RP183

A COMPARISON OF RESOLVING POWER AND SENSITIVITY OF PHOTOGRAPHIC PLATES WITH VARYING DEVELOPMENT

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ABSTRACT

Special developers recommended for reducing the graininess of photographic images are all based on increasing the solvent action of the solution on silver bromide, and decreasing the reduction potential. Five of these formulas were compared with ordinary pyrogallol and metol-hydroquinone by testing sensitivity and resolving power of three emulsions, each developed with each of the developers. These results were supplemented by practical spectrographic tests, and experiments with two other developers. Little useful improvement over the standard developers was obtained in any case, as increased resolution was, in general, accompanied by decreased sensitivity. These results do not apply to the pictorial use of special development to reduce graininess.

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I. INTRODUCTION

Both scientific and practical applications of photography tend to demand a better combination of sensitivity and resolving power than is now available. While recent investigations have shown that, other conditions being the same, sensitivity increases with the size of the silver halide grains in an emulsion so that there is a fundamental connection between the two, the resolving power of the developed image is always far less than the limit imposed by the silver halide grain size. Part of this is caused by clumps of grains in the emulsion, and part by the substitution of irregular and much larger grains of silver in the developed image for the original grains of silver halide. The latter at least is obviously susceptible to some control by the conditions of development. In the extreme case of development after fixation, where the silver halide grain has been removed and the silver of the developed image is deposited from the developing solution, Seyewetz[1] has shown that the metal may be deposited in compact hexagonal crystals quite different from the spongy grains produced by any developing agent[2] under the conditions of "chemical" development.

"Chemical" development may, however, be modified so as to produce smaller silver grains, with a probable decrease in the frequency of clumps, by decrease in the reduction potential, and increase in the solubility of the silver halide in the developing solution. The result is that a considerable proportion of the silver halide is reduced in solution, and the silver deposited on the development nucleus as in "physical" development. This type of developer was first used and explained by the Lumières and Seyewetz,[3] and the same principles are involved in the "borax" developers now in wide use by the motion-picture industry. A high concentration of sodium sulphite is used to increase the solubility of the silver halide, and carbonate is entirely omitted, so that the alkalinity is relatively low (pH approximately 9) and the reduction potential is correspondingly decreased. The alkalinity of sulphite solutions is somewhat too low and borax is generally added to raise it to the desired value; being a good buffer, it may be added in sufficient quantity to maintain the pH reasonably constant during development. The use of borax has given its name to this class of developer, although the high concentration of sulphite is really the more important feature. Practical studies of the variables in this class of developer are given by Carlton and Crabtree[4] and by Moyse and White.[5]

This comparison of a number of developer formulas by their effect on the characteristics of three emulsions was intended primarily for choice of developers for use in difficult spectography, such as stellar spectra, Zeeman patterns, or band spectra. The requirements may be summarized as (1) the minimum error in determination of the distance between closely separated lines, combined with (2) the minimum exposure for recording the lines. The first is not determined solely by the grain size of the image, since resolving power is dependent to a very large extent on fog, and contrast; the factors involved are summarized by Sandvik,[6] who emphasizes the necessity of measuring resolving power by tests related to the intended application. The second requirement makes it necessary to consider the effect of development on the effective sensitivity of the plate, since the differences in resolving power characteristic of emulsions differing by 50 per cent in speed are, in general, as great as any which can be produced by special development. There is obviously no advantage in the use of a high-speed emulsion and special developer if both sensitivity and resolving power can be equaled by a moderate speed emulsion with standard development, and we are unable to understand how the Lumières and Seyewetz[7] are able to pass so lightly over this point.

