

SENSITOMETRIC STUDIES OF SOME POSITIVE
EMULSIONS AND THE EVALUATION OF
CHARACTERISTIC CONSTANTS

By

Edward A. Rominski

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Photographic materials are classified very largely, both by the manufactures and by those who use them, with respect to that quality which is designated as "contrast". The trade names by which these materials are known contain some specifications of the contrast characteristic. Among the terms used are hard, soft, normal, medium, contrast, vigorous, etc. For the purpose of classification and as an indication of adaptability to various purposes, especially true reproduction of spectrographic lines, a knowledge of the contrast of a printing paper is probably of greater importance than that of any other of its characteristics.

The meaning of the term "contrast" as applied to printing paper, while understood in a general way by the manufacture, is somewhat difficult to define. In fact, the same word when applied to different brands of paper may indicate widely different contrast characteristics. The use of such terms for the specification of this very important characteristic is obviously inadequate, and it seems highly desirable to find some method whereby "contrast" can be measured precisely and specified in numerical terms.

The possibility of using various sensitometric constants of a printing paper for obtaining an expression of contrast has been considered by many experiments in the photographic field, and several proposals have been made.

Jones, Mees, and Nutting¹ were the first to attempt to apply to photographic materials the sensitometric methods originated by Hunter and Driffield² to determine their characteristics. The blackness of the silver deposit was defined in a manner similar to the density values commonly used when dealing with the light-transmitting materials, the logarithm of the reciprocal of the diffuse reflection being defined as reflection density. This method of defining reflection density is in agreement with that proposed by Renwick³ and used by him in a study of the relation between the density values of silver deposits when measured by reflected and transmitted light.

Formstecher^{4,5} has treated the subject of contrast especially from the standpoint of exposure latitude and of the relations existing between the characteristics of the negative and printing paper. While he did not make any definite proposal for the specification of contrast, his treatment of the subject is of general interest. Kiesser⁶ after describing the well-known Hunter and Driffield method of expressing the characteristics of photographic

materials, proposed that the slope of the straight line portion to be taken as a measure of contrast or graduation. He suggests that the angle which the straight line portion makes with the log Exposure-axis, expressed in degrees be used as a numerical specification. Hall^{7,8} proposed that the value of total scale be used as a means of expressing contrast and Taylor⁹ also proposed the use of total scale, but in the reciprocal form and multiplied by a constant in order to obtain a series of whole numbers. Glover^{10,11,12,13} has treated the subject very carefully from the sensitometric standpoint and emphasized the fact that exposure scale alone is quite inadequate as an expression of contrast. He concludes that values of 'gamma infinity', 'total scale', 'maximum density', and 'rendering power' are necessary for a complete specification of contrast. Of these he believes 'gamma infinity' to be of greatest importance and 'total scale' of almost as great a value. His final conclusion is that it is rather hopeless to attempt any expression of contrast in the form of a single numerical value. As an alternative plan he proposed the use of a multiple test-negative, consisting of six negatives, varying in contrast, from which test points can be made on various papers and a scale of six contrast steps be thus established.

From this review of literature it was decided to determine sensitometrically the value of:- (1) Maximum density

(2) Gamma, (3) Total Scale, (4) Latitude, and (5) Rendering power, for various groups of printing paper, in order that this adaptability to the printing of spectrographic plates be better understood.

Definition of Sensitometric Terms

Opacity, Density, and Transparency

Hunter, and Driffield² first stressed the importance of defining clearly opacity, density, and transparency, since the mathematical relationship of these qualities, one with another, forms the basis of sensitometry. Opacity was defined by them as the power of a substance to resist the passage of light, or simpler still, as the ratio between the unit of entering light, and the fraction allowed to emerge. Transparency is the inverse relation or may be defined as the reciprocal of opacity. Density is more difficult to define, because it is in effect, synonymous with opacity, the difference, being that while both terms define blackening in respect of a photographic emulsion, density implies the specific degree of blackening, or light stopping substance, and is a measure of the quantity of metallic silver deposited per unit area.

The Lambert-Beer law, $\text{Density} = \log_{10} (\text{opacity}) = -\log_{10} (\text{transparency})$, of absorption of light includes the statement that absorption increases in geometrical progression as the thickness increases in arithmetical progression, and in applying the argument to a series of densities occurring in a photographic negative, Hunter and Driffield revealed the set of conditions which gave rise to the characteristic curve.

Characteristic Curve

A typical characteristic curve for paper is here shown in figure 1. This curve is obtained by plotting the reflection densities of the paper obtained by full developement against the logarithm of the exposures that give rise to them. The reflection densities of a paper are measurements fulfilling the equation

$$\text{Density} = \log \frac{1}{R}$$

where R is the reflecting power measured when the silver deposit on the paper is illuminated by a narrow pencil of light at an angle of 45° and viewed at an angle of 90°. The measurement is analogous to the H. and D. density measurement in the case of plates where $D = \log \frac{1}{T}$, T being the transparency of the silver deposit under measurement.

The characteristic curve of a paper derived in this manner exhibits the following features:-

Total Scale (Exposure Range or Exposure Scale). In Fig. 1 an exposure E_a gives rise to the faintest discernible tone upon the paper and E_b gives rise to the deepest black. Then the quantity $\log E_b - \log E_a$ gives the total scale of the paper. It is the range of exposure which enables the paper to record all possible tones from the faintest gray to the deepest black upon full developemnt. The usual condition of successful printing is that the total scale of the paper in logarithmic units should be equal to or slightly greater than the density scale of the negative. Whereas two papers

with the same total scale my yield similar points from the same negative, two papers with different total scales can never yield points of the same appearance from the same negative. The total scale is, therefore, an important measurement descriptive of one feature of the characteristic curve of the paper.

Gamma:-

As in the case of plates, so in the case of papers, the straight line portion of the characteristic curve (c d in Fig 1.) when produced downward will intersect the exposure axis at an angle (α in Fig 1.) The tangent $\frac{DL}{EL}$ is the gamma of a paper. It is known that the gamma of a paper increases as its development progresses in the same manner as it does in the case of plates, yet after a comparatively short time of development, the gamma obtained is the maximum gamma of the paper and further development occasions no further increase. The gamma of a paper is therefore the gamma infinity (γ_{∞}) of that paper.

Maximum Density:-

The maximum density of the paper (D_{max} in Fig 1.) is a measurement of great importance. Other things being equal the deeper the black that a paper will yield, the more it is for practical point production. The surface of the paper has a marked influence upon this measurement. With similar emulsions the depth of black is determined by the "glossiness"

of the paper surface: the more glossy it is the more deeper the black recorded. With similar paper surfaces the depth of the black is determined by the nature of the emulsion: the deeper the black the better the emulsion. It is necessary, therefore, to add the measure of the maximum density (black) to the constants total scale and gamma already mentioned.

Exposure Latitude:-

The exposure latitude of a paper is the range of exposures that lie on the straight line portion of the characteristic curve. In Fig 1. c to d is this straight portion and subtends an exposure scale from $\log E_c$ to $\log E_d$. Between these points the ratio of the increase in density to increase in exposure is constant.

Rendering Power:-

By this term is meant the capacity of a paper to reproduce the negative graduations with relative fidelity. Relatively true reproduction is confined to the tones which lie upon the straight line portion of the paper curve. Other things being equal, the paper with the longer straight line portion of the characteristic curve in comparison with the total length of the curve is the better paper. In Fig 1. the whole curve ab subtends an exposure scale from $\log E_a$ to $\log E_b$. Of this whole curve the portion cd is straight and has an exposure latitude of $\log E_c$ to $\log E_d$. The rendering power is $\frac{\log E_d - \log E_c}{\log E_b - \log E_a}$ and, being a fraction, it is multiplied by

10 for convenience. Very few papers have more than half their total curve straight equivalent to a rendering power of $\frac{1}{2}$ or if multiplied by 10 equal to 5. A poor paper may have a rendering power of less than 2, indicating that it is capable of rendering by few tones with truth at one and the same line.

Papers may have the same total scale and the same maximum density, but lacking coincidence of the curves will indicate that prints upon them from the same negative would differ.

The five constants described would by their quality indicate with a fair degree that the paper curves were identical and similar prints could be expected from the same negative.

Summarized, they are the measurements of:

- (1) Maximum density (D_{max})
- (2) Slope of straight line (γ = gamma)
- (3) Total Scale
- (4) Latitude
- (5) Rendering power

No one of these constants is descriptive of the quality of the paper to be an indication of the print that it would yield.

Experimental Determination of Constants

Material

In order that the contrast values cover as large a range as possible, twenty-one various kinds of printing papers of both the chloride and bromide emulsions representing a great range in characteristics were exposed.

An attempt is made in Table 1 to state in a general way the physical characteristics of the materials. The columns designated as surface, thickness, and color contain approximate specifications of these values, and in the last column the contrast as designated on the package by the manufacture.

Table I

Physical Characteristics of Papers Used

Name	Surface	Thickness	Color	Contrast
Azo E	Semi-matte	SW	White	0
Azo E	Semi-matte	SW	White	1
Azo E	Semi-matte	SW	White	2
Azo E	Semi-matte	SW	White	3
Azo E	Semi-matte	SW	White	4
Azo E	Semi-matte	SW	White	5
Velox F	Glossy	SW	White	1
Velox F	Glossy	SW	White	2
Velox F	Glossy	SW	White	3
Velox F	Glossy	SW	White	4
Velox F	Glossy	SW	White	5
P.M.C. 2	Semi-matte	SW	White	Normal
P.M.C. 2	Semi-matte	SW	White	Medium
PLM.C. 2	Semi-matte	SW	White	Contrast
P.M.C. 2	Semi-matte	SW	White	Extra Contrast
Kodabrom F	Semi-matte	SW	White	1
Kodabrom F	Semi-matte	SW	White	2
Kodabrom F	Semi-matte	SW	White	3
Kodabrom F	Semi-matte	SW	White	4
Vitava Opal B	Semi-matte	DW	Cream White	Full Scale
Vitava Opal C	Semi-matte	DW	Cream White	Full Scale

Exposure

Since exposure is a product of intensity and time of action of light, the series of exposures were obtained as follows: In order to provide a sufficient number of points for the precise determination of the shape of the characteristic curve a tablet containing a series of known densities, known as a "step-wedge" was employed. This tablet was purchased from Eastman Kodak Co. and the densities of this step wedge increased regularly from step to step, so that the intensities transmitted decreased logarithmically, and the increments of exposure represented by equal segments of the "log E" axis and were of the power of the $\sqrt{2}$. The calibration of this tablet was done on an Eastman Densitometer and appears in Table II and Fig. 2.

Owing to the light-scattering properties of the silver particles, the effective printing densities of the wedge varies according to the type of exposure, employed- projection or contact- and in order to eliminate variation, the contact or diffused densities of the wedge were measured, and the material exposed in contact with the wedge. To limit the area of the material exposed a set of opaque masks of the same dimensions as the paper was provided in which are cut apertures of various dimensions, the area of the aperture increasing from mask to mask. The wedge, masks and material to be exposed were placed in a holder at a distance of 2 meters from the

Table II
Step-Tablet Calibration

Step	Rel. Exposure	$\text{Log}_{10} E$	Density
1	1	0	.04
2	1.414	.149	.19
3	2	.301	.33
4	2.82	.450	.48
5	4	.602	.63
6	5.64	.751	.78
7	8	.903	.92
8	11.28	1.053	1.07
9	16	1.204	1.22
10	22.5	1.352	1.37
11	32	1.505	1.52
12	45	1.653	1.67
13	64	1.806	1.82
14	90	1.954	1.96
15	128	2.107	2.11
16	180	2.255	2.26
17	256	2.408	2.41
18	360	2.556	2.56
19	512	2.709	2.70
20	720	2.857	2.85
21	1024	3.011	3.00

light source, so that the intensity incident upon all portions of the wedge was substantially constant. Extraneous reflections were excluded by placing the source at the end of a black cardboard tube. The source used for both chloride and bromide papers was an unfiltered electric filament and a 100 watt for the bromide. The exposures for each strip increased geometrically and were carefully timed with a stop watch at 4-8-16-32-64-128 seconds for the chloride and 15-30-60-120-240-480 seconds for the bromide papers.

