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INTERIMAGE EFFECTS IN VARIOUS SUBTRACTIVE COLOR MATERIALS

Philip F. Wychorski

June 1, 1976

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ABSTRACT

In three color photographic processes the cyan dye image is usually controlled by the red sensitive emulsion, the magenta dye image by the green sensitive layer, and the yellow dye image by the blue sensitive layer. Due to the proximity of these three layers in a color film interactions among the images are found to occur. It has been found that when the images are combined into a three color picture they do not have the same characteristics as they would have if they occurred separately. The density produced in each layer depends not only on the amount of exposure of that layer but also on the amount of exposure in the other layers. The amount of dye image produced in one layer is therefore influenced by the presence or absence of simultaneous development in the other layer. The specific nature of these interactions is an important characteristic of any given color photographic process and are known as interimage effects. These interactions may be studied by means of sensitometric exposures.

Interimage effects have been found in both Kodak Ektachrome Film 5258 (Tungsten) and GAF 2500 (Daylight). Data was obtained by exposing each film to produce single layer exposures and an additive neutral. Plotting the characteristic curves from the data revealed an interaction taking place in each film. Due to the inability to determine the equivalent

neutral densities this report can only justifiably say that an interaction is present in both films. For a more definitive statement on the interimage effects present in each film one must determine the equivalent neutral densities.

INTRODUCTION

In three color photographic processes the cyan dye image is usually controlled by the red sensitive emulsion, the magenta dye image by the green sensitive layer, and the yellow dye image by the blue sensitive layer. Due to the proximity of these three layers in a color film interactions among the images are found to occur. It has been found that when the images are combined into a three color picture they do not have the same characteristics as they would have if they occurred separately. The density produced in each layer depends not only on the amount of exposure of that layer but also on the amount of exposure in the other layers. The amount of dye image produced in one layer is therefore influenced by the presence or absence of simultaneous development in the other layer. The specific nature of these interactions is an important characteristic of any given color photographic process and are known as interimage effects. These interactions may be studied by means of sensitometric exposures.

The interimage effects in two subtractive color materials were analyzed by various sensitometric exposures on each film. This consisted of both single layer and multiple layer exposures. By utilizing these methods one is able to produce an additive neutral, single layer dye separations, and a series of blue, green, and red densities on the integral tripack material.

The effects can be studied by determining the analytical density equations from the yellow, magenta, and cyan separations. Graphically plotting the characteristic curves for the additive neutral versus the single layer exposures will display the effect present in each film.

The last published study of interimage effects was accomplished in 1952 by Hanson and Horton followed by Bates and Gerhardt in 1953. Since that time new emulsions have become availiable and old emulsions have been modified.

In a study of this type one becomes better equipped to understand color sensitometry and densitometry as they are the tools for this type of investigation. Herein lies the justification for this undertaking.

1. FILM STRUCTURE

The subtractive color materials for this study are Kodak Ektachrome Film 5258 (Tungsten) and General Analine Film (GAF) 2500 (Daylight). Since it is necessary to expose the film to narrow bands of radiation high speed films were chosen. This allows the use of a sensitometer that is readily availiable with the necessary luminance to correctly expose the film.

Both films are of the type that have incorporating couplers already present in the emulsion. Figure #1 shows an integral tripack material of the type used in this study.

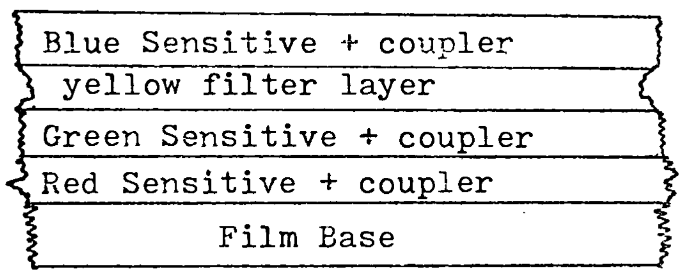


Figure #1. Integral tripack material

The couplers are prevented from wandering away from their proper layers by dissolving them in oily solvents and then dispersing them in the form of minute oil globules. The couplers present in the emulsion layer react with oxidized developing agent to form an insoluble dye.

One of the disadvantages of the subtractive color system is that the best availiable cyan, magenta, and yellow dyes have appreciable absorption in parts of the spectrum where they should have 100% transmission. These absorptions result in colors being reproduced considerably darker than in the orginal scene unless corrections are made. One of the methods to minimize these absorptions is to make each dye image dependent on more than one of the three exposures in such a way as to increase color saturation. This can be accomplished by means of interimage effects.

2. EXPOSURE METHODS

In order to study the interimage effects that occur in subtractive color materials it is necessary to expose the film to narrow bands of energy to restrict the exposure to separate layers of the film.

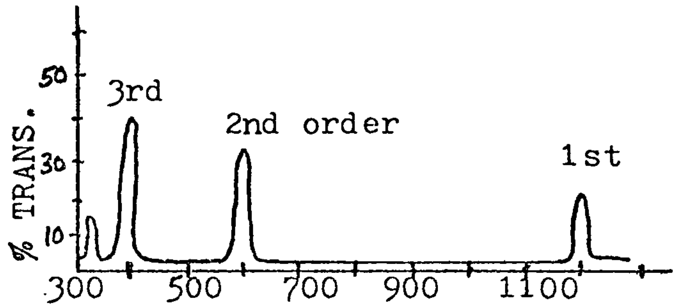
To accomplish the exposures an intensity scale monochromatic sensitometer and an alternative system using interference filters was chosen. The monochromatic sensitometer was designed and constructed by Jay Johnson Jr. This device uses a Bausch and Lomb monochromator as the monochromatic source. The lamp utilized is a GE 18A/T10/1 with ribbon filament operated at 16 amps (approx. 2800K).

The sensitometer has provision for filters in the light path and a M-type carbon step tablet (P67-50-5) hinged to a rotating platen. Exposure is accomplished by transporting the film and step tablet past a slit at a constant velocity. "Several film velocities and slit widths are availiable to produce exposure times from 0.003 to 2.0 seconds. A computer print out lists all speeds and energy availiable at 10 nanometer (nm) intervals. The spectral range is 400 to 670 nm's and the spectral purity is approximately 9nm band-width at half peak power point."[1]

The following modifications and repairs were accomplished to enable the sensitometer to be utilized in exposing the three layers of a color film. For some exposures the step tablet must be removed to uniformly expose (flash) one or two layers of the film. In its present configuration the step tablet is attached to a hinged holder that swings away from a platen for film insertion. A special clamp was designed to replace the hinge so that the entire holder and step tablet can be removed easily and in the dark. The clamp still allows the holder to swing out as originally designed. The second modification has to do with the necessity of changing the wavelength control for each layer of the color film. To accomplish this a removable fiberboard housing, sprayed flat black, was constructed. The housing can be placed over the entire platen which holds the film making it light tight. At this point a small light source (penlight) may be turned on ant the wavelength control adjusted to the next setting.

From misuse and age the external slits have been damaged. New 5 millimeter (mm) and 10 mm width slits were constructed following the procedure recommended by Mr. Johnson in his thesis. GEM razor blades were sprayed flat black except for the knife edges. Then isopropanol was used to deposit carbon black on the knife edge. Under 80X maginification a very uniform edge was observed over the entire edge of all blades. A NIKON #10462 microscope set at 20X was used to align the slits on their carriers. Using an adjustable X-Y vernier control the slits were found to have the following widths: the average width of the 10 mm slit is 10.025 mm and the 5.0 mm slit has a width of 4.99 mm.

An alternative method to the monochromatic sensitometer employing interference filters and a Kodak 101 sensitometer is assigned as a backup system to the Johnson sensitometer. These filters are Bausch and Lomb narrow band interference filters of the second order Fabry Perot construction. They have a 1st order transmission peak at approximately twice the wavelength of the 2nd order peak. They are deposited on clear glass and have a maximum background transmission between peaks of 0.5%. See figure #2 below. The filters have an inherent property that a decrease in wavelength position of a pass band is evident when the filter is tilted from normal incidence. To determine the expected change refer to figure #3. Both figures 2 and 3 are from Bausch and Lomb pamphlet 44-7160.



WAVELENGTH IN NANOMETERS

Figure #2

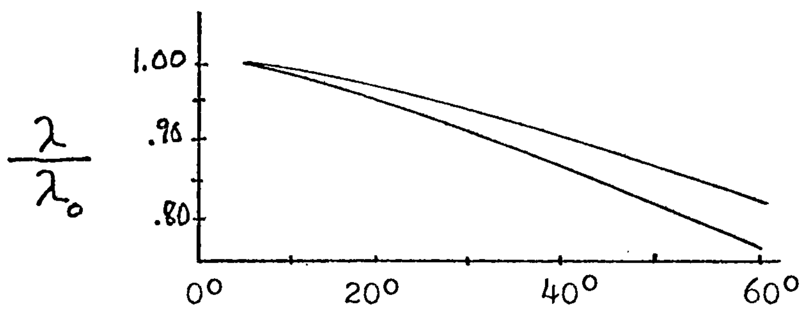


Figure #3

WAVELENGTH DECREASE B & L

These filters are stock items in 2 X 2 X 3/16 inch size with wavelength tolerences on the second order peak and they are stable up to 80°C with a second order peak transmittance of 28% minimum. The filters chosen are a 420 nm and a 540 nm nominal wavelength value. No filter above 600 nm's was readily availiable so a Kodak Wratten #92 red filter was chosen as it transmits only beyond 620 nm. The 420 nm filter has a half width of 9 nm and the 540 nm has a 8 nm half width. The problem with the Bausch and Lomb filters is that they have a 0.5% background transmittance between peaks. To eliminate this a #47B Kodak Wratten filter will be used with the 420 nm Bausch and Lomb (B&L) filter and a #74 Wratten filter with the 540 nm B&L filter. This will limit the background transmittance to a narrow region around that of the exposing wavelength.

The interference filters have been mounted so that they can be inserted into a Kodak 101 Sensitometer EK #101-890. The color temperature of the lamp is 2850°K and for the Kodak 5258 film a #80A filter is used to convert to 3200°K for the film. For the GAF 2500 film a 80A and a 82C will be used. A Kodak #2B absorbs ultraviolet radiation below 390 nm.

A photographic silver step tablet is used to attenuate the light. Specifically a calibrated #2 Kodak step tablet is mounted in its proper holder. The density range is 0.06 to

3.11 in approximately 0.15 density increments. Calibration values for the step tablet appears in appendix A-4. A total of twenty one steps is realized. Each step being five millimeters wide. A plot of density versus wavelength from 400 nm to 700nm shows the photographic silver step tablet to be virtually neutral.[2]

Examination of the 101 sensitometer reveals that it is not quite light tight. Some light can be seen coming from the closed rotary shutter. The light reflected inside the lamp housing gets around the rotary shutter. This can happen because the rotary shutter is about 2 or 3 mm behind the rectangular exit aperture window. To eliminate this problem a matte black housing with a sliding gate was constructed. With the gate in the down position whatever light leaks around the shutter is completely blocked from reaching the film plane. Just prior to exposure the gate is lifted and then dropped after exposure.

3. PROCESSING

All film processing was accomplished in accordance with manufacturers specifications for small tank processing.

For the Kodak film the E-4 process was used and the AR-1 process was used for the GAF film. See instruction sheet packed with processing kits for further instructions. Additionally a water temperature bath was utilized to hold all temperatures within tolerances set by the manufacturer for each respective process. Processing tank was of steel construction and designed to hold 16 ounces of solution.

4. EXPERIMENTAL

The Johnson monochromatic sensitometer was used to expose the film to wavelengths of 450 nm, 550 nm, and 650 nm. Appropriate exposure, in ergs/cm^2/nm, was accomplished by changing the platen rotation and width of the aperture. A series of exposures were completed to produce single layer yellow, magenta, and cyan dye formations. At this point a serious problem with the sensitometer was discovered. The dye images that were formed after processing were found to be non-uniform. An alternating light to dark area was formed across each and every strip.

The problem was traced to the physical construction of the sensitometer. The timing belts on the small matched gears which are required for correct exposure caused a resonance to be set up. This translated itself into a non-uniform exposure due to the uneven rotation given to the platen which holds the film. Suggestions to cure this problem range from using larger timing belts and larger gears to counter acting the resonance with a weight or spring mechanism. Since time is of the essence and these suggestions may not totally solve the problem it has been decided to use interference filters to expose the film.

It might also be mentioned that a number of platen revolutions per minute (rpm) were found to create a problem in the exposure sequence. The highest platen rpm's of $7\frac{1}{2}$, 15, and 30 when set up by proper gear ratios failed to activate the blocking shutter mechanism. The blocking shutter uncovers the lamp and subsequently closes to end the exposure sequence. The cam inside the platen just failed to operate for the above rpm's. The problems inherent in this device are just too great and time consuming to continue operating it for a study of interimage effects.

In order to produce the various exposures the alternative plan was put into use. This consists of the previously described interference filters, step tablet, neutral density (ND) filters, and Kodak 101 sensitometer. The exposure time is fixed at 1/5 of a second and the light source illuminates the film plane with 1700 lumens with no filters in place. Table #1 shows the filters used for each film and the density values of these filters.

KODAK EKTACHROME FILM 5258 (TUNGSTEN)					
BLUE LAYER EXPOSURE		GREEN LAYER EXPOSURE		RED LAYER EXPOSURE	
FILTER	DENSITY	FILTER	DENSITY	FILTER	DENSITY
80A	.15	80A	.50	80A	.74
2B	.24	2B	.04	2B	.04
420B&L	.53	540B&L	.53	92	.15
47B	.36	74	.89	P-ND	.40
P-ND	1.30	P-ND	.00	S-ND	.70
S-ND	1.60	S-ND	.30		
GAF 2500 FILM (DAYLIGHT)					
80A	.15	80A	.50	80A	.74
82C	.12	82C	.22	82C	.35
2B	.24	2B	.04	2B	.04
420B&L	.53	540B&L	.53	92	.15
47B	.36	64	.37	ND	1.70
ND	.60	15	.14		
		ND	.40		

TABLE #1
FILTERS AND DENSITY VALUES FOR EXPOSURE OF FILM

The exposure series for the Kodak and GAF film are the same except for the omission of a secondary neutral for the GAF film. See table #2 for the sequence.

After exposure the film was processed as mentioned previously in this report. It might serve to mention that not all processing was done on the same day. This day to day effect was not accounted for in the statistical analysis of the data. A sample size of three was accomplished for the Kodak film and a sample size of five for GAF 2500 film.

SENSITOMETRIC STRIP	EXPOSURE	KODAK 5258	GAF 2500
Primary Neutral	Blue (B) Green (G) Red (R)	Step Tablet Exposure (STE) " " " " " "	
Secondary Neutral	B G R	STE STE STE	None None None
Yellow Separation	B G R	Step Tablet Exposure Uniform Exposure (FLASH) " " "	
Magenta Separation	B G R	FLASH both films STE " " FLASH " "	
Cyan Separation	B G R	FLASH both films " " " STE " "	
Blue Single Exposure	B	STE both films	
Green Single Exposure	G	STE both films	
Red Single Exposure	R	STE both films	

EXPOSURE SEQUENCE

TABLE #2

5. DENSITOMETRY

In order to analyze the color materials one must distinguish between different types of density. Integral density of any type supplies information only on a functional characteristic of the color film; that is, some integrated effect of the three image absorptions. Analytical densities are designed to determine the composition of the image in terms of its component absorbers, such as yellow, magenta, and cyan which together form the image.

The densitometer used to record the density of all processed strips was a Macbeth TD504 digital densitometer with Status A-58 filter wheel in place. Recently Status A filters have been replaced by Status AA filters but were not used due to unavailiability.[3] The calibration for this densitometer and filter combination appears in appendix A-1.