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[1] Seyewetz, Chimie et Ind., Special No.; p. 418; September, 1925.
[2] Ross, The Physics of the Developed Silver Image, chap. 1.
[3] A. and L. Lumière and A. Seyewetz, Brit. J. Phot., **51**, pp. 630, 866; 1904.
[4] Carlton and Crabtree, Trans. Soc. Motion Picture Engrs., **13**, pp. 406–444; 1929.
[5] Moyse and White, Trans. Soc. Motion Picture Engrs., **13**, pp. 445–452; 1929.
[6] Sandvik, Proc. 7th Int. Cong. Phot., p. 243; 1928.
[7] A. and L. Lumière and A. Seyewetz, Sci. et. Ind. Phot., **12**, p. 128; 1928; "On compensera facilement l'inconvénient de la legère surexposition exigée par ce révélateur en s'addressant à une émulsion trés sensible comme celle de la plaque Lumière 'Étiquette Violette'."

II. EXPERIMENTAL PROCEDURE

1. CHOICE OF PLATES

All tests were made with plates, as the precision measurements of spectrography and astronomy are still impossible on film base.

The Seed's 23 was chosen as a moderate-speed emulsion of the general type most useful in spectrography. The Speedway and Press plates are the fastest emulsions available on glass from their respective makers. The resolving power most frequently becomes a serious consideration when it is necessary to use this type of plate, and the advantages of special developers may be expected to be most evident with those emulsions.

2. SENSITOMETRY

Sensitometric measurements were made by the standard methods of this bureau. Exposure was by nonintermittent sector wheel at an intensity of 1 m candle of the quality of noon sunlight.

The Seed's 23 and Speedway plates were tested with a light source consisting of a gas filled incandescent light operated at a color temperature of 2,810° K. and a filter of Corning "Daylite" glass. The Press plates were exposed to the source adopted by the Seventh International Congress of Photography, an incandescent light operated at 2,360° and the corresponding Davis-Gibson filter. The difference in speed numbers with these sources appears to be within the limits of error of sensitometry. Development was carried out at 20° using the brush method for the developers where the maximum time did not exceed 12 minutes. The slow developers, requiring 30 to 120 minutes, were necessarily used without agitation; the plates were left emulsion up in the solution and did not develop the streaks which are liable to occur in a vertical tank. Densities were measured in diffuse light, the fog density being automatically subtracted; using backed plates, the fog strip was uniform throughout. Speed numbers are $10/i$. Where a single number is given, the curves crossed on the exposure axis within the limits of error; a noticeable shift with time of development is indicated by the use of three speed numbers. Some indication of the changes in the underexposure region is given by the density at an exposure of 0.0294 candle meter second; the exponent (as $D_{0.029}^{1.0}$) indicates the contrast to which the plate was developed.

3. MEASUREMENT OF RESOLVING POWER

Resolving power was measured with the same parallel-line test object and lens used for this purpose by Davis and Walters,[8] their procedure being in complete agreement with the later recommendations of Sandvik.[9] The test object consists of groups of six parallel lines separated by spaces of equal width, in which the density exceeds that of the lines by approximately 4. This was photographed on the backed test strips at such scale that the distances between centers of lines in the image varied from 8.3 μ to 25 μ. Each test strip was given a series of exposures increasing by a factor of about one-third. The performance of the lens at $f/11$ was found to be slightly superior to that at $f/16$ because of the distinct appearance of diffraction at the smaller stop.

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[8] Davis and Walters, B. S. Sci. Paper No. 439.

[9] See footnote 6, p. 2.

Plates were developed to a contrast within their normal working range. On completing the sensitometer tests, γ was plotted against the time of development, and also against the corresponding values of fog, and the required time read off the curve. As a check on the interpolation, sensitometer exposures were developed with each set of resolution tests strips. Except where excessive fog would be produced, the Seed's 23 plates were developed to a γ of approximately 1.5 and the Speedway to approximately 1.0. The Press plates were developed to what was judged, from inspection of the curve of γ against fog, to be the optimum contrast; we consider the results with this emulsion the most satisfactory.

