remain unchanged in electrical resistance and will not acquire a charge from surface 42 and will not migrate. Neither will a green jacketed magenta containing particle migrate when struck by red light. Blue light will cause blue jacketed yellow containing particles to migrate while leaving the red and green jacketed particles unmoved, and green light will cause green jacketed magenta containing particles to migrate while leaving the cyan and yellow jacketed particles unmoved. Exposure to white light causes particles of all three jacket colors to migrate to surface 46. Following exposure the red jacketed cyan containing particles, blue jacketed yellow containing particles and green jacketed magenta containing particles will delineate on surface 46 red, blue and green areas of the original subject. These particles are transferred, preferably by electrostatic means, to a transparent base or to a white reflective base coated with a suitable transparent absorbent layer, such as gelatin. A similar sheet is laid over the particle carrying surface, absorbent surface in contact with the particles, and the resulting sandwich subjected to pressure as, for example, by passing between a pair of rollers. The pressure causes the particles to burst, and the dye previously contained within them is absorbed by the absorbent surface of the base material. The two base layers are stripped apart and the particles of debris removed by means of brushing or washing. The resulting image will be a color reversal of the original.

If the transfer is made from surface 42 after exposure the resulting color image will be a positive color photograph.

FIGS. 11 to 14 illustrate still another way in which the invention may be employed to produce subtractive color images. Here the particles 34 are non photoconductive and possess the characteristic described in connection with FIGS. 5 and 6. A layer of particles 34, 3 or 4 deep, is deposited on a photoconductive layer 60 of selenium or other suitable material supported on an electrically conducting base 62 of brass, aluminum or the like which is connected to one terminal of a voltage source such as described in connection with FIG. 7. Spaced from and parallel to the surface 60 is a sheet of glass 64 carrying at its under side a layer 66 of transparent electrically conducting material which is connected to the second terminal of the high voltage source. The layer of particles is exposed by light passing downwardly through sheet 64 and conductive layer 66 onto particles 34. For a given color or spectral band of exposing light one or more of bead colors, which are cyan, magenta or yellow, will transmit the light to the selenium layer below. The selenium layer thereupon becomes conducting, the transmitting bead becomes charged and migrates upwardly to layer 66.

As shown in FIG. 12, red, green and blue light ex-

5

posure results in migration of magenta and yellow, cyan and yellow, and cyan and magenta particles, respectively, to form subtractive color layers, and a reversed color image. In order to assure that the particles apply themselves in substantially layer form it is preferred that the sizes and conductivities of the particles be controlled. By making the cyan particles somewhat smaller and utilizing a relatively lower conductivity surface 38 over the core, these particles will migrate first to form a cyan layer. By increasing the size of the magenta particles and increasing the electrical resistivity of their surface the magenta particles will migrate next to form the second layer. Preferably the yellow particles are the largest and possess the highest resistivity, thereby being deposited last. While the diagrammatic representation in the drawing has been that of a single layer for the sake of simplicity, it should be borne in mind that multiple layers of the type described represent the actual structure. Where white light reaches the particle layer all particles migrate to surface 66. Where no light strikes the particle layer no particles migrate.

The intermediate image appearing on surface 66 is next used for printing as shown in FIGS. 13 and 14. The image on surface 66 is projected onto a selenium plate 70-72, similar to plate 60-62, through a transparent conducting plate 74-76 similar to plate 64-66 onto color particles 34. During exposure these particles migrate to surface 76 to form a subtractive color image, or negative color image, corresponding to the original subject of FIG. 11.