Processing Technique

(a) Choice of "standard" developer

In photographic practice different types of material often require different types of developers in order to produce their characteristic results. A developer made in accordance with a given formula would therefore give very unreliable information of the practical photographic properties of a material if it were universally applied as a sensitometric standard developer. Even for any one type of material a considerable range of developers is recommended by the various manufacturers and used in practice, each developer producing a different photographic result. No convention has yet been reached, and the choice of a "standard" developer is left to the individual sensitometric worker. Therefore, in this sensitometric study, development of the prints was carried out in a solution known as D-72 compounded in accordance with a well-known manufacturer's instructions.

The choice of developer having been made, it was essential that the composition and temperature of developer and time of development should be most accurately controlled.

(b) Development

Since the composition of a developer changes during development, no more than one batch of material (a batch representing a quantity developed at the same time) was passed thru a dish of developer. The constituents of a batch was spread out so

that no super-position of one portion upon another occurs, and treated so that fresh developer was continually applied to the surface of the material, and products of development continuously removed. The latter conditions were achieved most simply by continuously brushing the surface of the material with a camel hair brush. Finally the ratio of volume of developer to quantity of material developed was sufficient to ensure that the activity of the developer does not fall off appreciably during development. Developing time was sufficiently long enough to result in complete development (this condition of complete development may be defined as the minimum development time resulting in the maximum density and maximum gamma obtainable). All portions of the material was totally immersed during development.

The procedure of sensitometric development: a developer of the following formula was used as a "standard developer":

Elon-Hydroquinone developer (formula D-72)

Water (52°C)	500.0 c.c.
Elon	3.1 grams
Sodium Sulphite, desiccated	45.0 "
Hydroquinone	12.0 "
Sodium Carbonate, desiccated	67.5 "
Potassium Bromide	1.9 "
Water to make	1 liter

For use, part of the above stock solution was mixed with 2 parts of water for the chloride papers, and a 1-4 dilution

for the bromide. The temperature of this solution was kept constant at 21°C during development. The time of development was that recommended by the paper manufacturer (45 seconds for chloride and 90 seconds for bromide) and was carefully maintained by the use of a stop-watch. The sensitometric strips were placed side by side in the tray, and not less than 250cc of developer used per 8 x 10-inch sheet of material. The surface was brushed continuously by a camel hair brush, which passed over every portion at least once every five seconds.

(c) Fixation

Immediately after development was complete, the material was rapidly transferred to an acid stop bath, dilute acetic acid, followed by a brief wash and fixation in acid hardening fixing bath for 20 minutes. The temperature of the fixing bath was never allowed to exceed 21°C . and was discarded after fixing thirty 8 x 10-inch sheets per liter.

(d) Washing

After fixation, the material was removed to a large tray and washed for at least one hour in cold running tap water which flowed rapidly enough to replace the water in the tray 10 to 12 times per hour. The prints were separated several times during this period.

(e) Drying

When washing was complete, the prints were removed and the excess water allowed to drain off. They were then placed

between layers of cheesecloth and allowed to dry.

The Measurement of Densities

It was shown previous that density is optically defined as the logarithm of the opacity, which in turn is defined as the ratio of the incident intensity to the transmitted or reflected intensity. To accurately measure this reflected intensity a modified Capstaff-Purdy densitometer manufactured by Eastman Kodak Co., was employed.

As papers differ slightly from each other in reflecting powers of the stock, the reflection density values were compared with that reflected from the plain stock obtained by fixing the undeveloped material as zero.

For measurement a small area 4mm., is illuminated by nearly parallel light at 45° to the surface, and the intensity of the light reflected normally from the photographic deposit is measurement by comparison to the intensity transmitted by a standard calibrated comparison wedge.

Evaluation of Constants

The densities of the sensitometric strips having been determined the characteristic curves were plotted for each paper. These curves are shown in Figs. 3,4,5, and 6. The values of the various constants were evaluated as described in the section--Opacity, Density, and Frequency and tabulated in Table III where they can be compared conveniently with each other.

It will be noted that the maximum density is approximately the same for each group of papers. The slight variation occurring in this value is undoubtedly due to the fact that the age of the papers were not the same and the difference was enough to influence the characteristic constant. If perfectly fresh paper could have been obtained this variation would vanish.

Table III

Characteristic Constants of Positive Materials

Name	Contrast	Total Scale	Latitude	γ	Maximum Density	Rendering Power
Azo E	0	1.806	.755	1.35	1.52	4.18
Azo E	1	1.505	.602	1.48	1.53	4.00
Azo E	2	1.355	.525	1.68	1.57	3.88
Azo E	3	1.204	.450	2.07	1.57	3.73
Azo E	4	1.056	.301	2.36	1.56	2.85
Azo E	5	.755	.149	3.12	1.58	1.97
Velox F	1	1.806	.602	1.96	2.00	3.33
Velox F	2	1.654	.525	2.52	2.02	3.17
Velox F	3	1.504	.449	3.19	1.98	2.99
Velox F	4	1.051	.301	3.37	1.95	2.89
Velox F	5	.750	.149	4.78	2.08	2.00
P.M.C. 2	N	1.504	.750	1.44	1.47	4.97
P.M.C. 2	M	1.352	.602	1.54	1.42	4.45
P.M.C. 2	C	1.204	.449	1.98	1.42	3.73
P.M.C. 2	EC	1.204	.301	2.12	1.41	2.50
Kodabrom	1	1.657	.602	109	1.40	3.64
Kodabrom	2	1.505	.525	129	1.40	3.49
Kodabrom	3	1.355	.450	147	1.40	3.33
Kodabrom	4	1.056	.301	2.06	1.22	2.88
Vitava Opal B	Exposure not sufficient to evaluate constants.				1.32	
Vitava Opal C					.99	

Summary

1. The contrast or printing quality of a paper can be fully described by the measurement of:
 - (a) Maximum density
 - (b) Gamma
 - (c) Total scale
 - (d) Latitude
 - (e) Rendering power
2. Of these five constants the gamma measurement is essential, the total scale and latitude very desirable, and the remaining two helpful as far as reproduction is concerned.
3. For successful tone reproduction the density scale of the negative should be less than the total scale and greater than the latitude of the printing paper.
4. A stale or semi-stale paper should not be relied upon to possess the same characteristics as when fresh.

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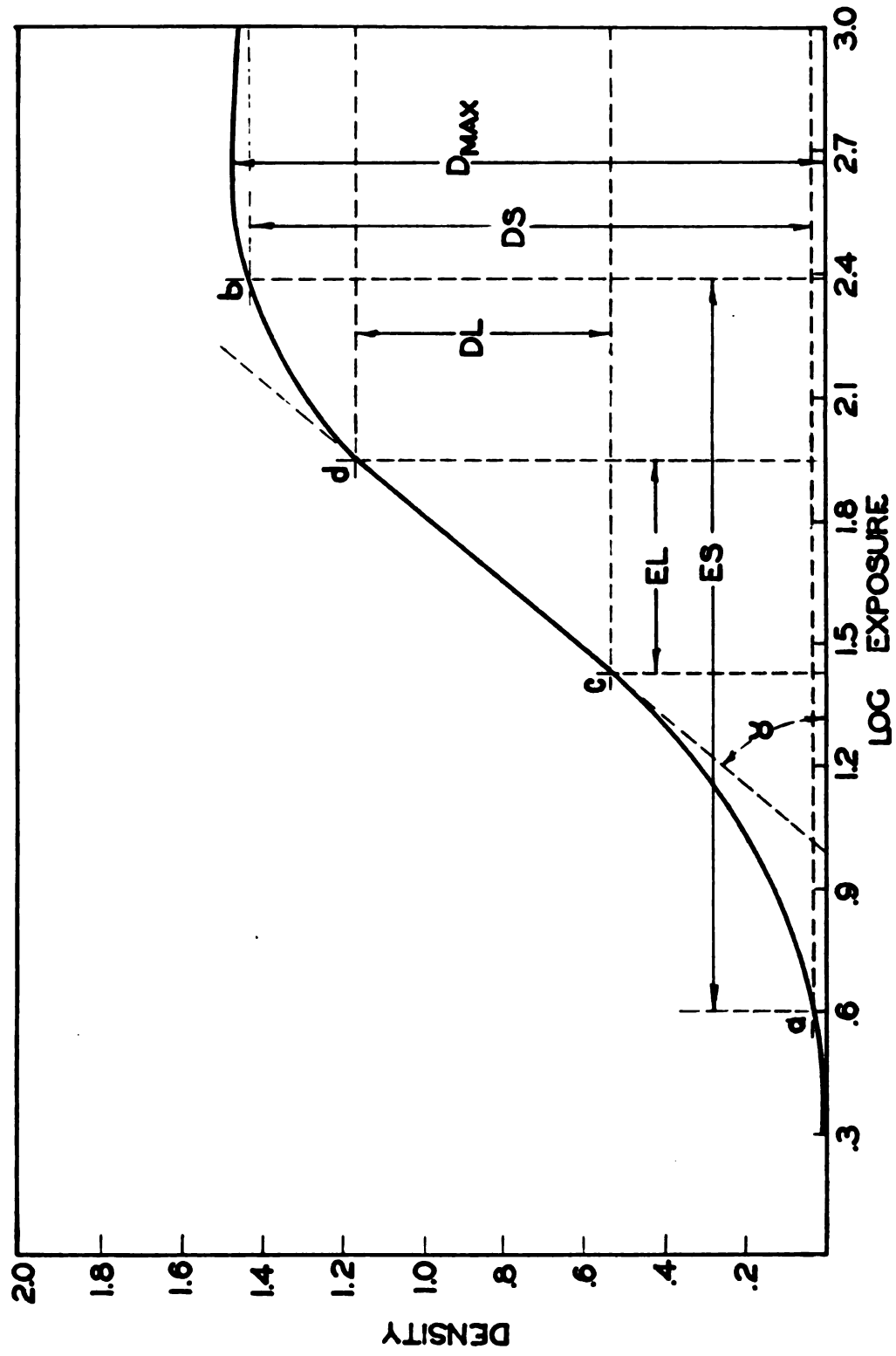


