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MTF ANALYSIS OF AN EMULSION
USED FOR COLOR PAPER

by
C. Alan Way

A thesis submitted in partial fulfillment of the requirements
for the degree of Bachelor of Science in the School of Photo-
graphic Arts and Sciences in the College of Graphic Arts and
Photography of the Rochester Institute of Technology

May 11, 1979

Advisor: Mohamed Abouelata

ABSTRACT

This thesis studied the relationship between the MTF's of a color emulsion used for photographic paper but coated on clear base. Analysis of the MTF curves show differences that can be attributed to interimage effects. The effects in the red and blue sensitive layers caused a decrease in the overall MTF of the film.

ACKNOWLEDGEMENT

I wish to express thanks to Terry NiCastro and Noel Chavez for their help during this project.

INTRODUCTION

In any trilayer color material we must be concerned with the relationship which exist between the three layers and their effect toward the overall performance of the emulsion. The Modulation Transfer Function (MTF) of the emulsion can be used to determine the amount of interaction between layers. The MTF is a quantitative measure of the emulsions reproduction capability. By definition, the MTF is the ratio of the image contrast to the object contrast (when the contrast is expressed in terms of exposure or illuminance) as it varies with spatial frequency. The spatial frequency for a black and white emulsion is somewhat independent of the wavelength of exposing radiation. A color emulsion on the other hand is highly dependent on wavelength of light used for exposure, due to its spectral selectivity.

The Modulation Transfer Function is a valuable tool for assessing image quality as a function of spatial frequency. Any image degradation will cause a reduction in the MTF. Image degradation in a color emulsion is caused primarily from the light scattering through the emulsion. Since color emulsions are generally thick and composed of many layers this is usually the problem.

There are other factors other than light scattering which can affect the MTF. One of the most well known factors is adjacency effects. Adjacency effects arise between exposure

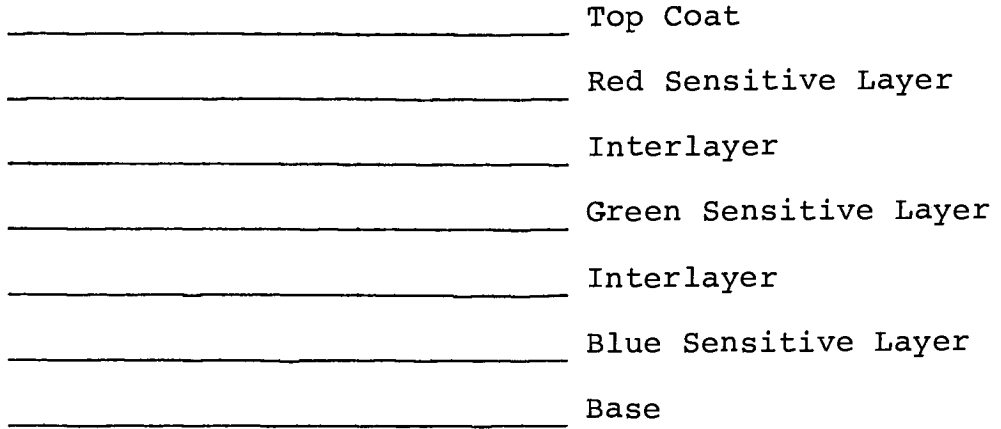
and density distribution separating two areas of unequal exposure. This is especially true when an edge is exposed. Adjacency effects are attributed to chemical actions of developers; emulsion components and processing.

This study along with the MTF determination will study the interimage effects which exist to some degree in all color films. Interimage effects for the most part are a direct result of the development of the image. Penetration of a developer into an emulsion will cause numerous chemical and kinetic interactions. Examples of this are oxidation products that are formed, and diffusion rates from one layer to another.

The actual existance of the interimage effects is most apparent through analysis involving dye density comparisons. A uniformly exposed trilayer will yield certain analytical densities. These densities will not match the densities of the individual layers separately.

In this experiment the material chosen to study the MTF and the interimage effects was 3M color paper emulsion, used primarily for commercial use in the photofinishing industry. The emulsion is normally coated on a clear 6 mill base. This was done so the analysis on the emulsion could be accomplished easier. With this alteration we will not achieve the exact results as if we were to do the analysis with the paper base, but this will give us a good indication of the emulsion's characteristics.

A crossview of the trilayer film pack is shown below:



Answer A not needed

Since there is an overlap in the emulsion sensitivities the MTF of each layer alone will be different from the combined MTF of the three layers. If we measure the microdensities in the same manner (analytical densities) the extent of the differences in MTF may be attributed to interimage effects.

EXPERIMENTAL PROCEDURE

In using any color emulsion we must be concerned with the response of the individual layers as well as the response of the total layer combined. This experiment directed itself to the study of the three separate layers (Cyan, Magenta and Yellow) and the three layers combined.

With the help of 3M a color paper emulsion was coated on a 6 mil triacetate base. The emulsions were coated separately on three individual bases and then together with an interlayer between each color sensitive emulsion. The trilayer emulsion was coated in the same order as when it is coated on a paper base.

The exposures on the emulsions were made on a sensitometer designed and built by 3M. The sensitometer consisted of a tungsten halogen source has an output of 1700 ± 30 lux. The exposure time of the sensitometer could be varied from 1/10 secs. to 5 secs. by varying the rotating shutter. The lamp was illuminated using a DC Power Source so that uniform illumination was obtained on the film plane.

Exposure

Each of red, green and blue sensitive single layers were exposed respectively through W92 for .4 sec., W93 for 2 sec., and W94 for 1 sec.

The tripack was exposed so that the top layer could be exposed followed by the middle layer and eventually the bottom

layer. The tripack was given successive red, green, and blue while the film sample remained in place.

For the separate exposure and the tripack over aim was to produce a visual neutral which will be tested using the CIE specification.

A summary of filters used and exposure times which were proved to produce a good neutral are found in Table 1.

TABLE 1

Filters and Exposure Times

<u>Sample</u>	<u>Wratten Filter</u>	<u>Exposure Time in Sec.</u>
Separate Sensitive Red	92	0.4
Separate Sensitive Green	93	2.0
Separate Sensitive Blue	94	1.0
<u>Trilayer</u>		
Red Sensitive Layer	92	0.4
Green Sensitive Layer	93	2.0
Blue Sensitive Layer	94 + .1ND	1.0

Processing

The processing for the samples had to be consistent and even throughout the entire strip. When determining the MTF of a film uniform exposure and processing is essential. Any change in processing could directly effect the MTF.

To ensure uniform processing, each process contained three color paper control strips. The controls were measured for Dmin, Dmax, Speed, and contrast, and compared to 3M specifications to make sure the process was in control.

The processing was done manually using a dip and dunk method, with agitation 15 times in 15 secs., and 5 times in 5 secs., every 30 secs.

The samples were processed at $91^{\circ}\text{F} \pm \frac{1}{4}$ in Kodak Ektaprint developer for 4 mins., followed by 1.5 mins. in Hunts Blix. The samples are then washed with tap water for 2 mins. and then finally dried.

Spectrophotometry

The exposed and processed samples were checked for neutrality by the 1931 CIE method of color specification. For this reason spectrophotometric curves between 400nm and 700nm of the .42 yellow patch, .40 magenta patch, .42 cyan patch, and a tripack of a visual density of .40 were obtained.

The density values were converted to transmission using the formula $t = 10^{-D}$, at every 10 nanometers.

The calculations for the CIE chromaticity coordinates were done using the 1931 CIE color specification relative to 3250°k source.

Since the patches we checked for neutrality were obtained from the sensitometric strips, which were exposed to produce a neutral, the neutral of these patches indicates that all the

other patches of the strips will be neutral assuming the densities of the patches are such that Beer's law is obeyed.

Edge Exposure

Exposures used to produce CIE neutral strips, were then used to make edge exposure for the purpose of determining the Modulation Transfer Function of the separate layers and the integral layers. In our experiment the edge together with the step tablet were contact printed in each case.

Microdensitometer

The microdensitometer used for this experiment was equipped with a Status A filter for reading color images, an optical viewing system, a digital computer and an electronic position control. The samples were aligned and focused visually using the magnified dye structure in the emulsion as a reference.

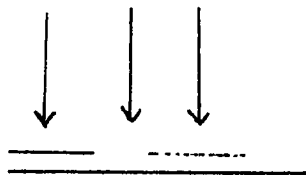
The images of the edges and step tablets were scanned with a slit measuring 12 micrometers by 400 micrometers. Each edge was scanned a distance of 400 micrometers with density readings at one micrometer.

The trilayer neutral samples were scanned with the four filters visual, blue, green, and red status A filters. Each single layer sample was scanned with its complementary filter.

Calculation of MTF

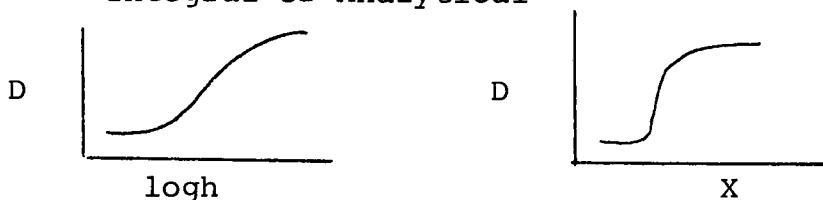
The MTF's were calculated as follows:

1. A Contact print of an edge and a step tablet was made on the emulsion.

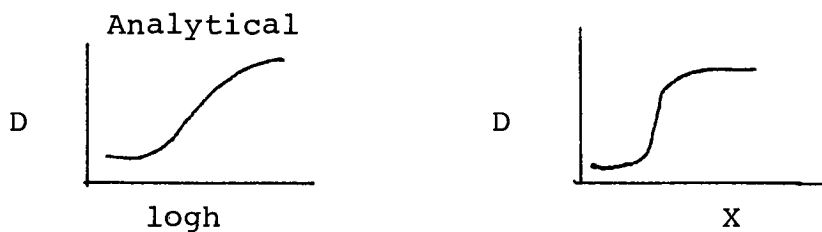


2. The results contact printed were plotted

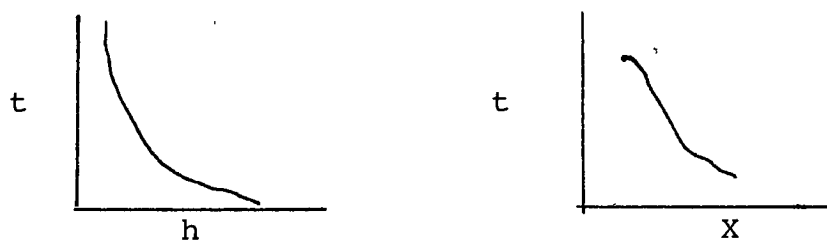
Integral or Analytical



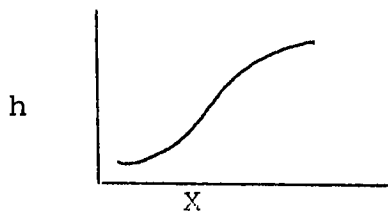
3. If the Integral density were converted to Analytical densities. If the densities were already in Analytical form step 3 was omitted



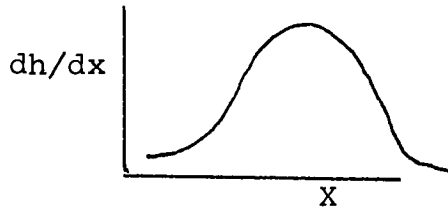
4. Density was converted to transmittance and log h was converted to h.



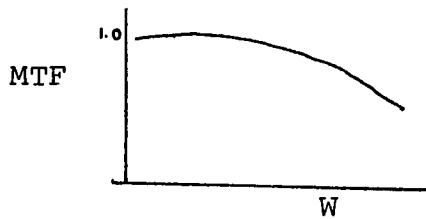
5. The curves from the $t - X$ and $t - h$ were cross plotted and a curve of h vs. X was formed.



6. The line spread function was calculated by differentiating the h vs. X . And plotted against X



7. The line spread function was fourier transformed and divided by the area under the line spread function to obtain the MTF curve



Computer Program

An MTF program was used to the MTF using data points from the effective exposure vs. distance curve. Sampling was done every 2 micrometers over a distance of 2mm. This resulted in an MTF curve with a frequency to 25 cycles/mm.

RESULTS

The curves obtained to achieve an acceptable neutral are found in Fig. 1. As shown in the curves the green layer has the greatest density of the three layers. At the high densities the image would appear magenta. The edge exposures were made on the linear portion of the D log H curves so that neutrals according to CIE color specifications were obtained.

Each of the separate layers were exposed with a Wratten filter corresponding to their basic sensitivity. The red sensitive layer (Fig. 2) has a small sensitivity to green light, and very small sensitivity to blue light. The green sensitive layer (Fig. 3) has little sensitivity to red and green. Fig. 4 indicates that the blue sensitive has virtually no red or green sensitivity.

Visually neutral samples were found on the trilayer pack and with the separate layers. The spectrophotometric curves shown in Fig. (5 - 9) were obtained. These curves together with the spectral energy distribution of 3250°k source and the tristimulus values ($\bar{x}(x)$, $\bar{y}(x)$, $\bar{z}(x)$) of the 1931 CIE system were used to calculate the chromaticity coordinates (x,y) for the tripack sample and the combined separate layer samples. The results are shown in Table 2.

Sample	Chromaticity Coordinates		Difference	
	x	y	x	y
Source	.4201	.3979	0	0
Tripack	.4572	.4147	.0371	.0168
Combined layers	.4357	.4110	.01560	.01310

From the table we see that the differences to the relative source to conclude the samples are equally neutral relative to the source. The edge traces obtained from the microdensitometer were plotted and shown in Fig. 10 - 16.

This study was directed to the MTF of a color paper emulsion. The resultant curves are shown in Fig. 17 - 20.

These curves are only an indication of how the emulsion acts since it is normally coated on a paper base. As expected, the material exhibits a very low MTF. Since this material is used in the commercial photofinishing industry the color characteristics are more important than the MTF.

Fig. 17 shows the MTF curve if the material was used for a black and white response.

Fig. 18 - 20 are the MTF curves for the trilayer pack for the different layers. These results were found by converting the stepped densities to their END and then finding the MTF's.

Fig. 21 - 23 are the MTF results for the three separate layers.