Status A filters offer a narrow enough wavelength transmittance to assume that "the integral densities are essentially linearly related to spectral densities up to densities of approximately 3.0."[4]

6. DATA ANALYSIS

The data for all strips, exposed and processed, appears in appendix A-2 (Kodak) and appendix A-3 (GAF). The tables contain the mean (μ) value based on respective sample sizes.

A systematic procedure is necessary to determine the analytical densities from integral densities. From the yellow, magenta, and cyan separations the minor densities are plotted versus the major densities. See appendix A-5 (Kodak) and appendix A-6 (GAF). Integral density equations are set up where the values of the analytical densities are the slopes of the respective minor plots.

$$\underline{D} = \underline{\underline{A}}\ \underline{L}$$

where $\underline{D} = \begin{pmatrix} D_b \\ D_g \\ D_r \end{pmatrix}$ $\quad \underline{\underline{A}} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$ $\quad \underline{L} = \begin{pmatrix} Y \\ M \\ C \end{pmatrix}$

Substitution of the GAF data from appendix A-6 yields.

$$\begin{pmatrix} D_b \\ D_g \\ D_r \end{pmatrix} = \begin{pmatrix} 1.0 & .237 & 0 \\ .097 & 1.0 & .209 \\ 0 & .217 & 1.0 \end{pmatrix} \begin{pmatrix} Y \\ M \\ C \end{pmatrix}$$

The analytical densities can be determined as follows:

$$\underline{\underline{D}} = \underline{\underline{A}}\ L$$

$$\underline{\underline{L}} = \underline{\underline{A}}^{1}\ \underline{\underline{D}} \qquad \text{where} \quad \underline{\underline{A}}^{1} = \frac{\text{Aadjoint}}{A}$$

Solving for the GAF $\underline{\underline{A}}^{1}$ matrix yields:

$$\underline{\underline{A}}^{1} = \begin{pmatrix} 1.03 & -.104 & +.023 \\ -.254 & 1.07 & -.233 \\ +.053 & -.224 & 1.05 \end{pmatrix}$$

Therefore the analytical density equations in matrix form for the GAF data are.

$$\text{GAF} = \begin{pmatrix} Y \\ M \\ C \end{pmatrix} = \begin{pmatrix} 1.03 & -.104 & +.023 \\ -.254 & 1.07 & -.233 \\ +.053 & -.224 & 1.05 \end{pmatrix} \begin{pmatrix} D_b \\ D_g \\ D_r \end{pmatrix}$$

The solution using the Kodak data is found in the same manner and yields the following analytical density equations.

$$\text{KODAK} = \begin{pmatrix} Y \\ M \\ C \end{pmatrix} = \begin{pmatrix} 1.01 & -.075 & +.026 \\ -.137 & 1.05 & -.361 \\ -.001 & -.114 & 1.039 \end{pmatrix} \begin{pmatrix} D_b \\ D_g \\ D_r \end{pmatrix}$$

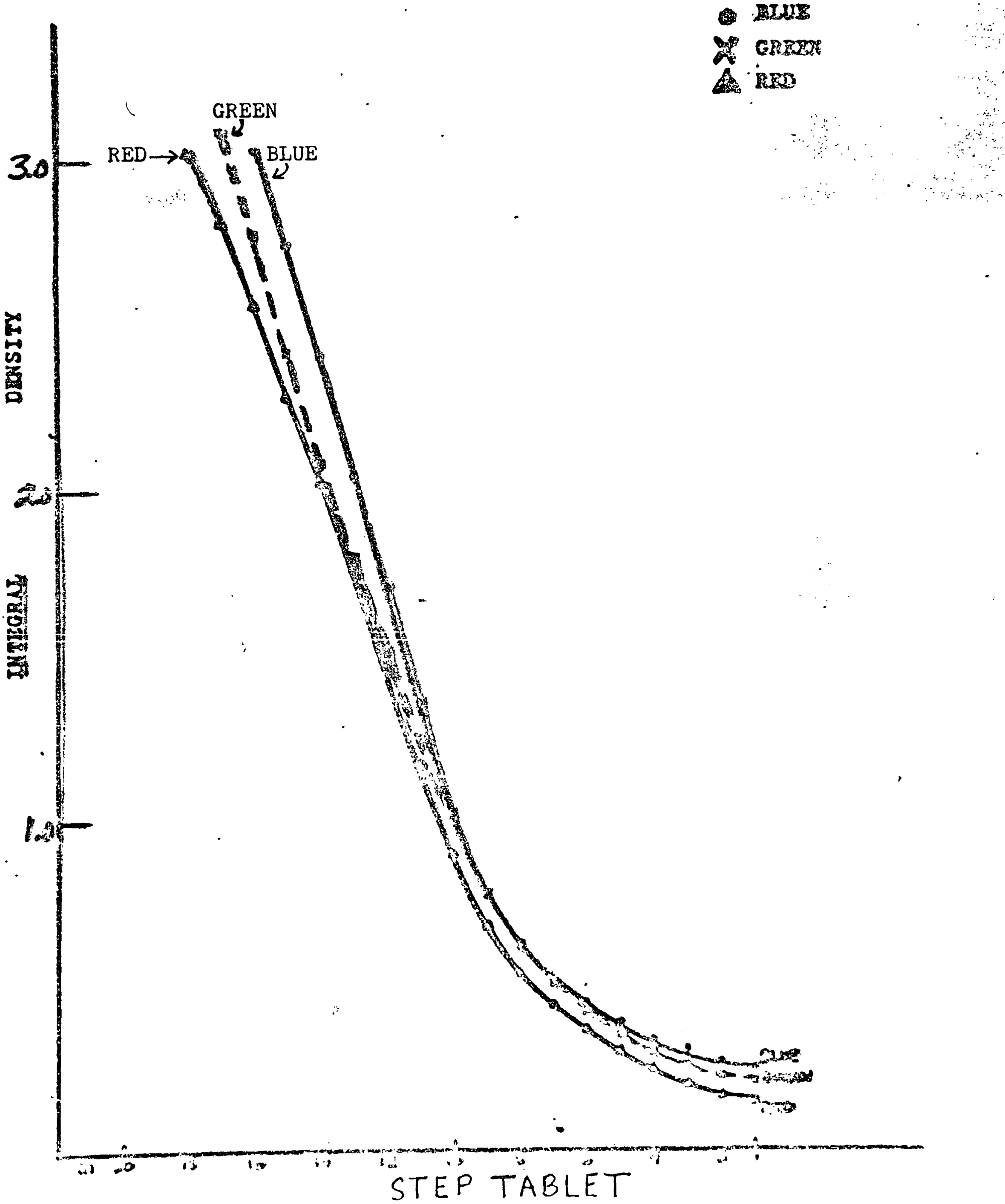
In order to represent the interimage effects in each film a series of graphs have been prepared to show the effect. The first set of figures to follow are those of the Kodak film. Figures 4 and 5 are plots of the primary and additive neutral exposures. If one plots the blue single layer exposure versus the blue curve from a neutral and finds any difference between the two curves interimage effects are present. The same procedure is accomplished with the green and red exposures as shown in figures 6, 7, and 8. It can be seen that an interaction has occurred as the curves do not overlap.

Using the analytical density equations one is able to calculate the density in each layer based on the matrix $\underline{\underline{A}}$ which was obtained from the yellow, magenta, and cyan separations. If a plot of the calculated versus measured additive neutral exposure is made for each layer and any deviation is present once again interimage effects are present. This was accomplished for each layer and appears as figures 9, 10, and 11. This method also shows an interaction as illustrated by the plotted data.

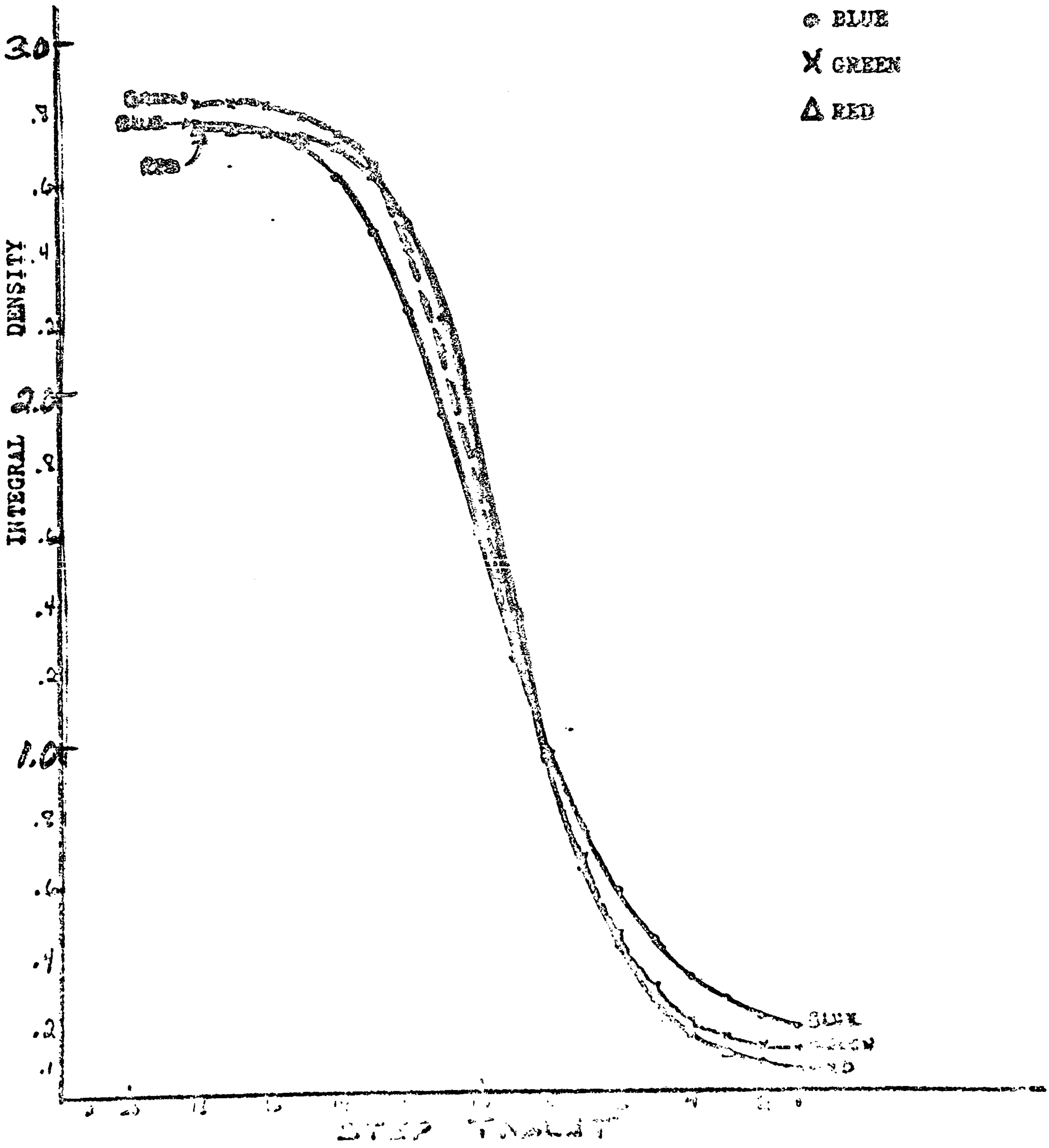
The GAF data was assembled and treated in the same manner. Figure 4A shows the additive neutral while 6A, 7A, and 8A show a single layer plotted next to its additive neutral layer exposure. The last three figures 9A, 10A, and 11A are plots of calculated density using the GAF matrix $\underline{\underline{A}}$ against the measured additive neutral exposure for each layer. As in the Kodak data an interaction is present and the figures illustrate interimage effects in all three layers.

Due to the inability to determine equivalent neutral densities (END's) this report can only justifiably say that an interaction is present in both films as determined by the data. For a more definitive statement on the interactions one must determine the END's. Utilization of equivalent neutral densities will specify a measure of the amount of yellow, magenta, and cyan dye present in each layer. This type of analysis would allow for a more thorough explanation of what is occurring in each layer of a particular film. Additionally it might be possible to correlate the objective measurements with subjective measurements obtained from another experiment using the film under study.

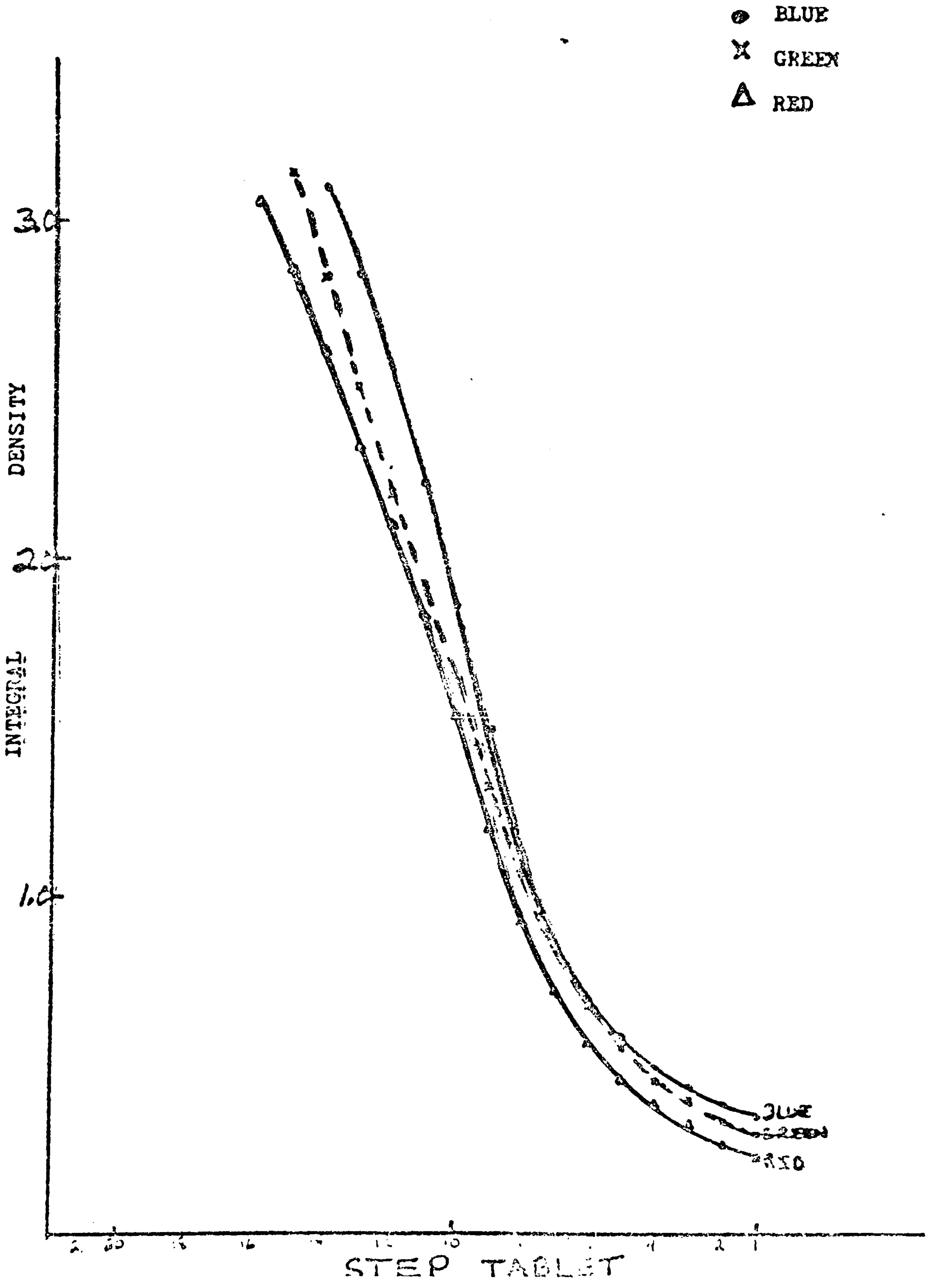
KODAK PRIMARY ADDITIVE NEUTRAL FIGURE #4