FIG. 1 CHARACTERISTIC CURVE OF PHOTOGRAPHIC PAPERS

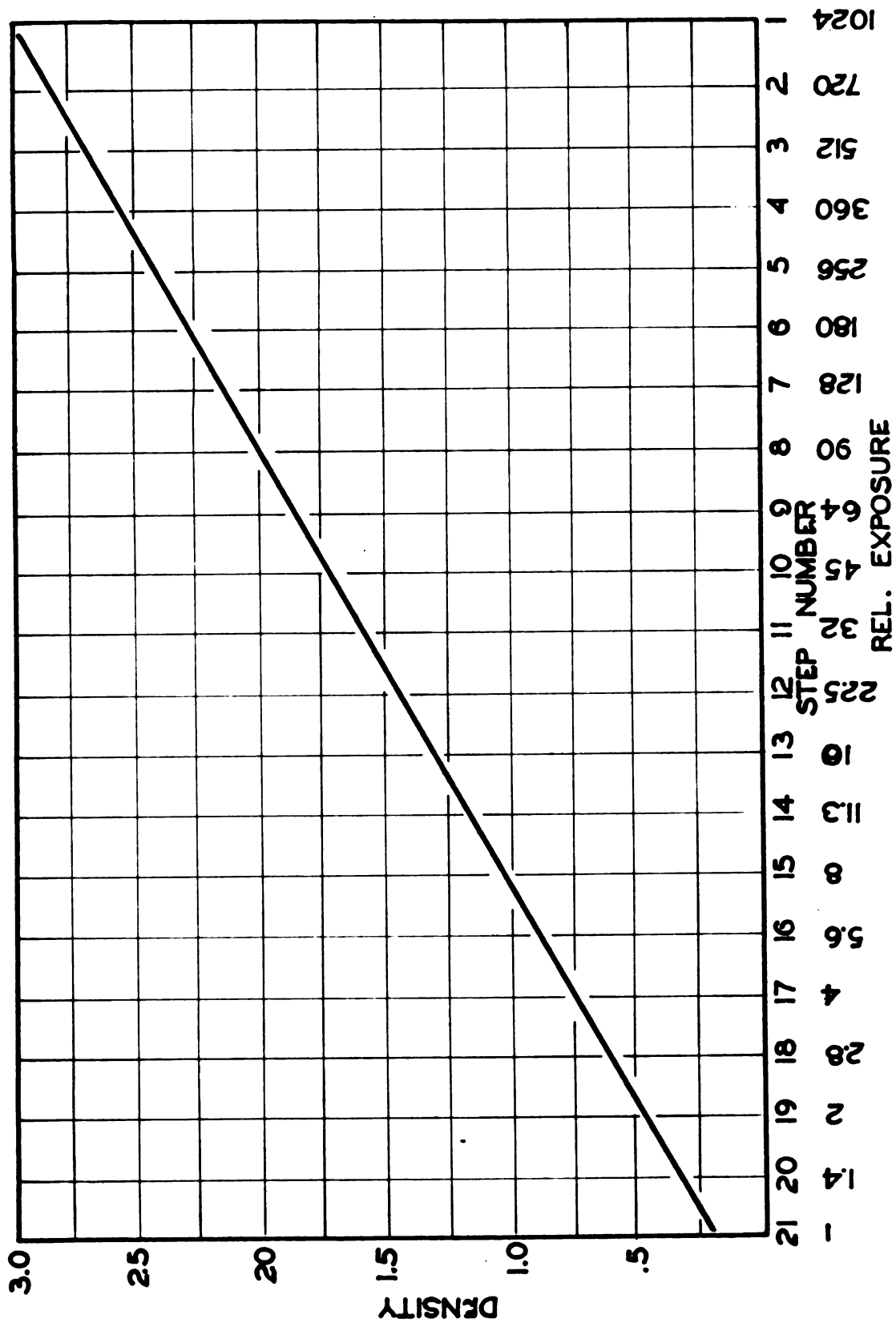


FIG. 2 STEP - TABLET CALIBRATION

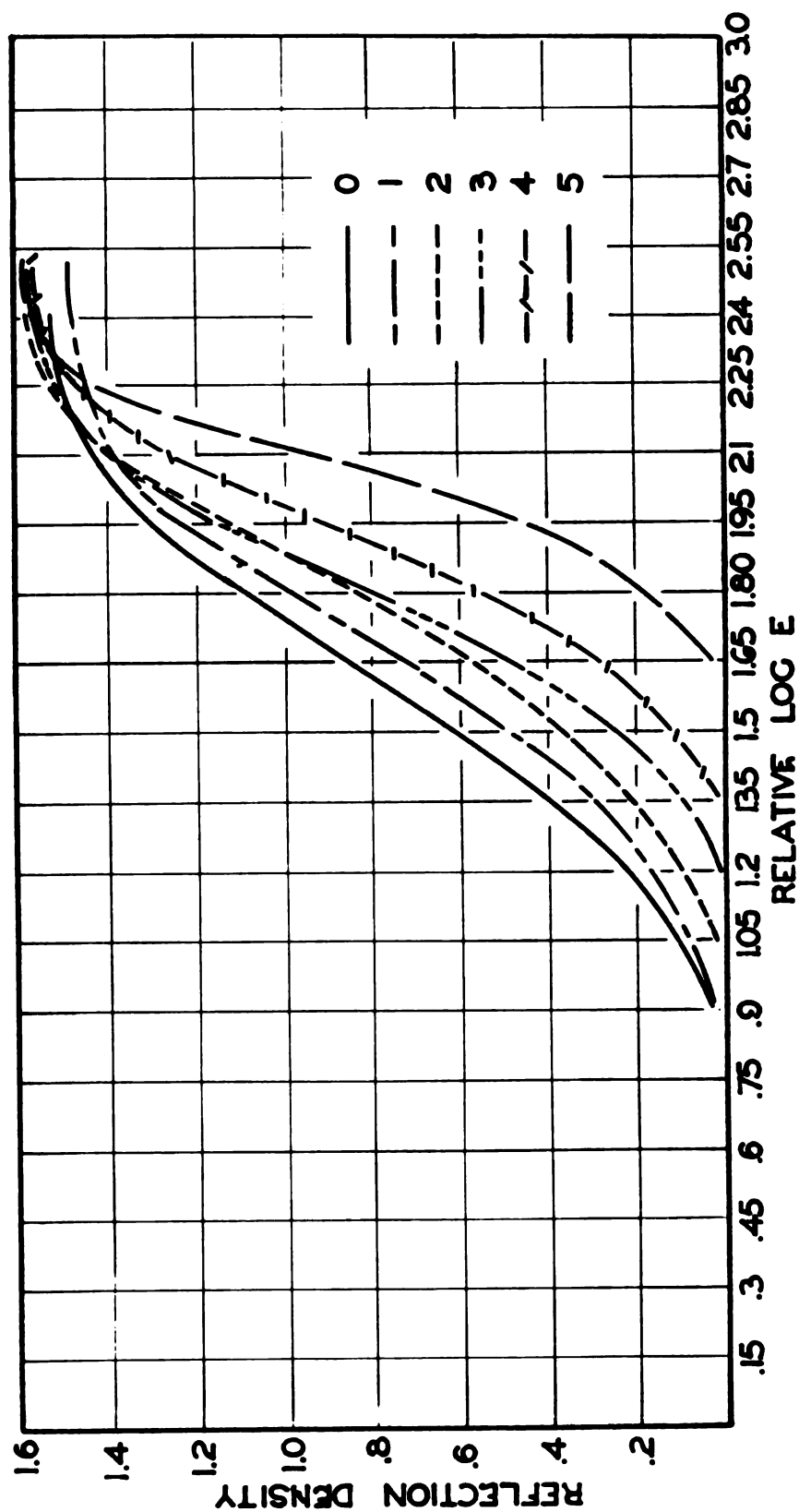


FIG. 3 AZO E

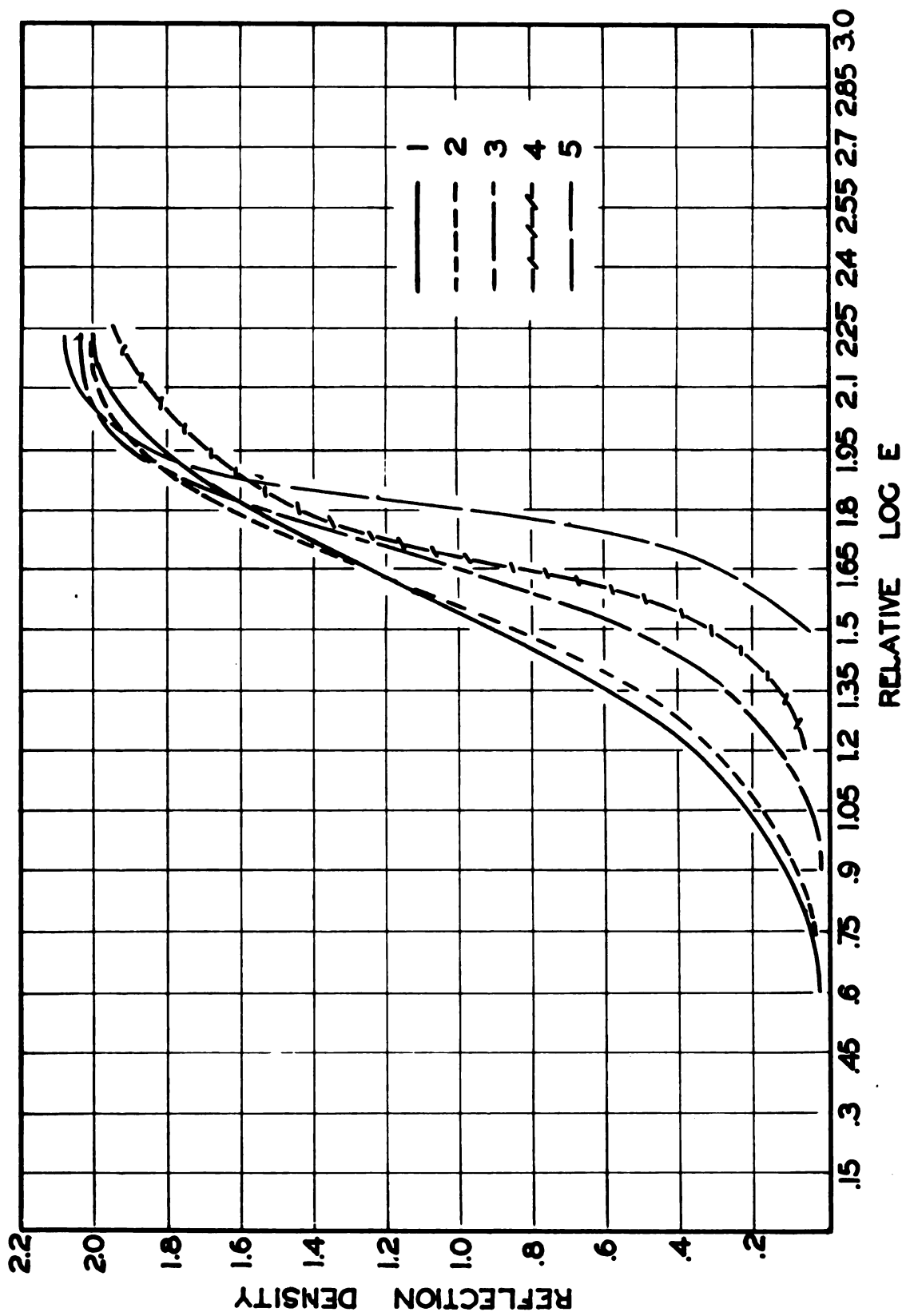


