copying the black-and-white print

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Reprinted from PSA JOURNAL, Photographic Science and Technique, Volume 16B, No.6, June 1950

tDelivered at the PSA Convention, St. Louis, Missouri, 20 October 1949. Received 21 April 1950.

*Communication No. 1342 from the Kodak Research Labora tories, Rochester, New York.

In accordance with the recommendation of the Colorimetry Committee of the Optical Society of America (see J. Opt. Soc. Am. 34, 245, 1944), the term *illuminance* is used in this paper instead of *illumination* to specify the amount of light incident on a surface. *Luminance* is used instead of *brightness.*

The following terms are also used:

Original subject: A scene or object.

Original negative: A photographic negative of a scene or object.

Original print: A paper positive printed from an original nega. tive.

Intermediaje print: A paper positive printed from the original negative specifically for copying.

Best visual print: The most satisfactory print from an aesthetic viewpoint.

Copy Negative: A camera negative of an original or intermediate paper print.

Copy Print: A paper print of the copy negative.

THE PRACTICE of copying photographs has been employed for various reasons almost since the advent of photography itself. In recent years improvements in sensitized materials and in the design and manufacture of lenses have made it possible to produce a copy print of *some* photographs which are virtually indistinguishable from the original. It does not follow that a perfect reproduction, a facsimile, can be made from all photographs. Paradoxically, it is more difficult to reproduce a high-quality photograph than it is to reproduce a poor one. An old, faded, or yellowed print, Figure 1, can be reproduced with an actual enhancement of quality, but the glossy commercialtype photograph, or any print with a long density scale, suffers from a loss of quality in the copying process. If an exterior sunlit scene of a luminance scale 160 or greater can be satisfactorily reproduced with some specific negative and positive materials, why is it not possible to use these same materials to reproduce a photographic print with a luminance scale of only 40 or less? The answer will be obvious when we evaluate the steps of the process and plot the results graphically.

The copying of continuous-tone photographs differs from other applications of photography in that it is possible to compare the copy print directly with the original print, since the two prints may be viftually alike in every respect and viewed side by side under identical lighting conditions. In viewing an original photograph, the evaluation must be largely subjective, since the original subject may not be available for comparison, and in any case, it is usually colored, three-dimensional, and larger or smaller than the photograph. It is possible to measure the actual luminance scale of a scene with laboratory instruments and to evaluate the reproduction objectively, but this has its difficulties and is seldom done for other than investigational purposes. The relationship between the density scale of a photographic print and the luminance scale of the scene may and does vary from one scene to another, or even from one print to another made from the same negative. The amount of compression or expansion of the density scale of an original print is derermined primarily by the luminance scale of the scene or object, and to a lesser degree by other factors.

The variation in the quality of prints made from the same negative is largely influenced by the judgment of the individual performing the printing and processing steps, and his judgment may be conditioned by many variables such as the spectral quality and intensity of the illumination under which he examines the print, the surface characteristics of the paper while wet, and the sequence in which he prints negatives of varying subject types. This is not the case in the copying process, where generally the desired result is a facsimile, and the two-dimensional original is available for comparison. Differences in quality or tone reproduction are, therefore, immediately obvious. In the reproduction of a photographic print of an average density scale, these differences usually appear as a loss of highlight detail (contrast) and a loss of shadow contrast. When the contrast of either the shadows or highlights is preserved, the contrast of the middletones is excessive. The middle-tones can be reproduced faithfully if good reproduction of the highlights is not required, or if the picture contains no highlights. Figure 2 is an example of a photograph containing mostly middletones.

In general, the distortion of tone reproduction in the copying process is largely a cumulative result of the inherent characteristics of sensitized materials, particularly of the paper, the optical properties of the photographic lens, and the technique employed in the copying procedure. Ideally, the lens selected should be one designed for process work, coated, inspected regularly for dirt and smudges, aligned optically with the copy and the film, and used at its best working aperture (adequate field coverage and the maximum tolerable diffraction). Use of apertures smaller than the optimum impairs the image definition, and consequently the picture quality. The camera must be of rugged construction to maintain the lens and film precisely parallel, and the filmholders should be designed to hold the negative material flat in the focal plane. Uniform illumination of the copy is necessary but is often neglected. Precise control of the factors in negative development-time, temperature, agitation, exhaustion of the developer-is as important as any other step in the process. In the printing operation, the choice of adequate equipment and its careful maintenance is no less important.