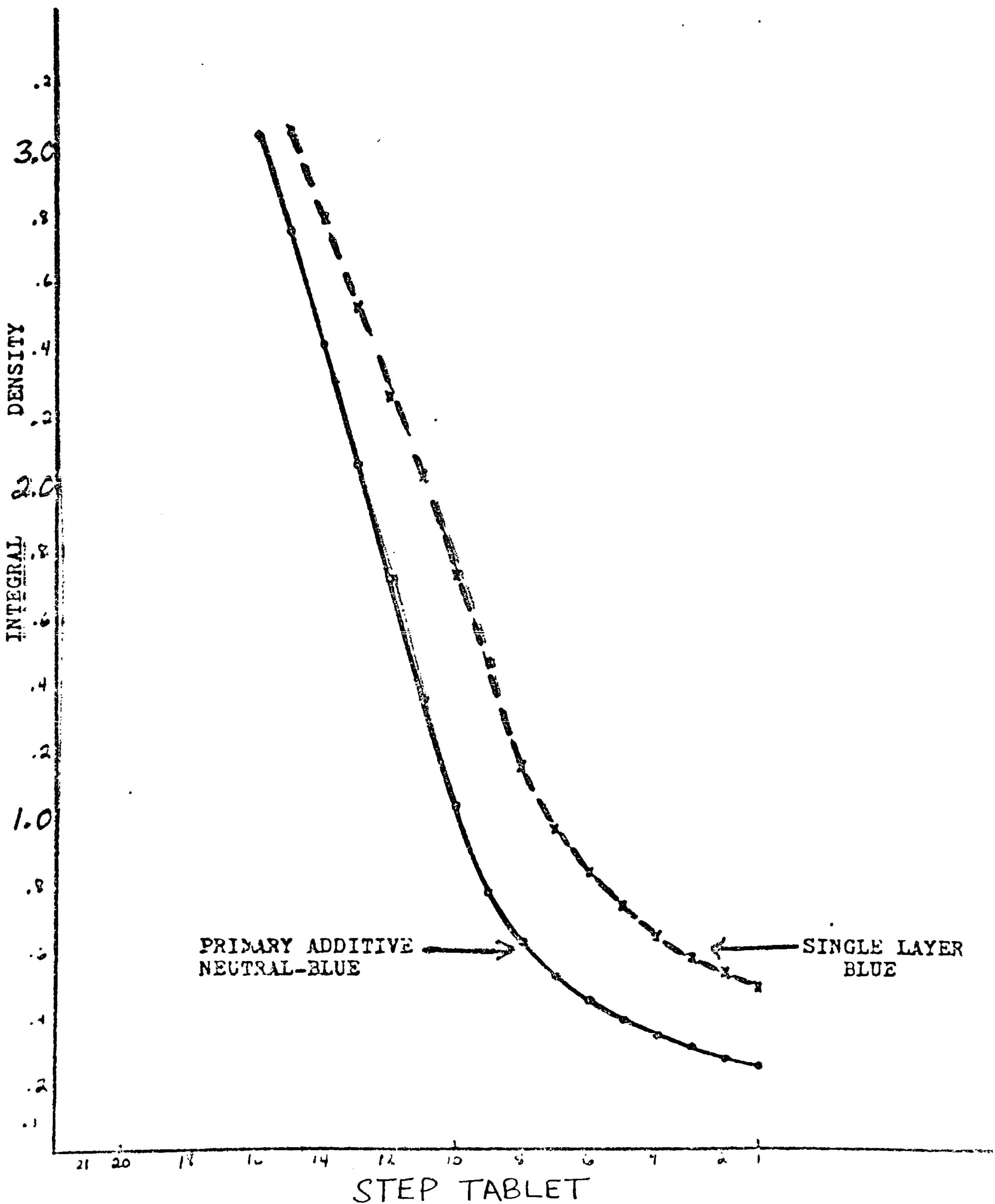
GAF ADDITIVE NEUTRAL FIGURE #4A



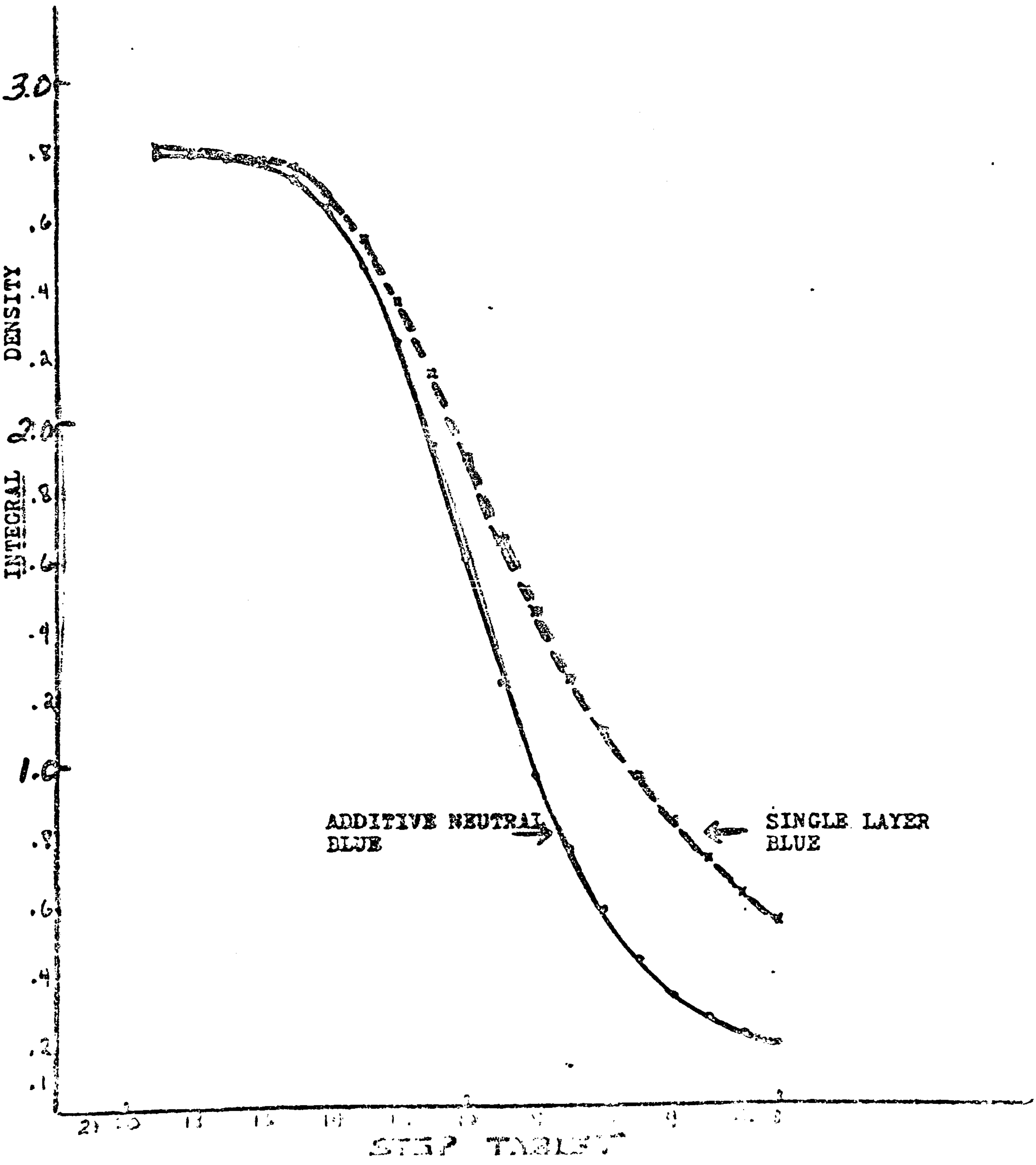
KODAK SECONDARY NEUTRAL FIGURE 5
#5



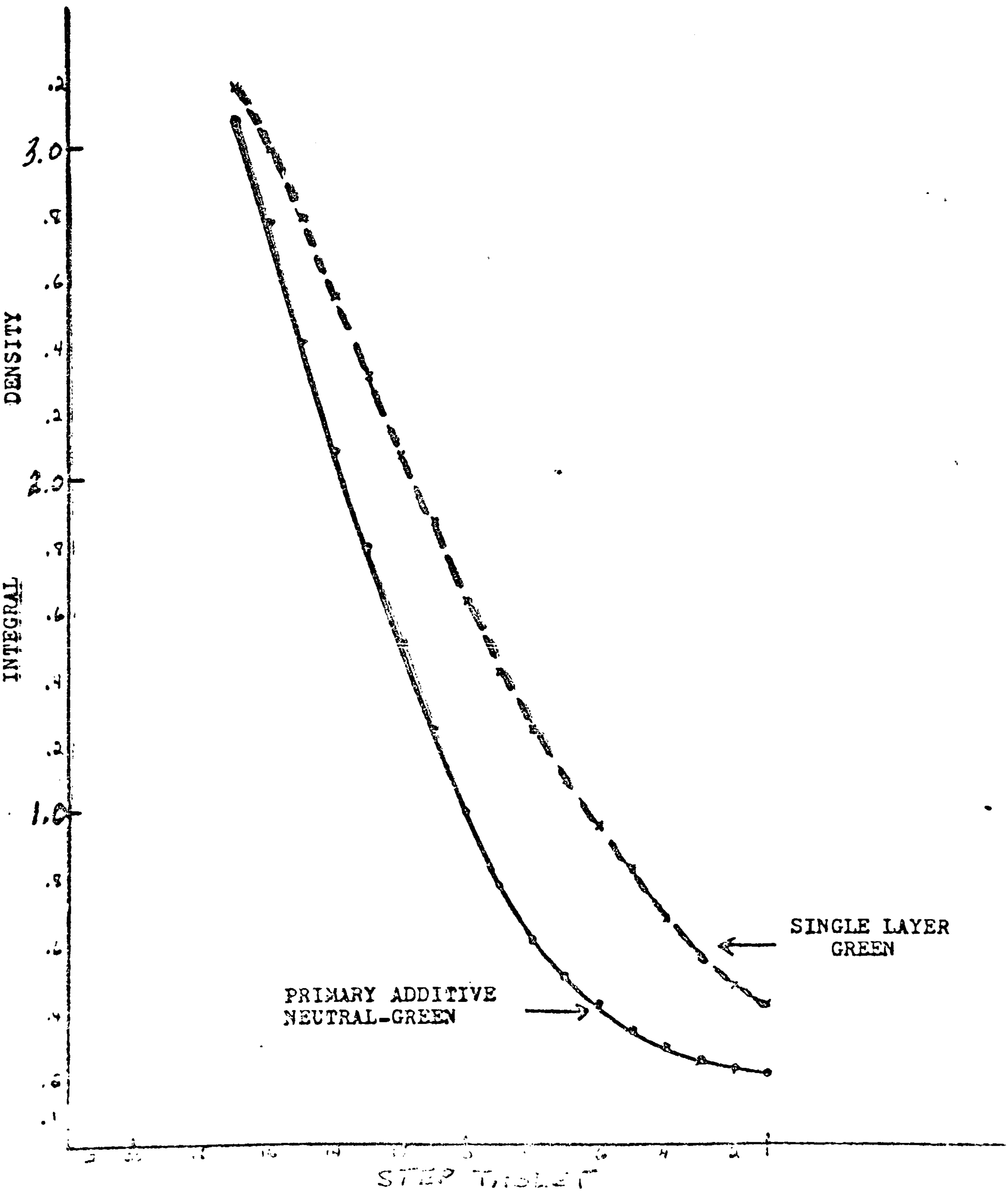
KODAK FIGURE
#6



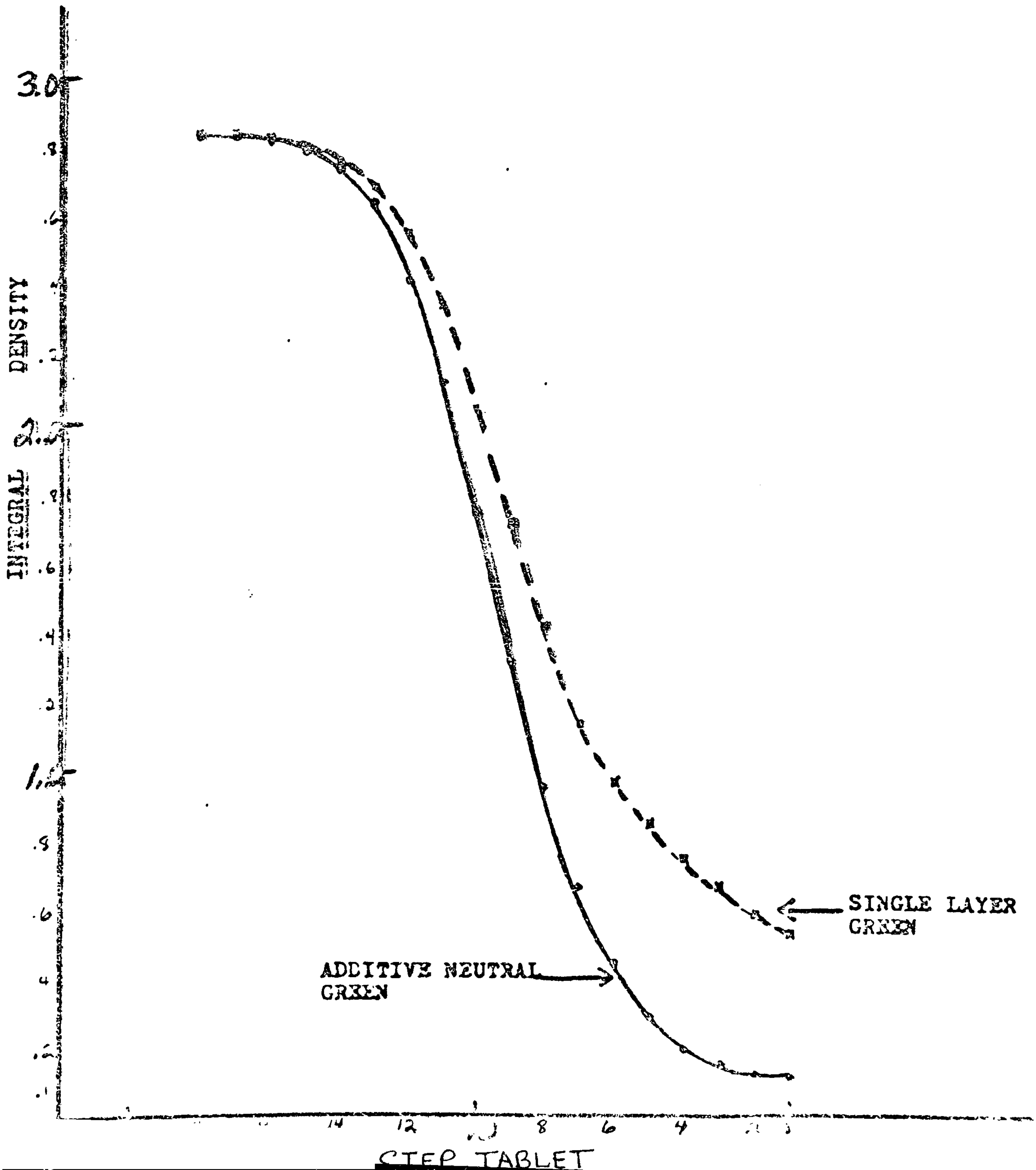
GAF FIGURE
#6A



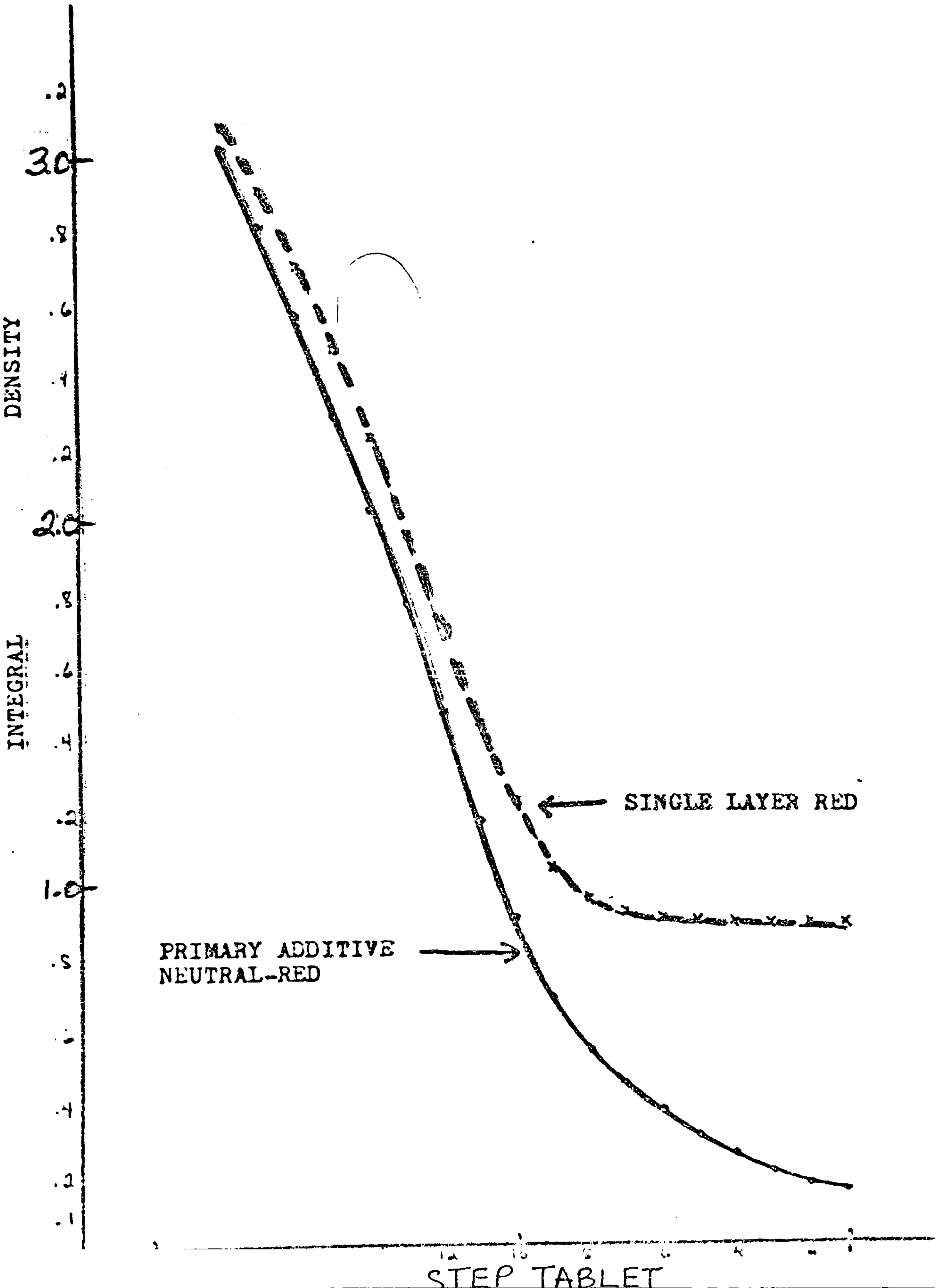
KODAK FIGURE
#7



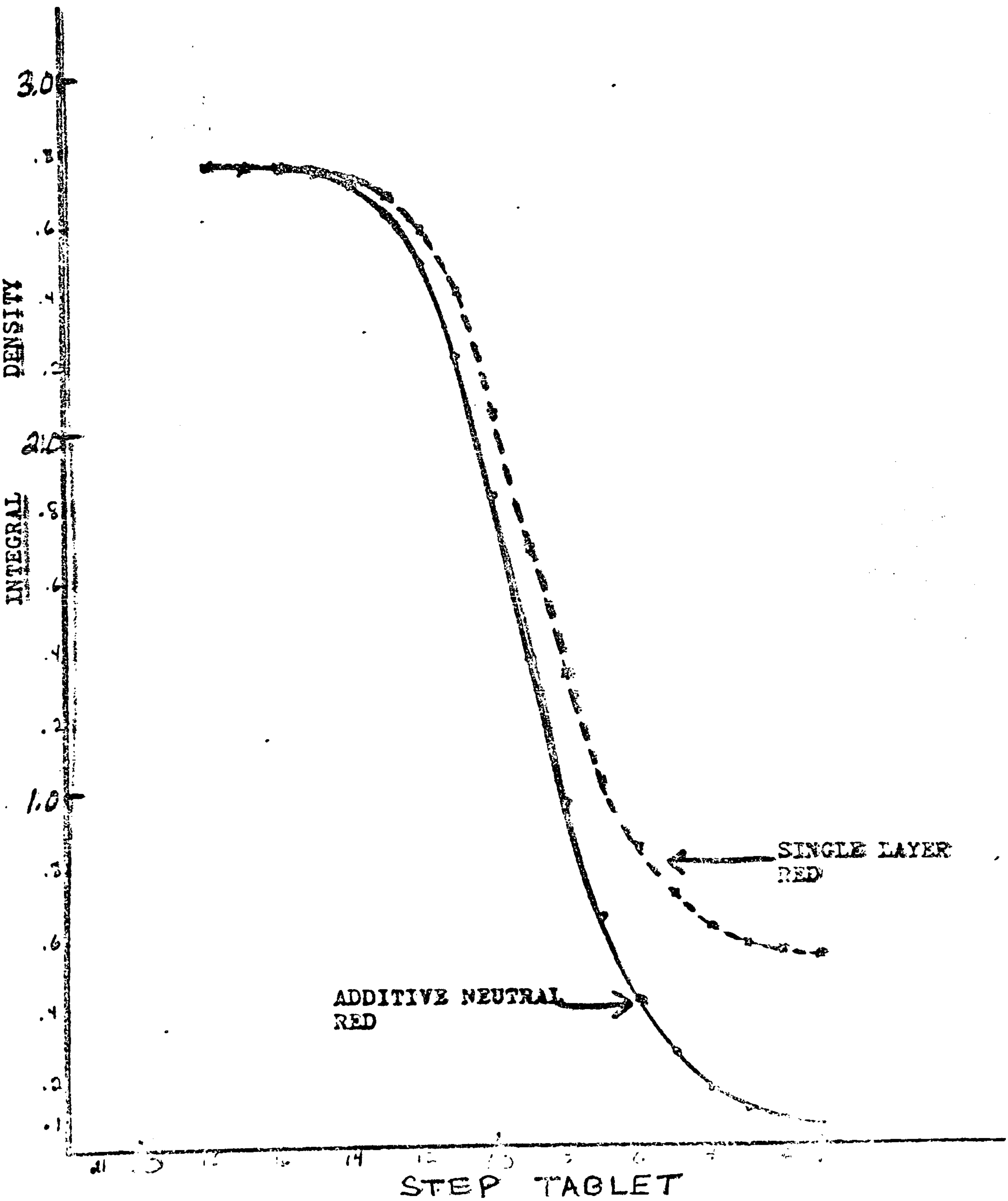
GAP FIGURE #
#7A



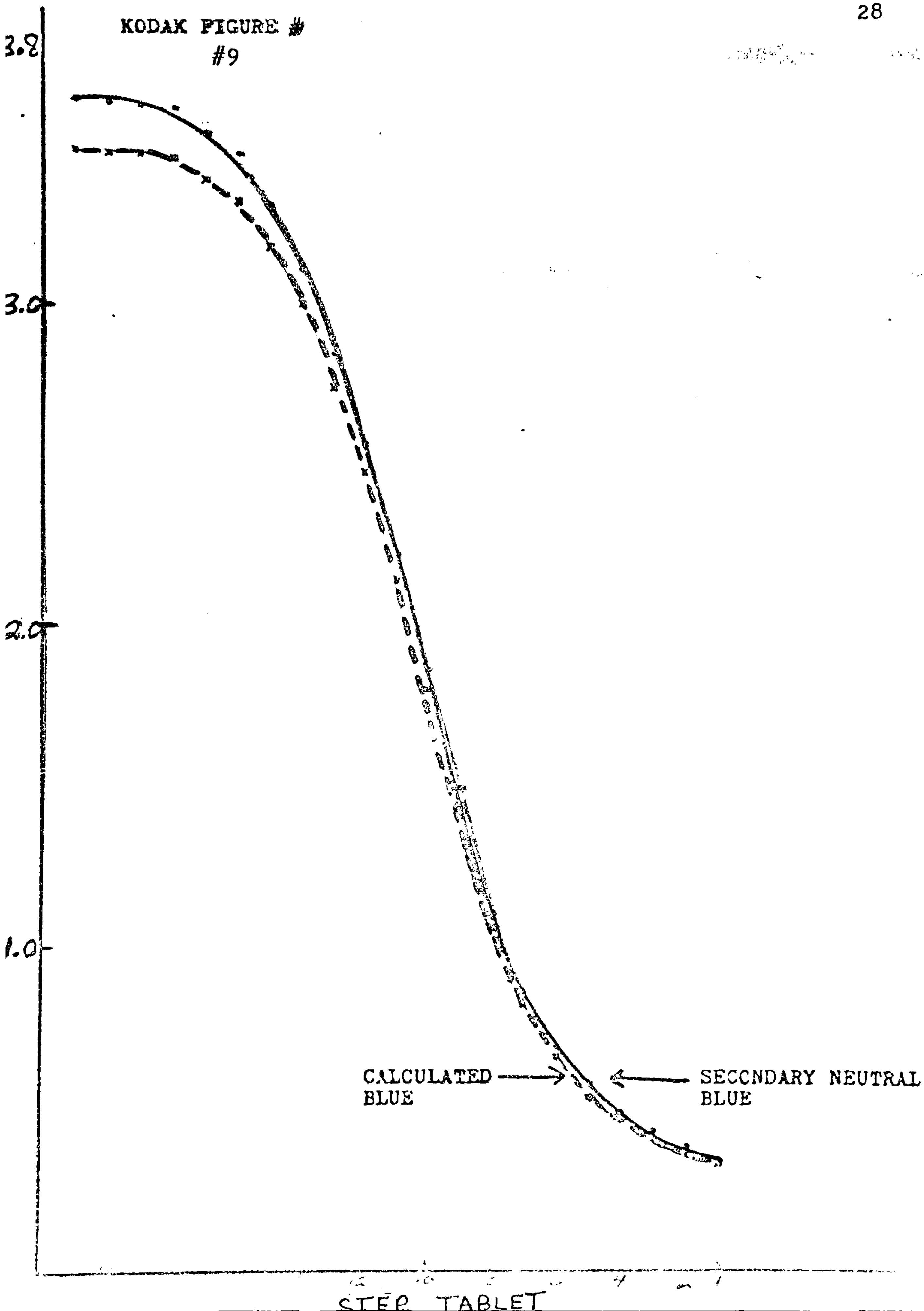
KODAK FIGURE #8



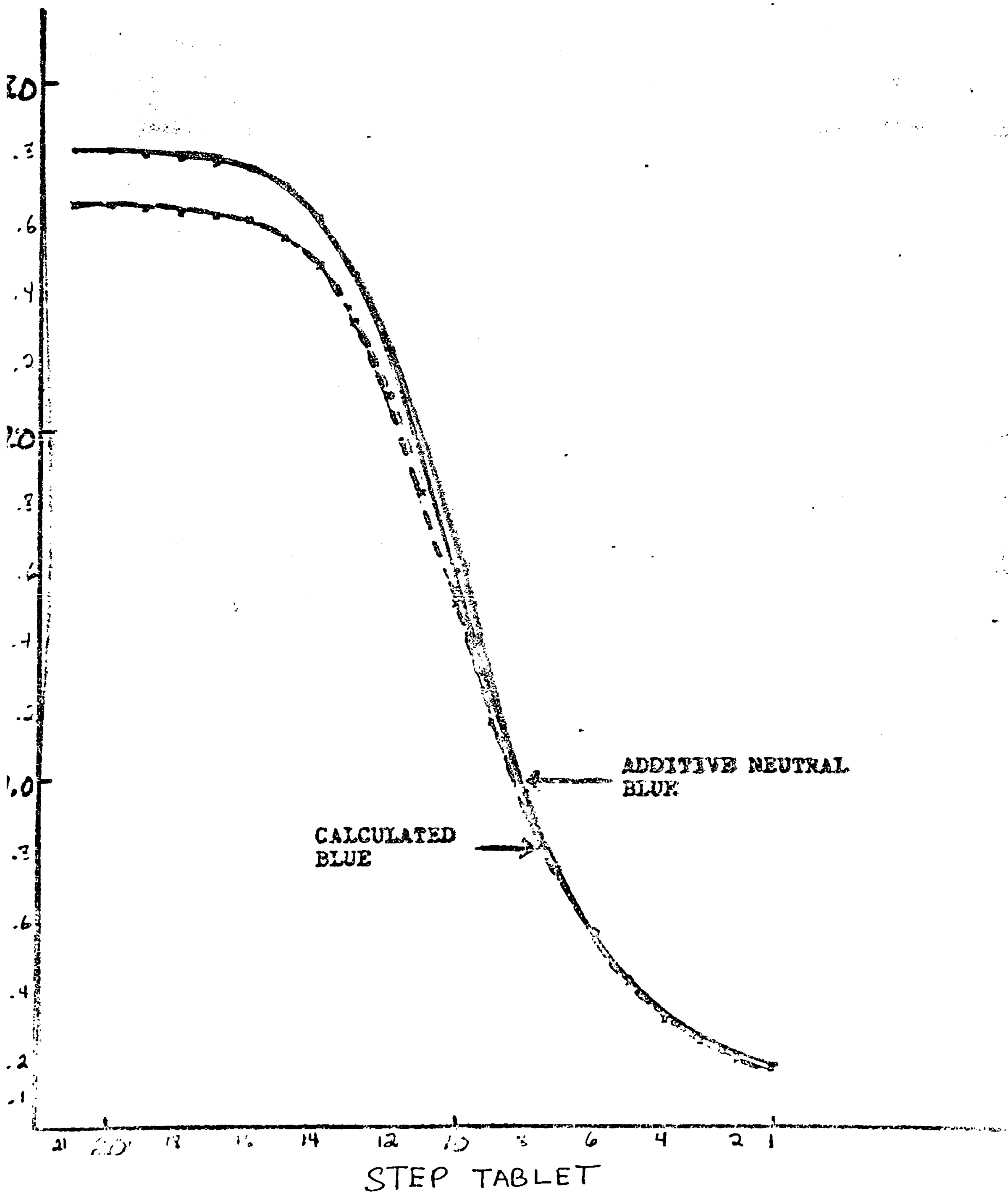