The greatest uncertainty in determination of resolving power lies in assigning a number to any given test image. The strips were observed with a binocular microscope with 25 mm objectives and 10× eyepieces under lighting conditions found to impose very little eyestrain. A considerable number of readings were also made by projection at 800 diameters, the image being observed from 1 or 2 m distance; the light intensity was too low for comfort, and the results while in reasonable agreement with those by the other method, are considered less satisfactory. The criterion for resolution which was applied, was that all six lines of a group should appear suitable for definite settings of a cross hair. The resolution number assigned to a test strip was the minimum separation resolved at any one of the series of exposures. All tests were made in quadruplicate; the number given in the tables for a given emulsion, developer, and observer is the average of four strips.

Three or four observers were used in all cases. The identity of the test strips could not be entirely concealed from the observers, but there is little evidence of prejudice. The errors of observation will be discussed with the results.

4. SPECTROGRAPHIC TESTS

Some of the developers were compared under conditions of actual spectrographic work. The carbon arc band at 3,883 A was photographed with the large grating spectrograph of the spectroscopic section of this bureau, using a concave grating of 21-foot radius, 15,000 lines per inch and a 5 μ slit width. After careful focusing on backed lantern-slide plates, Speedway plates (emulsion 2469) were given a series of eight exposures each to the same source. Figure 1 is a reproduction at 163 diameters of the band head on the lantern slide focus plate and on Speedway plates developed with five formulas, the best exposure in each case being selected for enlargement.

5. DEVELOPERS

(a) MATERIAL

The developing agents were commercial materials passing the United States Government specifications with the exception of paraphenylenediamine (base). This is very unstable in air. The available material was twice sublimed under reduced pressure at the start of the investigation, the product being white and giving a nearly colorless solution, but it was distinctly darkened in a few weeks. Sodium carbonate was assayed by acid titration, and sodium sul-