In a commercial plant where copy negatives are routinely made, it is possible to establish a standard procedure which can reduce the variables to a minimum. On the other hand, those photographers who are not professionally engaged in copying may not have adequate equipment or sufficient skill. The use of equipment not designed for process photography, or the failure to follow an exact procedure, may introduce distortions of tone reproduction other than those which are an inherent part of the conventional process. The loss in print quality is relatively great for only small deviations from an established photographic technique. The characteristic curves of the camera negative and the sensitized paper, together with the related tone reproduction curves, clearly illustrate the limitations of the copying process and explain why distortions other than those normal to the process degrade the reproduction in general.

In Figure 5A, the density scale of the original photographic print including the unexposed border is 1.70. Nevertheless, it is virtuall~ impossible to obtain a paper facsimile reproduction of it with the available materials and conventional methods. It is a suitable subject to demonstrate the limitations of the copying process, as the centers of interest are composed of large dark areas containing what is commonly termed "shadow detail," and contrasting light tones of fine gradation blending with the middletones. Minor changes in the highlight contrast or the highlight-middletone relatiQnship produce a seemingly disproportionate change in the quality of the reproduction. But a corresponding loss of contrast or detail in the shadows does not subjectively degrade the quality of the copy to the same degree for two reasons: (1) The eye is little sensitiye to contrast differences at relatively low illuminance levels (normal room illumination). (2) The lack of detail in a shadow area may suggest to the viewer only an absence of light.

In Figure 3 a calibrated gray scale is attached to the original print to be copied to serve as a control and to aid in plotting the steps of the copying process. In all of the preliminary tests, a series of paper gray scales were p051-tioned in random patterns on the large print, from which a family of curves was plotted to establish a representative characteristic curve of the negative, thereby compensating for a possible lack of uniform image illuminance. The curve of the negative of the gray scale made on Kodak Commercial Film, developed in Kodak DK-50 Developer (1-1), 3_ minutes, 680 F., is plotted in this manner in the lower right quadrant of Figure 4 and differs from a sensitometric characteristic curve of the negative material in that flare of the camera lens system, which lowers the gradient of the negative, is included. In making the copy negative of the print, the densities of the original paper gray scale serve as a log exposure scale for the copy negative. These densities are plotted along the base axis of the lower right quadrant of Figure 4. The darkest tone of the paper scale at the optimum negative exposure for a long-density-scale original print is reproduced at *A* on the toe of the negative curve, and the lightest tone in the print is reproduced on the straight-line portion of the curve at *C* and not on the shoulder. Under this particular set of conditions, the density range of the paper gray scale (1.70) is compressed in the negative to a density range of 1.22, the difference between the minimum density, *A,* and the maximum density, *C.*

The characteristic curve of the copy print is determined by enlarging the copy negative of the paper gray scale and plotting the reflection densities of the steps of the copy print against the densities of the corresponding steps of the copy negative. The flare characteristics of the enlarging system are thereby included. The characteristic curve of the copy print as determined by this method is plotted in the lower left quadrant, Figure 4. The densities of the copy negative serve as the log exposure scale for the paper, and with such an arrangement the relationship of the densities of the copy negative to the densities of the copy print is easily traced. In projecting the copy negative in the enlarger, the minimum density, *A,* of the negative transmits most of the incident light and produces the maximum density on the paper at or near the shoulder of the paper curve, *B.* Conversely, the maximum density of the negative, *C,* produces the minimum density on the paper, *D.*

In the upper right quadrant, the reflection densities of the copy print of the gray scale are plotted along the vertical axis and the densities of the original gray scale along the horizontal. The resuJting curve is the tone reproduction curve of the paper gray scale and a deviation from the diagonal indicates the distortion of tone reproduction and its magnitude. The reproductions of several steps of the gray scale are traced by the dotted lines. *E* is the point of intersection of the extension of the lines from points *A* and *B* to the upper right quadrant by the graphical con-struction indicated. Similarly, F is the intersection of the lines extended from *C* and *D.* The density scale of the original gray scale, 1.70, is compressed to a density scale of 1.52 in the reproduction. The minimum density of the copy print is higher and the maximum density lower than the corresponding steps of the original gray scale.

In Figure 3, the selected density areas in the original photographic print which match the steps of the original gray scale are indicated by the connecting lines. The tone reproduction of these related densities is plotted in the upper right quadrant of Figure 4.