GAB FIGURE
#8A



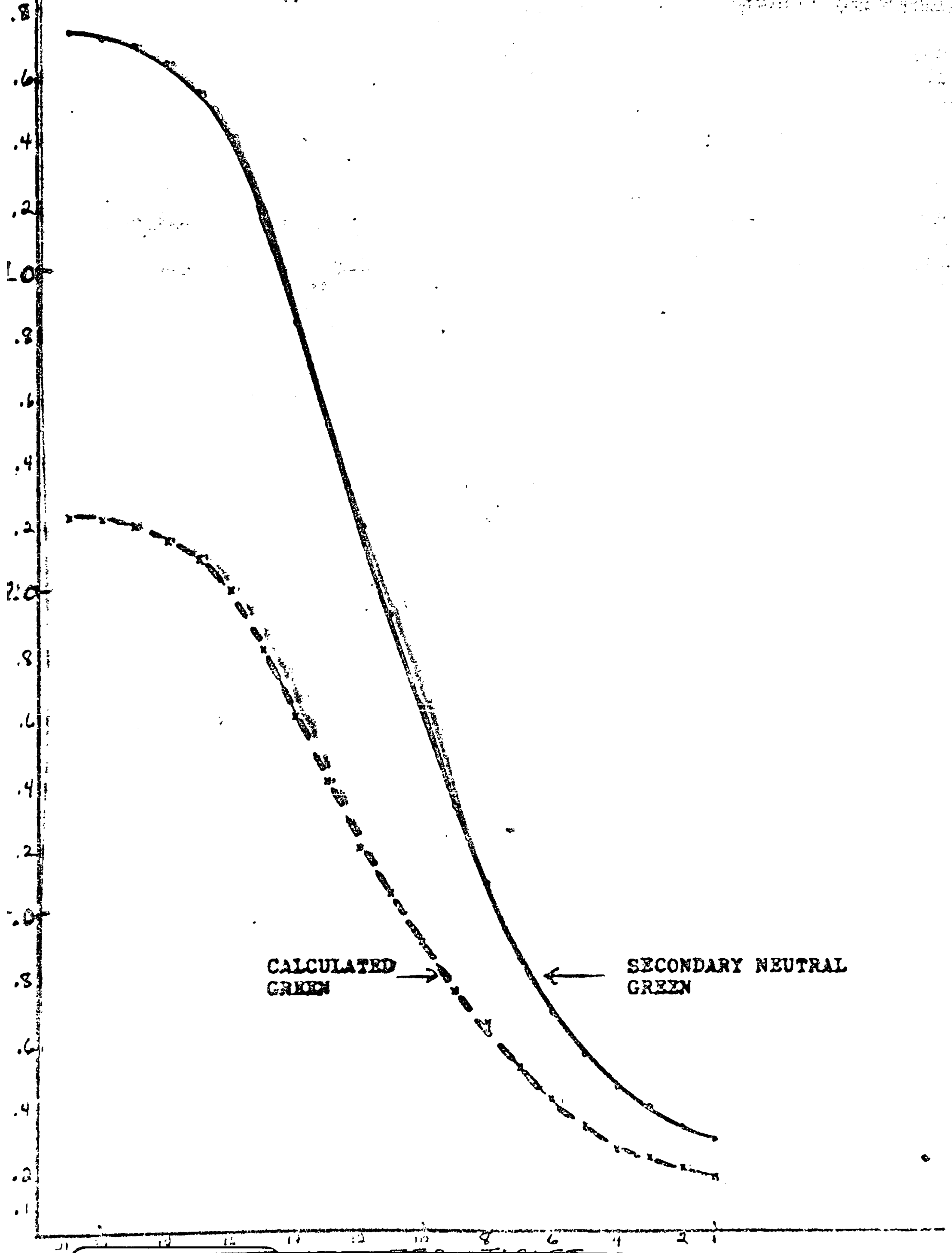
KODAK FIGURE #
#9



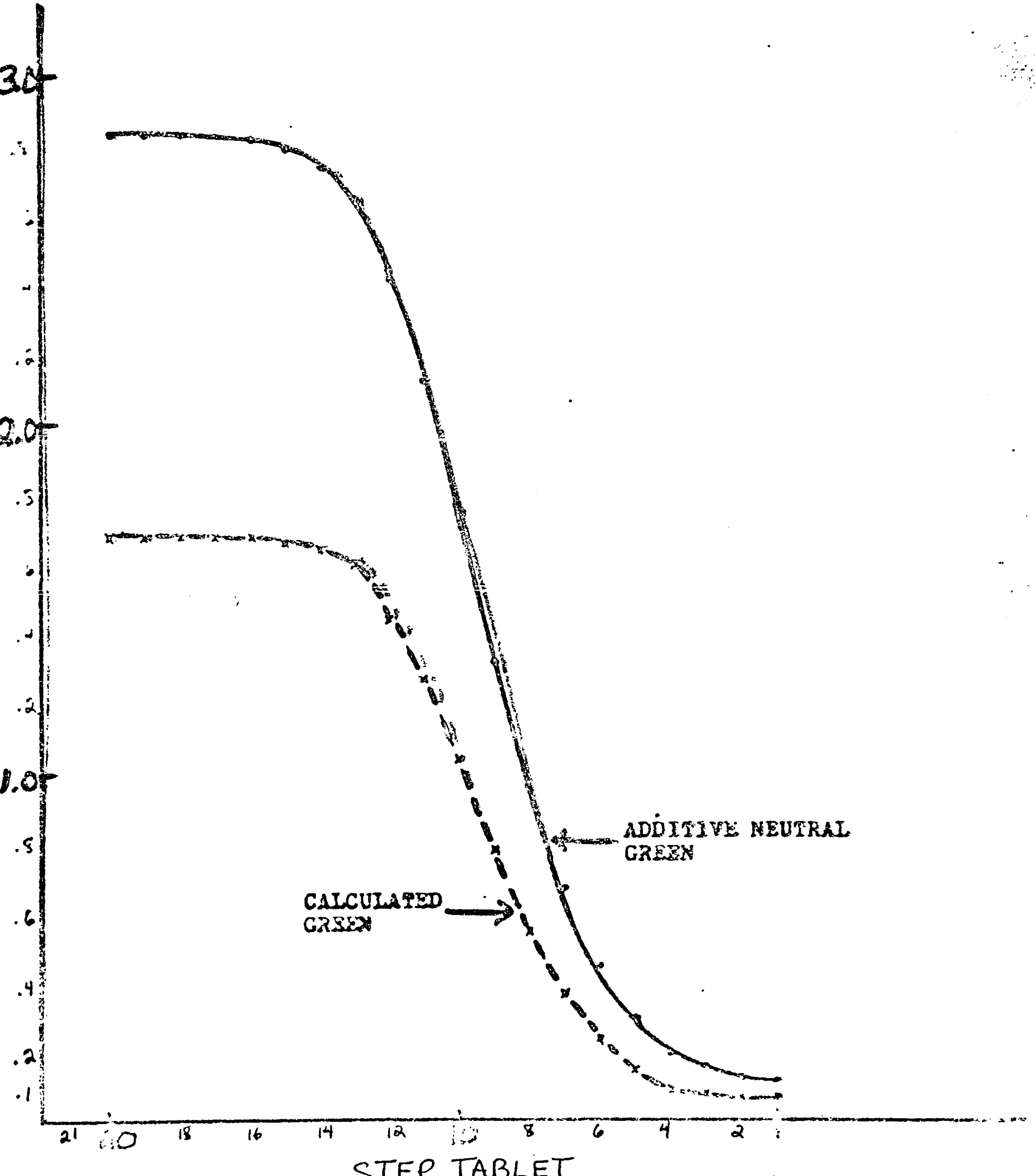
GAF FIGURE # 9A



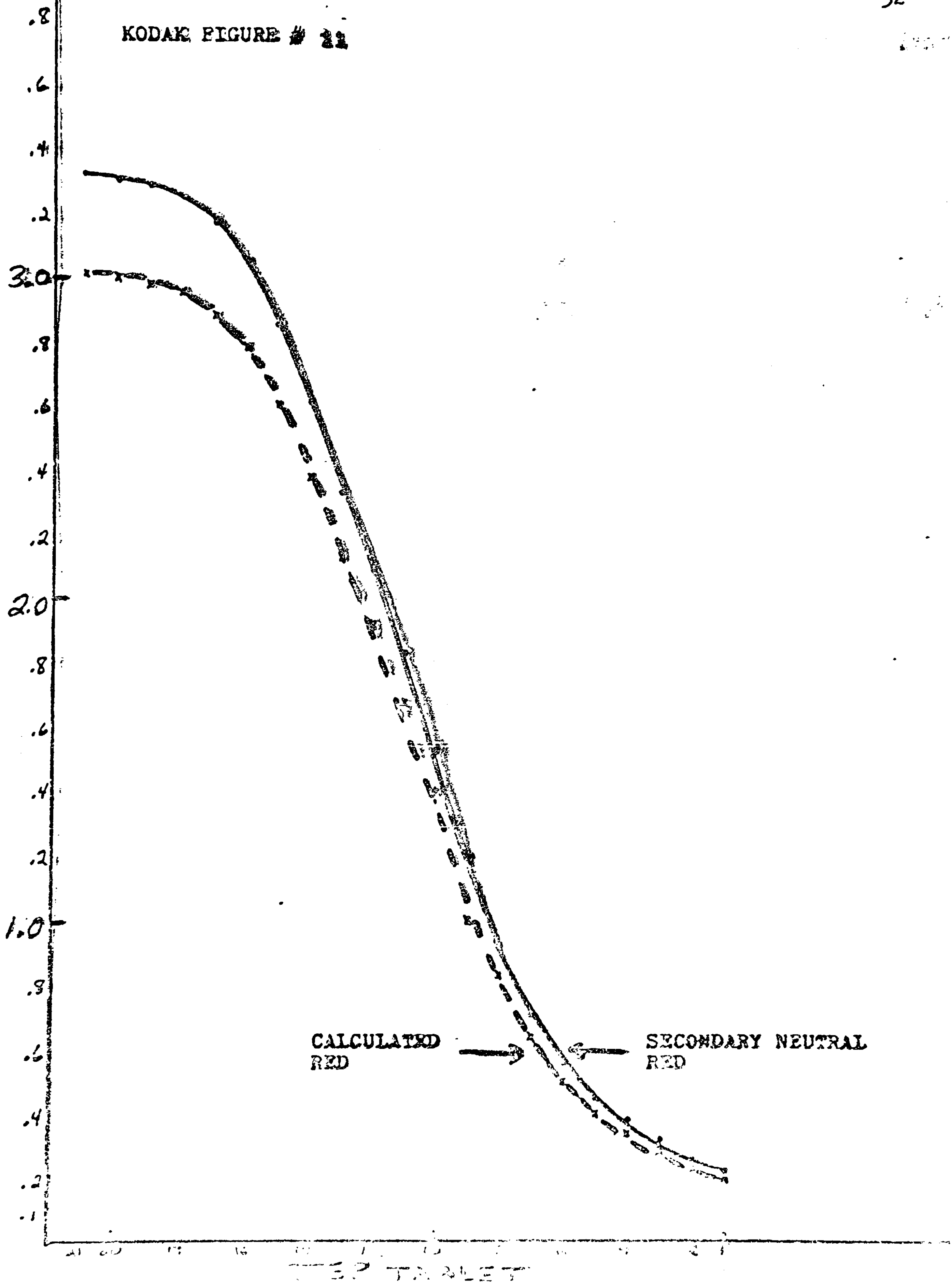
KODAK FIGURE # 10



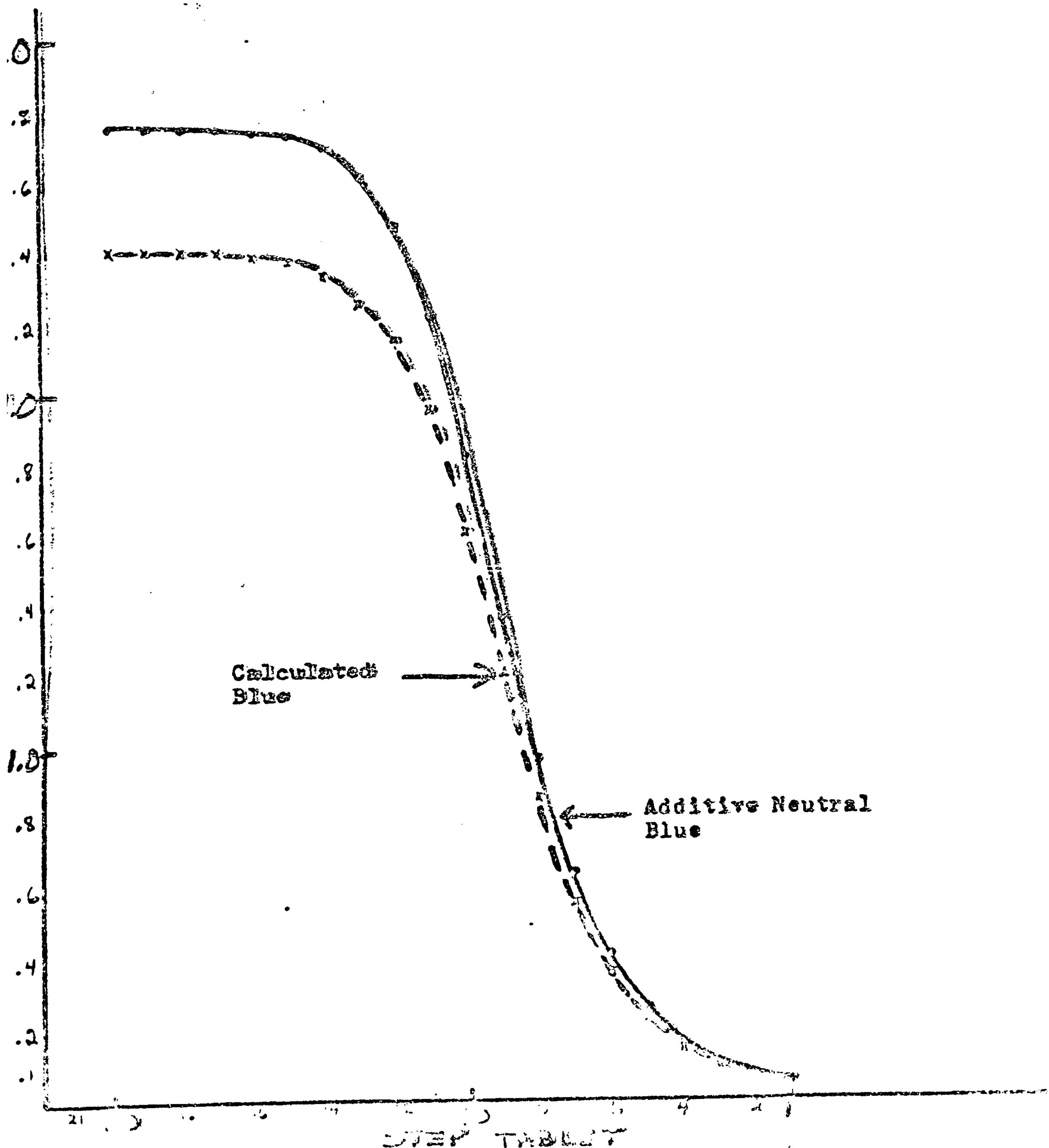
GAF FIGURE # A
#10A



KODAK FIGURE # 21



GAP FIGURE #
#11A



Footnotes

[1]Johnson, Jay Jr., Design, Fabrication and Evaluation of a Monochromatic Sensitometer (New York, Rochester Institute of Technology, 1972) pp.

[2]Kodak Neutral Density Attenuators, P-114 (New York, Eastman Kodak Company, 1975) pp.5-10

[3]Ryan, Roderick T., editor, Principles of Color Sensitometry,(New York, Society of Motion Picture and Television Engineers, 1974) pp. 52-63

[4]Evans, Hanson, and Brewer, Principles of Color Photography (New York, John Wiley and Sons, 1953) pp. 438-441

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APPENDIX A-1

Calibration for Macbeth TD504 digital densitometer employing Status A-58 filters and visual (Wratten 106) filter.