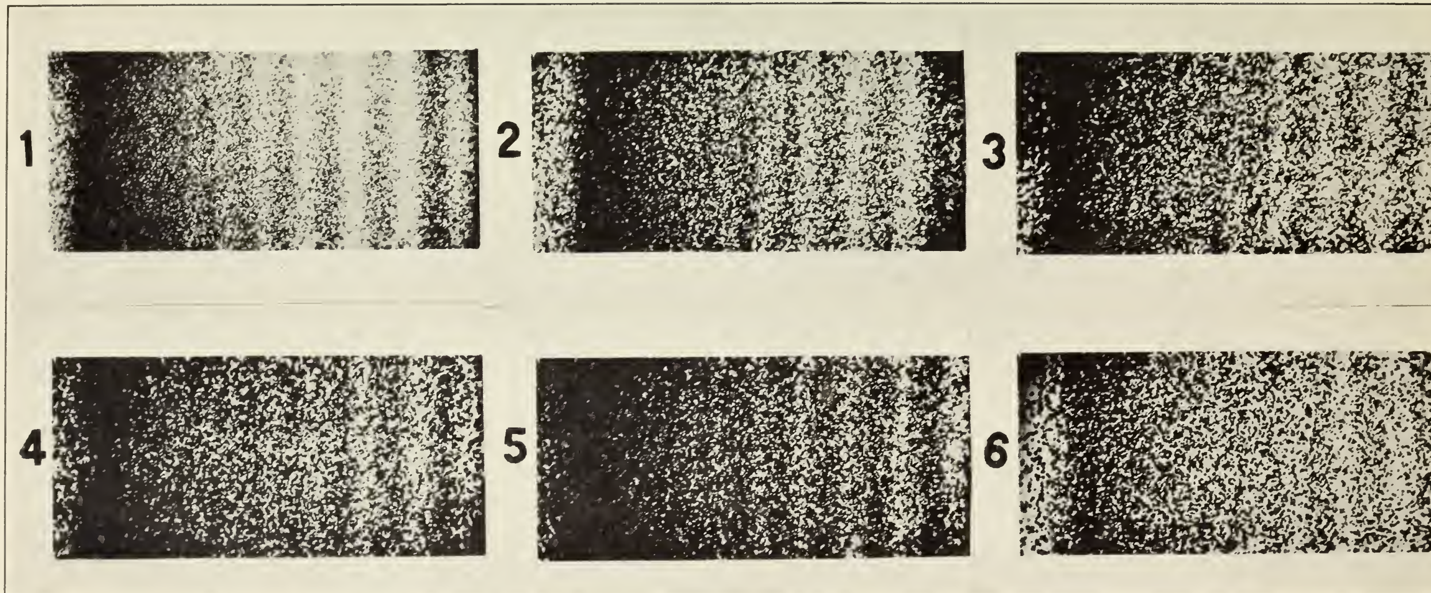

FIGURE 1.—*Spectrograms of carbon arc band at 3,883 A*

Taken on—

1. Lantern slide plate.
2. Speedway plate developed with *p*-phenylenediamine-borax formula.
3. Speedway plate developed with metol-hydroquinone-borax formula.
4. Speedway plate developed with metol-borax formula.
5. Speedway plate developed with metol-borax formula +0.5g KBr/liter.
6. Speedway plate developed with concentrated metol-hydroquinone formula.

phite by iodine titration. The amounts given represent actual Na_2CO_3 and Na_2SO_3; U. S. P. borax was twice recrystallized for use.

(b) FORMULAS

Pyrogallol.—This is the developer normally used for sensitometry at the Bureau of Standards:

Stock solutions:

A	Water	ml	1,000
	Pyrogallol	g	60.0
	Potassium metabisulphite	g	12.0
B	Water	ml	1,000
	Sodium sulphite	g	95
C	Water	ml	1,000
	Sodium carbonate	g	70

For use, 1 volume each of A, B, and C plus 7 volumes of water.

Concentrated metol-hydroquinone.—A developer of the universal type much used for practical work at this bureau:

Water	ml	1,000
Metol	g	1.6
Hydroquinone	g	5.6
Sodium sulphite	g	21.3
Sodium carbonate	g	30.0
Potassium bromide	g	.75

Dilute metol-hydroquinone.—Recommended by Lumières and Seyewetz [10] as giving a slight reduction in grain size, equivalent to the Metol-hydroquinone-borax formula:

Metol	g	0.16
Hydroquinone	g	.30
Sodium sulphite	g	3.0
Sodium carbonate	g	1.6
Potassium bromide	g	.2
Water to make	liter	1.0

Metol-hydroquinone-borax.—Recommended for reduction of graininess in motion-picture negatives: [11]

Metol	g	2.0
Sodium sulphite	g	100
Hydroquinone	g	5.0
Borax	g	2.0
Water to make	liter	1.0

Carlton and Crabtree [12] state that graininess can be further decreased by reducing the concentration of developing agents in this formula to one-half, other concentrations being unchanged.

Metol-borax.—Recommended by Moyse and White for use with motion-picture negatives.[13]

Metol	g	2.5
Sodium sulphite	g	75
Borax	g	5.0
Water to make	liter	1.0

p-Phenylenediamine-borax.—Recommended by the Lumières and Seyewetz [14] as "giving the best results."

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[10] Lumières and Seyewetz, Sci. et. Ind. Phot., **8A**, p. 126; 1928.
[11] Crabtree, Trans. Soc. Motion Picture Eng., p. 77; 1927.
[12] See footnote 4, p. 2.
[13] Moyse and White, Trans. Soc. Motion Picture Eng., **13**, p. 445; 1929.
[14] Lumières and Seyewetz, Sci. et. Ind. Phot., **7A**, p. 108; 1927.

p-Phenylenediamine (base)	g	10
Sodium sulphite	g	60
Borax	g	50
Water to make	liter	1.0

p-Phenylenediamine-carbonate.—The Lumières and Seyewetz [15] state that this formula gives more rapid development and better density than the diamine-borax, but the grain is noticeably coarser.

p-Phenylenediamine (base)	g	10
Sodium sulphite	g	60
Sodium carbonate	g	3.0
Water to make	liter	1.0

Hydroquinone-borax:

Hydroquinone	g	5.0
Sodium sulphite	g	75.0
Borax	g	5.0
Water to make	liter	1.0

Physical developer:[16]

Metol	g	25.0
Citric acid	g	50.0
20 per cent gum arabic solution	ml	50.0
Water to make	liter	1.0

For use add 2 ml of 10 per cent silver nitrate to 50 ml of the above.