At low densities, the tone reproduction curve lies above the diagonal, which is to say, that the density of the repro-duction at that point is greater than the corresponding highlight area of the original print. While the difference appears to be small on the curve, the actual visual difference is substantial. The lines coincide at some values, but the significant fact is that the highlights have a higher density and less contrast than the original, which explains the terms often used to describe copies, "no life," "no sparkle," "lacks brilliance," "flat-looking." In the middletones, the reproduction is almost linear, since the negative and print curves have straight lines throughout this range, or are more nearly complementary. In the dark areas, the loss of contrast and the reduced maximum density are evident. From aesthetic considerations, this distortion of tone reproduction in the dark tones is considerably less objectionable than the loss of highlight contrast and detail.

As was stated earlier, the lack of detail in the dark portions of some types of reproductions may indicate to the viewer only an absence of light in the original scene, but the lack of gradation in the highlight tones produces an unnatural effect.

The distortion of tone reproduction in a copy made with conventional materials is very real. From the reproduction quadrants, the reason for the degradation is quite clear, and the result of the distortion is evident when the reproduction, Figure SC, is compared with the original, Figure SA. The loss of quality is more obvious in an 1 1x14 in. photographic print than it is in the smaller reproduction illustrated in Figure 5. Because of the limitations of the halftone process, the differences in quality between the original on the left and the reproduction exhibit to a lesser degree the actual differences observed in the photographic prints. The loss of highlight contrast has changed the rendering of the highlights appreciably-a loss which can be traced to the shape of the toe portion of the print. The typical sloping toe of a photographic paper is illustrated in Figure 6. It can be seen that the highlights, the minimum density components of the picture, are reproduced on the toe where equal increments of exposure do not produce a proportionate increase in density as they do at higher densities. For example, a log exposure increase of 0.30 in the toe portion increases the density only 0.07, but in the middletones where the gradient is higher, the exposure falls on the straight-line portion of the paper curve, and an exposure increase of lo'g 0.30 increases the density 0.52. The gradient of the toe is lower than the gradient of the straight-line portion. If a paper of a contrast grade is selected on which the middletones are accurately reproduced, the highlights obviously will be too flat, and conversely, if the highlight contrast of the original is retained by choosing a more contrasty paper, the middletone contrast will be too high.

The highlight-middletone relationship cannot be changed without altering the reproduction of the shadows, the maximum density components of the print. Like the highlights, the shadows are reproduced on the non-linear portion of the paper curve, the shoulder, and, therefore, may show a corresponding loss of contrast, or a loss of detail. The gradient of the shoulder, like the gradient of the toe, is lower than the gradient of the straight-line portion. A 0.30 log exposure increases the density 0.13 in the region of the shoulder indicated, compared to the 0.52 increase in the middletones. For the most satisfactory rendering of the shadows with the negative materials now available, the maximum densities of the original print, the shadows, should fall on the straight-line portion of the copy negative curve so as to obtain changes in negative density, which are proportional to the reflection values of the darker areas of the print. Distortion of the shadow reproduction then would be entirely attributable to the characteristics of the paper. But perfect shadow reproduction is possible only when the density scale of the print is considerably less than the normal 1.7. Figure 2 is an example of the type of photograph which can be reproduced saflsfactorily. The reproduction on the right is quite acceptable and the quality of the reproduction is evident in its tone reproduction curve in Figure 7. The density scale of the print is reproduced on the straight-line portion of the paper curve as the negative density scale, 0.9, is not greater than the straight-line portion of the paper curve.

In copying the short-density-scale, high-key photograph, a print composed primarily of light, areas with no dark tones, it is difficult to retain the contrast relationship of the light tones when the minimum density of the reproduction, the white, is printed no darker than the minimum density of the original print. The loss of highlight contrast is illustrated in Figure 4, where it is shown that highlights are reproduced on the toe of the paper curve.