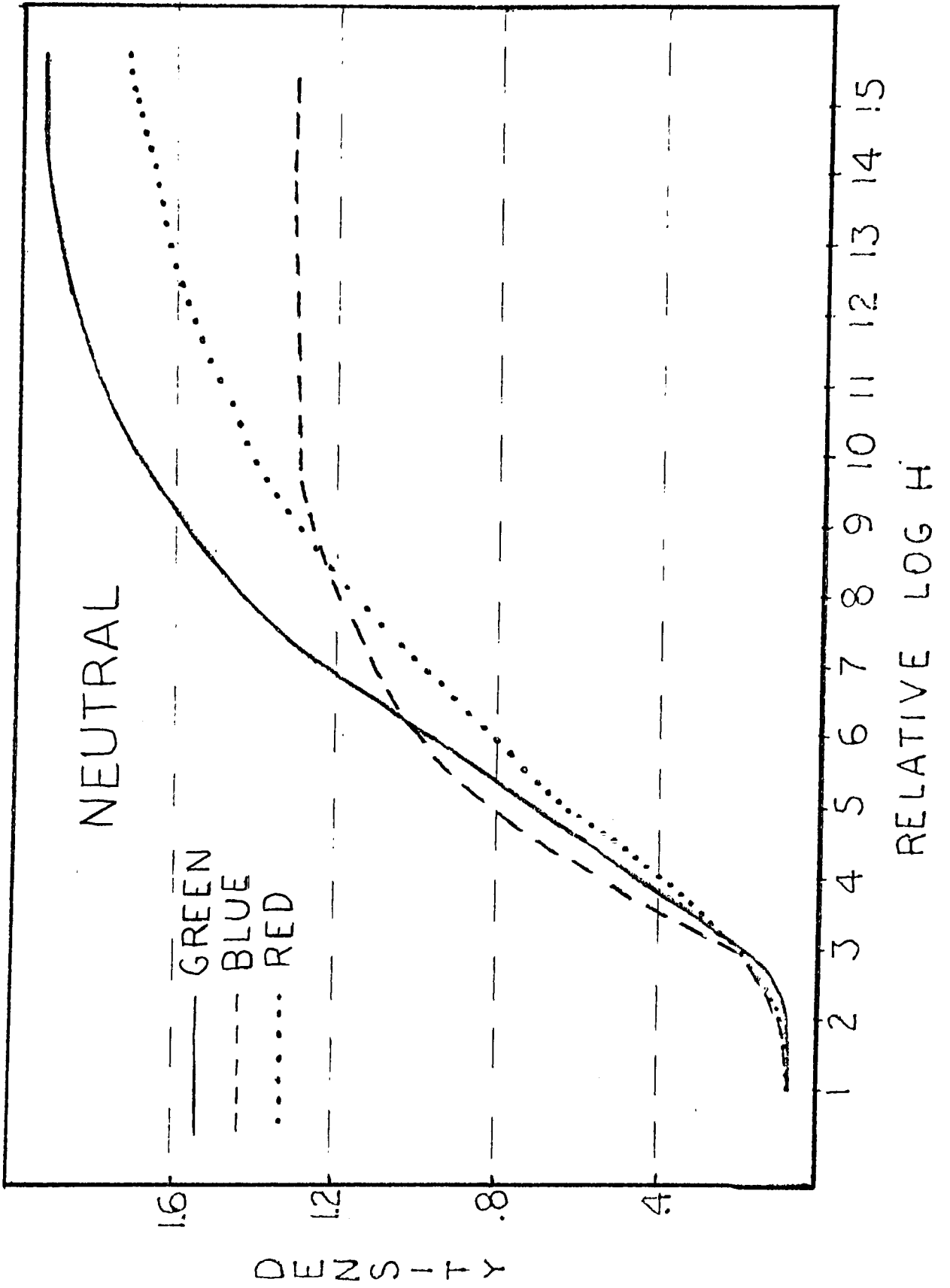


Fig. 1

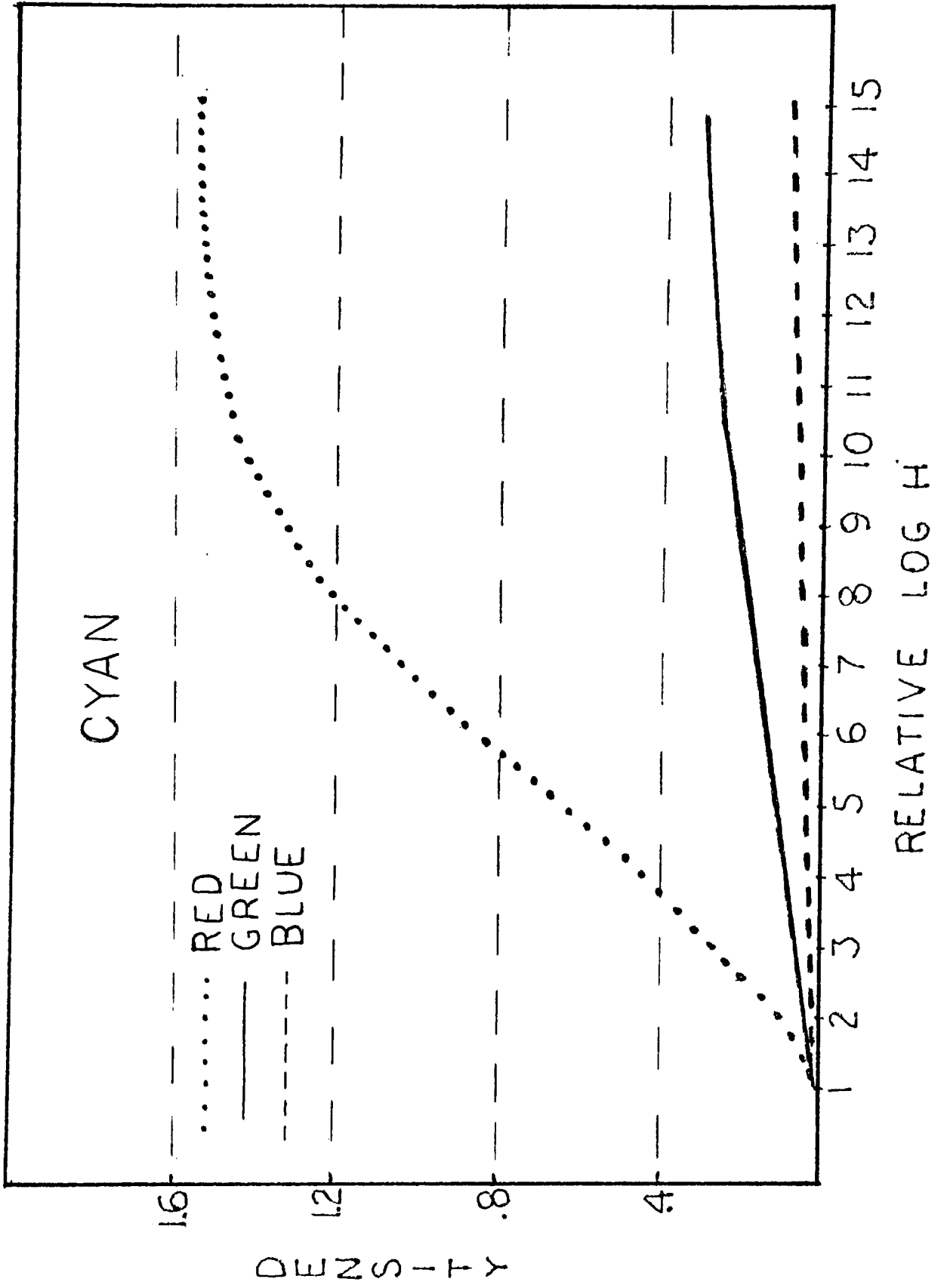


Fig. 2

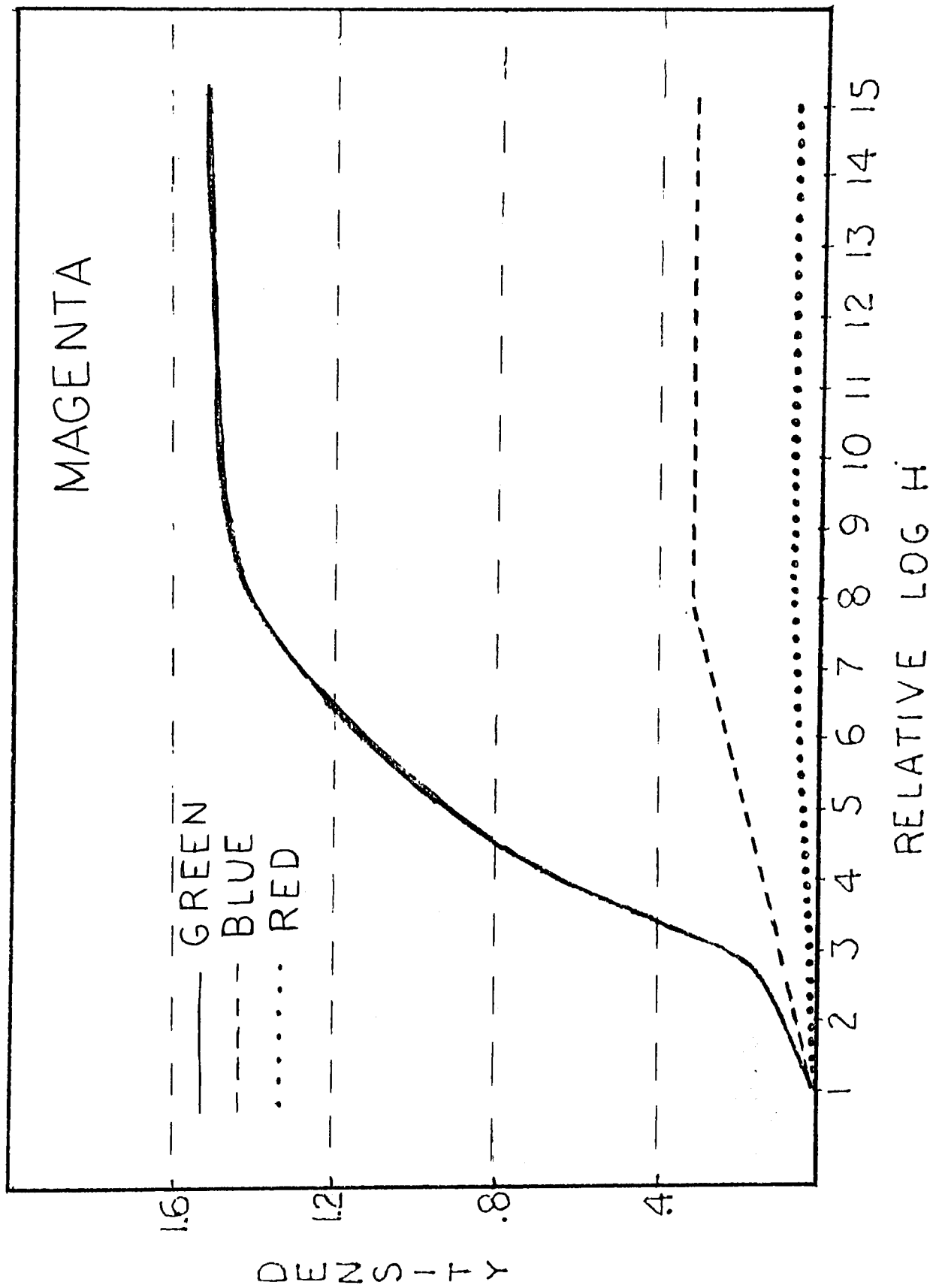


FIG. 3

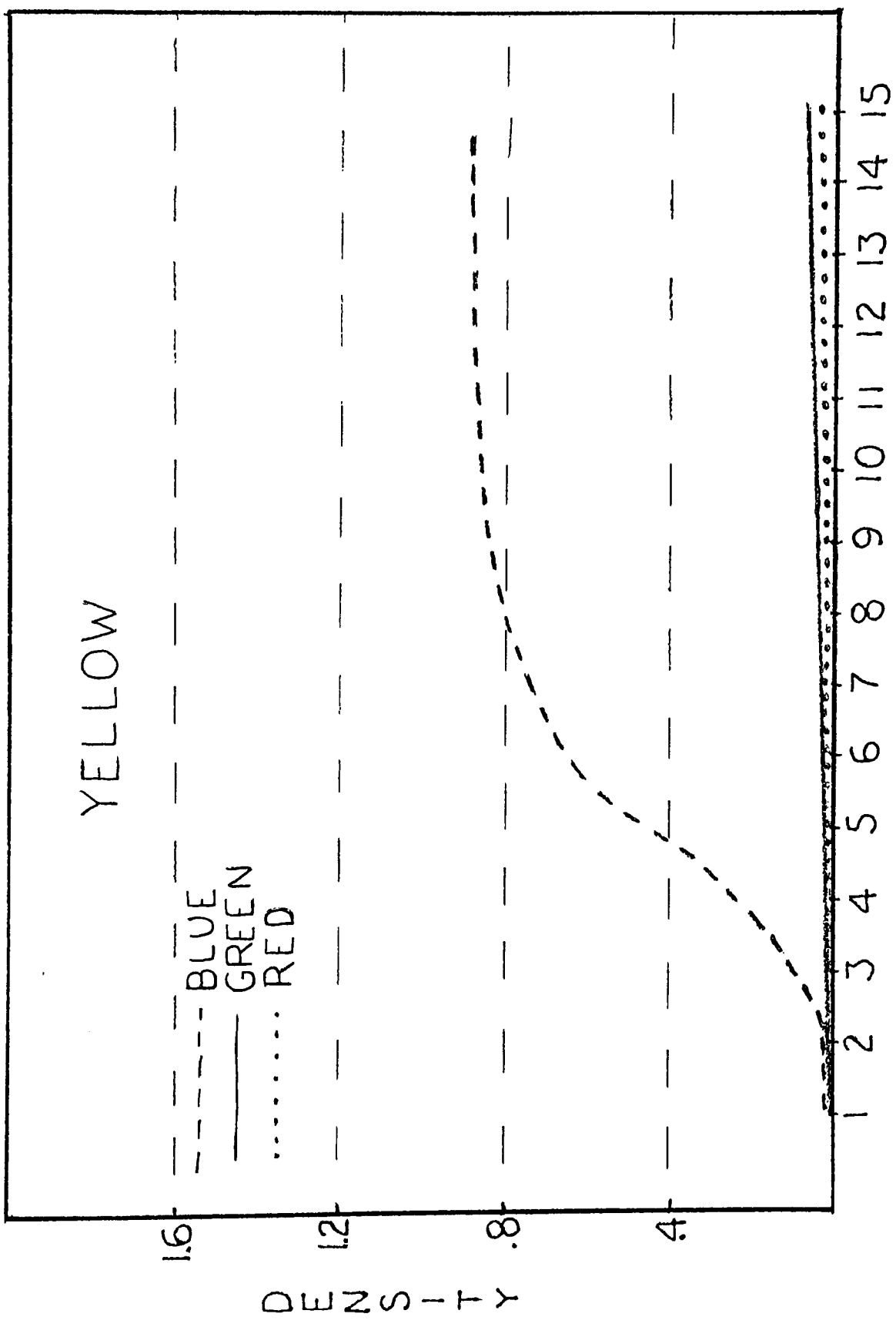
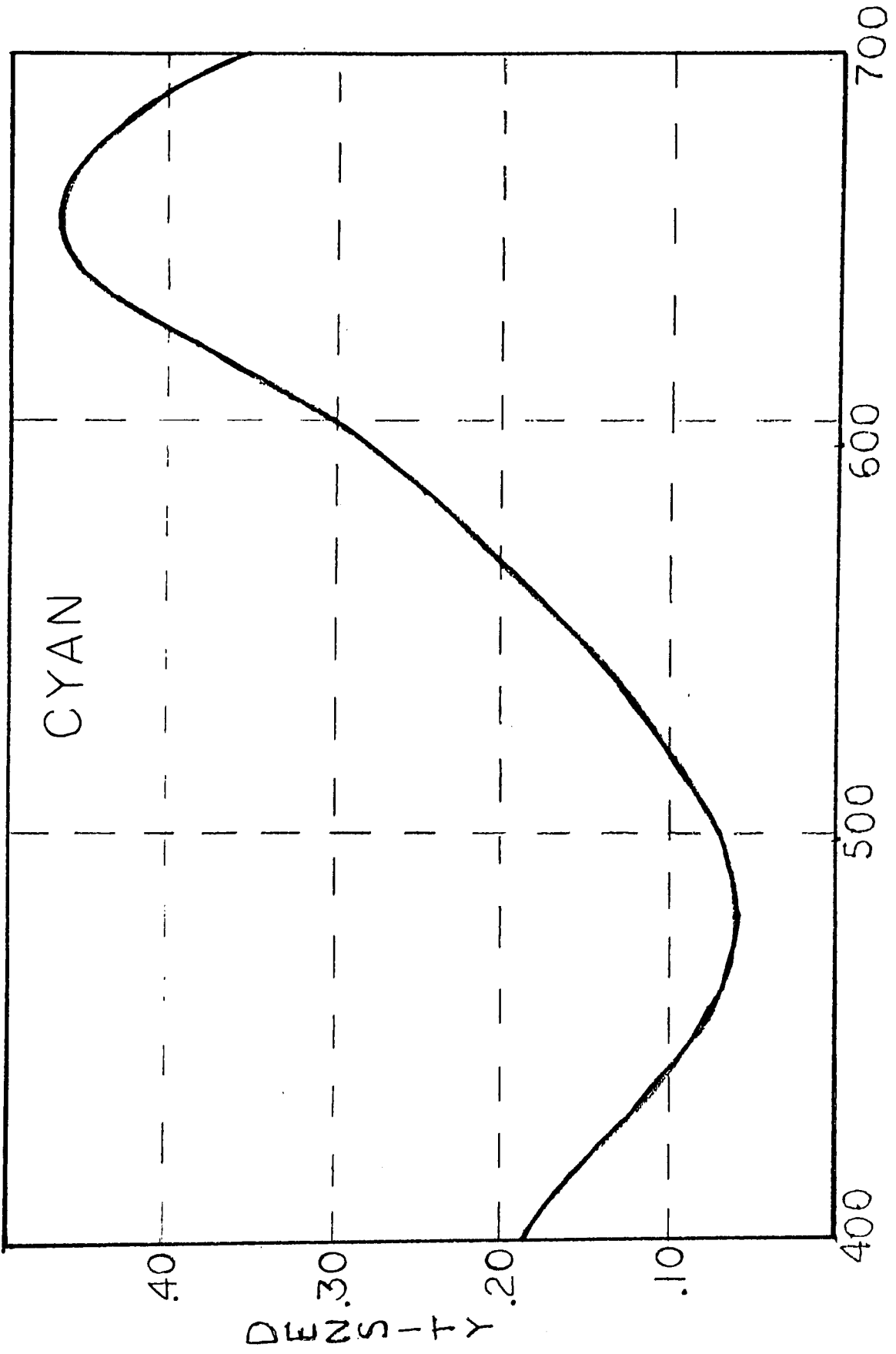