Step #	Control Patch	Visual Density	Blue	Green	Red
1	.25	.25	.26	.24	.24
2	.45	.46	.46	.45	.45
3	.65	.66	.67	.65	.65
4	.86	.87	.88	.86	.86
5	1.06	1.07	1.07	1.06	1.06
6	1.26	1.27	1.28	1.26	1.27
7	1.46	1.48	1.48	1.46	1.48
8	1.66	1.68	1.68	1.66	1.68
9	1.87	1.88	1.88	1.86	1.88
10	2.08	2.09	2.09	2.07	2.09
11	2.27	2.28	2.28	2.26	2.29
12	2.48	2.51	2.52	2.49	2.53
13	2.68	2.70	2.71	2.68	2.71
14	2.88	2.88	2.89	2.87	2.90
15	3.07	3.07	3.08	3.05	3.09
16	3.26	3.26	3.27	3.24	3.28
17	3.47	3.48	3.49	3.45	3.49
18	3.66	3.67	3.68	3.65	3.68
19	3.85	3.86	3.89	3.84	3.88
20	4.00	4.09	4.14	4.06	4.11

APPENDIX A-2

Density readings from Kodak strips. Average (μ).

1. Primary additive neutral				2. Secondary additive neutral		
Blue	Green	Red	STEP #	Blue	Green	Red
.25	.21	.15	1	.35	.30	.23
.27	.23	.17	2	.39	.34	.27
.31	.26	.20	3	.44	.40	.33
.34	.30	.25	4	.50	.46	.39
.39	.35	.30	5	.59	.56	.46
.45	.43	.37	6	.70	.69	.57
.52	.51	.44	7	.87	.86	.72
.62	.62	.54	8	1.11	1.09	.93
.77	.78	.68	9	1.50	1.33	1.20
1.03	1.00	.90	10	1.87	1.64	1.54
1.36	1.25	1.17	11	2.23	1.93	1.84
1.71	1.51	1.47	12	2.57	2.20	2.10
2.05	1.80	1.77	13	2.85	2.52	2.34
2.41	2.09	2.03	14	3.11	2.84	2.62
2.75	2.42	2.29	15	3.31	3.15	2.86
3.04	2.78	2.57	16	3.46	3.41	3.06
3.29	3.09	2.81	17	3.53	3.55	3.17
3.46	3.37	3.03	18	3.60	3.64	3.25
3.55	3.53	3.16	19	3.61	3.69	3.28
3.61	3.61	3.24	20	3.62	3.71	3.30
3.65	3.66	3.28	21	3.64	3.73	3.32

APPENDIX A-2 (cont.)

3. Yellow separation				4. Magenta separation		
Blue	Green	Red	STEP #	Blue	Green	Red
.34	.26	.19	1	.33	.30	.22
.36	.26	.19	2	.33	.33	.23
.40	.26	.19	3	.34	.39	.24
.43	.26	.19	4	.34	.45	.25
.48	.26	.19	5	.35	.52	.26
.52	.26	.19	6	.36	.60	.27
.56	.26	.19	7	.36	.67	.29
.63	.27	.18	8	.37	.74	.32
.68	.27	.18	9	.38	.81	.35
.74	.28	.18	10	.40	.89	.39
.81	.28	.18	11	.41	.95	.42
.87	.29	.18	12	.42	1.00	.44
.93	.30	.18	13	.43	1.05	.46
.98	.30	.18	14	.43	1.08	.47
1.01	.30	.18	15	.44	1.10	.48
1.02	.31	.18	16	.44	1.11	.48
1.03	.31	.18	17	.44	1.13	.49
1.03	.31	.18	18	.44	1.14	.49
1.03	.31	.18	19	.44	1.16	.50
1.03	.31	.18	20	.44	1.17	.50
1.03	.31	.18	21	.44	1.18	.50

APPENDIX A-2 (cont.)

4. Cyan separation

Blue	Green	Red
.31	.27	.24
.31	.27	.28
.31	.27	.36
.31	.27	.45
.31	.28	.56
.31	.29	.67
.31	.30	.77
.31	.31	.86
.32	.32	.99
.32	.34	1.11
.32	.35	1.20
.32	.36	1.28
.32	.37	1.33
.32	.38	1.37
.32	.38	1.41
.33	.39	1.43
.33	.39	1.44
.33	.40	1.46
.33	.40	1.48
.35	.41	1.49
.35	.41	1.51

5. Blue single layer exposure

STEP #	Blue	Green	Red
1	.49	1.28	2.08
2	.53	1.40	2.22
3	.58	1.57	2.37
4	.64	1.74	2.51
5	.73	1.94	2.65
6	.83	2.13	2.77
7	.96	2.34	2.86
8	1.15	2.58	2.97
9	1.41	2.80	3.06
10	1.72	2.99	3.13
11	2.00	3.16	3.19
12	2.26	3.29	3.23
13	2.53	3.39	3.26
14	2.79	3.48	3.28
15	3.06	3.54	3.30
16	3.28	3.59	3.31
17	3.46	3.62	3.32
18	3.57	3.64	3.33
19	3.64	3.65	3.33
20	3.67	3.65	3.33
21	3.71	3.65	3.33

APPENDIX A-2 (cont.)

5. Green single layer exposure — 6. Blue single layer exposure

Blue	Green	Red	STEP #	Blue	Green	Red
.78	.42	1.31	1	3.57	3.16	.88
.95	.48	1.45	2	3.57	3.16	.88
1.25	.57	1.61	3	3.57	3.16	.88
1.63	.68	1.75	4	3.57	3.16	.88
2.10	.83	1.93	5	3.57	3.16	.89
2.51	.97	2.11	6	3.57	3.21	.90
2.80	1.10	2.30	7	3.57	3.22	.91
3.02	1.25	2.46	8	3.58	3.24	.95
3.16	1.42	2.60	9	3.59	3.24	1.04
3.24	1.64	2.73	10	3.63	3.30	1.21
3.33	1.87	2.85	11	3.63	3.34	1.44
3.74	2.09	2.94	12	3.64	3.37	1.70
3.41	2.32	3.01	13	3.66	3.40	1.97
3.47	2.57	3.09	14	3.68	3.42	2.23
3.51	2.79	3.14	15	3.68	3.46	2.47
3.58	3.00	3.20	16	3.70	3.47	2.70
3.62	3.19	3.25	17	3.71	3.51	2.91
3.65	3.37	3.29	18	3.72	3.55	3.08
3.68	3.47	3.32	19	3.72	3.60	3.20
3.70	3.53	3.34	20	3.72	3.62	3.27
3.71	3.56	3.35	21	3.72	3.62	3.31

APPENDIX A-2 (cont.)

7. Calculated analytical densities from secondary neutral.

Yellow	Magenta	Cyan	STEP #
.34	.18	.20	1
.38	.21	.24	2
.42	.24	.30	3
.48	.27	.35	4
.57	.34	.41	5
.67	.42	.51	6
.83	.52	.65	7
1.07	.66	.84	8
1.45	.76	1.10	9
1.81	.91	1.41	10
2.16	1.06	1.69	11
2.49	1.20	1.93	12
2.75	1.41	2.14	13
3.00	1.61	2.39	14
3.18	1.82	2.61	15
3.32	2.00	2.79	16
3.38	2.10	2.89	17
3.45	2.16	2.96	18
3.46	2.20	2.98	19
3.46	2.21	3.00	20
3.48	2.22	3.02	21

APPENDIX A-3

Density readings from GAF film strips. Average (4).

1. Additive neutral				2. Yellow separation		
Blue	Green	Red	STEP #	Blue	Green	Red
.19	.12	.06	1	.20	.11	.06
.22	.13	.08	2	.22	.11	.06
.27	.16	.11	3	.26	.12	.06
.33	.20	.17	4	.32	.12	.06
.44	.30	.27	5	.40	.13	.06
.58	.45	.42	6	.48	.14	.06
.76	.67	.65	7	.57	.15	.06
.97	.96	.97	8	.70	.16	.06
1.24	1.32	1.37	9	.83	.17	.06
1.60	1.75	1.83	10	.98	.19	.06
1.94	2.13	2.22	11	1.13	.20	.06
2.24	2.42	2.48	12	1.26	.21	.06
2.46	2.65	2.62	13	1.39	.23	.06
2.62	2.74	2.70	14	1.47	.23	.06
2.71	2.79	2.72	15	1.54	.24	.06
2.76	2.82	2.74	16	1.58	.25	.06
2.77	2.83	2.75	17	1.61	.25	.06
2.78	2.83	2.75	18	1.63	.25	.06
2.79	2.83	2.75	19	1.64	.25	.06
2.80	2.83	2.75	20	1.64	.25	.06
2.80	2.83	2.75	21	1.64	.25	.06

APPENDIX A-3 (cont.)

3. Magenta separation				4. Cyan separation		
Blue	Green	Red	STEP #	Blue	Green	Red
.16	.11	.06	1	.17	.12	.07
.16	.11	.06	2	.17	.12	.07
.17	.12	.06	3	.17	.12	.09
.17	.15	.07	4	.17	.13	.11
.17	.21	.08	5	.17	.13	.15
.20	.28	.10	6	.17	.14	.18
.22	.37	.12	7	.17	.16	.23
.24	.48	.15	8	.17	.16	.29
.27	.57	.17	9	.17	.17	.34
.29	.67	.18	10	.17	.18	.38
.30	.73	.19	11	.17	.19	.41
.31	.78	.20	12	.17	.20	.44
.32	.83	.21	13	.18	.20	.47
.33	.86	.22	14	.18	.21	.49
.34	.89	.23	15	.18	.21	.51
.35	.92	.24	16	.18	.21	.51
.35	.94	.24	17	.18	.21	.54
.36	.96	.24	18	.18	.22	.56
.37	.97	.25	19	.18	.23	.58
.38	1.01	.26	20	.18	.23	.61
.39	1.04	.27	21	.18	.24	.65

APPENDIX A-3 (cont.)

5. Blue single layer exposure				6. Green single layer exposure		
Blue	Green	Red	STEP #	Blue	Green	Red
.55	1.68	2.15	1	1.92	.52	1.08
.63	1.87	2.30	2	2.01	.59	1.33
.73	2.09	2.44	3	2.08	.68	1.58
.84	2.28	2.55	4	2.09	.76	1.80
.97	2.45	2.64	5	2.14	.85	2.00
1.10	2.55	2.69	6	2.20	.97	2.13
1.25	2.61	2.72	7	2.27	1.14	2.25
1.45	2.66	2.74	8	2.35	1.42	2.37
1.66	2.70	2.75	9	2.45	1.72	2.48
1.90	2.74	2.76	10	2.56	2.05	2.57
2.15	2.78	2.77	11	2.64	2.35	2.64
2.36	2.81	2.77	12	2.69	2.56	2.69
2.54	2.83	2.77	13	2.74	2.69	2.72
2.65	2.84	2.77	14	2.76	2.77	2.73
2.71	2.85	2.77	15	2.78	2.78	2.75
2.75	2.85	2.77	16	2.79	2.83	2.75
2.77	2.85	2.77	17	2.79	2.84	2.77
2.79	2.85	2.77	18	2.79	2.84	2.77
2.80	2.85	2.77	19	2.79	2.84	2.77
2.80	2.85	2.77	20	2.79	2.84	2.77
2.81	2.85	2.77	21	2.79	2.84	2.77

APPENDIX A-3 (cont.)

7. Red single layer exposure

Blue	Green	Red	STEP #
2.63	2.28	.54	1
2.63	2.28	.55	2
2.65	2.30	.58	3
2.65	2.30	.62	4
2.68	2.33	.71	5
2.68	2.34	.84	6
2.70	2.40	1.03	7
2.71	2.46	1.33	8
2.72	2.55	1.69	9
2.74	2.65	2.06	10
2.77	2.73	2.40	11
2.78	2.78	2.58	12
2.80	2.81	2.67	13
2.80	2.82	2.72	14
2.80	2.83	2.74	15
2.80	2.84	2.75	16
2.81	2.84	2.75	17
2.81	2.84	2.75	18
2.81	2.84	2.75	19
2.81	2.84	2.75	20
2.81	2.84	2.75	21

8. Calculated analytical density from additive neutral

STEP #	Yellow	Magenta	Cyan
1	.19	.07	.05
2	.21	.07	.07
3	.26	.08	.10
4	.32	.09	.15
5	.43	.15	.24
6	.56	.24	.37
7	.73	.37	.57
8	.92	.56	.86
9	1.17	.78	1.21
10	1.51	1.04	1.61
11	1.83	1.27	1.96
12	2.11	1.44	2.16
13	2.32	1.60	2.26
14	2.48	1.64	2.36
15	2.56	1.66	2.38
16	2.61	1.68	2.39
17	2.62	1.68	2.40
18	2.63	1.68	2.40
19	2.64	1.68	2.40
20	2.65	1.68	2.40
21	2.65	1.68	2.40

APPENDIX A-4

1. Calibrated Photographic Silver Step Tablet

STEP #	DENSITY
1	.06
2	.18
3	.32
4	.47
5	.64
6	.79
7	.92
8	1.07
9	1.23
10	1.40
11	1.55
12	1.69
13	1.83
14	1.99
15	2.14
16	2.29
17	2.43
18	2.60
19	2.76
20	2.93
21	3.11

APPENDIX A-5

1. Kodak Yellow Separation

   a. Determination of slopes, correlation coefficient (r), and coefficient of determination (R^2).

   b. Regression analysis to determine the quantities in part a above.

Mathematical Model : $y = b_o + b_1 x$

$$\text{where } b_o = \frac{\Sigma X^2 \Sigma Y - \Sigma X \Sigma XY}{n \Sigma X^2 - (\Sigma X)^2}$$

$$\text{slope} = b_1 = \frac{n \Sigma XY - \Sigma X \Sigma Y}{n \Sigma X^2 - (\Sigma X)^2}$$

$$r = \frac{n \Sigma XY - \Sigma X \Sigma Y}{\sqrt{(n \Sigma X^2 - (\Sigma X)^2)\ (n \Sigma Y^2 - (\Sigma Y)^2}}$$

$$R^2 = r^2$$

   c. Their are two slopes to determine as each separation has two minor densities. The minor densities (Y_1 and Y_2) and the major densities (X_1) are obtained from each set of separation data listed as appendix A-2 for Kodak and A-3 for GAF.

   d. One only needs to substitute the data into the above equations to determine the slope which is used in integral to analytical density equations.

APPENDIX A-5 (cont.)