When an original negative of a high-key subject is available, it is possible to make a darker print which is more suitable for reproduction by the photographic or photomechanical processes. The darker print will be decidedly less interesting, since the highlights will be "muddy," but its density scale is expanded because the toe portion of the paper curve is not used, and all the tones are printed on the straight-line portion of the paper curve where the gradient is higher. The lighter, more pleasing print may have a density scale of 0.60. When printed darker on the same grade of paper, the density scale is increased to 0.95, and the contrast relationship of the tones corresponding to the highlights is greater. In copying this darker intermediate print, the copy negative is exposed so that the density scale of the print is reproduced on the toe of the negative curve, rather than on the straight-line portion, by reducing the negative exposure to a critical minimum. Since the toe of a negative curve is somewhat bow-shaped, the gradient progressively rises until the straight-line portion is reached. The extreme light tones are, therefore, reproduced at a relatively higher contrast on the negative than the more dense areas of the print, which are copied on the extreme toe where the gradient is lower.

In copying the lighter but more pleasing print, the loss of quality is unavoidable as the light tones can be reproduced only on the toe of the paper curve if the minimum density of the highlight of the original print is retained in the copy print, Figure 8A. The density scale of 0.60 remains the same, but the highlight contrast is reduced. The highlight contrast of a reproduction made from the darker print more closely matches that of the original lighter print, Figure 8B.

When a high-key photographic print, or any print which contains highlights but no dark shadow areas, is to be reproduced either photographically or photomechanically, the best reproduction can be made from a print exposed so that all tones (the entire density scale) are reproduced on the straight-line portion of the paper curve. However, a normal lighter print is also required as a guide, so that the reproduction from the darker print can be held at approximately the same density and contrast as that of the lighter guide print.

It is evident from the illustrations that the copying materials, the equipment, and the methods available today, are capable of producing reproduction of many photographs which closely match the quality of the originals. In employing conventional copying methods in reproducing a photograph of a moderately long brightness scale, a sacrifice of highlight quality is to be expected. Added distortions of tone reproduction resulting from the neglect of equipment maintenance, or the abuse of copying principles, even though they may be small, generally degrade the copy to a degree which may not seem consistent with a minor violation of photographic technique.

Lens flare influences the shape of the toe of the negative curve, and consequently affects the reproduction. Flare may be defined as the non-image light at the film plane which arises from the intersurface reflections between the glass-air-lens surfaces, and from reflections within the lens mount and within the camera or the enlarger, as the case may be. While this light is non-image-forming light, it, nevertheless, contributes to the image, as the density of the print is affected by the quantity of the flare light. Flare is not a constant factor with a given lens system and camera. It varies from one scene to another, depending upon the luminance scale of a scene and the area relationship of the luminance values, and with the environment. The flare factor of the camera system is determined by the ratio of the luminance scale of the object to the luminance scale of the image. It may be high for a scene with an extreme luminance range, and small for a high-key subject, even though the actual total flare in the latter- case is greater. In the copying process, flare other than the inherent flare of the lens system is largely controllable by the photographer. The physical condition of the lens is dependent upon the care it has received. The presence of dust, scratches, fingerprints, smudges, and the opalescent coating with which exposed glass surfaces are eventually coated, is responsible for a higher 'flare factor than the combined inherent flare properties of a well-designed lens and camera. Surprisingly, an unclean lens is much more common than a clean lens, and the amount of dirt that collects on it is even more surprising.

Light falling on the lens from extraneous sources, such as light-colored walls, near-by windows, and the direct rays from the copy lights, is a second source of flare no less common than the dirty lens. A properly designed lens hood helps to shield the lens and eliminates flare from these sources, but to reduce flare to a minimum, the print must be attached to a black copyboard which is considerably longer than the print itself. All lights but the copy lights should be extinguished. By replacing the black copyboard with a white one and leaving other factors, including exposure, constant, the shape of the camera negative curve is changed appreciably, as seen in Figure 9. An increase in flare is accompanied by an increased loss of shadow contrast.

The same general principles of flare apply in making projection prints from copy negatives. Camera flare lowers the contrast of the shadows. Flare in the enlarger degrades the highlights, a most undesirable factor, because a slight loss in highlight rendition produces a substantial loss in the photographic quality of the reproduction. The effect may be demonstrated by making two enlargements from a negative step tablet which is substantially smaller than the enlarger negative carrier. One print is made with the negative framing mask positioned so that only the light transmitted by the step tablet reaches the lens. A second print is exposed with the mask removed, permitting other than image-forming light to be transmitted to the lens. The change of the shape of the toe portion of the paper curve of the print by the introduction of flare is seen in Figure 10. The so-called "muddy highlights" of projection prints in many cases may be traced to a dirty enlarger lens or to the lack of framing masks in the negative carrier, or to both.