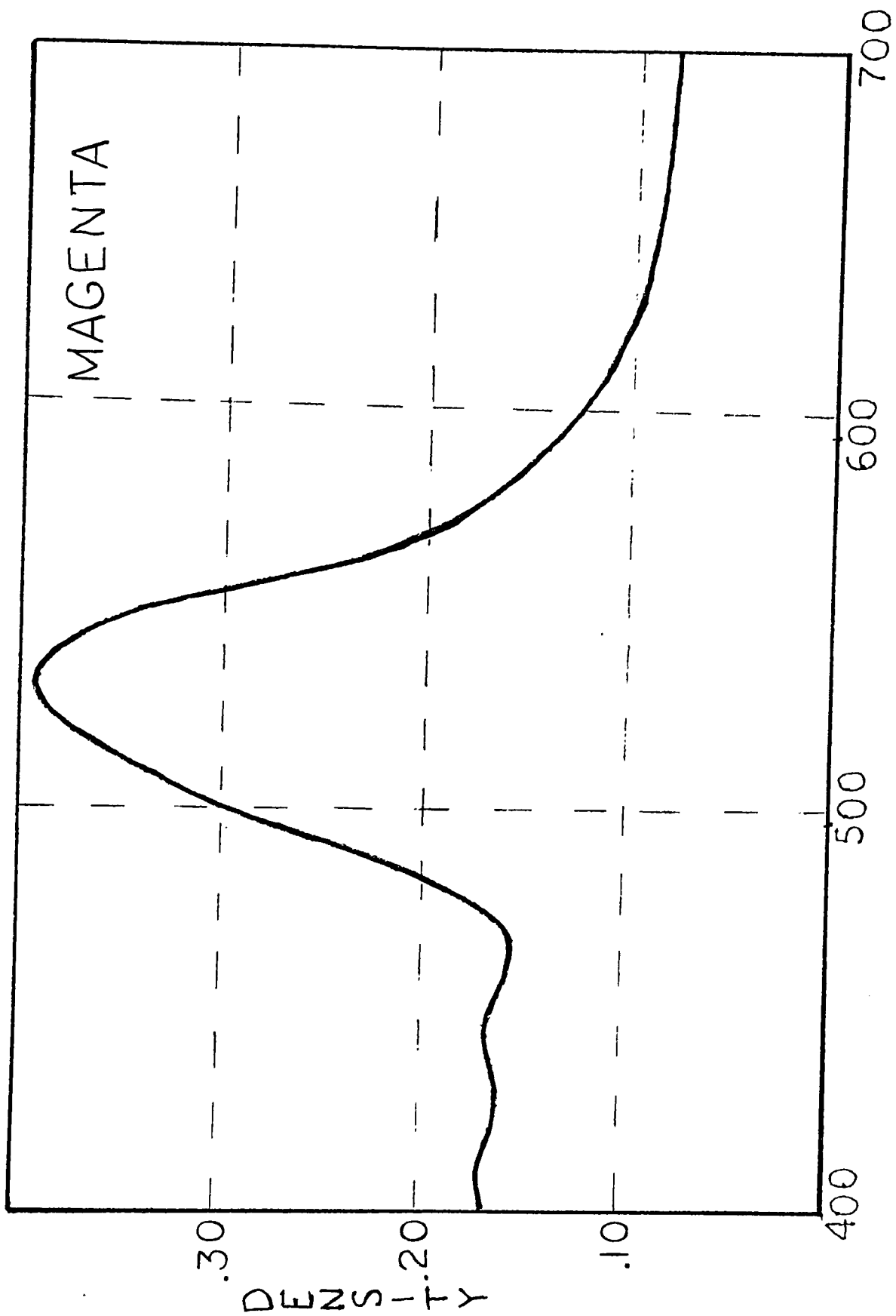
Fig. 4



CYAN

WAVELENGTH

Fig. 5



WAVELENGTH

FIG. 6

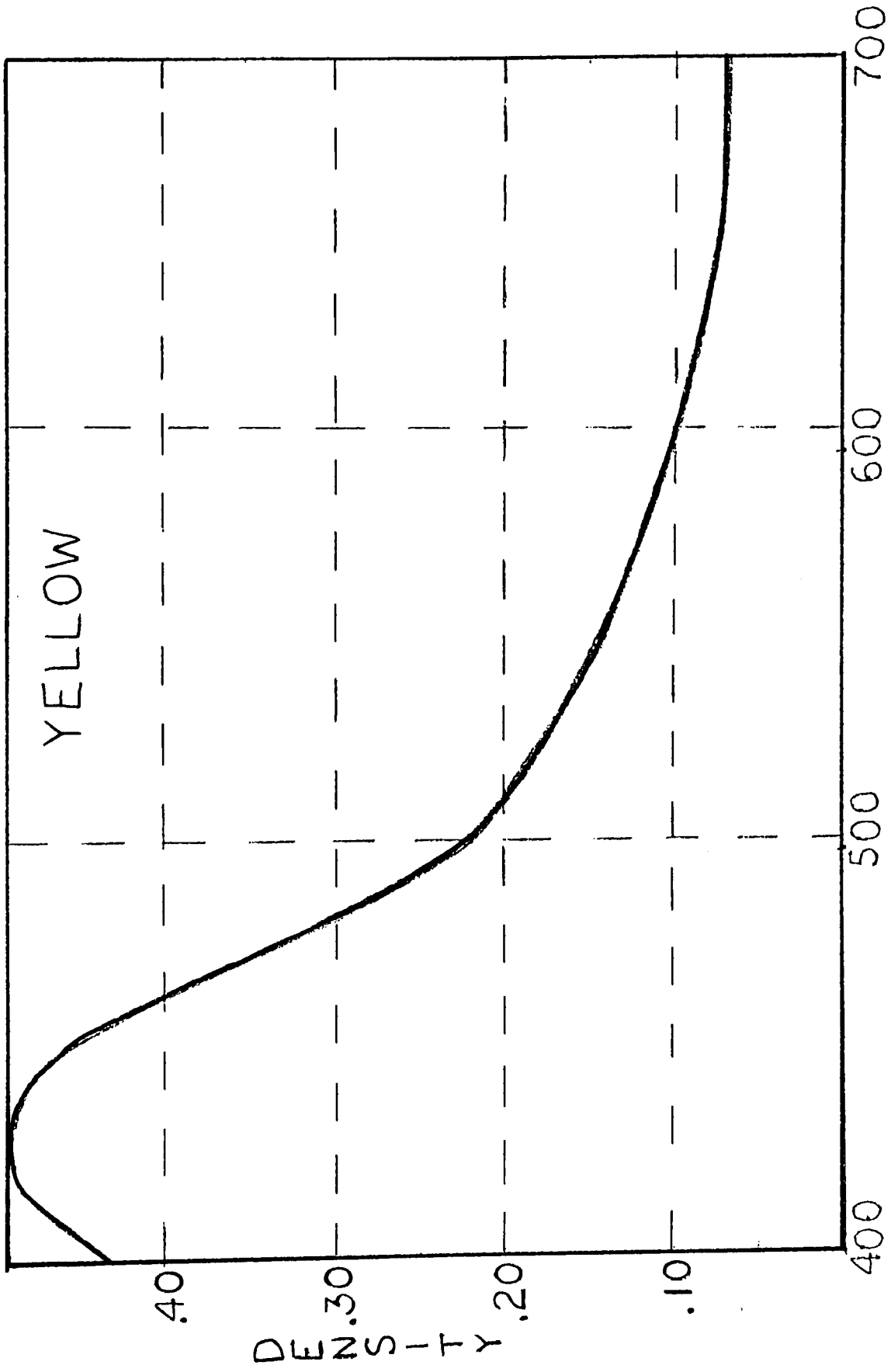


FIG. 7

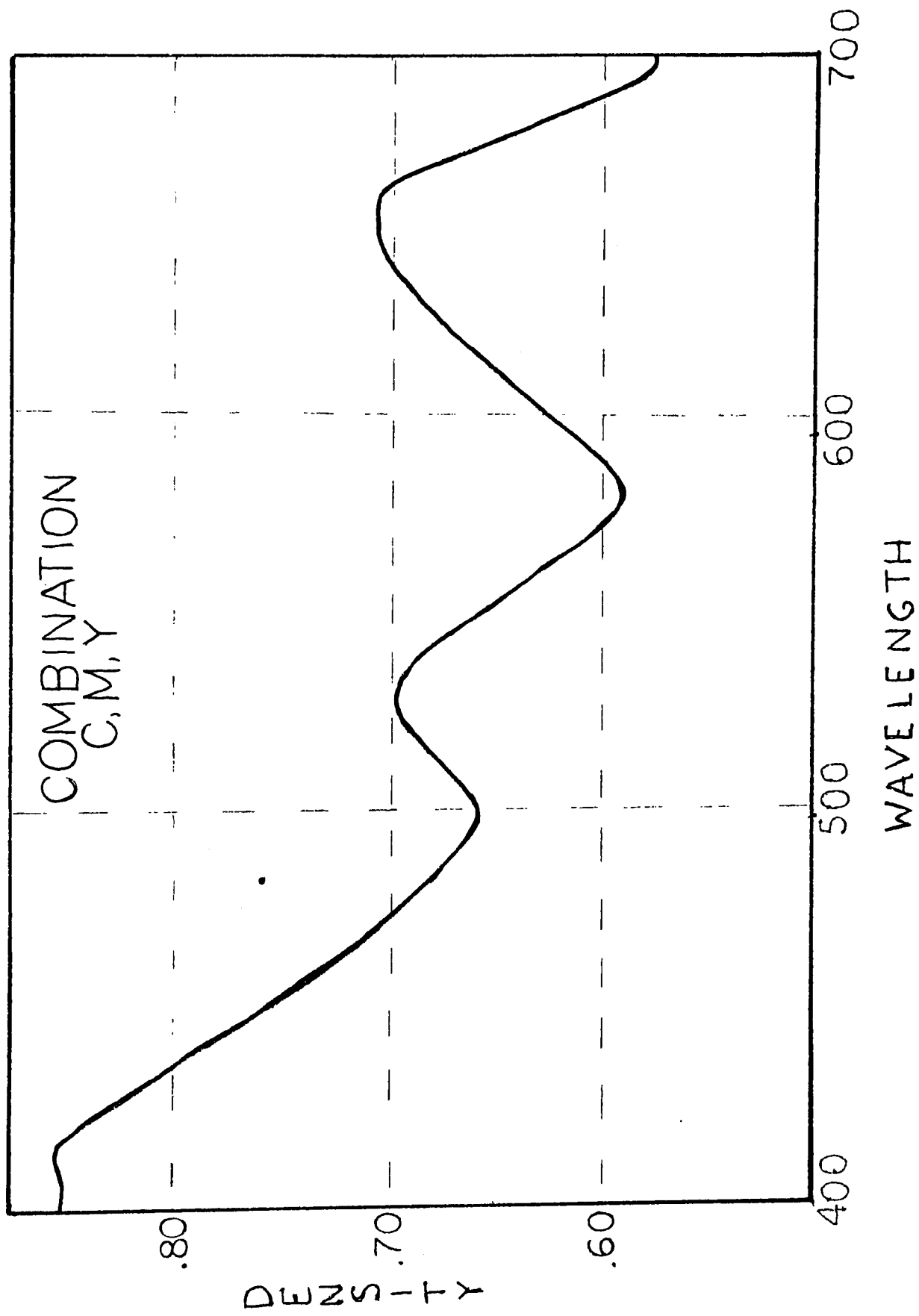
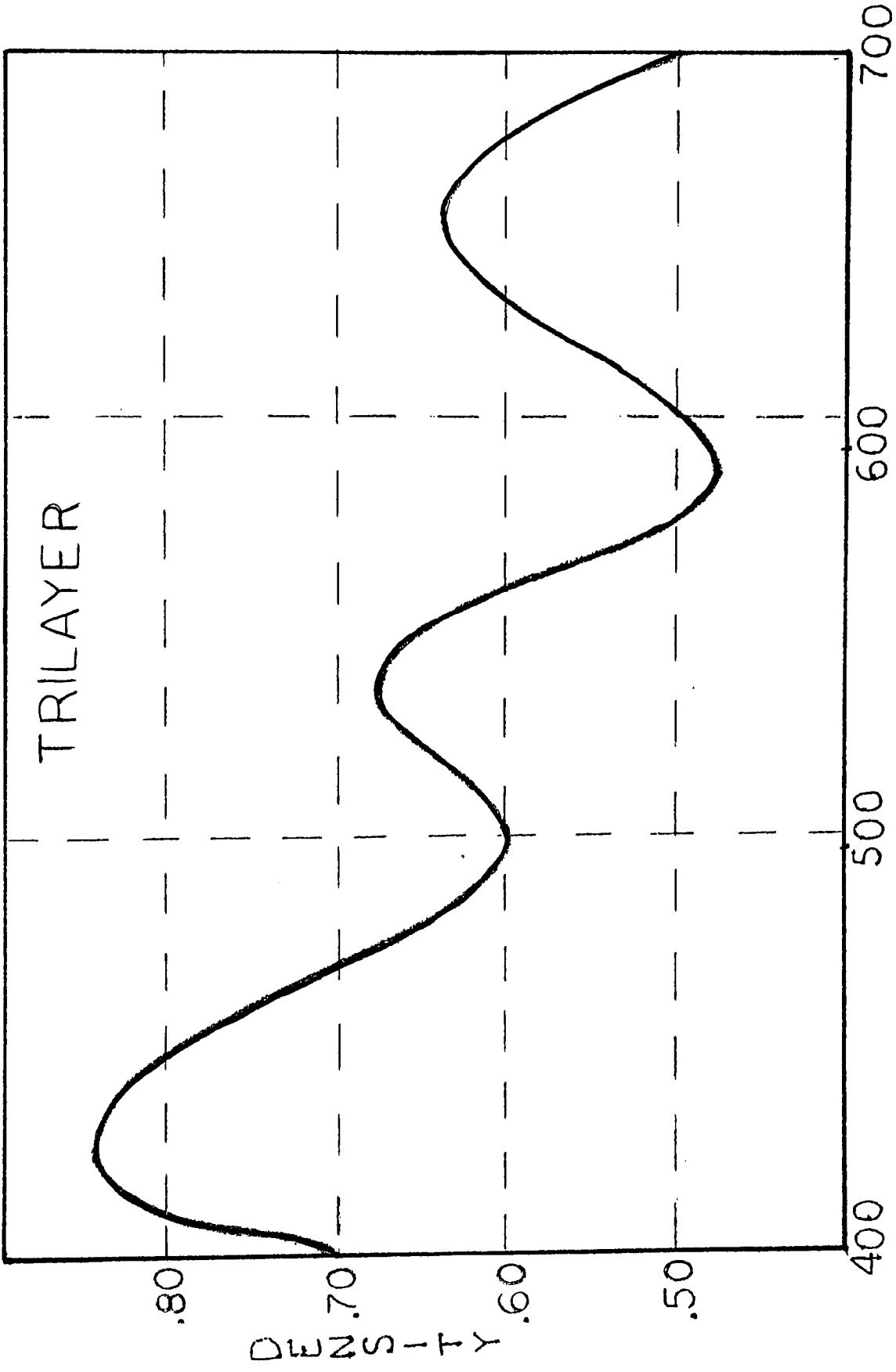