1. Kodak Yellow Separation

a. $y_1 = .227 + .071X_1$ $\qquad \frac{\Delta Y_g}{\Delta Y_b} = a_{21} = .071$

. $r = .928$

. $R^2 = .860$

b. $y_2 = 0$ $\qquad \frac{\Delta Y_r}{\Delta Y_b} = a_{31} = 0$

2. Kodak Magenta Separation

a. $y_1 = .280 + .136X_1$ $\qquad \frac{\Delta M_b}{\Delta M_g} = a_{12} = .136$

$r = .984$

$R^2 = .968$

b. $y_2 = .092 + .344X_1$ $\qquad \frac{\Delta M_r}{\Delta M_g} = a_{32} = .344$

$r = .987$

$R^2 = .975$

3. Kodak Cyan Separation

a. $y_1 = .302 + .016X_1$ $\qquad \frac{\Delta C_b}{\Delta C_r} = a_{13} = .016$

$r = .883$

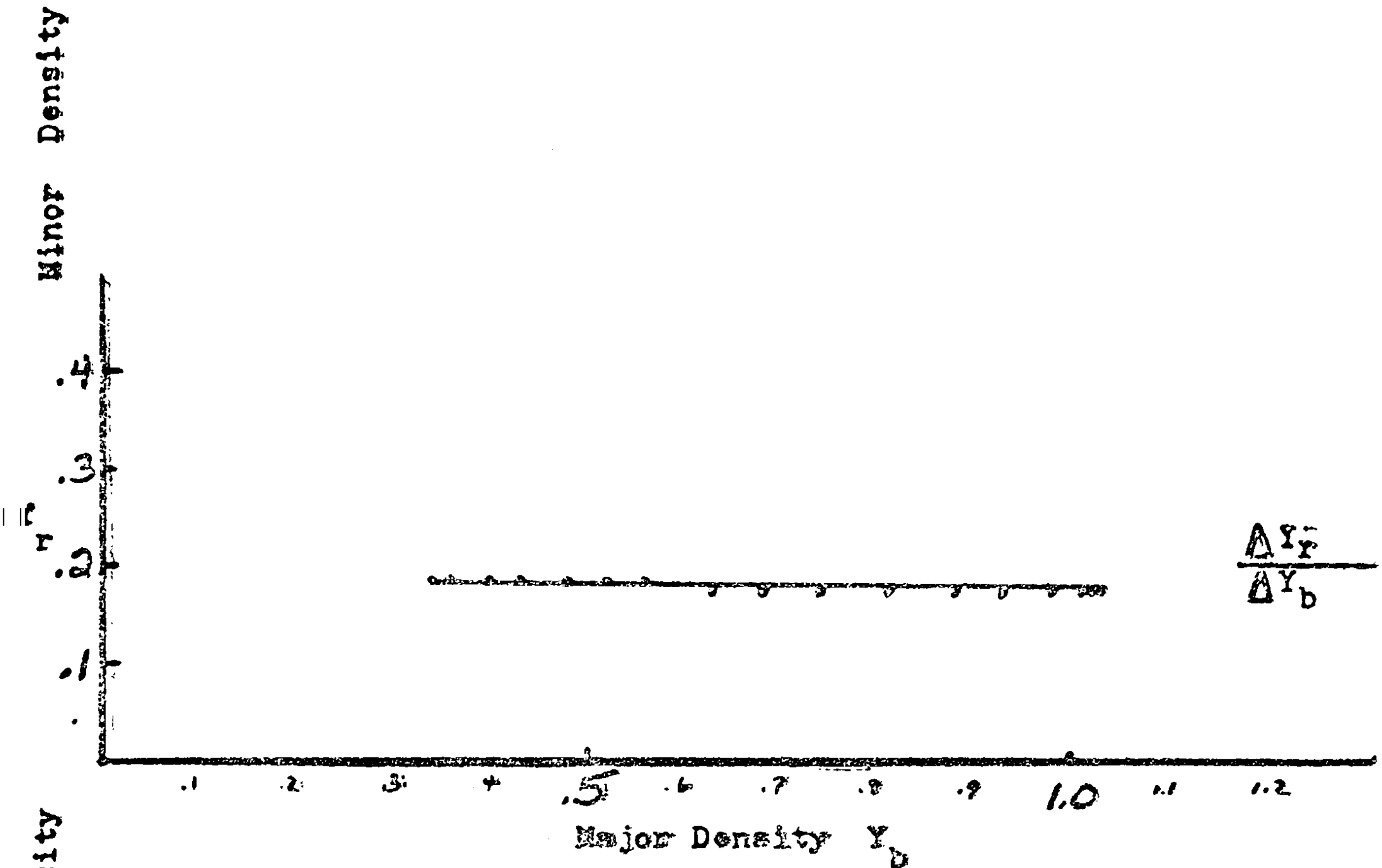
$R^2 = .780$

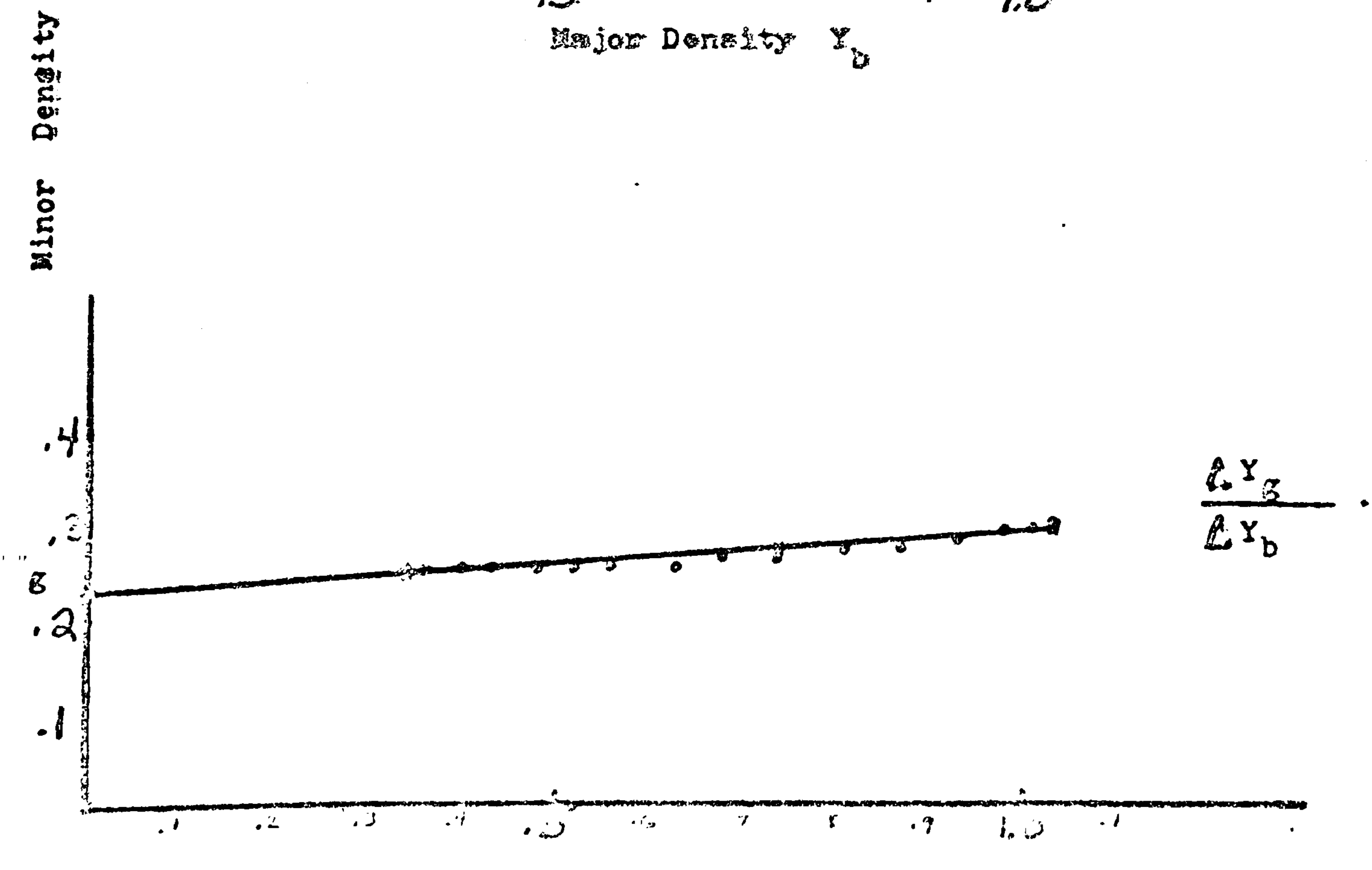
b. $y_2 = .225 + .110X_1$ $\qquad \frac{\Delta C_g}{\Delta C_r} = a_{23} = .110$

$r = .981$

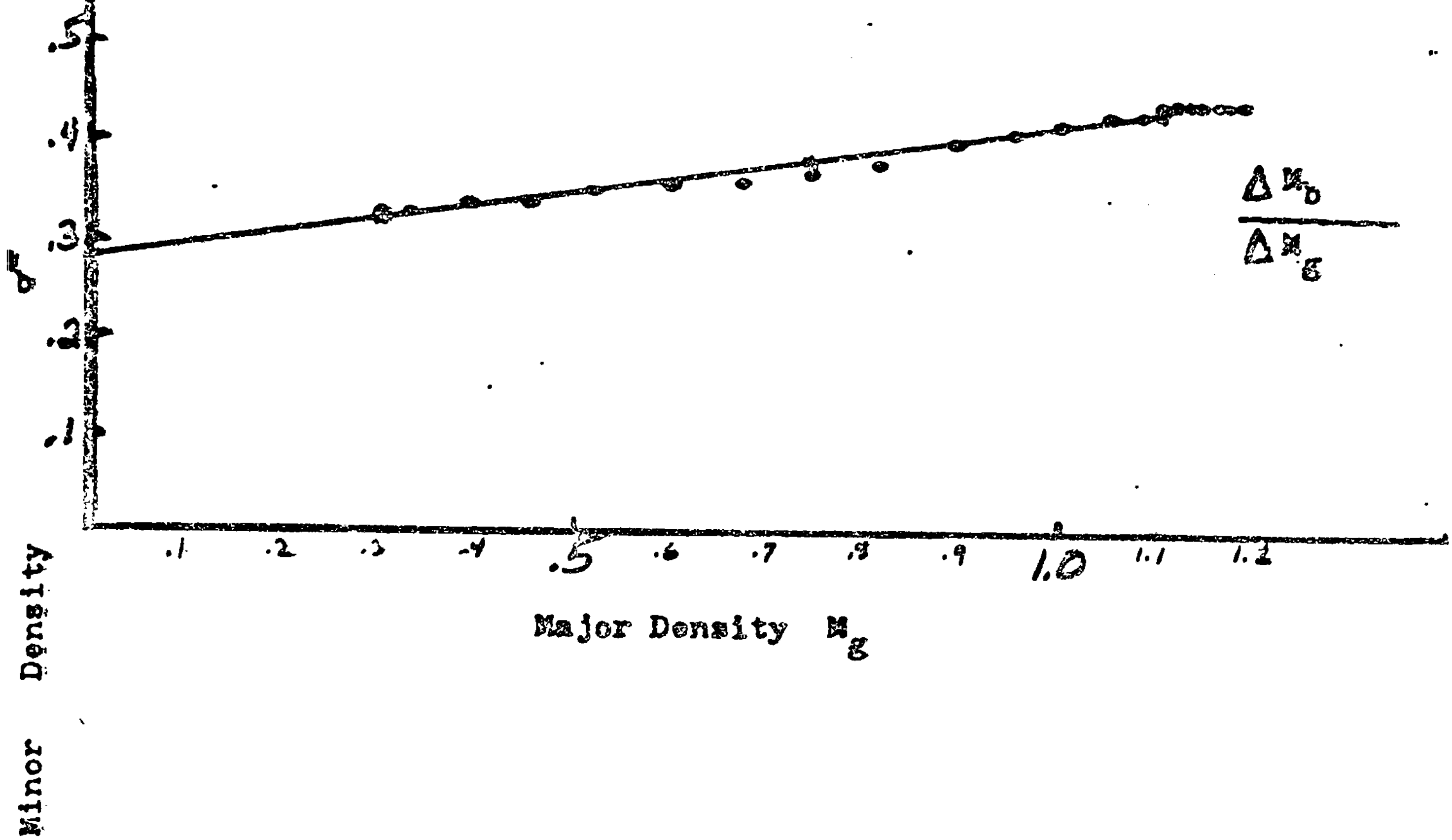
$R^2 = .962$

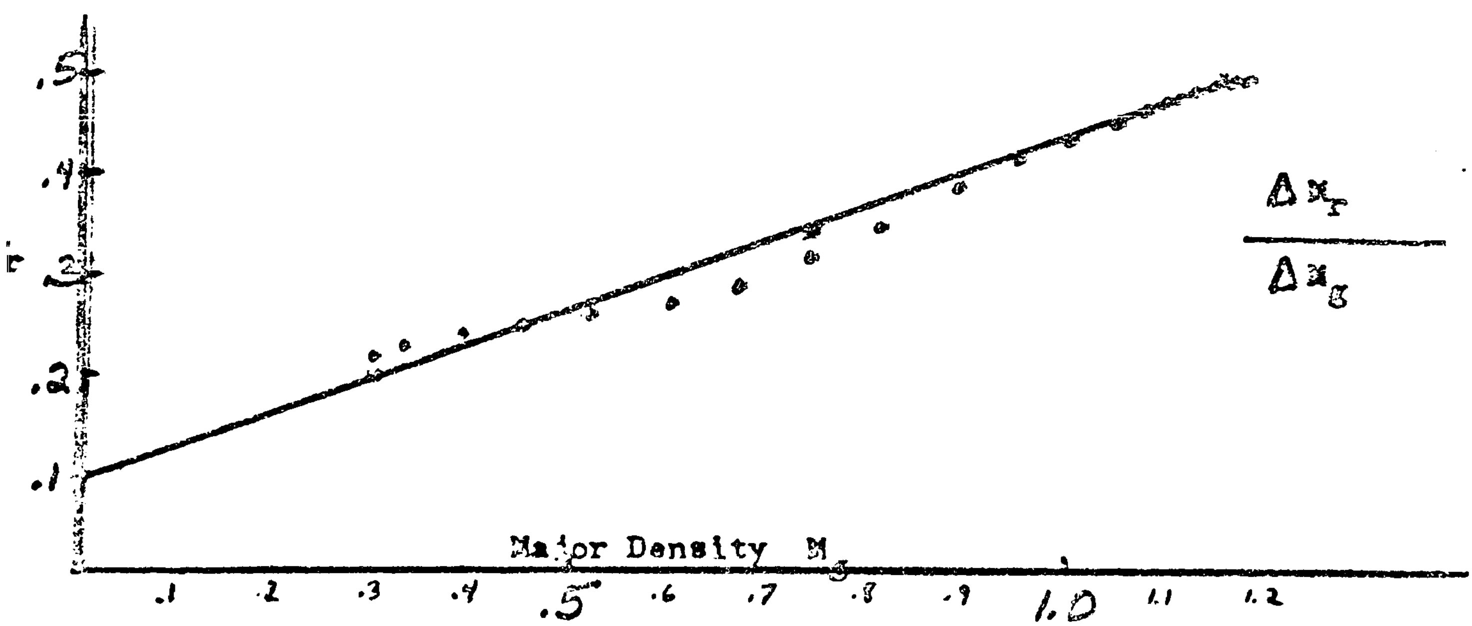
KODAK YELLOW SEPARATION



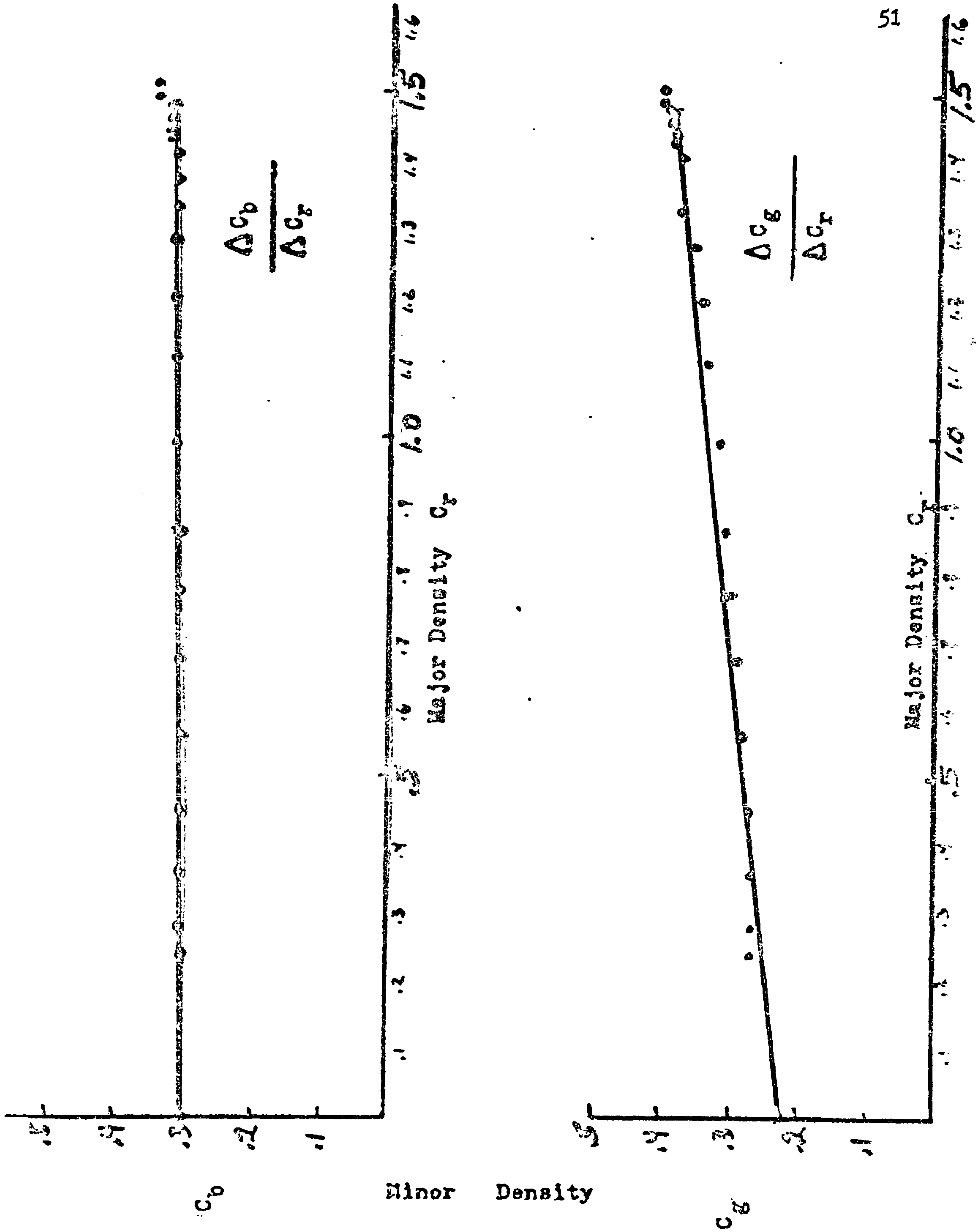


KODAK MAGENTA SEPARATION





KODAK CYAN SEPARATION



APPENDIX A-6

1. GAF Yellow Separation

a. $y_1 = .091 + .097X_1$ $\qquad \dfrac{\Delta Y_g}{\Delta Y_b} = a_{21} = .097$