Of these developers, the pyrogallol and concentrated metol-hydroquinone are common practical formulas. The metol-hydroquinone-borax and metol-borax formulas, which can now be classed as practical, are based on the use of high sulphite concentration and greatly reduced alkalinity with a developing agent of high reduction potential; the rate of development indicates that only a small proportion of the silver in the developed image can be derived from the slow process of solution of silver halide and reduction in solution. In the *p*-phenylenediamine developers the "chemical" development is greatly decreased by the use of a developing agent of low reduction potential,[17] and reduction takes place at a low rate which probably corresponds to "physical" development. The hydroquinone-borax formula is comparable to the *p*-phenylenediamine-borax, in reduction potential and solvent action; it was introduced only to see if a specific effect of the developing agent on the resolution was detectable, as we did not expect it to be of practical value. Physical development is known to have a favorable influence on resolution both by its effect on grain size and because it gives a surface image free from the effects of irradiation. It might be of value in spite of the known depression of speed in case it made possible a resolution which could not be obtained with any emulsion by normal development.

III. DISCUSSION OF RESULTS

1. SENSITIVITY

The sensitometer tests of the three emulsions listed in Tables 1, 3, and 5 show a wide variation in effective sensitivity of a given emulsion developed with the different formulas. This variation increases with

[15] Lumières and Seyewetz, Sci. et. Ind. Phot. 8A, p. 126; 1928.
[16] Lüppo-Cramer, Phot. Ind., 13, p. 660; 1915.
[17] Nietz, Theory of Development, rates *p*-phenylenediamine hydrochloride at 0.4 and metol at 20, hydroquinone being taken as 1.0; *p*-phenylenediamine base probably has a slightly higher potential than its salt.

the speed of the plate, but the order in which the developers fall is practically the same for all three emulsions.

The special developers with high solvent action and low reduction potential (*p*-phenylenediamine-borax, *p*-phenylenediamine-carbonate, hydroquinone-borax) caused a very considerable depression in speed; in the extreme case of purely physical development, the loss was 80 to 90 per cent. The dilute metol-hydroquinone developer, which would be closely reproduced merely by diluting the concentrated formula to ten times its volume and doubling the bromide, gave normal speed numbers, but, by far, the worst fog for a given contrast.

The metol-hydroquinone-borax and metol-borax developers somewhat unexpectedly gave higher speeds than the standard formulas, and better densities in the underexposure region at moderate values of γ.

TABLE 1.—*Sensitometric characteristic of Seed's 23 plate (emulsion No. 7855) with the different developers*

[Figures in parentheses indicate time of development in minutes]

Developer	Speed	$D^{1.5}_{0.029}$	γ			Fog		
Standard pyrogallol	230	0.12	(3) 1.05	(6) 1.50	(12) 2.03	(3) 0.07	(6) .19	(12) 0.42
Concentrated metol-hydroquinone	200	.09	(1.5) 1.44	(3) 2.03	(6) 2.17	(1.5) .08	(3) .14	(6) .41
Dilute metol-hydroquinone	245	--------	(30) .65	(60) .96	(120) 1.30	(30) .31	(60) .65	(120) 1.12
Metol-hydroquinone-borax	320	.13	(3) .73	(6) 1.13	(12) 1.50	(3) .05	(6) .15	(12) .29
Metol-borax	330	.15	(3) .77	(6) 1.20	(12) 1.69	(3) .07	(6) .18	(12) .33
p-Phenylenediamine-borax	165	.10	(30) .84	(60) 1.17	(120) 1.60	(30) .13	(60) .19	(120) .24
p-Phenylenediamine-carbonate	165	.08	(15) .86	(30) 1.07	(60) 1.31	(15) .18	(30) .21	(60) 0.26
Physical developer 10°	(10) 19 (20) 27 (40) 37	.00	(10) .77	(20) 1.30	(40) 1.64	(10) .05	(20) .10	(40) .18