The quality of the reproduction then is dependent upon many variables, most of which fortunately are under the control of the photographer. How can the quality of a reproduction be improved? The use of crossed Pola-Screens effectively increases the luminance scale of a photographic print, but this increase is partially compensated for by the slightly diffuse nature of the Pola-Screen which adds flare to the toe of the negative curve. The advantages of the screens in eliminating reflections, fine abrasions, and the pattern of surface texture outweighs the slight lQss in tone reproduction induced by the increased luminance scale.

When an original negative is available, a print can be made from it which is more suitable for copying than the print which may be more satisfying in appearance. The print quality of the original photograph, Figure SA, was achieved using the devices of dodging, diffusion, and even a two-stage development. The original, viewed under sufficient illumination, has a rich quality that sets it apart from the ordinary print. Unfortunately, it has a density scale of 1.7, which exceeds the range that can be successfully copied with conventional materials. In printing the same original negative on a paper of lower contrast, the density scale is reduced to 1.45, Figure SB, a range which can be reproduced with less distortion. The highlights of the shorter-density-scale print are printed to a higher density to increase their contrast relationship, and the shadows printed no darker than is necessary to preserve the highlight detail. The reproduction of this lower-contrast print, Figure SD, more closely matches the quality of the higher-contrast print, Figure SC. The reproduction of the high-contrast print is not as satisfactory. From this we can conclude that in making a print to be reproduced by the normal photographic or halftone process, the original print should have a luminance scale not exceeding 1.45. This can be accomplished usually by using a somewhat lower contrast grade of paper than the normal, or by developing the paper in a less contrasty developer.

The reproductions of prints of a relatively long luminance scale, as we have seen thus far, cannot be called facsimiles because of the obvious differences in the luminance values of the original and the copy. There is a method whereby facsimiles or near-facsimiles can be made by the use of two camera negatives, one of higher density and slightly higher contrast than the normal copy negative, and one of low density but extreme contrast. The two negatives are printed by contact or projection in sequence and in registration at a definite exposure ratio. This is a modification of the Person Process With careful control it is capable of yielding nearly perfect objective tone reproduction. In the copying process, perfect tone reproduction can be realized only when the products of the slopes of the curve of the negative and the printed characteristic positive curve, as determined by the printing method used, equal unity at corresponding points throughout the usable range. The ideal negative curve then is a mirror image of the print curve rotated 90 degrees. Figure 11 is a representative charaderistic curve of Kodak Kodabromide F-2, as determined by projection printing. Now, if we turn the page, rotate it 90 degrees, and view the diagram by transmitted light, we see the theoretical negative for perfect tone reproduction, Figure 12. There is no one negative material available today that has such a curve, but it is possible to synthesize an acceptable curve by the use of two different types of negatives. One, the principal negative, is developed to a garrna of 1.0 and the other, a high-contrast highlight negative, is exposed and developed to obtain a maximum density of approximately 1.2. Glass plates are substituted for the more common film since the difficulties associated with the precise superimposing of enlarged images are considerably reduced. The Kodak 50 Plate, which is similar in characteristics to Kodak Commercial Film, is a suitable material for the principal negative. Curve *A,* Figure 13, is the camera characteristic curve of the plate developed in OK-SO (1:1) for 61/2 minutes at 680 F., with continuous agitation in a tray. The camera exposure is adjusted in the case illustrated so that the maximum density is 2.0 and the minimum density 0.55. It is significant to note that the toe of the curve is not used.

The auxiliary or highlight negative is exposed on a Kodak Kodalith Ortho Plate. The speed of this plate is approximately one tenth that of the Kodak 50, when developed in the standard Kodalith Developer modified by the addition of one part of Kodak SDR-1 to two parts of Solutions A and B. The developing is extremely critical and depends largely upon the inspection method rather than upon the time and temperature procedure. When the Kodalith Plate is correctly exposed, a faint image is distinguishable in safelight illumination at the end of two minutes and Continues to increase slowly in density until a rapid and marked increase takes place at the end of approximately 3_ minutes. It is at this critical stage that the plate is removed and immediately immersed in a stop-bath to arrest d&velopment. After fixing, the low-d&nsity image is brownish and its effective density is therefore greater than the visual density. The curve of the negative, B, Figure 13, is determined by reading the densities through a blue filter. As the two negatives are not printed at the same exposure ratio, the effective curve is calculated by combining that fraction of the transmission of the highlight curve with transmission of the principal negative curve, the fraction being determined by the printing exposure ratio. The formula for calculating the effective characteristic curve is:

where

T = transmtssion of principal negative

T = transmission of highlight negative

T = transmission of effective negative

E = printing exposure time of highlight negative

E = printing exposure time of principal negative.