FIG. 15 shows one means for employing particles for the production of color photographs. A transparent plate 64 carrying a conductive layer 66, such as shown in FIGS. 7 to 10 is spaced away from and parallel to a grid 80. Layer 66 and grid 80 are maintained at a suitable potential difference by connection to a source 48 of high voltage. Spaced away from the opposite surface of grid 80 and parallel thereto is a particle distribution head indicated generally at 82, consisting of spaced apart plates 84 which form a series of alternate duct areas 86 and 88. Duct areas 86 are connected to a supply chamber 90 while ducts 88 are connected to a return chamber 92. An air blast shown by arrow 94 carries mixed color particles, such as those shown in FIGS. 1, 2 and 3, into duct areas 86, through screen 80 and against layer 66 in a direction generally perpendicular to the latter. The appropriately colored particles are charged by their passage through the grid and adhere to layer 66. Particles which remain inactive, because of their non-response to light of a wavelength to which their resistance remains unchanged, are drawn into duct areas 88, through chamber 92, and returned as indicated by arrow 96 to a receiving chamber, not shown. The color particles on layer 66 are transferred to a black paper or plastic base and are there fixed by heat or other well known means.

FIG. 16 shows diagrammatically a continuous color print machine employing color particles. An endless belt 100 of electrically conducting flexible material carries on its outer surface a layer 102 of selenium or other photoconductor and is supported by a pair of pulleys 104. Spaced parallel to and spaced from belt 100 is a web of suitable base material 106 such as transparent plastic fed from roll 108 under rollers 110 and onto takeup roll 112. One terminal of a voltage source 48 connects to belt 100 and the other to a transparent electrode 114 in contact with base material 106. An exposure station 116 is located above electrode 114; the image at 116 moves synchronously with belt 100 and web 106.

Layer 102 receives a charge of color particles such as that shown in FIG. 5 from a hopper-like distributor 118 which cascades the particles onto the belt, the angle of repose of the latter being such that only a sufficient depth of particles is retained, the remainder being carried away for reuse through duct 120. Layer 102 is cleaned of unused particles by means of a rotary brush 122, and the

6

unused particles are retained in chamber 124 for reclassification and reuse. Reclassification of the particles into three portions, each containing a single color is accomplished in a fashion analogous to the color process itself, i.e. by successive exposure of the particles, while on a photoconductive surface, to light of a given color.

The continuous printer shown in FIG. 17 employs a rotary transparent drum 130 carrying on its outer surface a transparent conductive coating 132. Within the drum is an exposure station comprising a light source 134, condensers 136 and projection lens 138. The transparency to be printed is shown in the form of a web 140 passing under the condenser and moving synchronously with drum 130 onto takeup spool 142. The color particles employed are of the type shown in FIG. 4 and are suspended in a liquid dielectric such as light mineral oil or carbon tetrachloride, the mixture 144 of particles and liquid vehicle being carried in a sump compartment 146. A high voltage source 48 connects to the conductive layer 132 and to a fine mesh grid 148 beneath the mixture 144 and spaced from 0.1 to 10 mm. from layer 132 depending upon particle size and concentration as well as potential. An air squeegee 150 directs air against the surface of the drum to remove unwanted particles and to wholly or partially dry the drum surface.

A web of transparent plastic base material 152 is held in contact with the drum by means of a roller 154 and passes under a suitable fixing station 156 before being taken up on reel 158. A brush 160 cleans the drum surface prior to exposure. An ultrasonic generator 162 is located in the developer sump below grid 148 and causes the impingement of developer particles against the drum in a direction substantially normal to the drum surface.

In operation, the original on film 140 is imaged through the drum and onto the layer of particles between surface 132 and the grid 148, the image moving at the same speed as the periphery of the drum. Particles of the correct color are energized in accordance with the showing in FIGS. 9 and 10 and adhere to coating 132. Accidentally entrained particles are removed by the air jet 150 and the color image is transferred to base 152 and fixed by heat or similar means at station 156. The cleaning action of brush 160 insures that surface 132 is free of contaminating particles prior to exposure. From time to time the proper relationship of relative concentration of the color particles in the mixture 144 must be restored by addition of the needed color or colors.

It is apparent that other arrangements for creating an electrostatic field and for causing selection of color particles according to the exposing color are readily possible and that other constructions of the color particles themselves are practical and could be devised by those skilled in the art. The applications are not limited to photography alone, the method lending itself well for example, to the printing of posters, signs, labels and reflective traffic signs.