FIG. 4 VELOX F

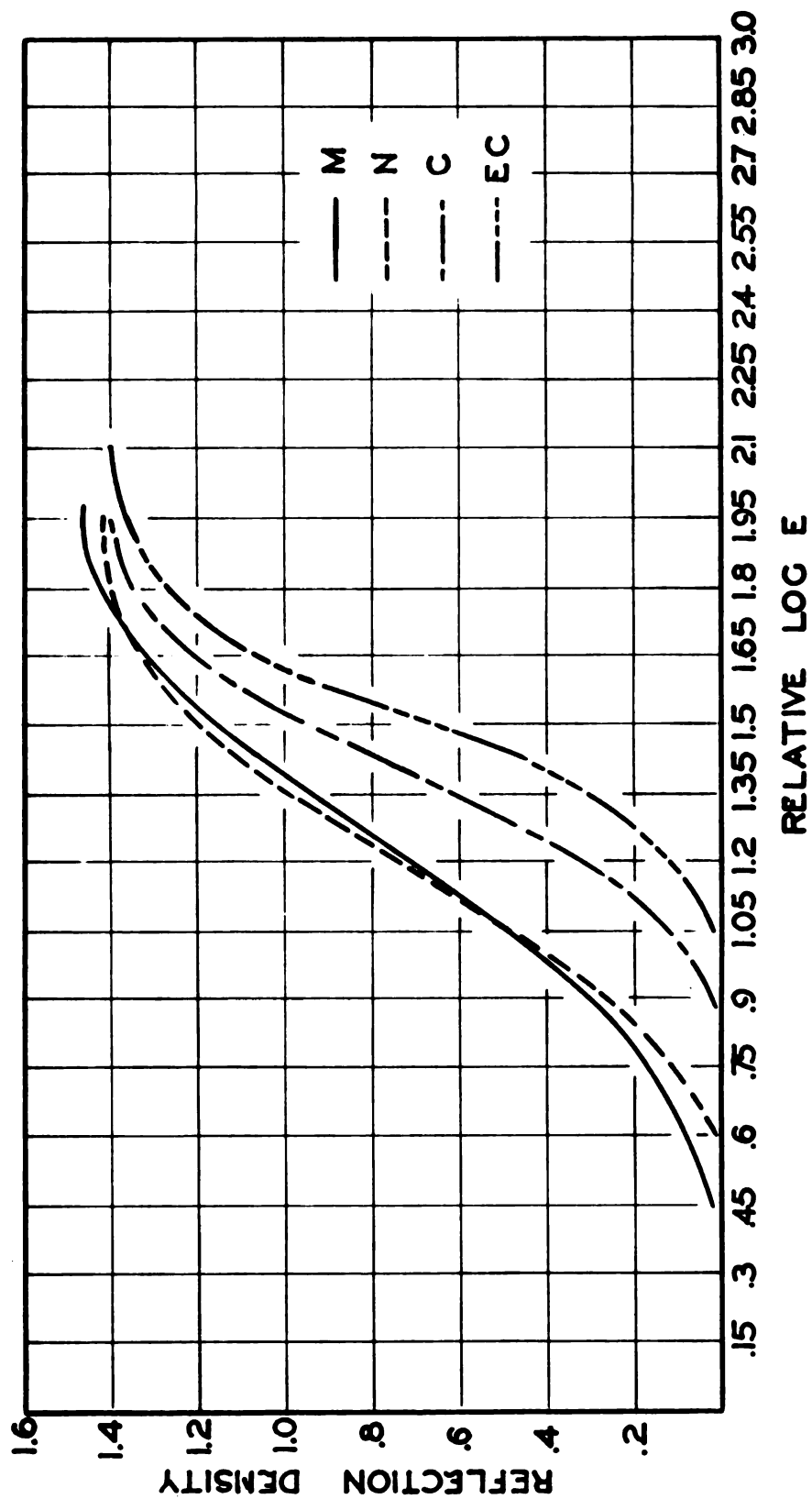


FIG. 5 PMC #2

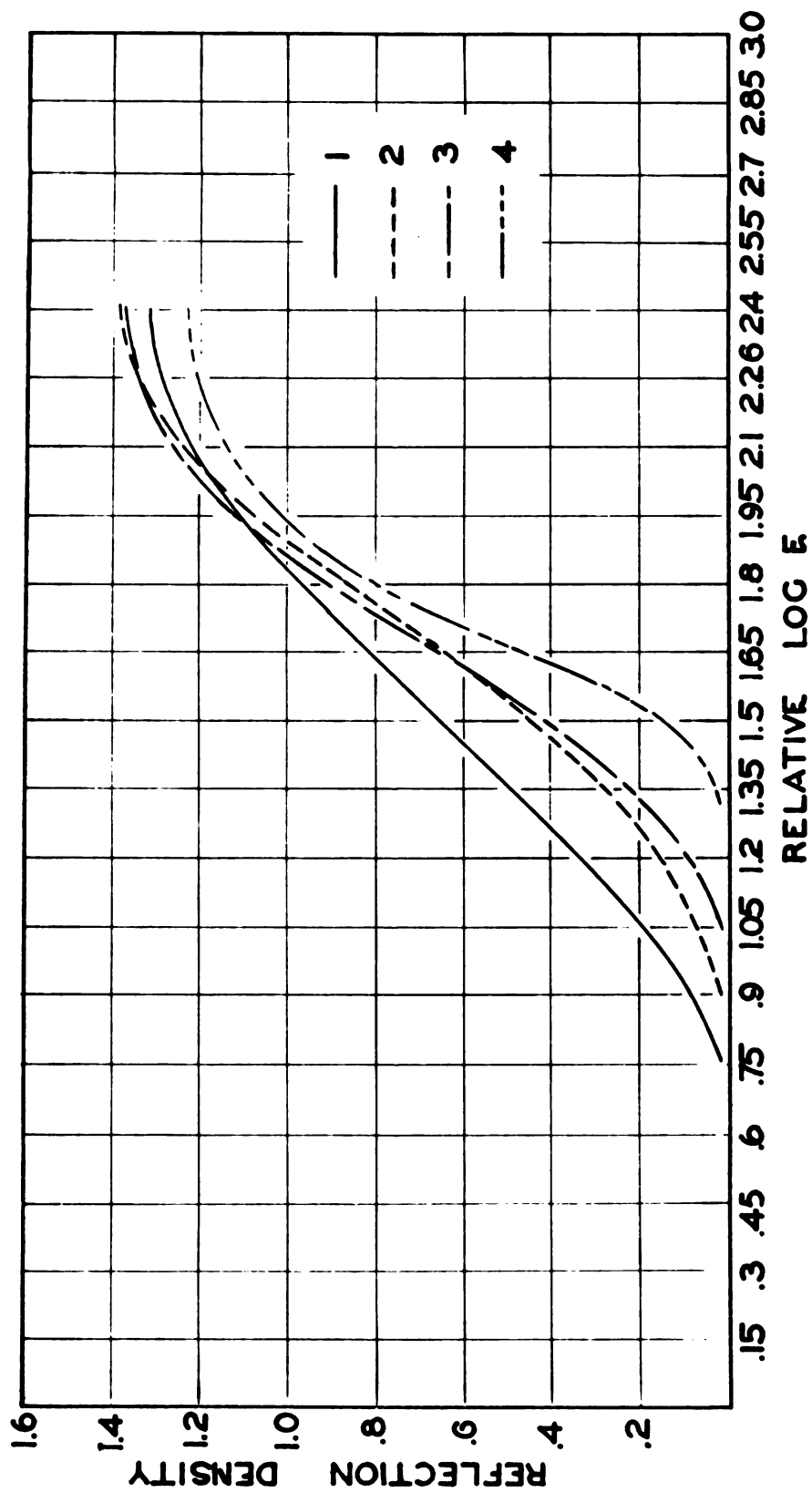
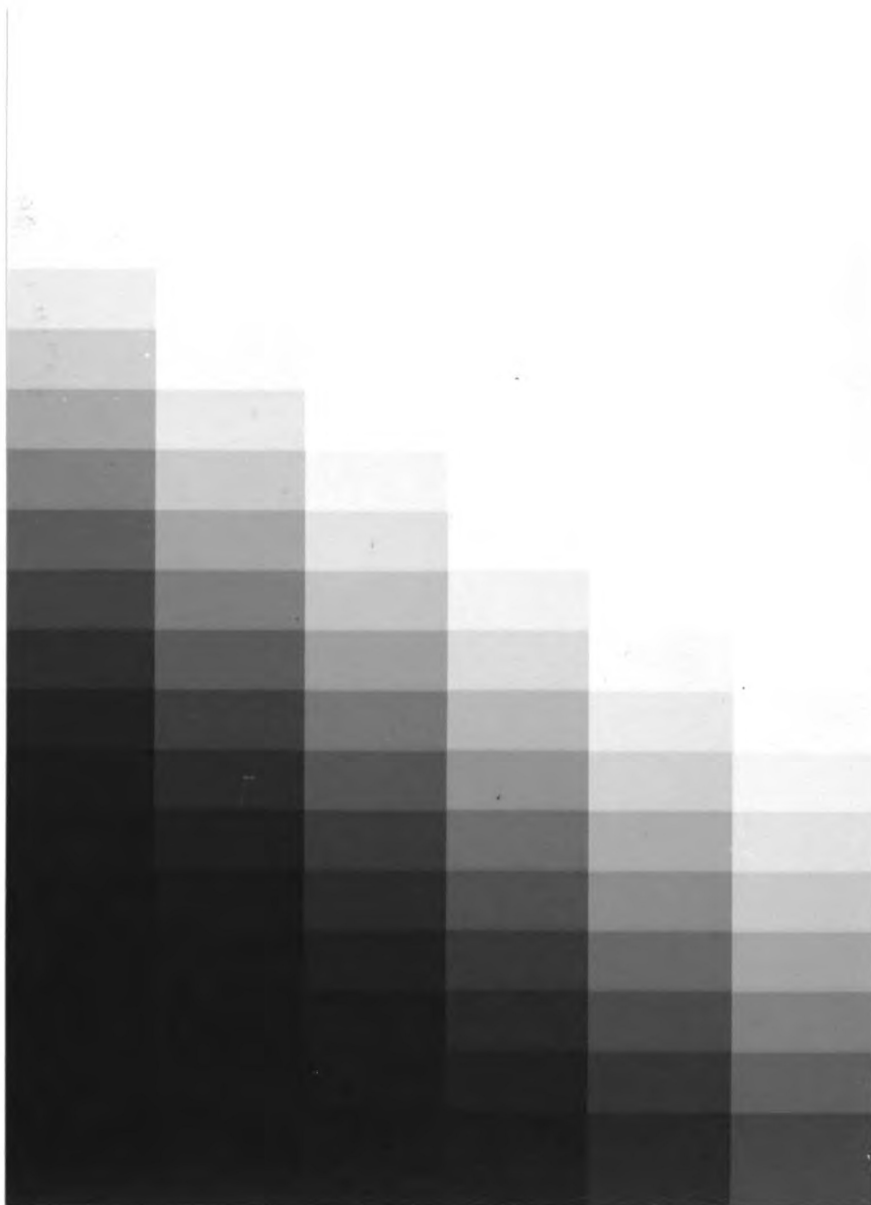
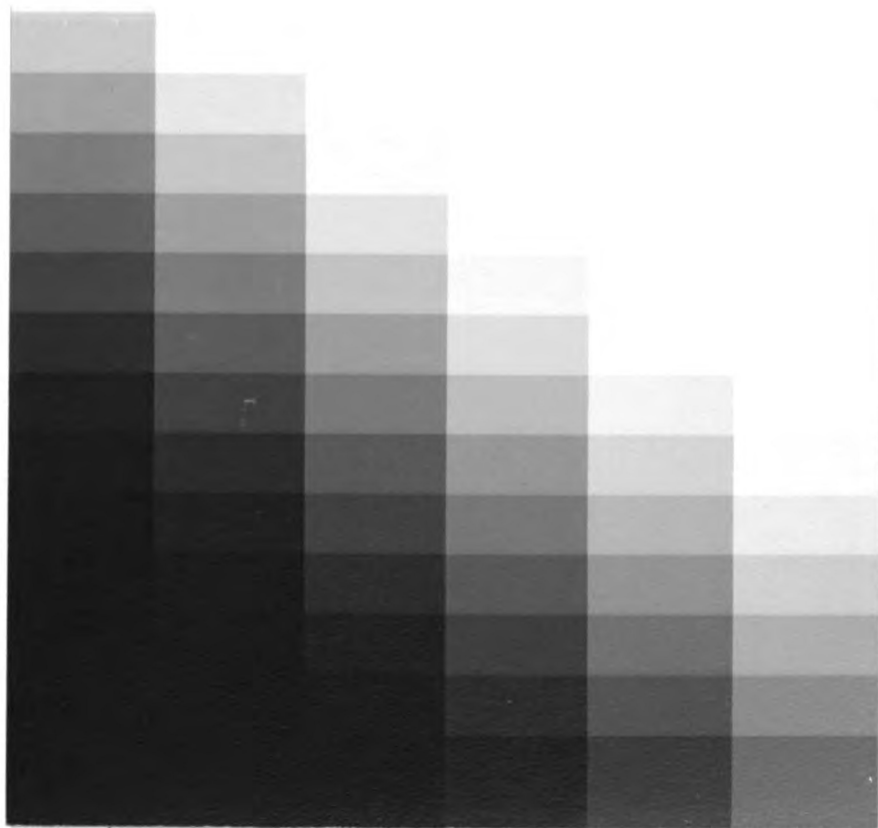