The exposure ratio of highlight exposure to principal exposure is of the order of one to fourteen. Relatively long exposure timeg are essential to maintain the ratio accurately.

The negatives must be carefully registered to preserve definition in the print. This may be facilitated by mounting the original on a white card only slightly larger than the print. On this white card, a narrow black line is drawn on all four sides so that they intersect at the corners. This provides a sharp line image which may be easily traced on the enlarging easel. With the principal negative positioned in the enlarger, the movable parts are firmly secured. A sheet of ordinary white paper somewhat larger than the projected print is taped carefully on the paper masking board, and the masking board is securely taped in place once it has been properly located with respect to the projected image. The negative image of the black line, which is, of course, a white line on a black background, is traced with a pencil with a point no wider than the image line. A lack of registration in the subsequent printing steps is easily detected and readily corrected. The sensitized paper is carefully positioned for each exposure with three fixed aligning pins, two along the length of the paper and one centrally along the width. After the principal negative is projected, the exposed paper is removed from the masking board and the highlight negative substituted for the first negative. The tape holding the masking board is removed so that the board can be moved about to locate it properly for accurate registration. When the registration pencil-lines, which are traced on the paper secured to the masking board, coincide with the projected image of the ink line, drawn on the original photograph, the line will virtually disappear and the images in the final print will be precisely superimposed. The masking board is again taped securely, the partially exposed paper replaced, carefully positioned, and then re-exposed. The order of exposing the negatives must not be altered once the ratio -of exposure times is established, as a marked difference in density of the print may result. It is another one of those instances where the sum of the parts is not equal to the whole. The effect is illustrated in Figure 14. In print B, the principal negative was exposed for 86 seconds and the highlight negative 6 seconds. In print A, the order of exposure was changed but nothing else. The highlight and principal negatives were exposed for the same exposure times as before. In all other examples, the principal negative was exposed first and followed by the highlight negative exposure.

If, after processing, the print appears to be too dark or too light, the usual compensation in exposure is made, but without varying the exposure ratio of the two negatives. It is difficult to compare the quality of the wet print with that of the original as the wet print darkens appreciably on drying. If a close match is required, the wet print should be printed slightly lighter than the original. If your efforts are reasonably successful, the reproduction and original should be identical twins, alike but with some dissimilarities. The reproduction, Figure 15, does not match the original perfectly, but it is quite close to a facsimile according to the actual tone reproduction curve, plotted not only from the control paper gray scale, but also from the various density areas of the prints, Figure 16. The reproduction in general is superior in every respect to those made by the conventional but simpler methods. The extreme highlights are actually too contrasty for objective reproduction, but subjectively, the extreme highlights are seldom too contrasty as the quality of the reproduction is actually enhanced.

In summary, the photographic print of a relatively long density scale is reproduced with some distortion of tone reproduction with the standard copying materials and methods because of the inherent characteristics of the negative and positive materials. If the original negative of a relatively long luminance scale subject is available, a print can be made from it which is more suitable for copying.

A negative of this type is printed on a lower contrast grade paper than the normal so that the density scale is compressed and is less than that of the best visual print. But the high-key subject to be copied is printed with greater contrast by increasing the printing exposure so that all tones are reproduced on the straight-line portion of the paper curve. The resulting print is darker and has an expanded density scale. In a similar manner, the density scale of a low-key subject to be copied is expanded by reducing the exposure below the normal to avoid the use of the shoulder of the paper curve. In either case, those prints which are less pleasing than the best visual prints make better reproductions.

The photographer then has methods which enable him to prepare master prints modified by various devices to make them more suitable for the intended purpose. Where cost and time are not primary considerations, but quality is, those photographs of a long density scale can best be reproduced by the modification of the more complicated Person Process method.

Acknowledgment

The author is indebted to Mr. Harold Fromm and Mr. Bernard Donahue, of the Kodak Research Laboratory, Photographic Service Department, for their contributions and suggestions, and for their assistance in making the great number of practical tests from which the illustrations were selected.

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