TABLE 2.—*Resolution of Seed's 23 plate (emulsion 7855)*

[The resolution is expressed in microns spacing of the closest set of lines resolved, and values are rounded to 0.5 μ]

Developer	γ	Fog	Resolution as determined by observer			
			C	D	H	S
Standard pyrogallol	1.50	0.24	15.0	15.0	15.0	15.0
Concentrated metol-hydroquinone	1.45	.06	14.0	15.0	16.0	14.5
Dilute metol-hydroquinone	.56	.17	14.5	15.0	17.5	15.0
Metol-hydroquinone-borax	1.57	.36	14.0	15.5	16.0	16.0
Metol-borax	1.33	.24	13.0	15.5	16.5	16.0
p-Phenylenediamine-borax	1.35	.19	12.0	13.5	14.5	14.0
p-Phenylenediamine-carbonate	1.37	.27	13.5	13.5	16.5	15.0
Physical	.90	.08	13.0	14.0	14.5	15.5

TABLE 3.—*Sensitometric characteristics of Eastman Speedway plate (emulsion Nos. 2357 and 2469) with the different developers*

[Figures in parentheses indicate time of development in minutes]

Developer	Emulsion No.	Speed	$D_{0.029}^{1.0}$	γ			Fog		
Standard pyrogallol	(2357)	400	0.15	(3) 0.70	(6) 1.10	(12) 1.30	(3) 0.10	(6) 0.18	(12) 0.35
	(2469)	490	.12	(3) .55	(6) .86	(12) 1.33	(3) .05	(6) .20	(12) .37
Concentrated metol-hydroquinone.	(2357)	300	.12	(1.5) 1.31	(3) 1.33	(6) 1.52	(1.5) .18	(3) .20	(6) .35
Dilute metol-hydroquinone	(2357)	530	.17	(30) .45	(60) .61	(120) .95	(30) .18	(60) .32	(120) .53
Metol-hydroquinone-borax	(2357)	510	.22	(3) .54	(6) .77	(12) .97	(3) .10	(6) .20	(12) .32
Metol-borax	(2469)	525	.20	(3) .45	(6) .80	(12) 1.10	(3) .05	(6) .16	(12) .27
	(2357)	430	.18	(3) .66	(6) .88	(12) 1.20	(3) .12	(6) .20	(12) .30
Metol-borax+0.5 g *KBr/liter*	(2357)	(3) 300 (6) 440 (12) 510	.25	(3) .51	(6) .77	(12) 1.00	(3) .04	(6) .09	(12) .15
p-Phenylenediamine-borax	(2357)	210	.11	(30) .72	(60) .87	(120) 1.05	(30) .15	(60) .26	(120) .39
p-Phenylenediamine-carbonate	(2357)	(30) 220 (60) 220 (120) 420	-------	(30) .67	(60) .95	(120) .90	(30) .23	(60) .30	(120) .41
Physical developer 20°	(2357)	(2) 31 (4) 34 (8) 52	.00	(2) .20	(4) .60	(8) 1.06	(2) .10	(4) .13	(8) .23

TABLE 4.—*Resolution of Eastman Speedway plate (emulsion 2357)*

[The resolution is expressed as microns spacing of the closest set of lines resolved, and values are rounded to 0.5+ μ]

Developer	γ	Fog	Resolution as determined by observer			
			C	D	H	S
Standard pyrogallol	0.84	0.15	15.0	16.5	17.5	16.0
Concentrated metol-hydroquinone	.87	.06	15.5	17.5	17.5	17.0
Dilute metol-hydroquinone	.47	.24	16.0	19.0	19.0	16.0
Metol-hydroquinone-borax	1.09	.36	14.5	18.5	18.5	17.5
Metol-borax	.84	.20	14.0	18.5	18.5	16.5
p-Phenylenediamine-borax	.97	.36	14.0	15.0	15.5	15.0
p-Phenylenediamine-carbonate	.72	.30	15.0	17.5	16.0	15.0