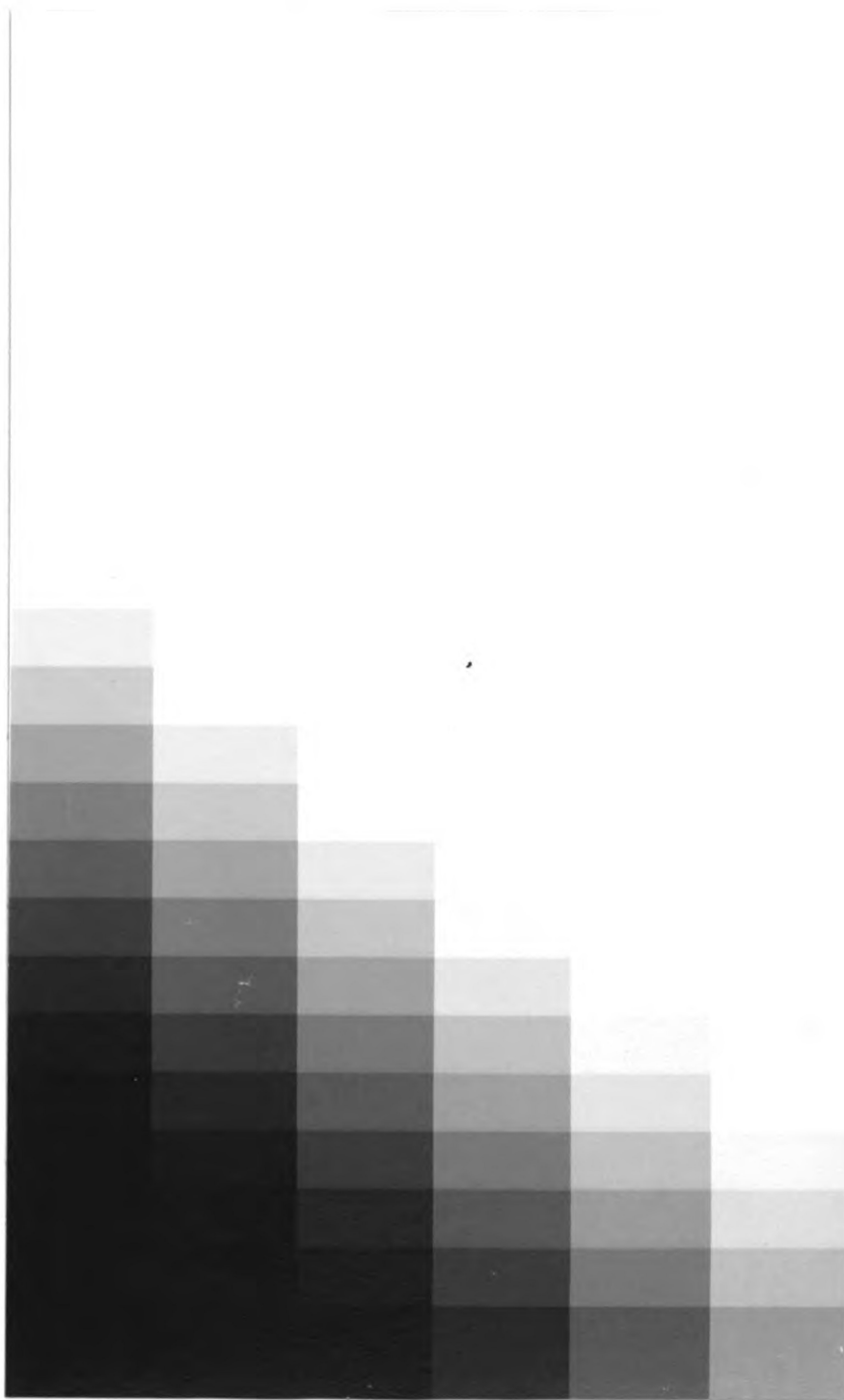
FIG. 6 KODABROM



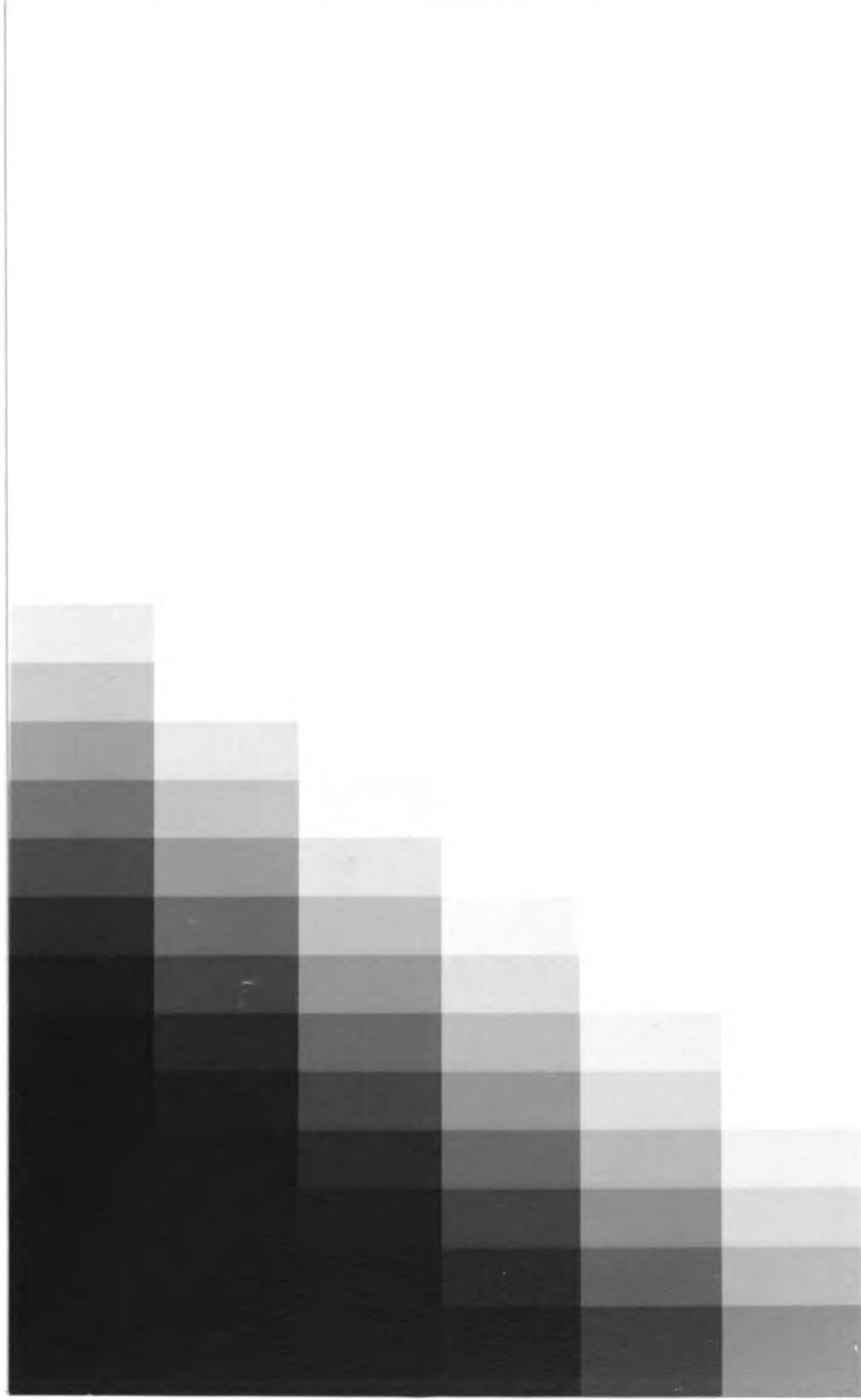
AZO E-O

AZO E - I



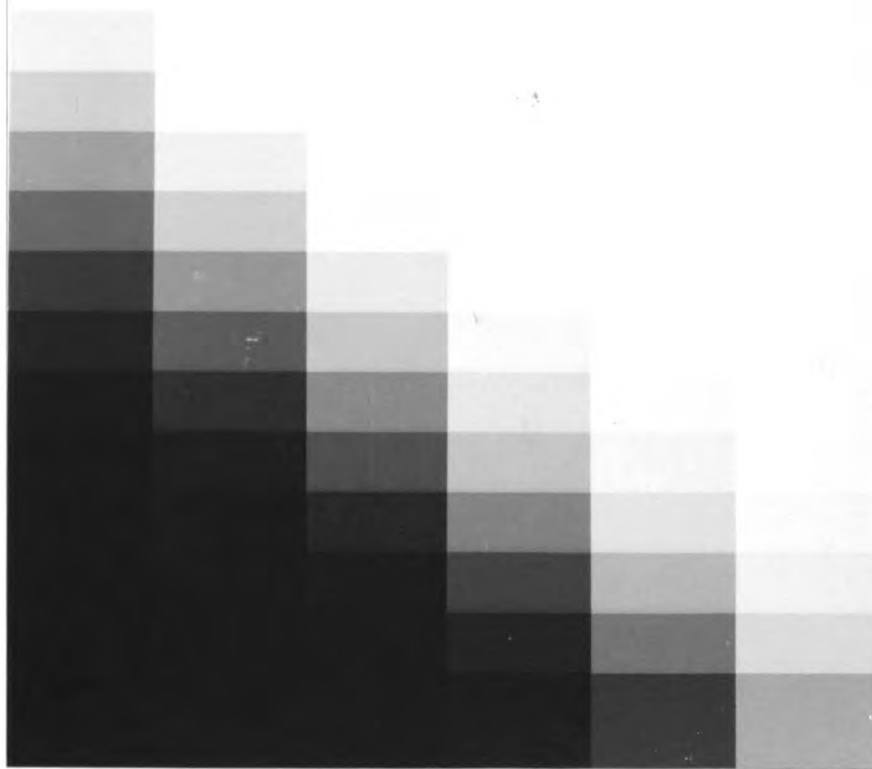


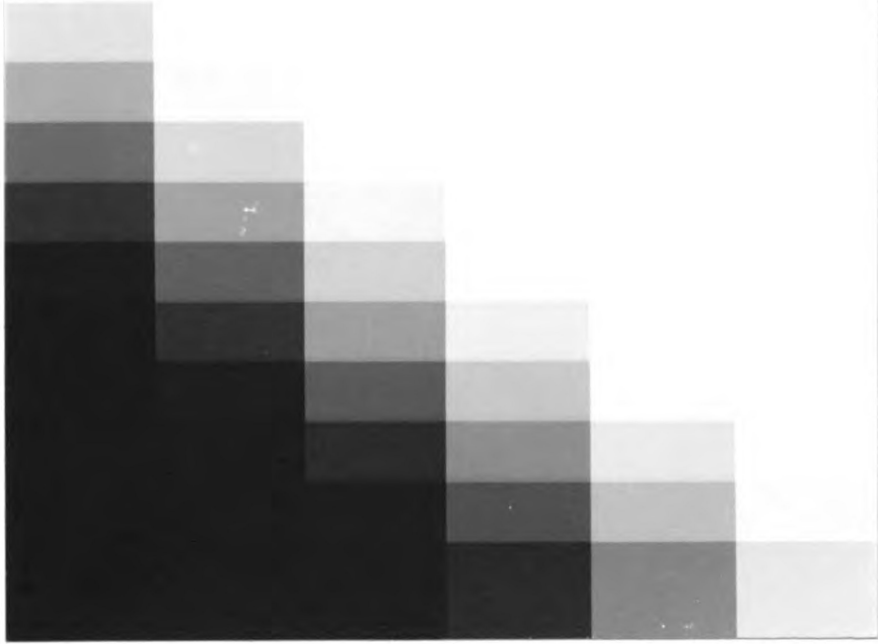
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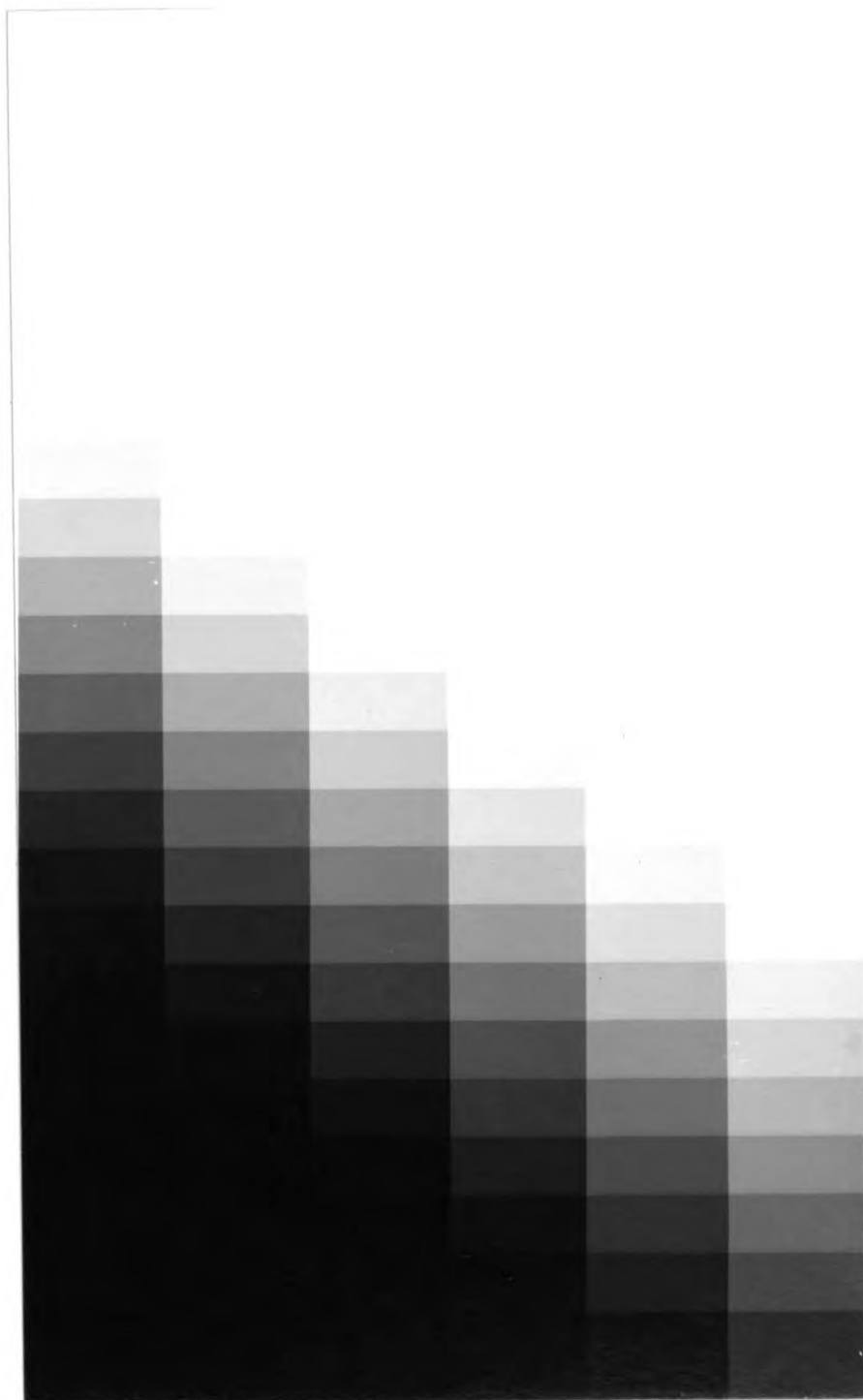