$r = .998$

$R^2 = .996$

b. $y_2 = 0$ $\qquad \dfrac{\Delta Y_r}{\Delta Y_b} = a_{31} = 0$

2. GAF Magenta Separation

a. $y_1 = .132 + .237X_1$ $\qquad \dfrac{\Delta M_b}{\Delta M_g} = a_{12} = .237$

$r = .999$

$R^2 = .999$

b. $y_2 = .037 + .217X_1$ $\qquad \dfrac{\Delta M_r}{\Delta M_g} = a_{32} = .217$

$r = .998$

$R^2 = .996$

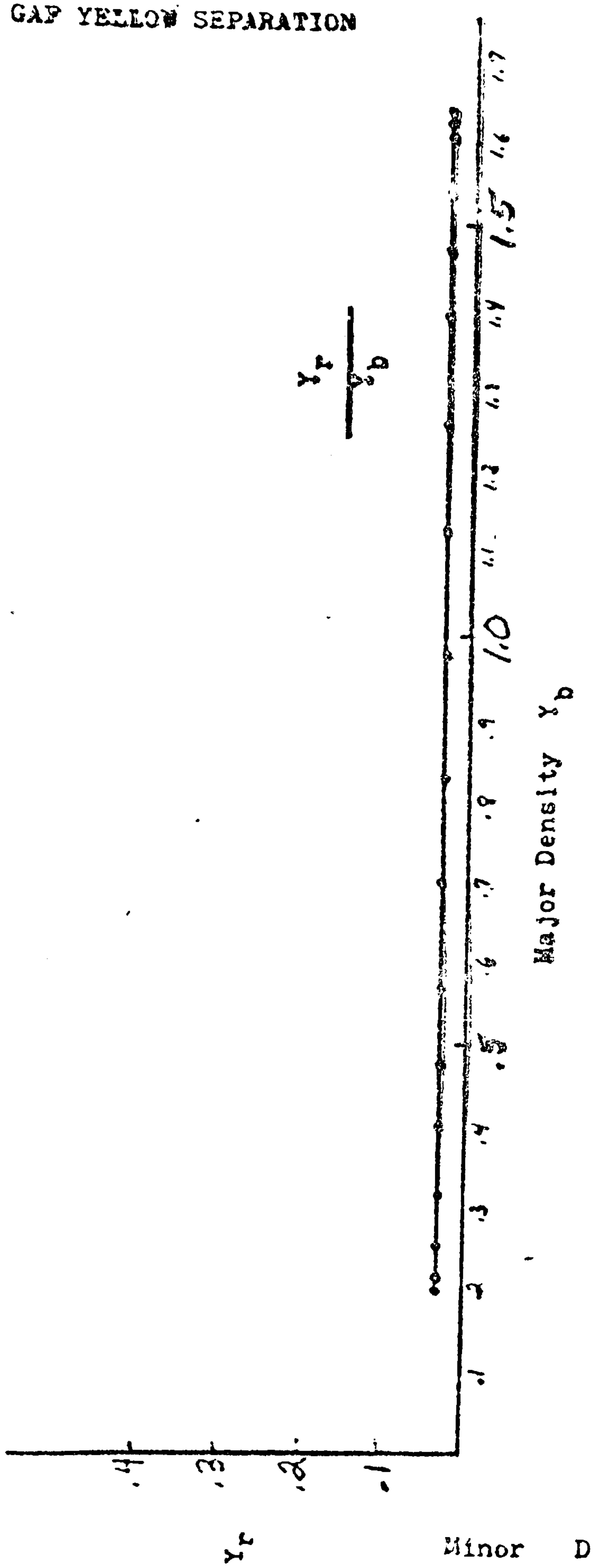
3. GAF Cyan Separation

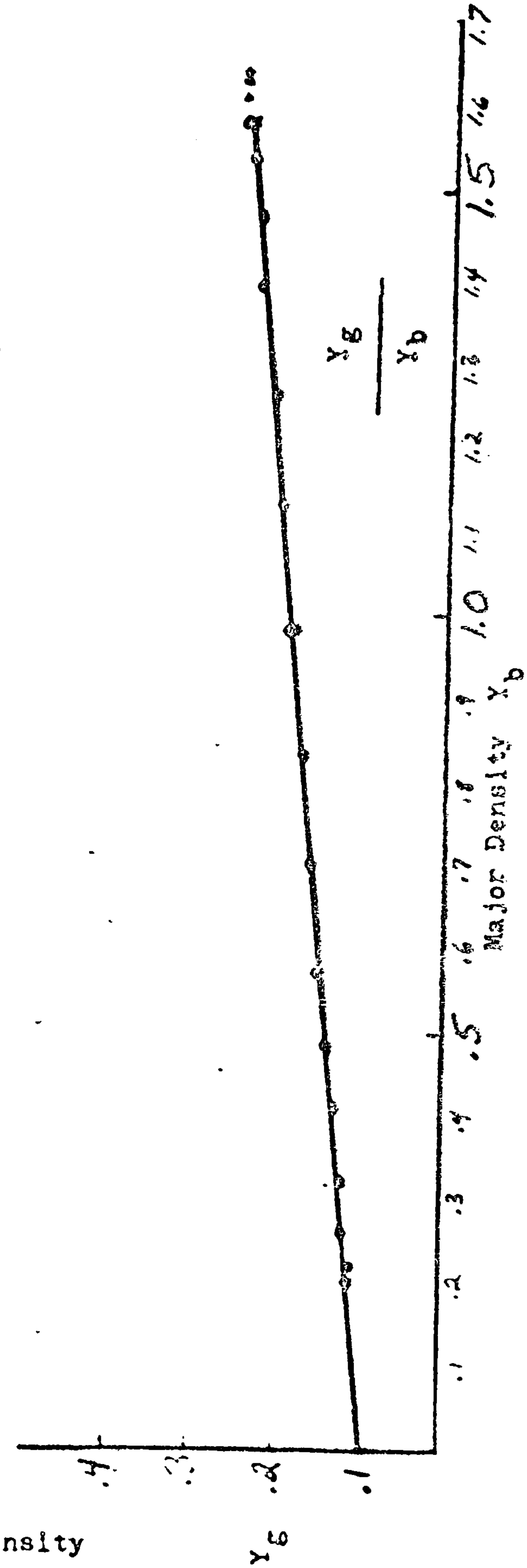
a. $y_1 = 0$ $\qquad \dfrac{\Delta C_b}{\Delta C_r} = a_{13} = 0$

b. $y_2 = .104 + .208X_1$ $\qquad \dfrac{\Delta C_g}{\Delta C_r} = a_{23} = .208$

$r = .99$

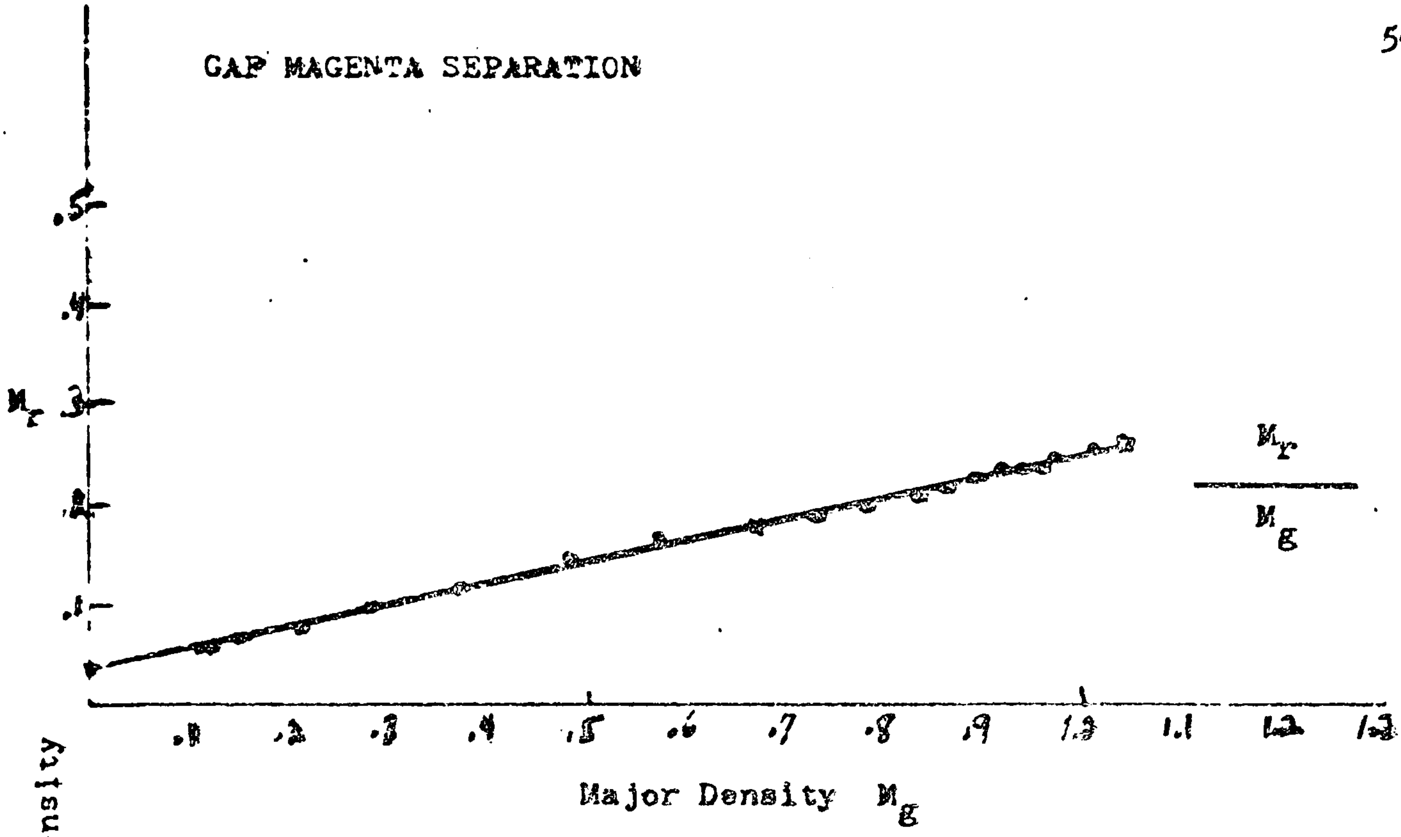
$R^2 = .99$

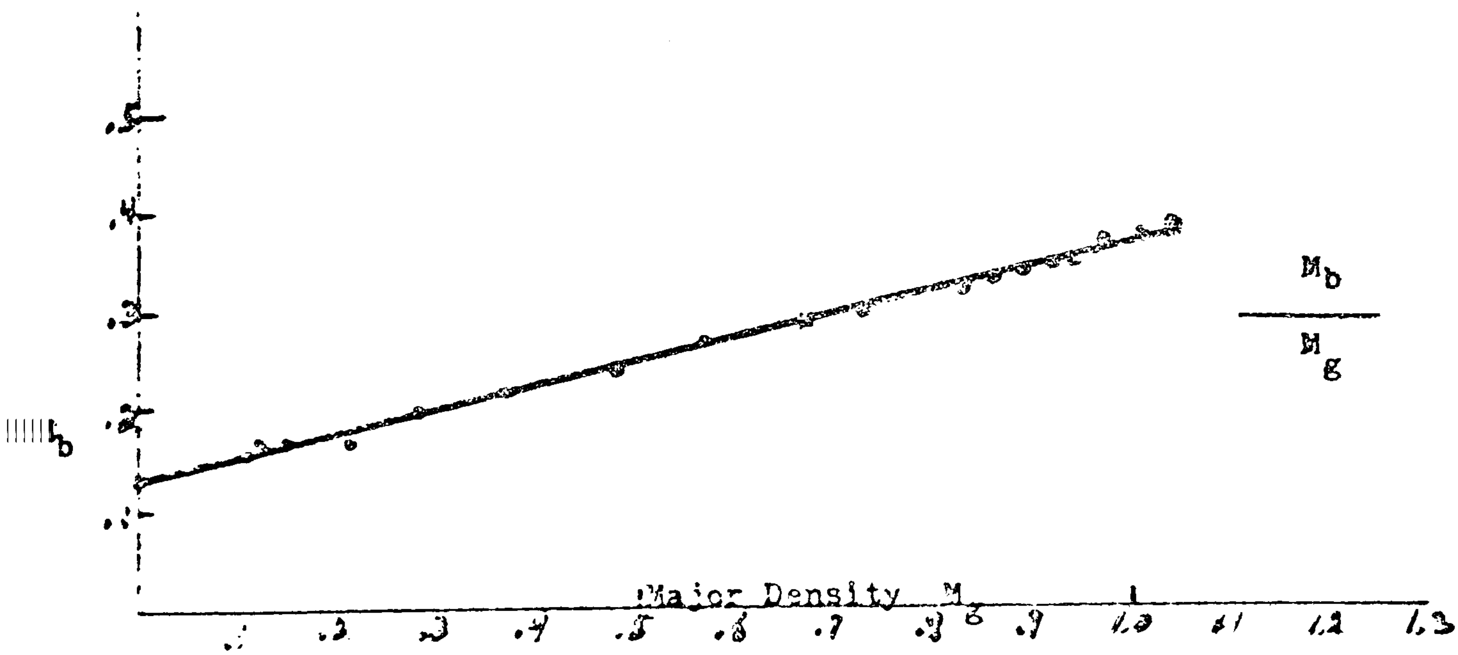




Minor Density

GAP MAGENTA SEPARATION





GAF CYAN SEPARATION