TABLE 5.—*Sensitometric characteristics of Hammer Press plate (emulsion 4063) with the different developers*

[Figures in parentheses indicate time of development in minutes]

Developer	Speed	$D_{0.029}^{1.0}$	γ			Fog		
Standard pyrogallol	680	0.32	(3) 0.64	(6) 1.05	(12) 1.33	(3) 0.08	(6) 0.13	(12) 0.27
Concentrated metol-hydroquinone	495	.26	(1.5) 1.00	(3) 1.45	(6) 1.57	(1.5) .06	(3) .12	(6) .24
Dilute metol-hydroquinone	730	--------	(15) .36	(30) .61	(60) .77	(15) .09	(30) .17	(60) .33
Metol-hydroquinone-borax	715	.33	(3) .40	(6) .75	(12) 1.20	(3) .06	(6) .13	(12) .26
Metol-borax	725	.36	(3) .51	(6) .82	(12) 1.13	(3) .07	(6) .14	(12) .23
p-Phenylenediamine-borax	215	.12	(30) .68	(60) .88	(120) 1.13	(30) .14	(60) .19	(120) .27
p-Phenylenediamine-carbonate	300	.22	(15) .54	(30) .73	(60) .92	(15) .14	(30) .18	(60) .24
Hydroquinone-borax	(30) 155 (60) 290 (120) 400	.17	(30) .28	(60) .70	(120) 1.00	(30) .03	(60) .14	(120) .40

TABLE 6.—*Resolution of Hammer Press plates (emulsion 4063)*

[The resolution is expressed in microns spacing of the closest set of lines resolved, and values are rounded to 0.5 μ]

Developer	γ	Fog	Resolution as determined by observer		
			D	H	C
Standard pyrogallol	1.14	0.15	15.0	15.0	19.0
Concentrated metol-hydroquinone	1.35	.11	15.5	15.5	18.0
Dilute metol-hydroquinone	.50	.11	17.0	17.0	18.0
Metol-hydroquinone-borax	1.03	.22	16.5	15.5	18.0
Metol-borax	.92	.16	16.0	15.0	18.5
p-Phenylenediamine-borax	.75	.19	16.0	14.5	15.5
p-Phenylenediamine-carbonate	.75	.16	14.0	14.0	16.5
Hydroquinone-borax	.57	.08	16.0	14.0	16.0

TABLE 7.—*Rating of developers, on resolving power only, by the different observers*

[Two or three numbers are assigned where the resolution numbers for the corresponding developers were identical]

Developer	Numerical order of the developers on scale of decreasing resolution										
	Observer D			Observer C			Observer H			Observer S	
	Seed's 23	Speedway	Press	Seed's 23	Speedway	Press	Seed's 23	Speedway	Press	Seed's 23	Speedway
Standard pyrogallol	3–4–5	2	2	7	5	7	2	3–4	3–4	3–4–5	3–4
Concentrated metol-hydroquinone	3–4–5	3–4	3	4	6	3	3	3–4	5–6	2	6
Dilute metol-hydroquinone	3–4–5	7	7	6	7	6	7	7	7	3–4–5	3–4
Metol-hydroquinone-borax	6–7	5	6	5	3	4	4	5	5–6	6–7	7
Metol-borax	6–7	6	4–5	2	2	5	5–6	6	3–4	6–7	5
p-Phenylenediamine-borax	2	1	4–5	1	1	1	1	1	2	1	1–2
p-Phenylenediamine-carbonate	1	3–4	1	3	4	2	5–6	2	1	3–4–5	1–2

2. RESOLVING POWER

The discrepancies between the observers are of the same order as the differences produced by the developers, so that the only unqualified statement possible is that the development has little effect on resolution. This is disappointing, since both our own photomicrographs and those of the Lumières and Seyewetz [18] show distinctly smaller silver grains in the images developed by the special formulas, while the increasing use of the metol-hydroquinone-borax developer for reducing graininess in motion-picture negatives indicates that this type can decrease the number of clumps of grains. It seems necessary to conclude that resolution as measured by the standard test is not directly dependent on grain size, or on the factors controlling graininess. Preliminary experiments on the accuracy of setting a cross hair on fine lines developed by standard and special formulas gave no indication of any marked improvement; refinements on the technique employed will be necessary, but we believe that a study of the factors influencing accuracy of such distance measurements on plates might be of greater utility than the usual determination of resolving power.