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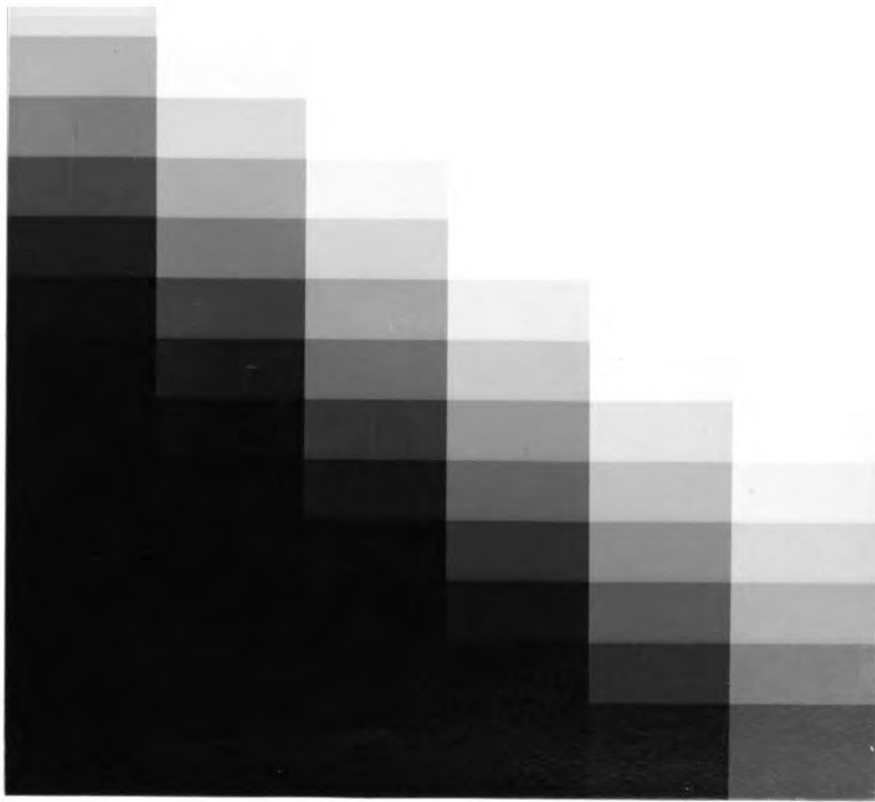
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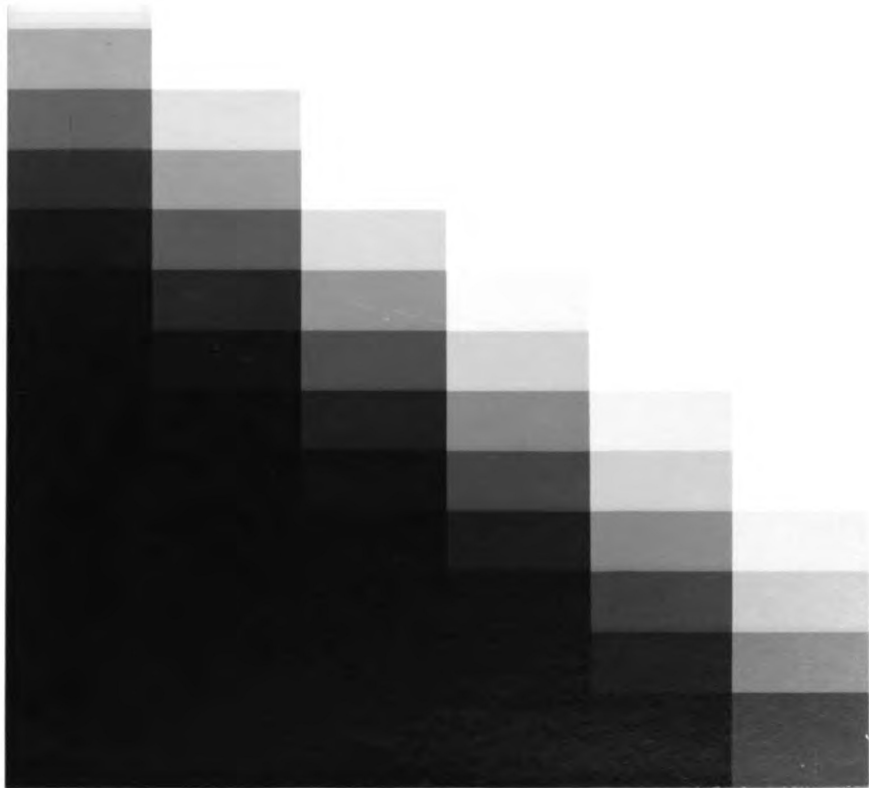
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VELOX F-2