Fig. 8



TRILAYER

Fig. 9

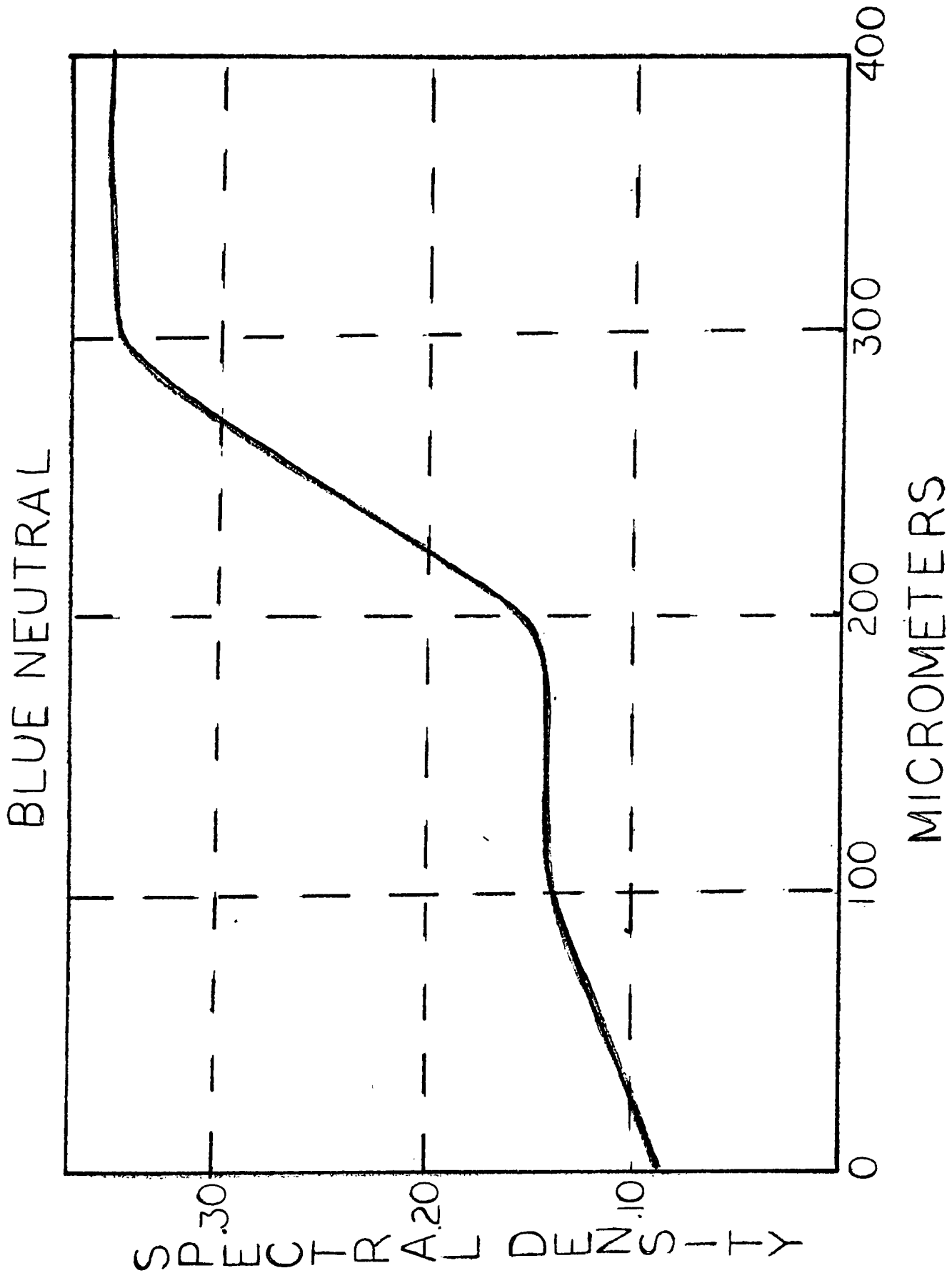
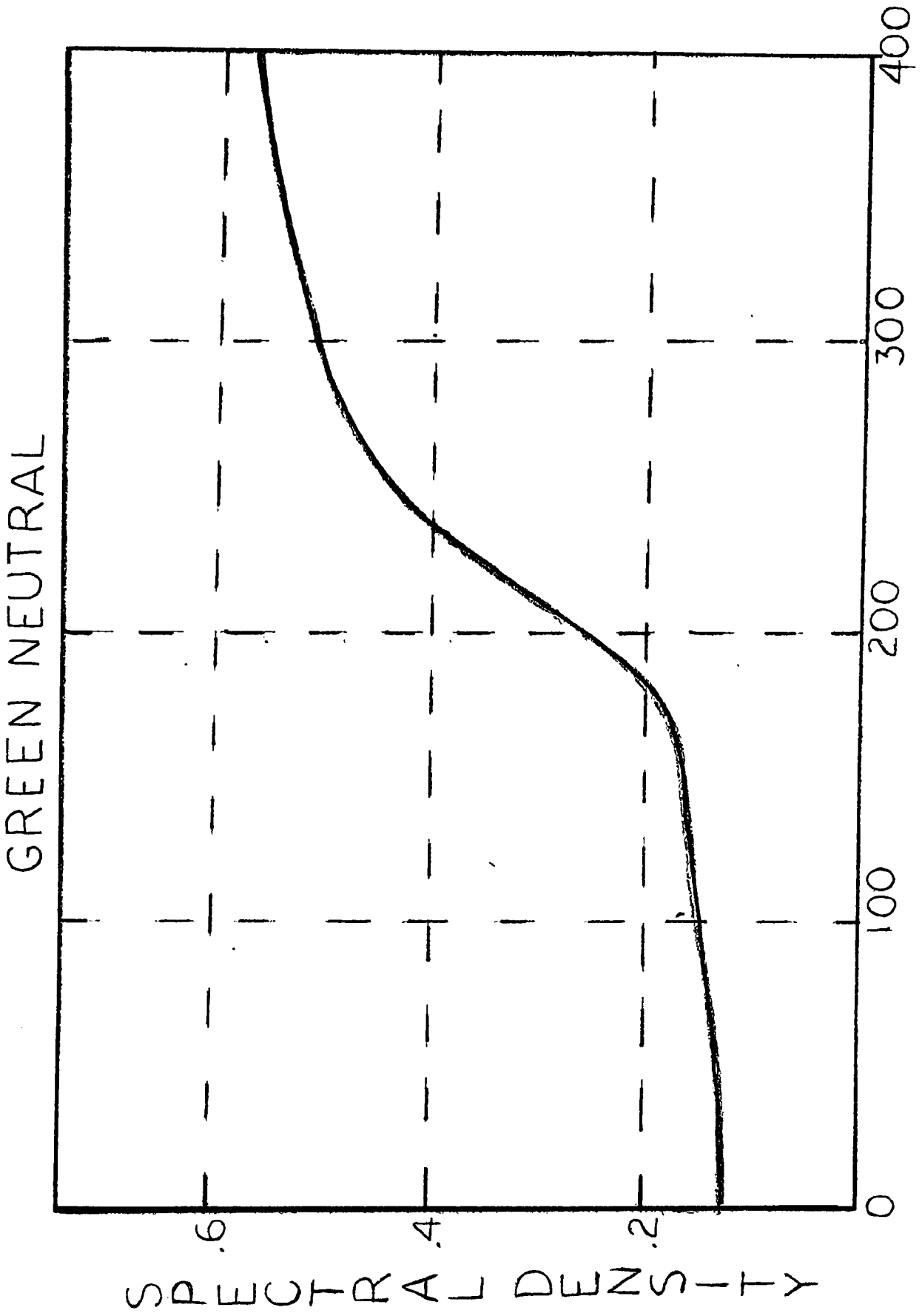