Table 7 shows that the individual observers were more likely to agree on the order in which they placed the developers than on the absolute magnitude of the resolution numbers; there was, however, also a tendency to individual preferences for or against one or two developers, which were maintained on all emulsions and which can not be ascribed to previous bias. The data indicate:

1. Both *p*-phenylenediamine formulas, the hydroquinone-borax, and the physical developers, improved resolution over the standard formulas. The physical developer was no better than those first mentioned.

2. The metol-hydroquinone-borax and metol-borax developers were no better than the standard pyrogallol or metol-hydroquinone in their effect on resolution.

3. The dilute metol-hydroquinone formula gives probably the worst resolution. It is interesting to compare this with the concentrated formula, which gives a much coarser grain, but is so far superior as to contrast and fog that resolution is distinctly better; on a test object of lower contrast ratio, or in actual spectrographic work with faint lines, the superiority would be more marked.

Such improvement as was obtained was as distinct with the Seed's 23 as with the faster plates. The Lumières and Seyewetz [18] report that in the case of a process plate the grain is practically independent of the developer.

In spite of the negative results of the resolution test, there has been general agreement that the spectrum plates developed with the metol-hydroquinone-borax and metol-borax formulas show more detail than the plate developed with the concentrated metol-hydroquinone; this is unquestionably true with the *p*-phenylenediamine-borax. Viterbi [19] has already illustrated good results obtained with the metol-hydroquinone-borax formula, but unfortunately gives nothing for comparison.

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[18] See footnote 14, p. 5.
[19] Viterbi, Proc. 7th Int. Cong. Phot., pp. 365–367.

The resolution number and silver grain obtained with the hydroquinone-borax and *p*-phenylenediamine-borax developers are very similar. We doubt that the latter reducing agent has a specific influence independent of its reduction potential.

3. UTILITY OF THE DEVELOPERS

Judging the developers by their effects both on resolution and sensitivity, it appears that none of those tried offer a marked improvement over the standard formulas. The *p*-phenylenediamine developers are unfortunately eliminated by their effect on sensitivity. By way of illustration, the Press plate, developed with *p*-phenylenediamine-borax to a γ of 0.75 and fog of 0.19, has a speed of 215 and resolution number of 15; the Seed's 23, developed with concentrated metol-hydroquinone to a γ of 1.45 and fog of 0.06, has a speed of 200 and resolution number of 14. In practice, the use of the latter combination is very obviously preferable. The metol-hydroquinone-borax and metol-borax developers increase the effective sensitivity and may appreciably improve the detail of the image in some cases. They are thoroughly practical developers if it is remembered that they are quite sensitive to the soluble bromide which accumulates in use. A small amount can be compensated by increasing the development time (see Table 3) and may be an advantage; but it is well to remember that in most scientific applications of photography the overhead expense on a given exposure normally makes it very false economy to endanger results by saving developer.

IV. SUMMARY

1. Six developers characterized by increased solvent action on silver bromide and decreased reduction potential have been compared with standard pyrogallol and metol-hydroquinone formulas. The comparison is based on (*a*) sensitometric tests, using three emulsions; (*b*) tests of resolving power by the parallel-line test object, using the same emulsions; and (*c*) spectrographic exposures with one of the emulsions.

2. Only the developers with lowest reduction potential effected an appreciable improvement in resolving power. These developers are of no practical use because they greatly decrease the effective sensitivity.

3. The "borax" developers used in motion-picture laboratories are satisfactory for spectrographic work, but improvement over the standard formulas can not be expected to be large.

V. ACKNOWLEDGMENTS

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