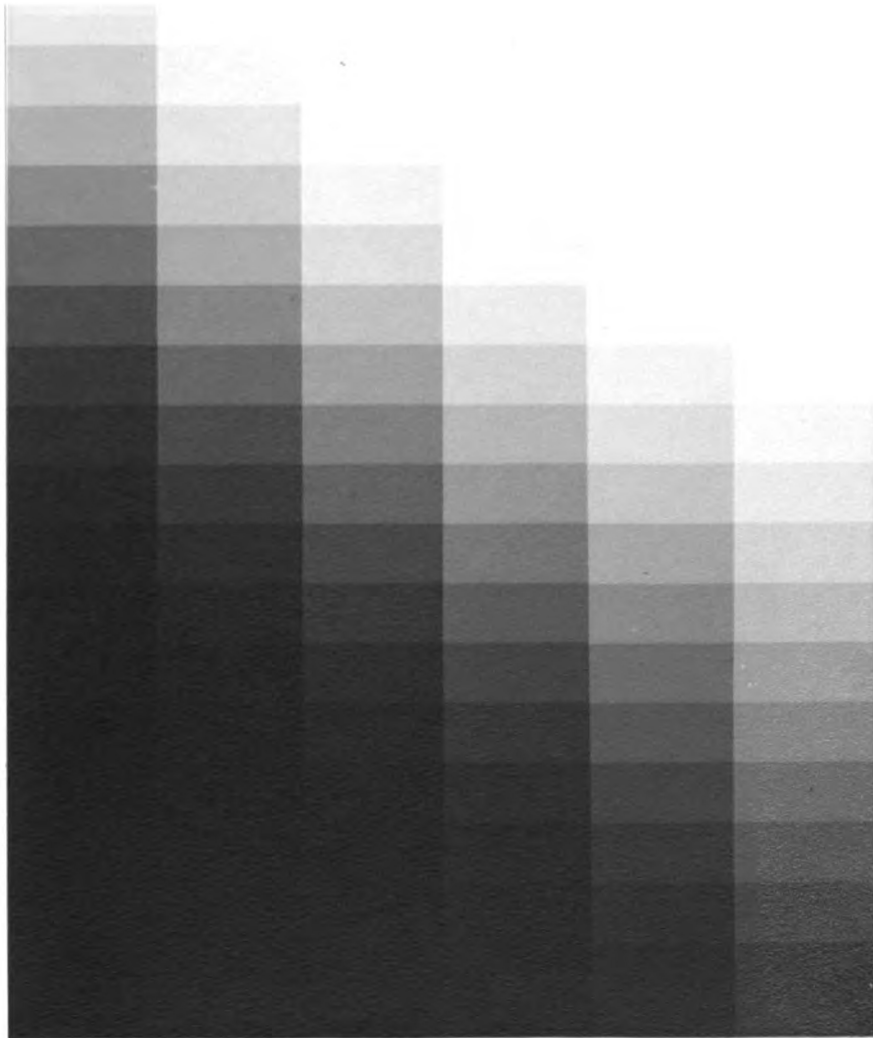
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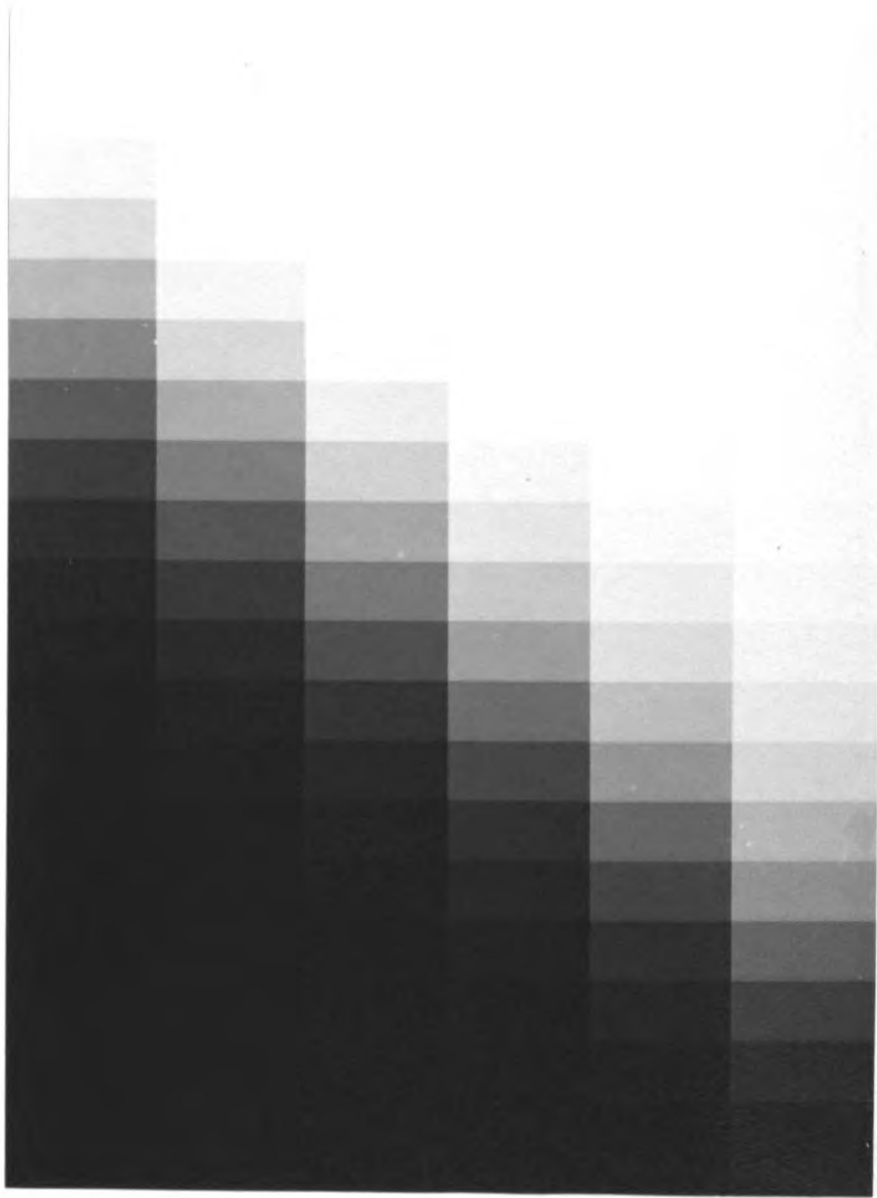
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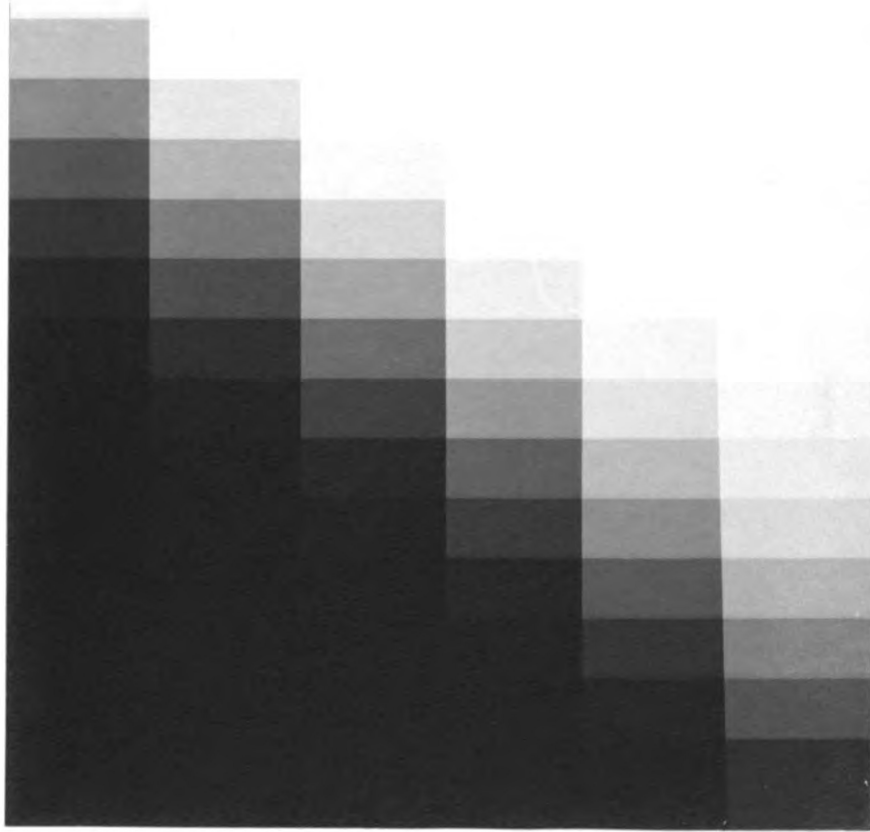
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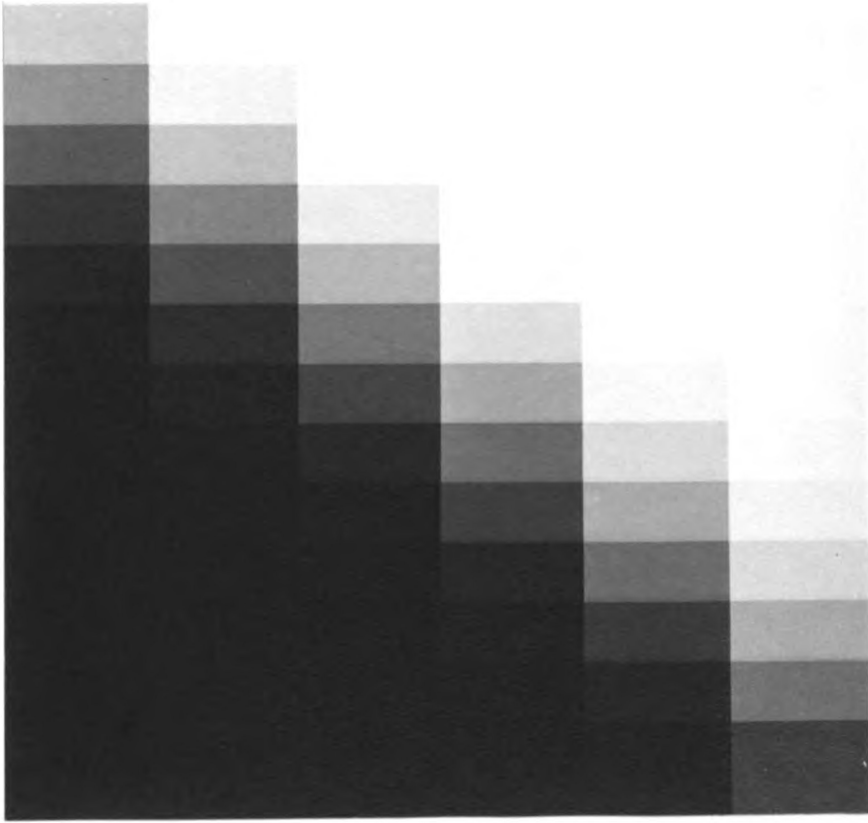
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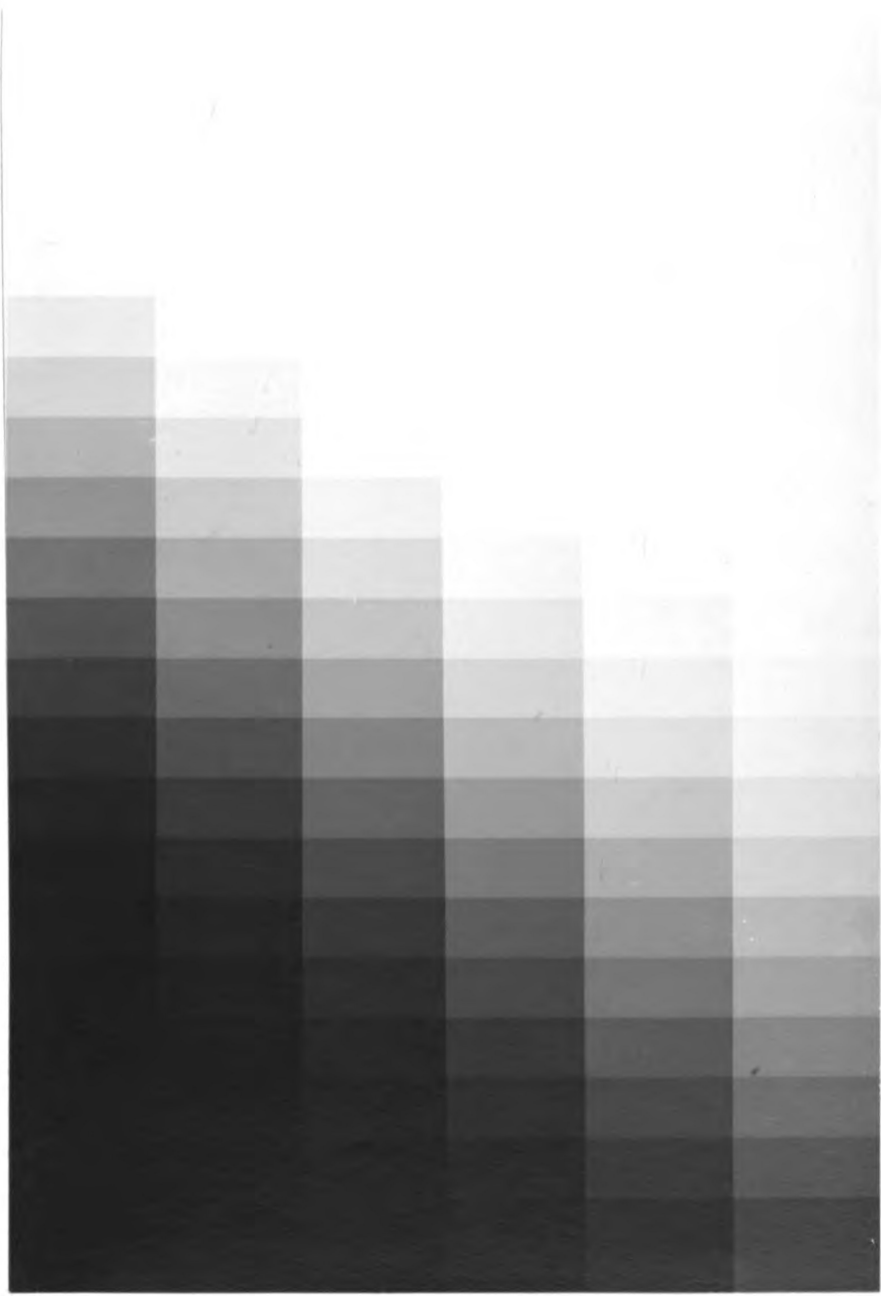