Fig. 10



GREEN NEUTRAL
MICROMETERS
Fig. 11

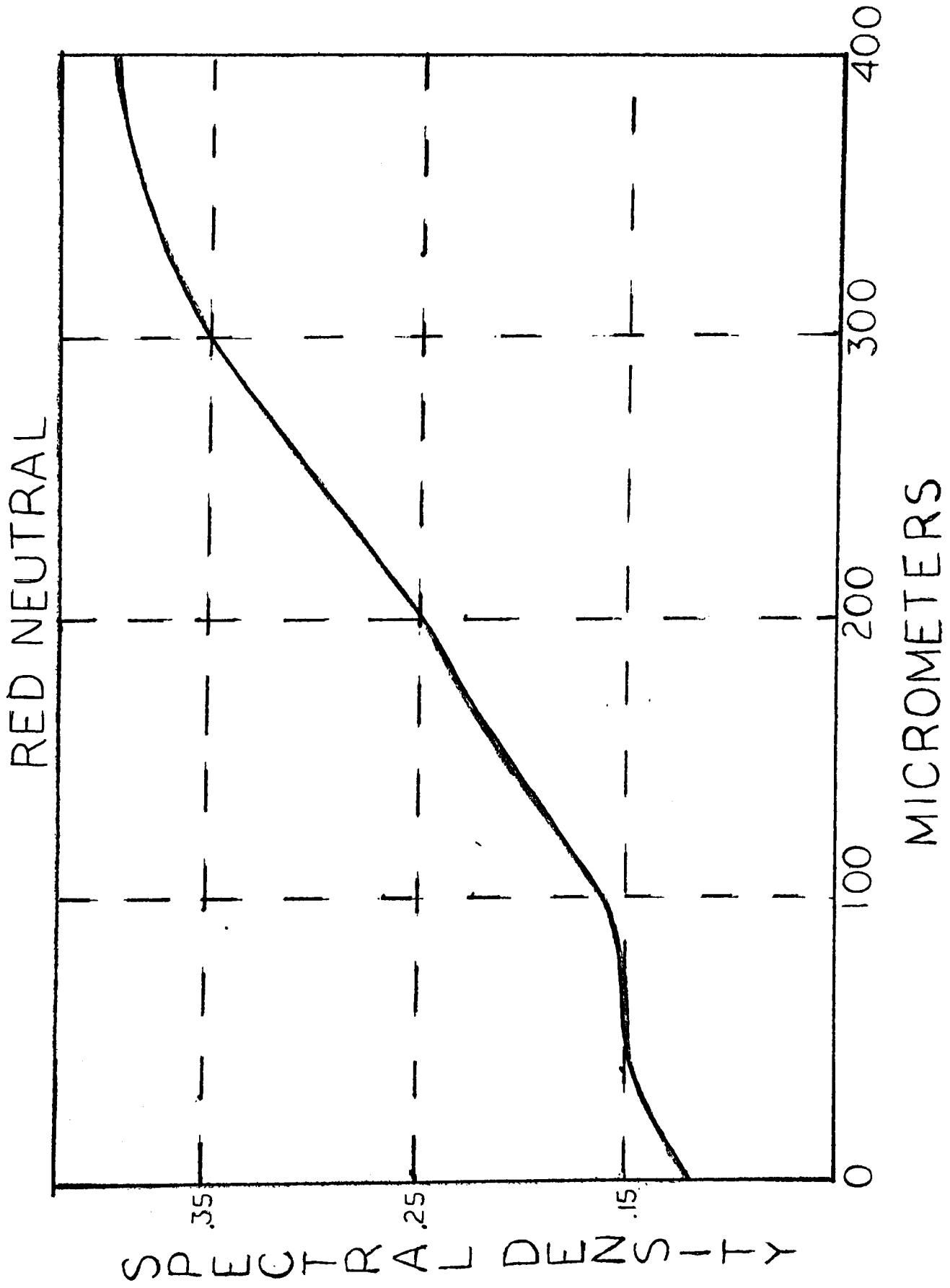


Fig. 12

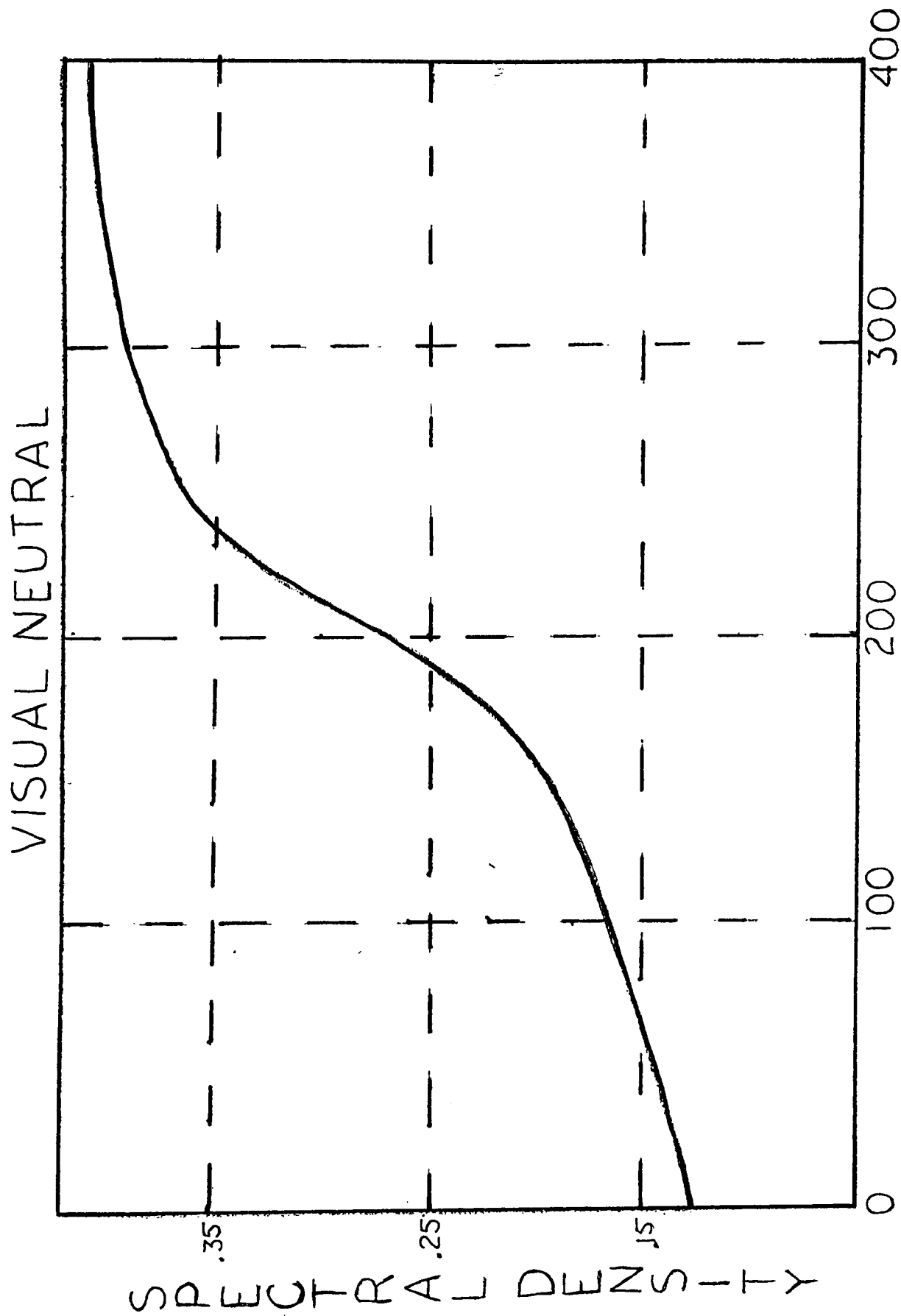


Fig. 13

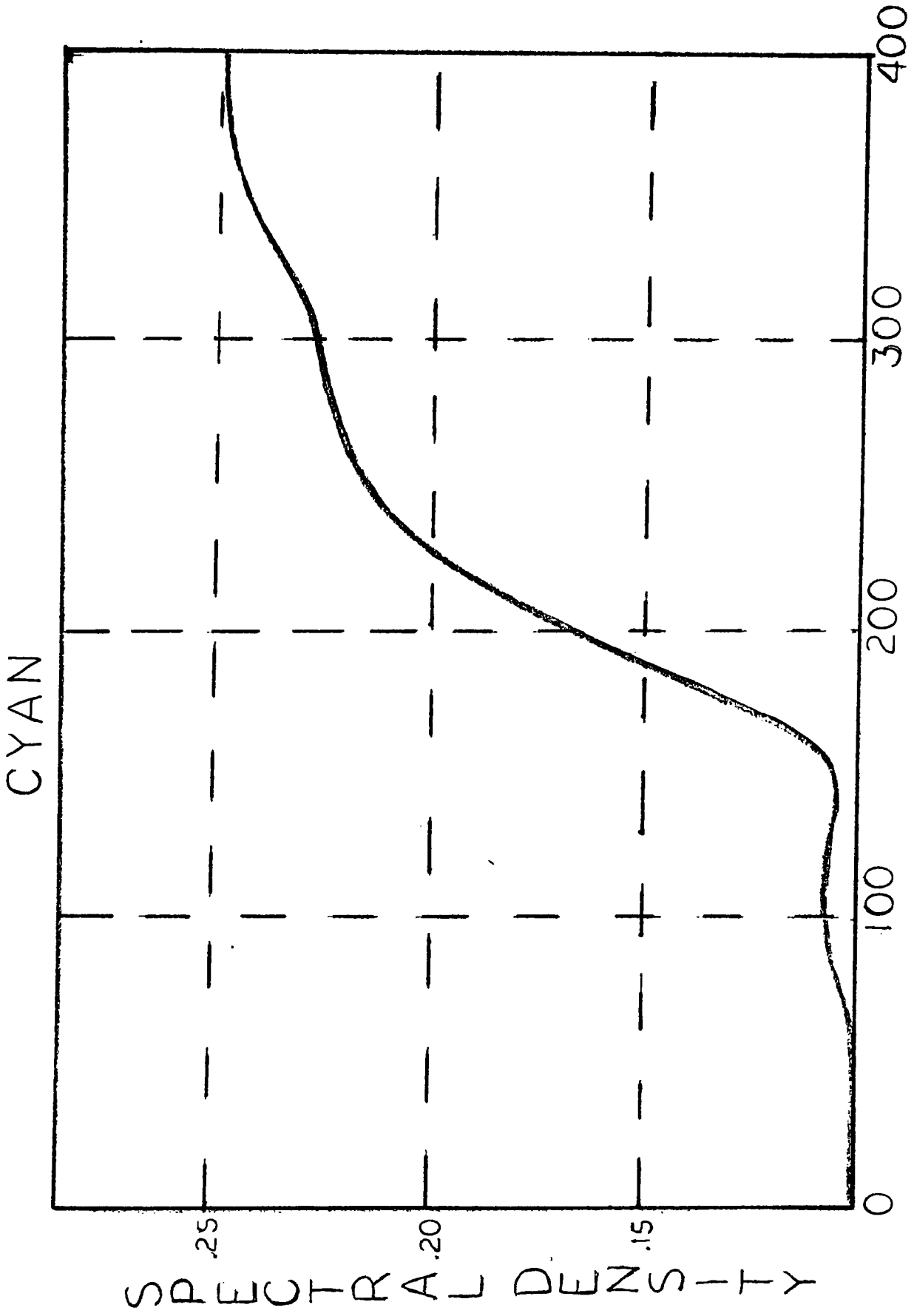


Fig. 14

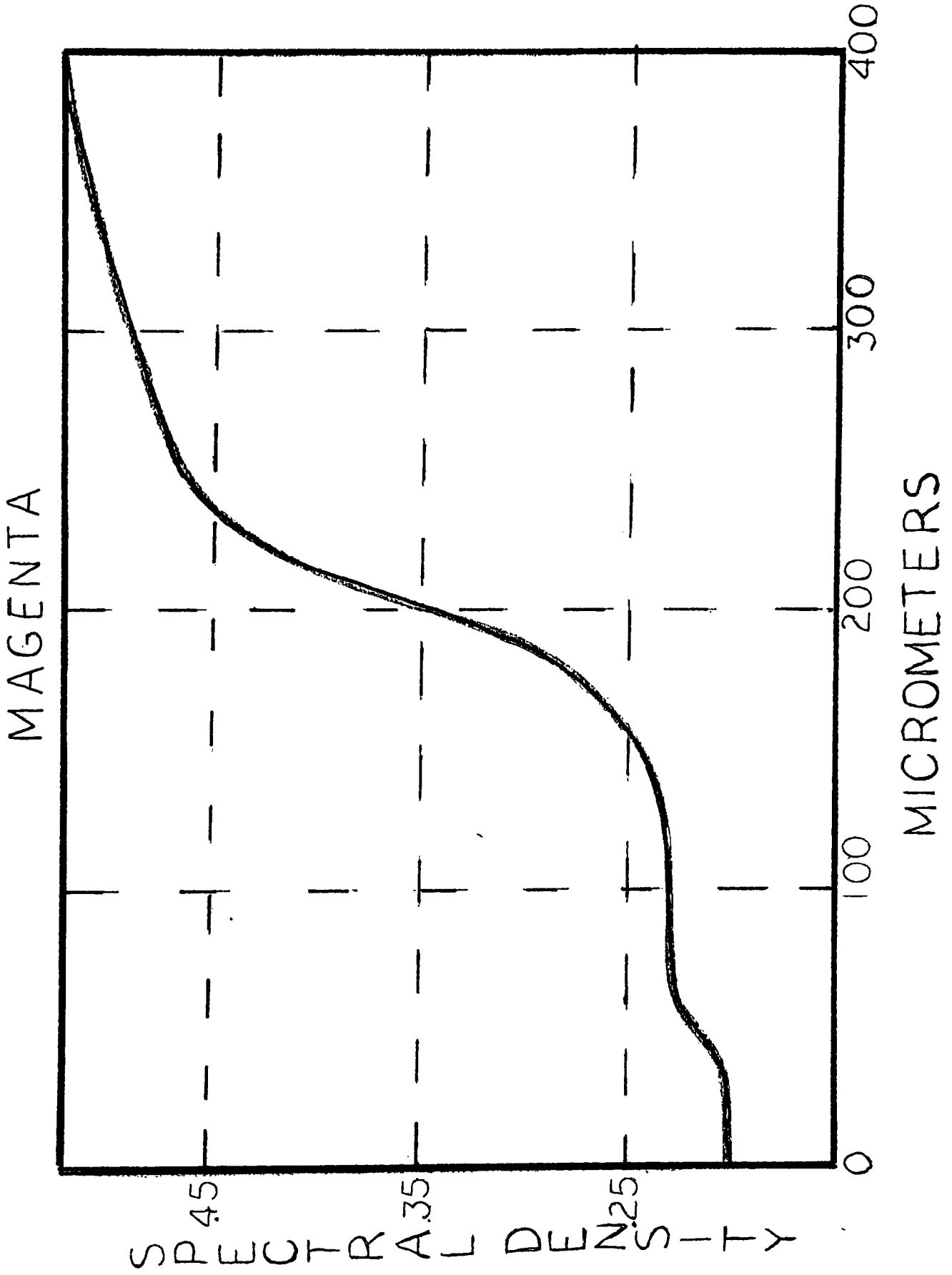


Fig. 15

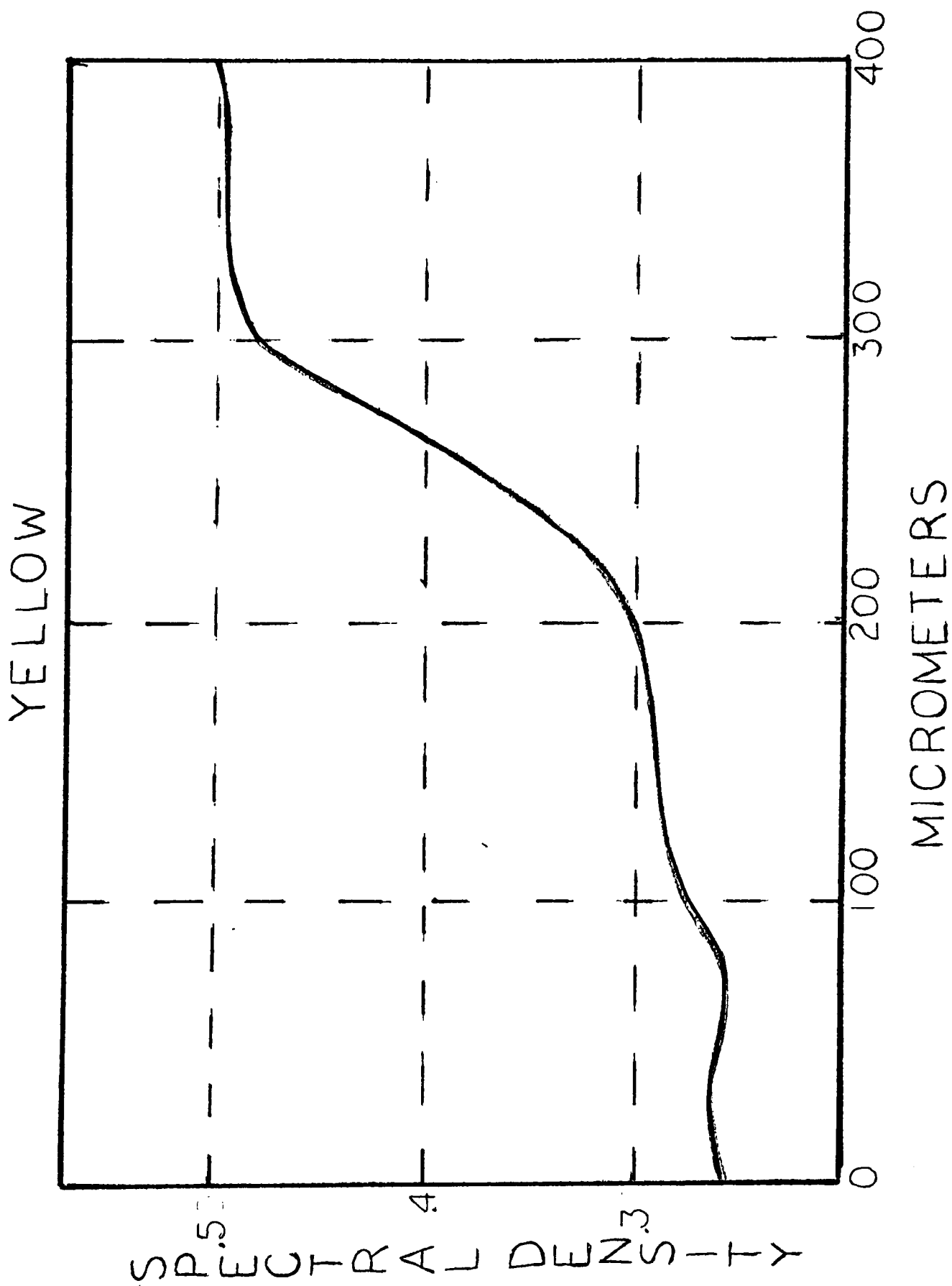


Fig. 16

VISUAL

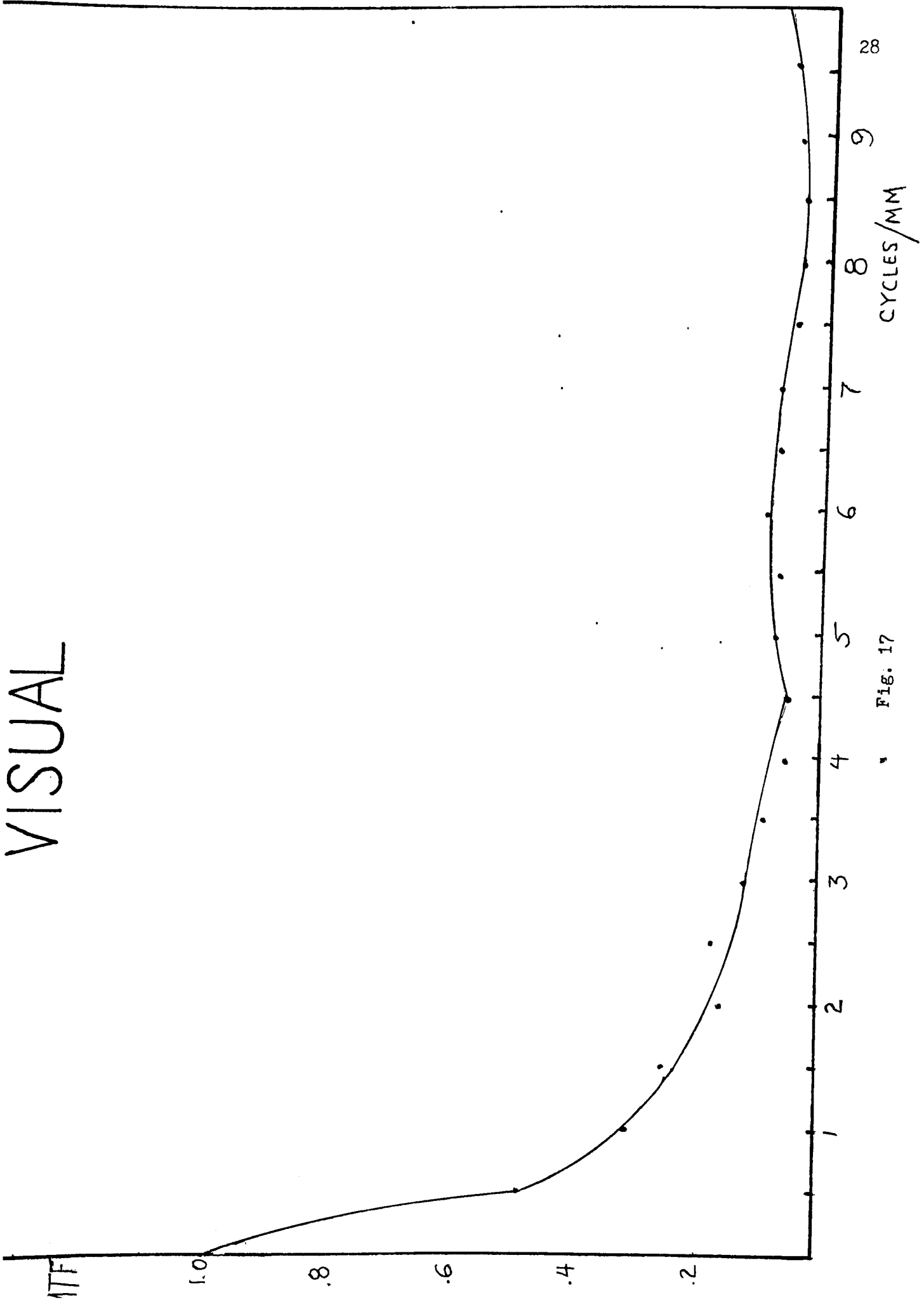


FIG. 17

RED TRIPACK

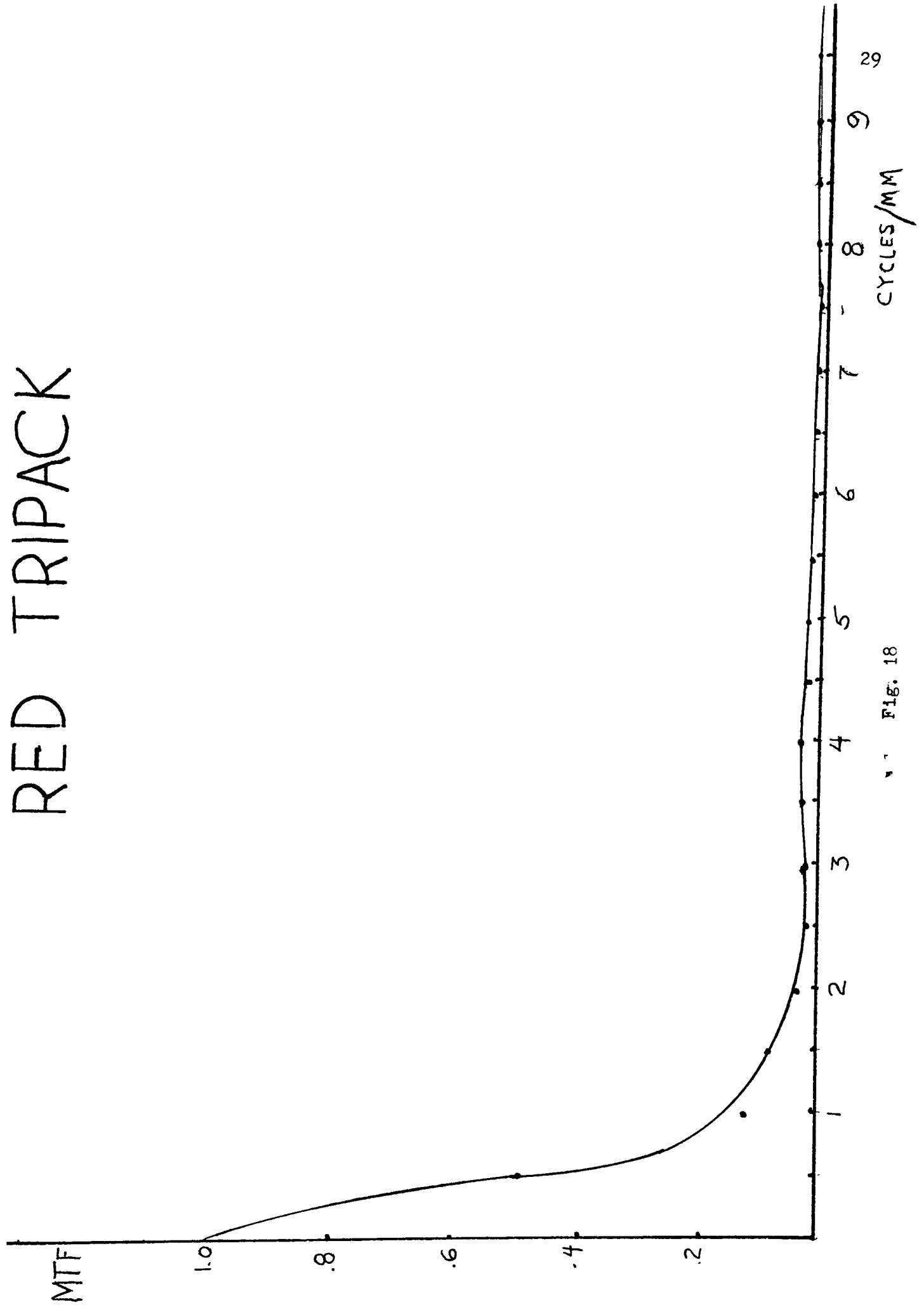


FIG. 18

GREEN TRIPACK

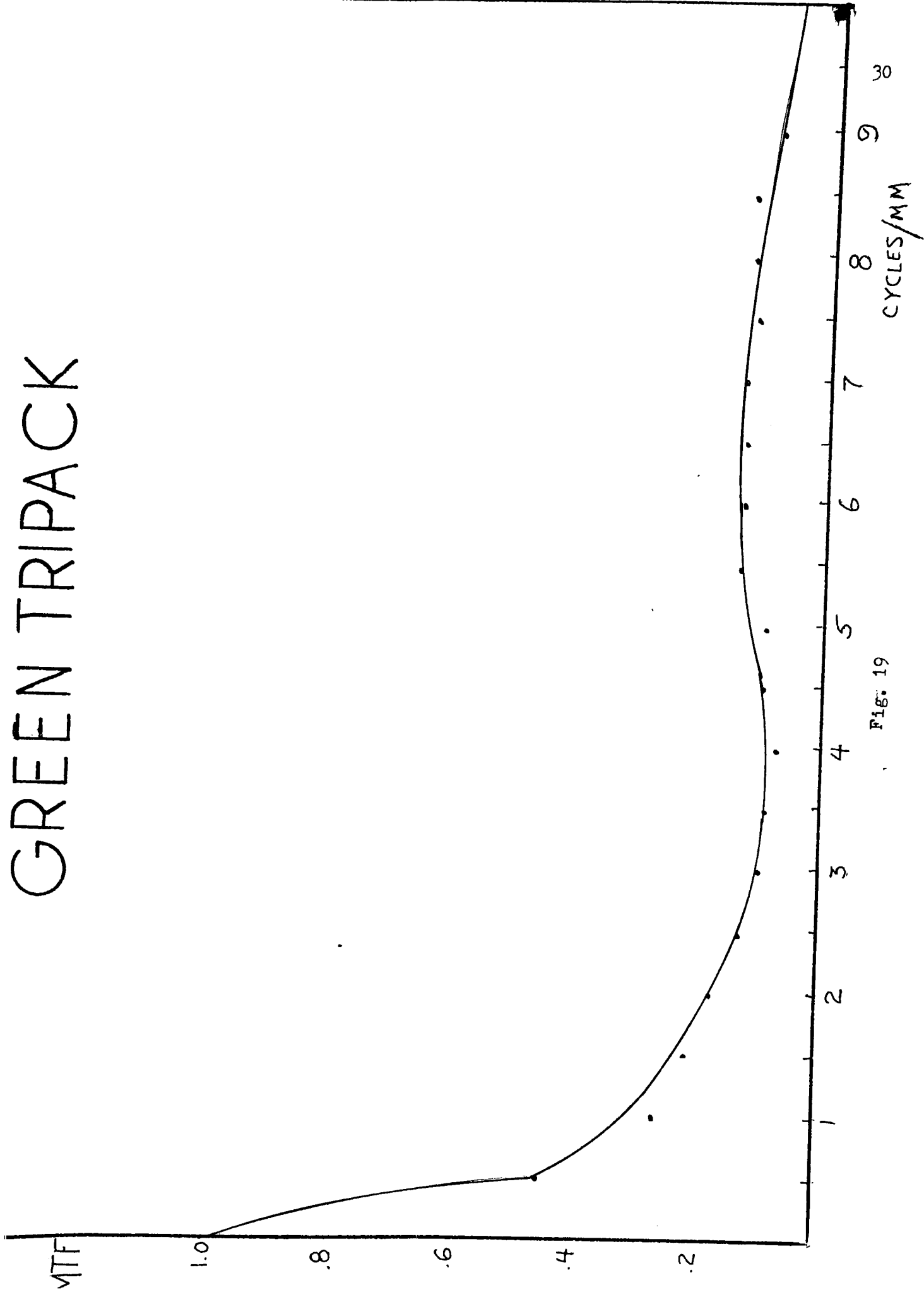


Fig. 19

BLUE TRIPACK

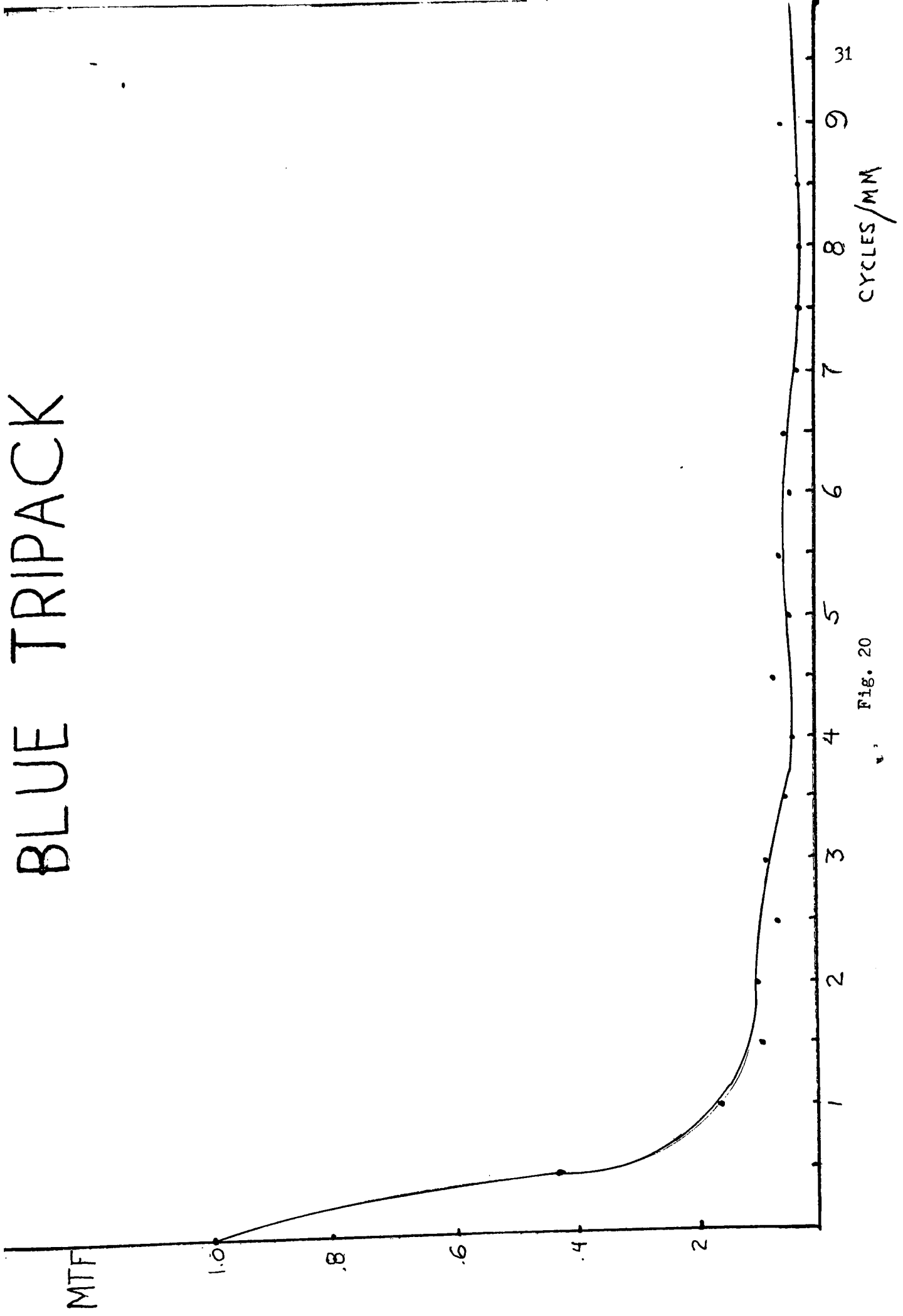


FIG. 20

CYAN

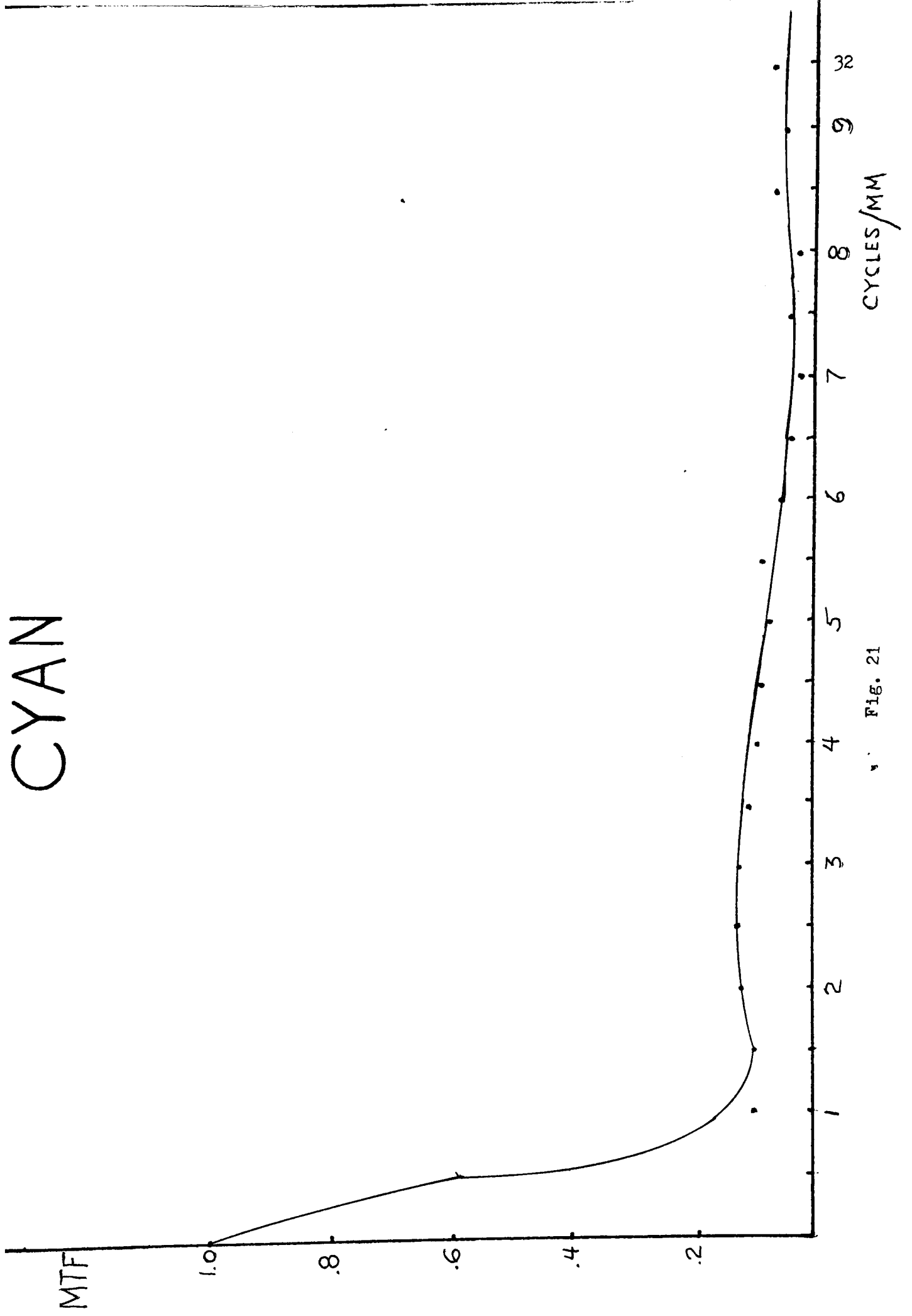


Fig. 21

MAGENTA

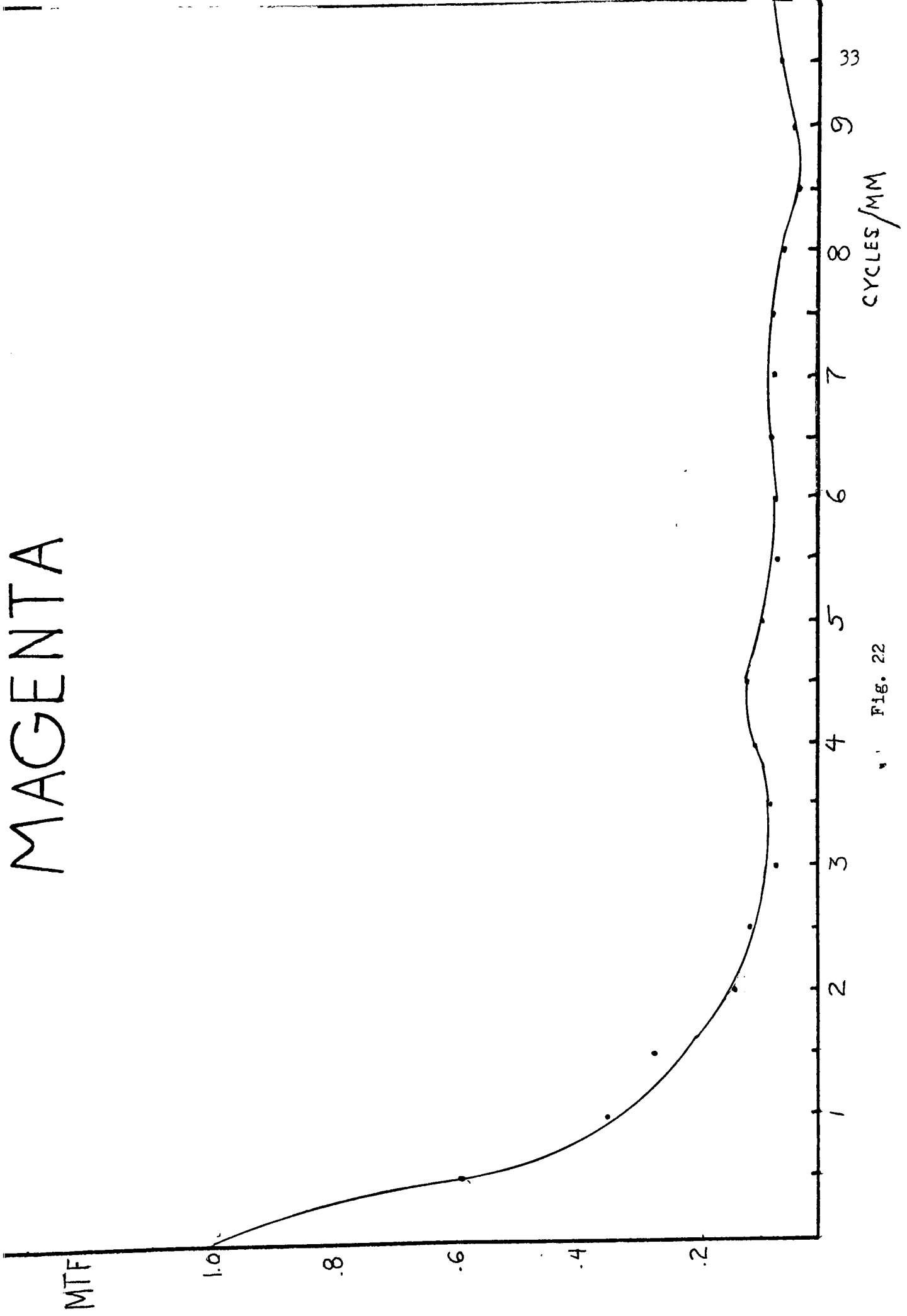


FIG. 22

ANALYSIS

The introduction of this paper stated that any interimage effects will be shown through differences in the MTF curves. The differences between the corresponding MTF's of the tripack neutral sample and those of the separate layers will reveal the extent of the interimage effects between the layers.

In order to draw any conclusions about the emulsion in question we should first analyze the microdensitometer curves and how they relate to the MTF curves. The microdensitometer traces are found in Fig. 10 through 13, and the corresponding MTF curves are found in Fig. 17 through 20. In studying the edge curves in terms of edge gradient the results of the MTF curves become predictable and consistent. The results of the tripack neutral are as follows:

Neutral Tripack

- 1) The green trace has the greatest slope and has the highest MTF.
- 2) The blue edge trace has a slope which is less than the green and as a result the MTF is lower than the green.
- 3) The red edge trace has the lowest gradient and the largest latitude. The result is the lowest MTF.

The separate layer samples (which we shall refer to as cyan, magenta, and yellow) follow the same pattern as the tripack, the higher the slope the greater the MTF. The edge traces are found in Fig. 14 through 16, and the MTF curves are found in Fig. 21 through 23. The results that have been obtained

from the separate layers and are as follows:

- 1) Magenta MTF is the highest for the three separate layers and has the highest edge gradient.
- 2) The yellow MTF is lower than the green MTF and is obtained from the edge slope which is less than the green.
- 3) The cyan layer which would correspond to the top layer on the tripack has the smallest slope for the edge and results in the lowest MTF.

The extent of the interlayer interimage effects will be shown in terms of the differences of the MTF's of the tripack and MTF's of the separate layers. The comparison MTF curves are found in Fig. 24 through 26. The effective exposures that were used to calculate the MTF's was in terms of its Analytical density. The results show that:

- 1) The yellow MTF is slightly higher than the blue trilayer MTF. Fig. 24.
- 2) The cyan MTF is higher than the red MTF. Fig. 25.
- 3) The green MTF is the only trilayer emulsion which exceeds its separate layer (magenta). Fig. 26.

This material has the characteristics that the red and blue tripack layers are hindered by the interimage effects, and the green tripack layer on the other hand is improved by these effects. Factors other than thickness and emulsion characteristics which would cause any significant differences in the MTF's are restricted to granularity and the dyes used.

If the system is linear, the MTF's obtained from the red, blue and green trilayer when multiplied together should be proportional to the visual MTF. A linear regression was done on

the Visual MTF versus the product of the MTF's. The results indicate that the MTF's obtained by multiplying the three tripack layers is proportional within 21%. This could be due to the interimage effects.

If the separate layers (cyan, magenta, and yellow) are treated in the same manner; it was found that the separate layered MTF were proportional to the visual within 22%.

If a linear regression is done on the product of the tri-layer MTF as it relates to the individual product of the separate MTF's, it was found that it is proportional to within less than 1%.