I claim:

1. A method of color electrophotography comprising the steps of providing a uniform substantially continuous layer of transparent image forming particles of at least two colors on a photoconductive insulating surface, projecting an image containing at least said two colors through said layer of particles and then onto said photoconductive surface, and applying a potential between said surface and an electrode parallel to said surface sufficient to cause charged particles to migrate away from said surface.

2. A method for photographically reproducing images in color comprising providing a uniform substantially continuous layer of developer consisting of light transmitting developer particles of at least two colors on a photoconductive insulating surface supported on a lower electrode and spaced from a light-transmitting upper electrode, exposing the developer particles by projecting an image of said colors on to said surface through said layer of particles while applying an electric field between said electrodes, thereby to charge those particles which receive light

of their own color, and to attract the charged particles to said upper electrode to adhere thereto and form a color image thereon.

3. The method of claim 2 including the further steps of removing remaining developer particles from the photoconductive surface following said exposure, depositing on said photoconductive surface a new layer of the developer particles, spacing a third electrode parallel to and between said first electrodes, exposing said new layer to the projected light pattern of the image adhering to said upper electrode, simultaneously applying electrical potential between said third electrode and said lower electrode whereby the particles in said new layer of developer are caused to migrate and adhere to said third electrode in an image configuration having colors reversed with respect to said first adhered image pattern.

4. The method of claim 2, wherein said developer comprises substantially equal parts of cyan colored particles, magenta colored particles and yellow colored particles.

5. The method of claim 4, wherein the average size of the particles of a given color differs from that of the other colors.

6. The method of claim 4 wherein the average electrical conductivity of the particles of a given color differs from that of the other colors.

7. The method of claim 4, wherein particles of one color possess the smallest size and highest electrical conductivity, those of a second color possess the largest size and lowest electrical conductivity and those of the third color possess a size and electrical conductivity median to the others.

8. The method of claim 4 wherein the color image comprises portions of superposed layers of cyan particles, magenta particles and yellow particles.

9. A method for photographically reproducing images in color which comprises providing a uniform, substantially continuous layer of light-transmitting developer particles of at least two colors on the upper surface of a photoconductive insulating layer supported on a lower electrode and spaced from a light-transparent upper electrode; simultaneously applying an electric field between said electrodes and projecting a light image containing at least said two colors through said layer of developer

particles and upon said photoconductive insulating layer, thereby to charge such developer particles as receive and transmit light of their own color and to attract the charged particles away from the photoconductive insulating layer leaving a first color image thereon.

10. A method as claimed in claim 9 including intercepting the charged developer particles attracted away from said photoconductive insulating layer at the lower surface of the upper electrode to produce on said lower surface a second, negative color image having colors reversed with respect to those in said first image.

11. A method as claimed in claim 10 including the further steps of projecting said second negative color image onto a second layer of light-transmitting color developer particles of at least said two colors on the upper surface of a second photoconductive insulating layer supported on a lower electrode and spaced from a second light-transmitting upper electrode, simultaneously applying an electrical field between said second lower and upper electrodes, thereby to charge those developer particles which receive and transmit light of their own color and to attract said charged particles away from the second photoconductive insulating layer and against the second upper electrode to produce thereon an image in natural colors.

12. A method as claimed in claim 9 wherein the individual developer particles are colored cyan, magenta and yellow.

References Cited in the file of this patent

UNITED STATES PATENTS

2,297,691	Carlson	Oct. 6, 1942
2,752,833	Jacob	July 3, 1956
2,758,525	Moncrieff-Yeates	Aug. 14, 1956
2,758,939	Sugarman	Aug. 14, 1956
2,808,328	Jacob	Oct. 1, 1957
2,901,374	Gundlach	Aug. 25, 1959
2,907,674	Metcalfe et al.	Oct. 6, 1959
2,940,847	Kaprelian	June 14, 1960
2,962,374	Dessauer	Nov. 29, 1960
2,962,375	Schaffert	Nov. 29, 1960
3,010,883	Johnson et al.	Nov. 28, 1961
3,045,644	Schwartz	July 24, 1962