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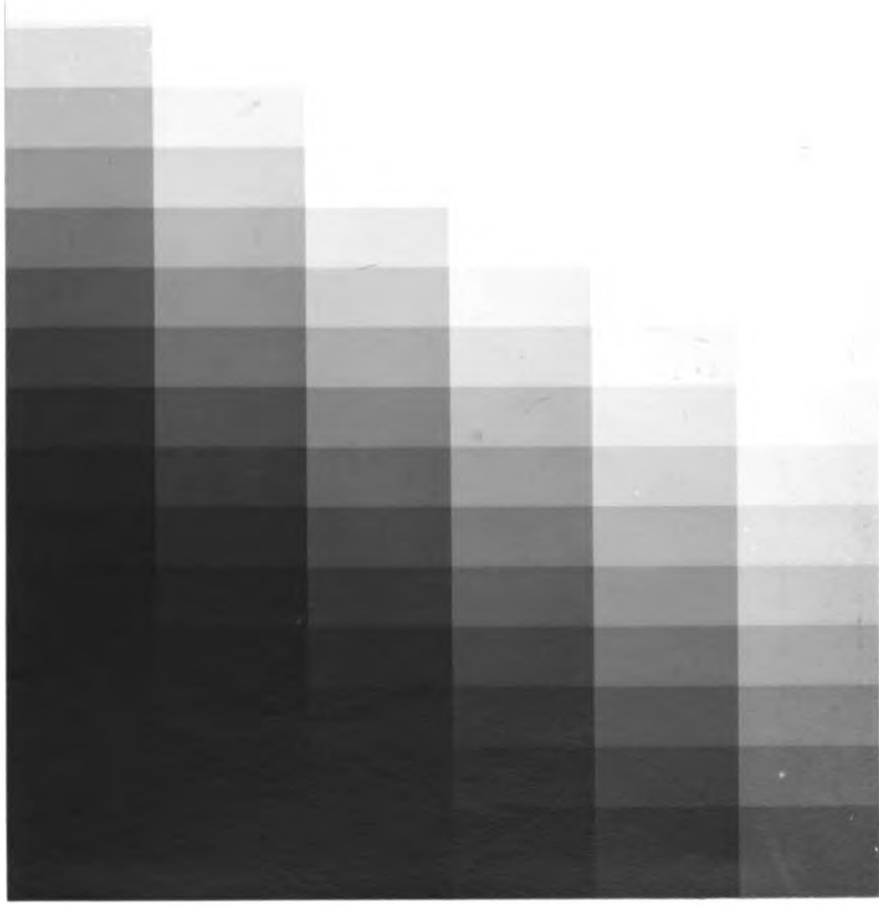
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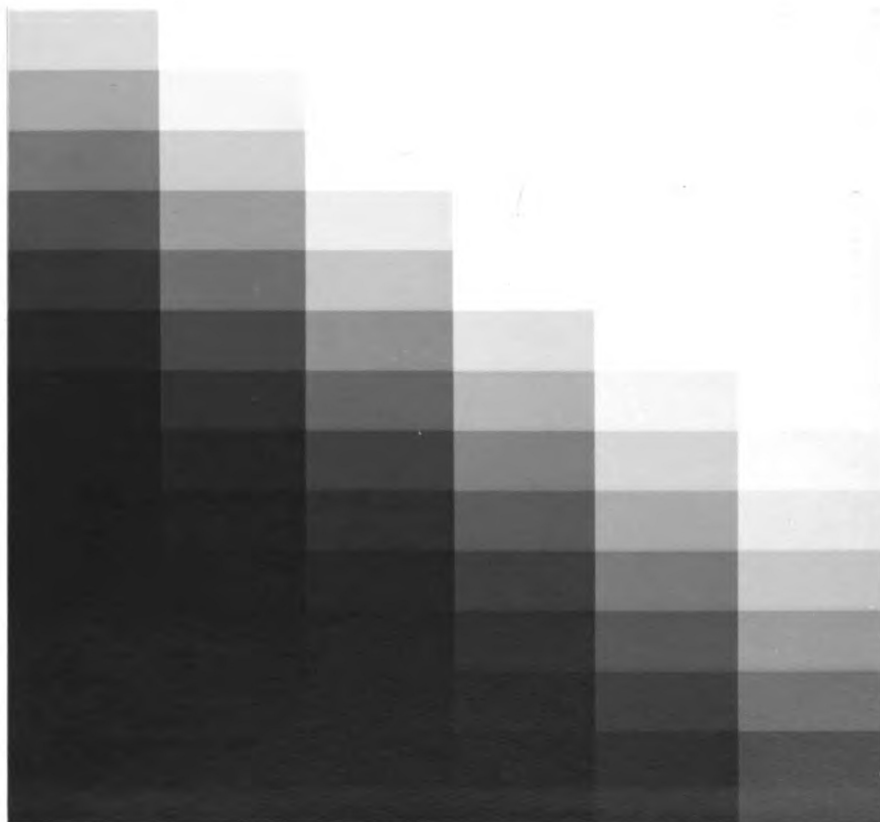
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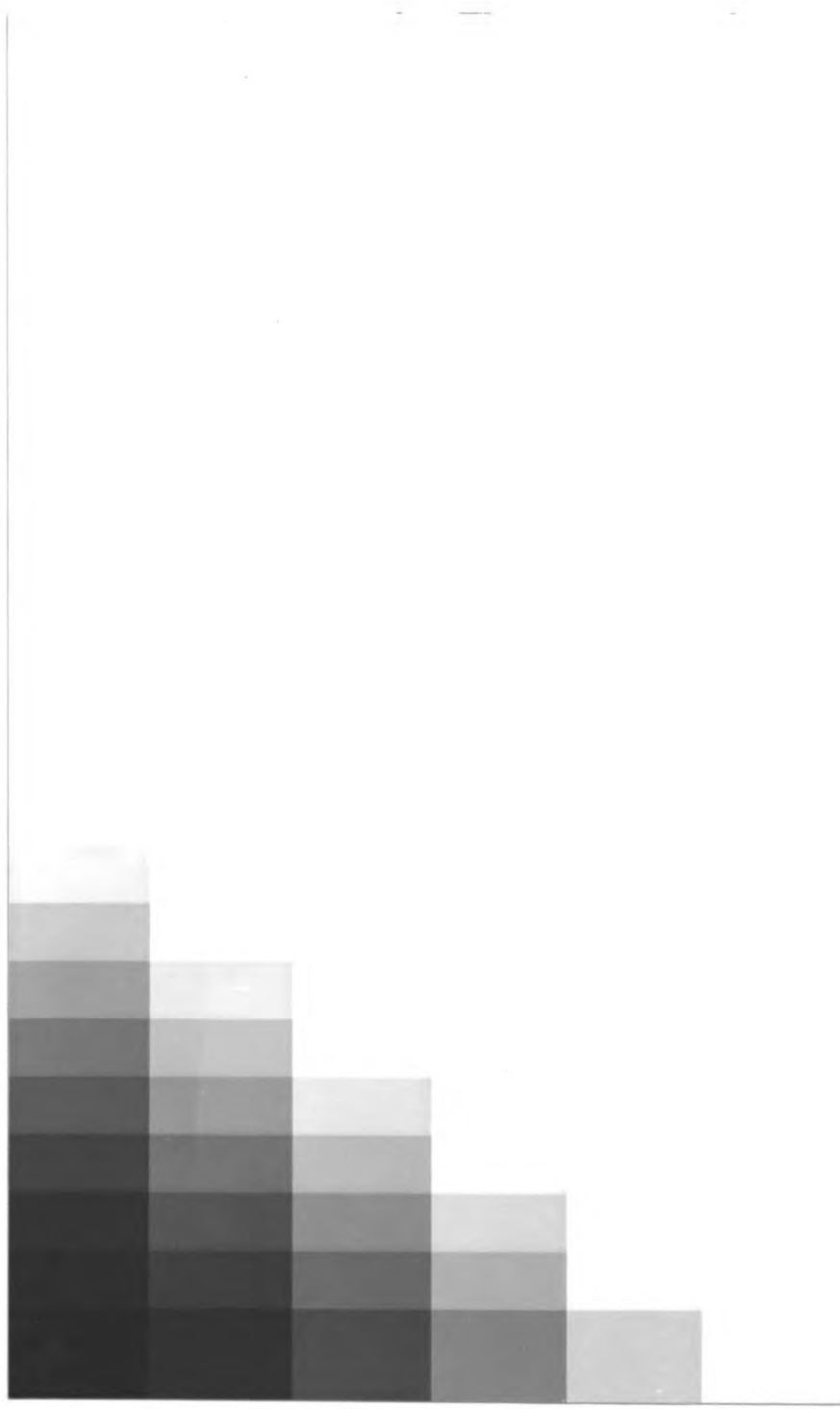


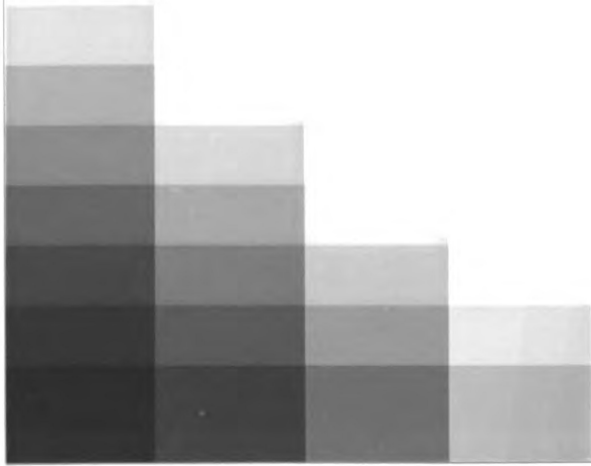
KODABROM 2





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