YELLOW

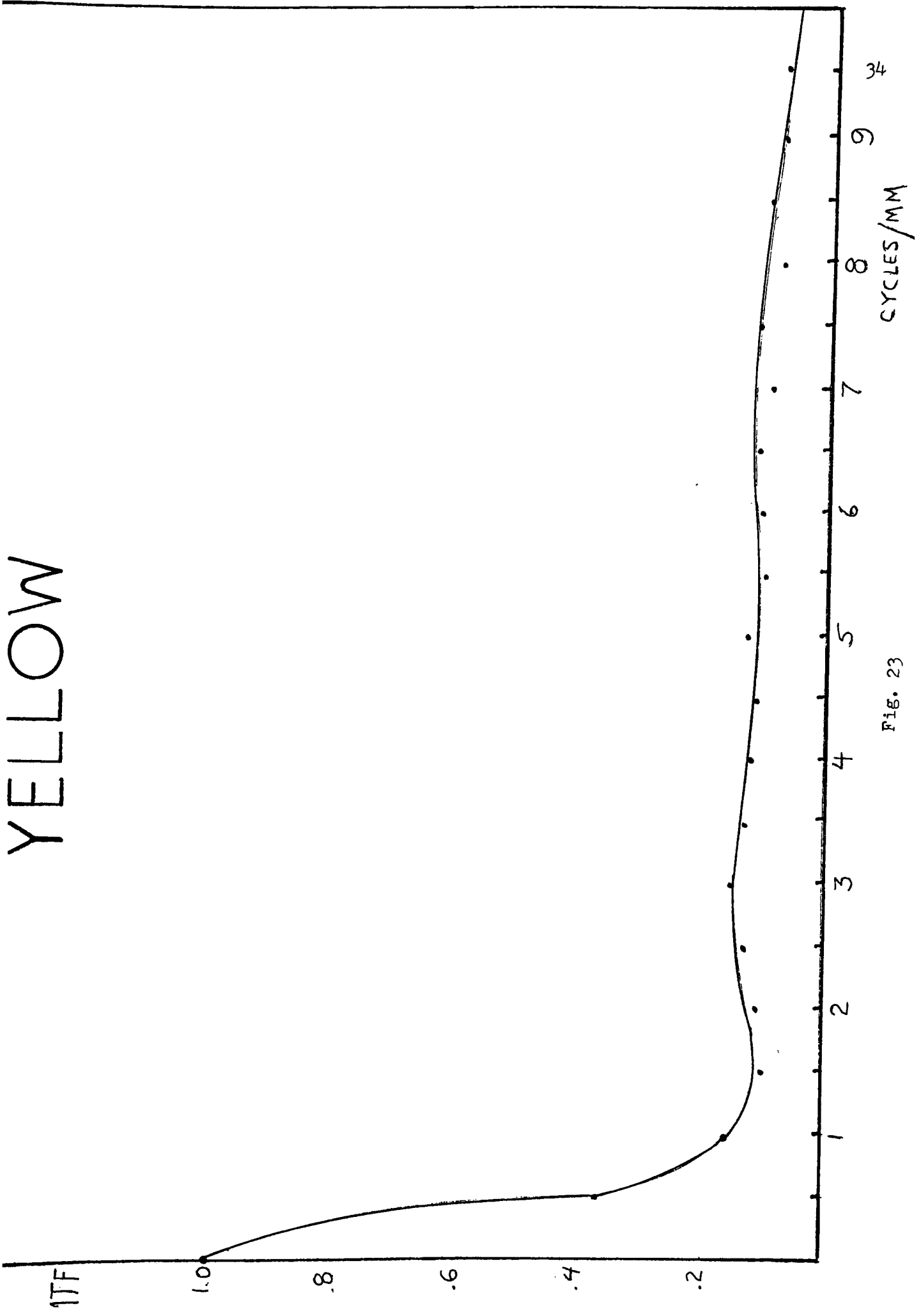


Fig. 23

• BLUE
○ YELLOW

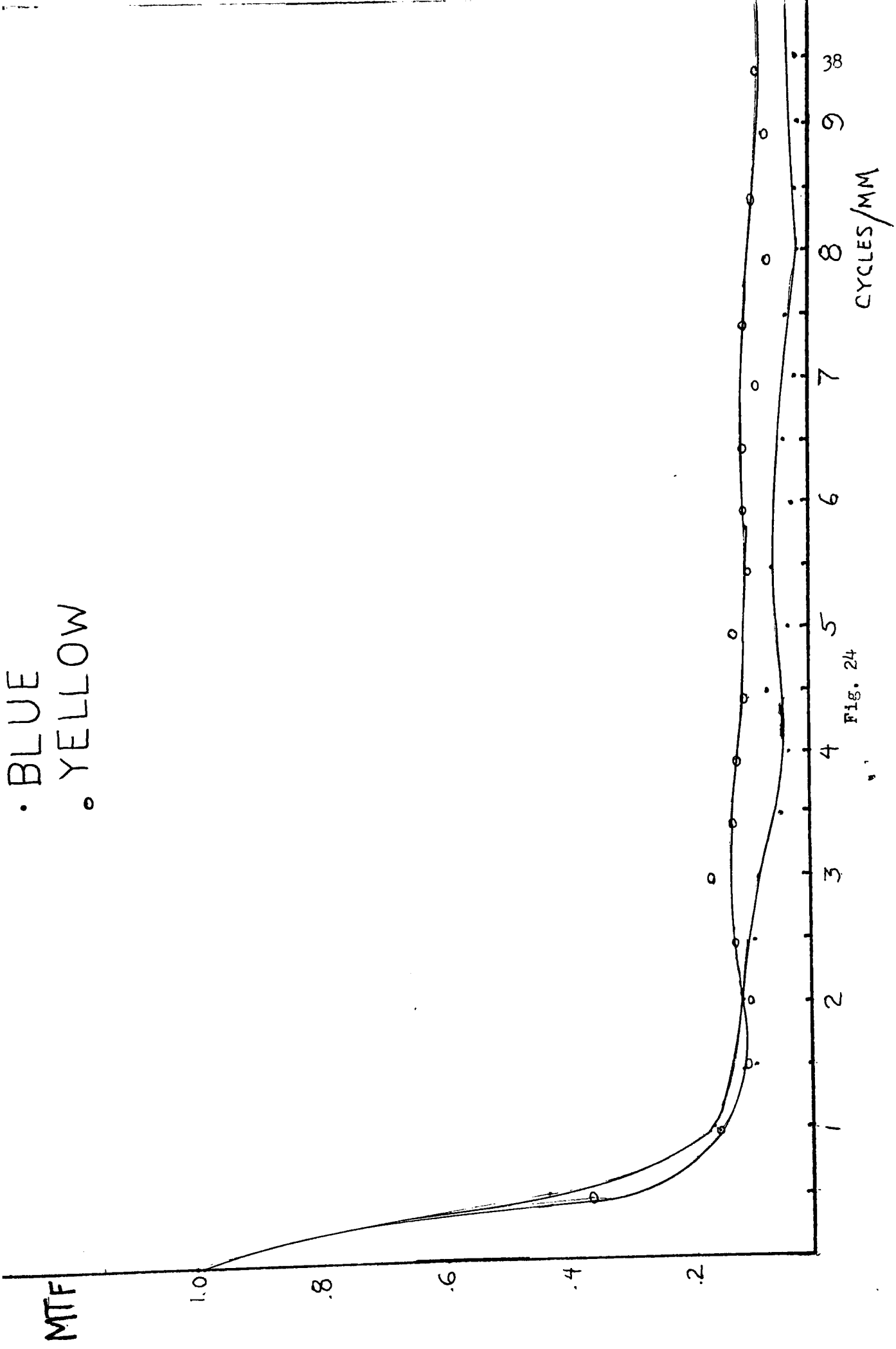


Fig. 24

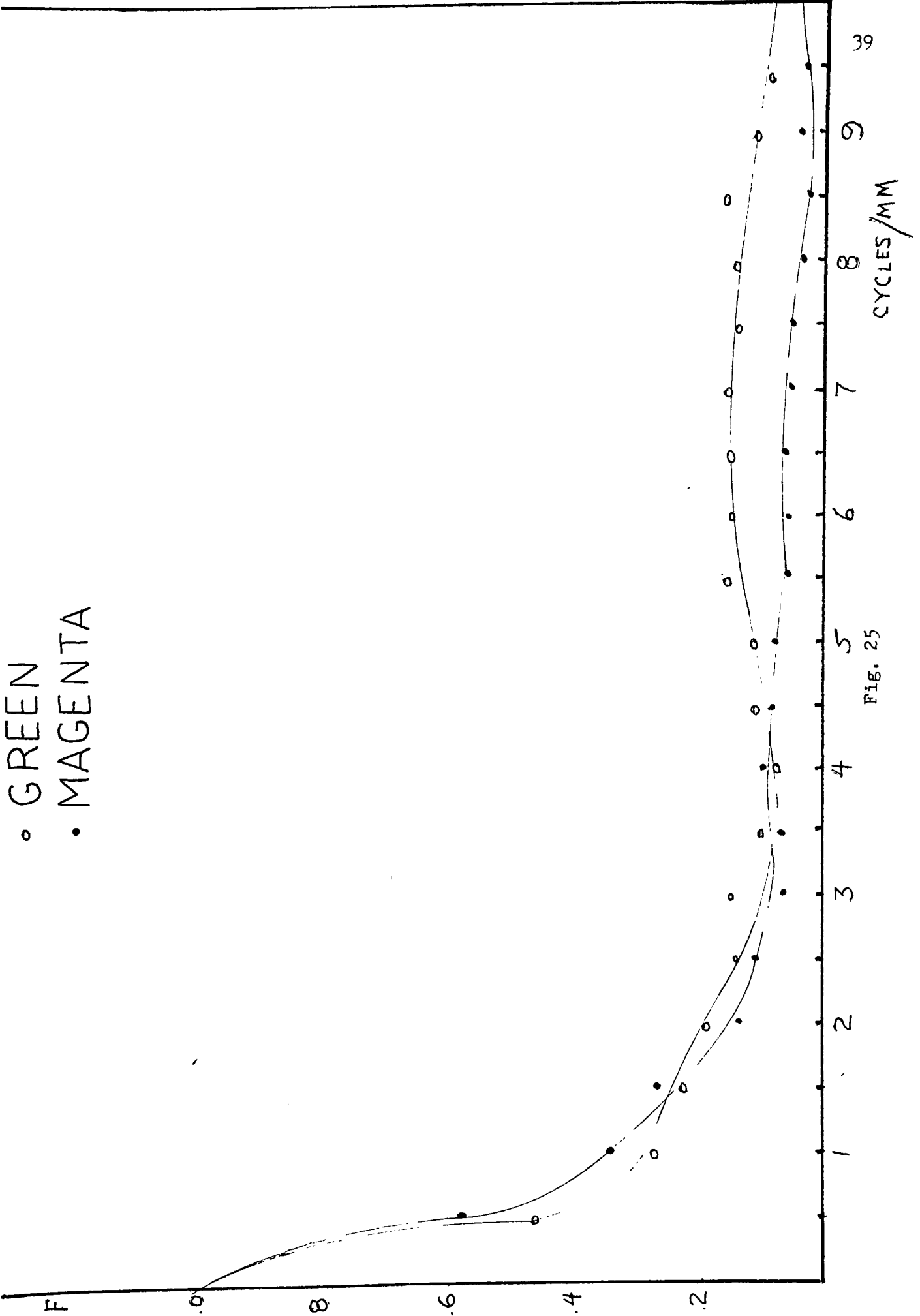


FIG. 25

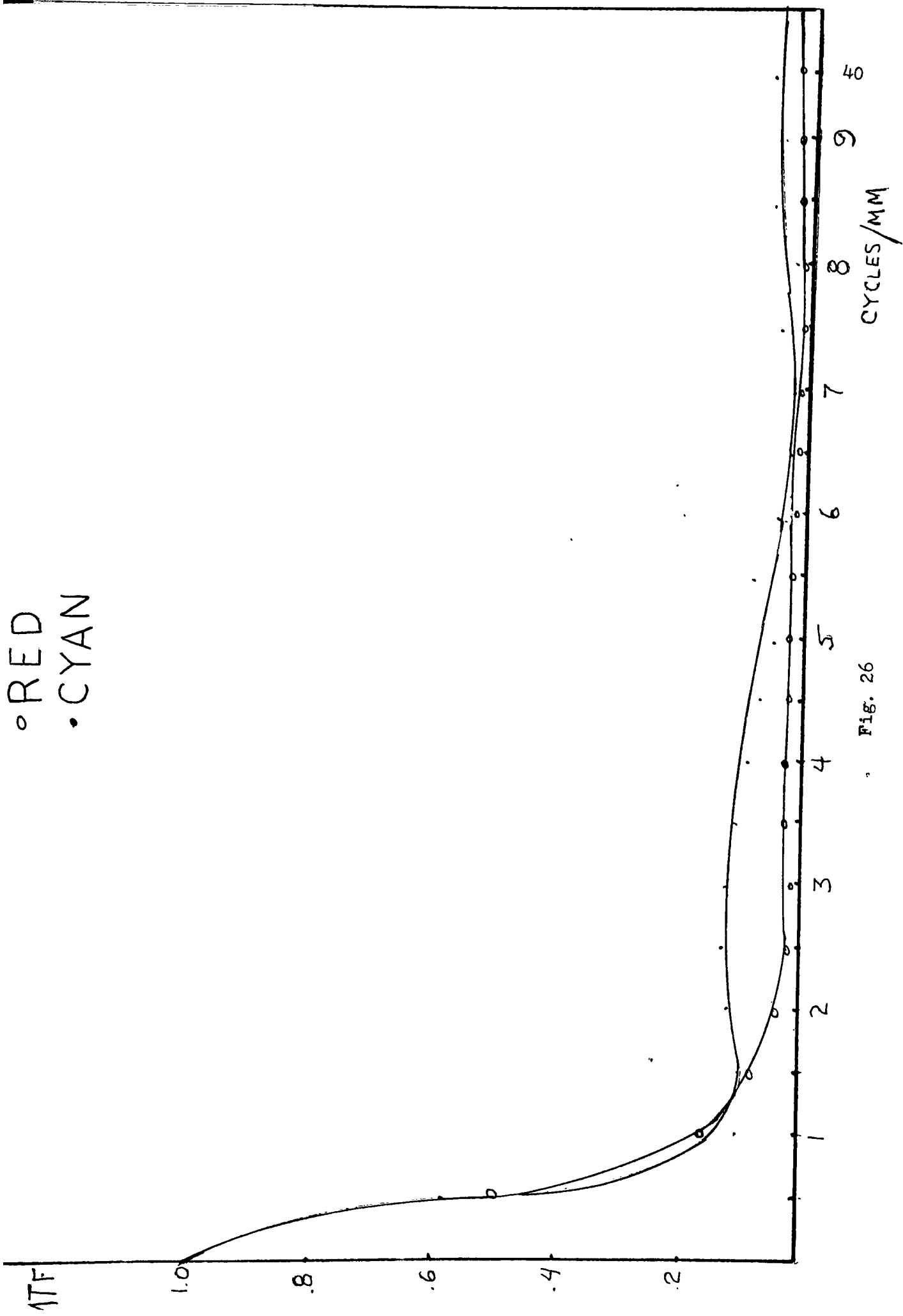


FIG. 26

CONCLUSIONS

This experiment has studied the MTF's of 3M color paper emulsion coated on a clear base. The study has found that the MTF's obtained from the neutral tripack are not equal to the MTF's from each layer separately. This difference could be the result of processing thickness, or emulsion characteristics, these effects termed Interimage Effects.

In evaluating the tripack sample the results show that the red top layer has the lowest MTF of the trilayer pack, and the green layer has the highest MTF. The fact that the red MTF has the lowest must be the result of the emulsion characteristics.

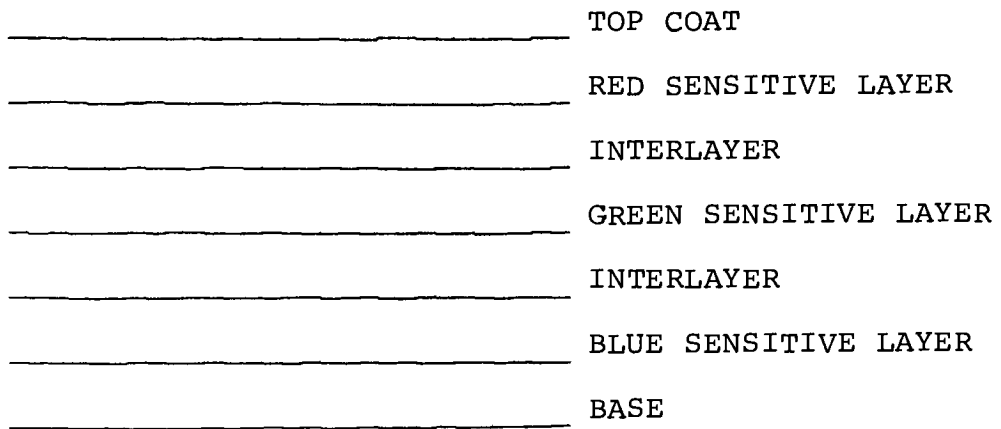
The product of the MTF's of the trilayer is linearly proportional to the visual MTF within 22% and the product of the separate layers is proportional to within 23%. This difference is the result of the interimage effects which exist within the emulsion.

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APPENDIX A

CONSTRUCTION OF 3M COLOR PAPER EMULSION



APPENDIX B

CALCULATION OF CIE CHROMATICITY COORDINATES

X, Y, Z CIE Tristimulus Values

E Relative Energy of Source

$\bar{x}, \bar{y}, \bar{z}$, Tristimulus values of the equal energy spectrum

T Transmittance from Spectrophotometer

$$X = \int_{\lambda_{min}}^{\lambda_{max}} E(\lambda) T(\lambda) \bar{x}(\lambda) d\lambda / \int E(\lambda) \bar{y}(\lambda) d\lambda$$
$$Y = \int E(\lambda) T(\lambda) \bar{y}(\lambda) d\lambda / \int E(\lambda) \bar{y}(\lambda) d\lambda$$
$$Z = \int E(\lambda) T(\lambda) \bar{z}(\lambda) d\lambda / \int E(\lambda) \bar{y}(\lambda) d\lambda$$

x, y Chromaticity Coordinates

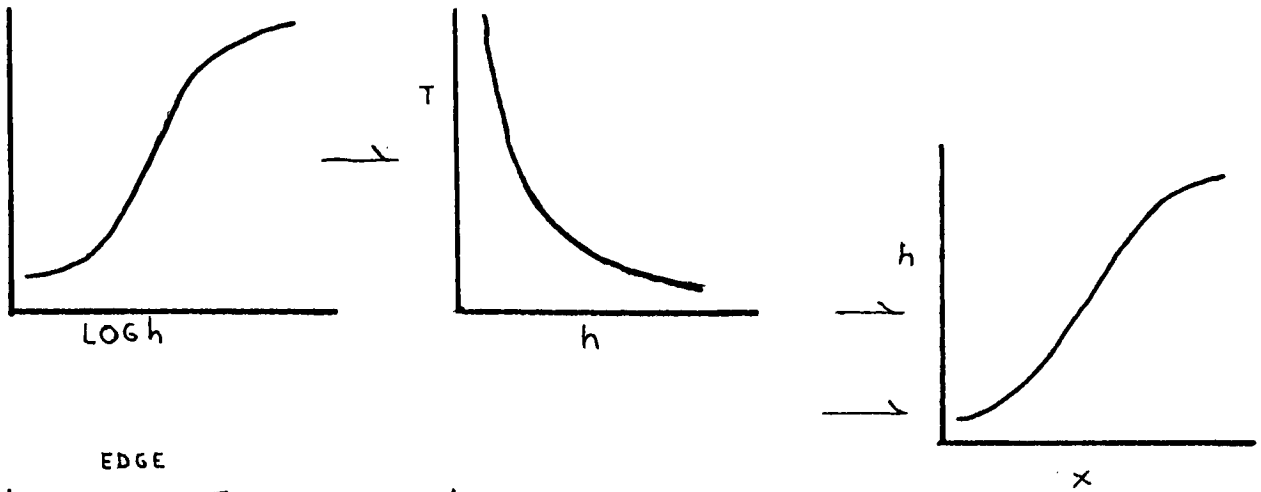
$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

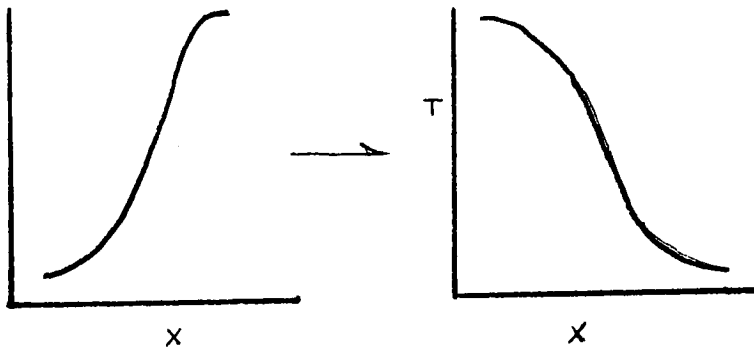
APPENDIX C

DETERMINATION OF MTF BY EDGE GRADIENT METHOD

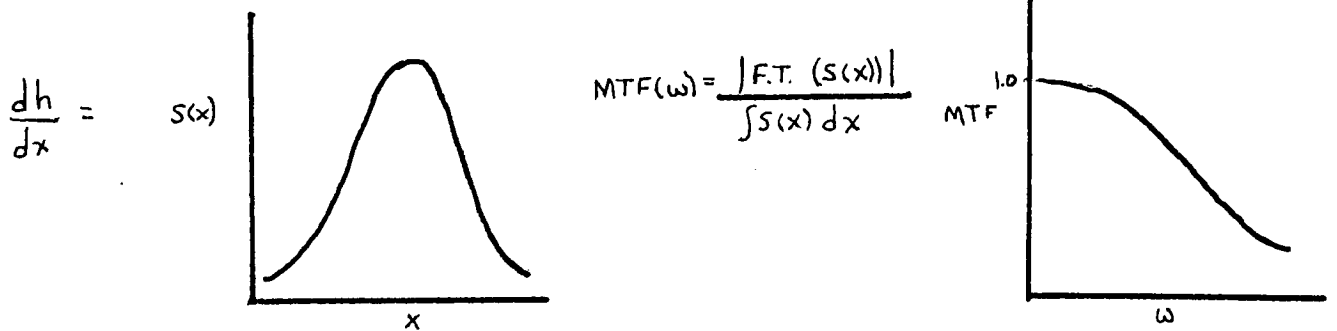
STEP WEDGE



EDGE



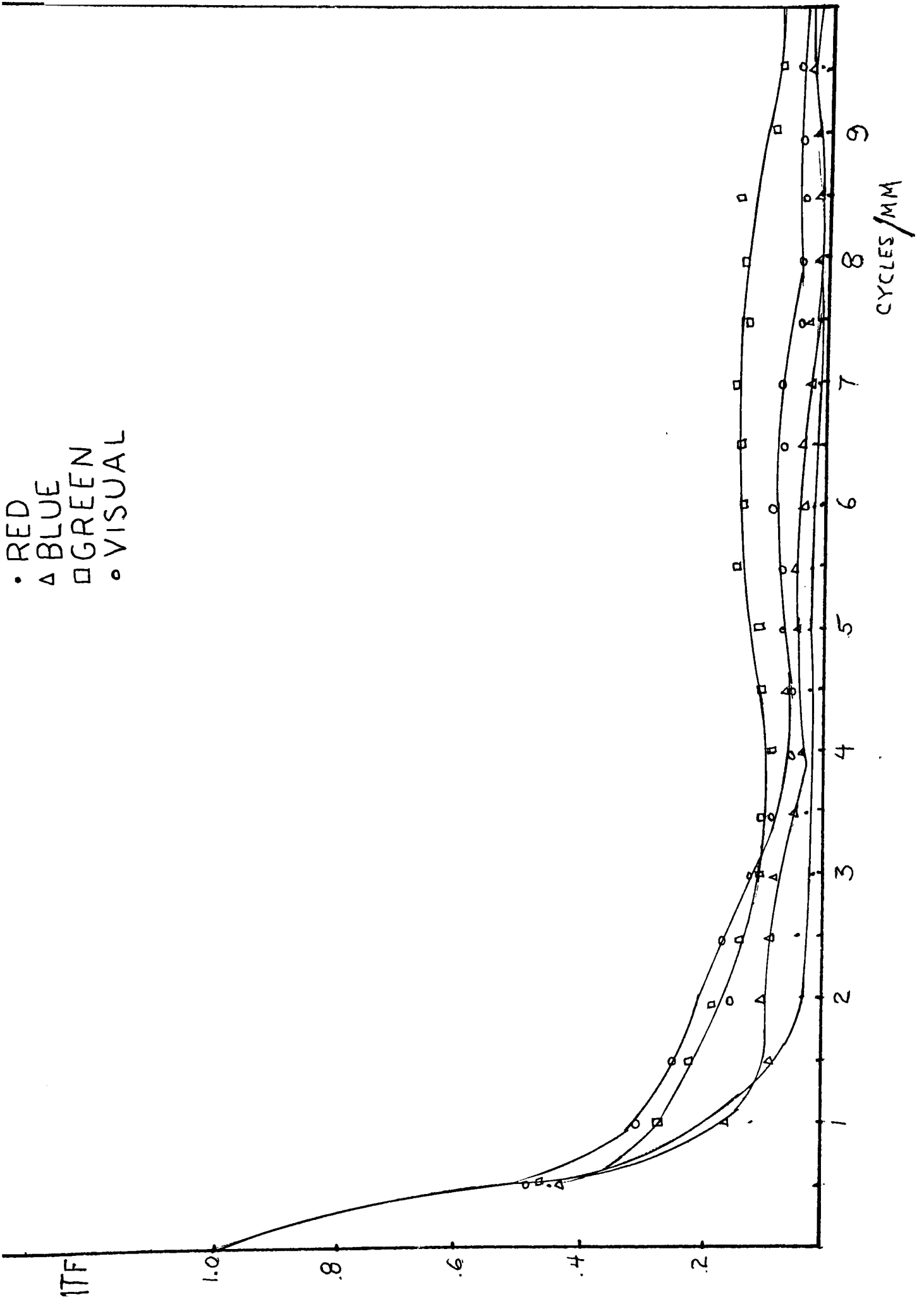
MTF CURVE



APPENDIX D

MTF'S OF THE TRILAYER

- RED
- △ BLUE
- GREEN
- VISUAL



APPENDIX E

MTF OF THE SEPARATE LAYERS

- CYAN
- YELLOW
- △ MAGENTA

