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Tutorial

A Review of Speed Methods

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The speed of a photographic material is not a fundamental concept, but provides an index number useful for calculating camera settings. Various methods of speed determination are tabulated. These methods differ in the calculation of exposure and the specification of the response of the material.

The earliest attempts of measuring speed can be traced to the beginning of photography. The problem of expressing speed, however, did not become critical until the advent of the gelatin dry plates in about 1880. Over a period of approximately 100 yr there have evolved many ways of measuring speed, determined primarily by the various types of materials and their use.

An examination of published statements was made in order to bring together information about speed methods. Most attention was paid to Federal and American Standards and to manufacturers' literature, since these probably comprise most of the presently accepted methods; some proposals from the periodical literature are included in the summary in Tables I and II.

The tables are preceded by brief statements of different views of the concept of exposure and of the criteria of image quality. These statements suggest that the problems associated with determining photographic speed have by no means been solved.

Definition of Speed

Arithmetic speed values are usually found from an equation of this form:

$$S_a = k/E$$

where S_a is the speed value, k is an arbitrary constant, and E is the exposure which is sufficient to produce a satisfactory image. Logarithmic speed numbers are found from an equation such as:

$$S_l = k' - \log E$$

Arithmetic speed numbers have the advantage of familiarity; logarithmic numbers facilitate computations.

In ASA PH2.5-1960[3] the speed of photographic films is defined in part as "a numerical expression of its sensitivity." In PH2.21-1961[7] the corresponding statement is "a quantitative measure of the response of the photographic material." Neither of the terms sensitivity or response is synonymous with speed. The term sensitivity includes many kinds of film performance in addition to those related only to speed. The term response often includes density, gradient, resolving power, or other characteristics of the image.

Speed was at one time considered to be a property of a photographic emulsion, one of a set of properties which included fog and contrast among others. This attitude toward speed seems, according to most published statements, to have been replaced by a practical approach so that perhaps a number that one can index into a meter is thought to be sufficient. For the consumer of the product, the speed is intended to facilitate computations of camera settings that will permit him to make a satisfactory photographic image. The user is generally interested in finding the minimum conditions under which the product can be used. For the manufacturer, a speed number is useful in product quality control.

Two kinds of major problems are involved in the attempt to devise a rational speed number: the definition of exposure, and the criterion of excellence for the photographic image.

Definitions of Exposure

The earliest attempts to devise speed methods were in association with outdoor pictorial photography. Hurter and Driffield defined exposure by the relation:

$$E = I \times t$$

where E is exposure, I is the intensity (now, illuminance) and t the time of exposure. Illuminance specifies the rate at which *light* is received by the photographic material. Exposure as thus defined means the amount of energy received by the film, the energy being weighted according to the luminosity function of the standard observer. The unit of exposure is usually given as meter-candle-seconds, which is equivalent to lumen-seconds of light per square meter of receiving surface.

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TABLE I. Some Present Methods of Expressing Speed of Photographic Materials

Application	Criterion[a] (speed point)	Calculation	Source
Pictorial; black-and-white			
(a) negative	0.10 density	$S_x = 0.8/E$ (arithm.) $2^{S_v} = 0.24/E$ (log)	ASA PH2.5-1960
		Speed = $\log_{10} 0.49/E$	DIN 4512-1957
	0.20 density	Rel. sens. = $1/E$	Fed. Standard No. 170, Method A
(b) positive and reversal	1.00 density	Rel. sens. = $10/E$	*Ibid.*, Method B
(c) neg.-pos. (Polaroid)	0.5 density of print	Speed = $4.0/E$	Polaroid (private comm.)
Motion Picture			
(a) negative	practical tests	Speed = $100/E$	*SMPTE*, Ref. 13, pp. 95-97
(b) reversal	some fixed gradient or fixed D on *shoulder* of curve		*Ibid.*, p. 103
(c) sound recording	st. line region of neg-pos characteristic curve, 0.55 density		*SMPTE, op. cit., p. 123*
1. variable-density			*Ibid.*, p. 124
2. variable-area	based on cross modulation tests and listening tests		*Ibid.*, p. 125
Aerial			
(a) negative	slope of 0.5 × gamma	Speed = $0.5/E$	Fed. Spec. L-F-330, Method B
	0.6 to 0.8 density		Kardas (Ref. 23)
	0.85 density		Levy (Ref. 24)
	0.9 × max. resolution		Howlett (Ref. 18)
Copying & Duplicating			
(a) Commercial film	practical tests implied		manufacturer's data sheet
(b) Gravure film	1.50 to 1.70 highlight density		Kodak booklet, "Copying"
(c) Motion Pictures	st. line region of characteristic curve		*SMPTE, op. cit.*, p. 113
Pictorial; Color			
(a) negative	0.10 density		under consideration by a subcommittee of ASA
(b) reversal	midpoint between gradient shadow point and fixed highlight density	$S_r = 8/E$ (arithm.) $2^{S_r} = 2.4/E$ (log)	ASA PH2.21-1961
(c) Polaroid	textured highlights		Adams, ref. 9, p. 3 of color supplement
(d) reversal print film	practical test based on projected print		Ektachrome Reversal Print film data sheet
(e) inter-negative	min. st. line density		Eastman Color Internegative data sheet
Print Material, black-and-white			
(a) paper	variable point on shoulder of curve (determined by use of special meter)		ASA PH2.2-1953
	max. useful density	Speed = $10{,}000/E$	Kodak booklet, "Photographic Papers," p. 7
	0.60 density	Printing Index = $10{,}000/E$	*Ibid.*, p. 7
	0.60 density	Speed = $1000/E$	Proposed revision PH2.2
(b) transparency	1.20 density	Speed = $1000/E$	Fed. Spec. L-F-330, Method F
	0.7 to 1.0 density		Hornsby (Ref. 12)
X-rays			
(a) industrial	1.5 density	Speed = $1/E$	ASA PH2.8-1956
(b) medical	1.0 density	Speed = $1/E$	ASA PH2.9-1956
(c) gamma rays for monitoring	low Reference E: 0.05 density; high ref. E: the smaller of either (a) 5.0 density or (b) shadow gradient of 0.10 × max. gradient. (E is in roentgens)	Speed = $1/E$	ASA PH2.10-1956
Cathode-Ray Recording	1.0 density	Speed nos. relative to that of reference film	Kodak booklet, "Kodak Films for Cathode-Ray Tube Recording"
Television Recording	about 0.15 to 0.20 total density (E is in bias voltage)		Eastman Television Recording Film data sheet

[a] Densities are density over base plus fog unless otherwise specified.

TABLE I. Cont'd

Application	Criterion (speed point)	Calculation	Source
Oscillographic Recording			
(a) negative	0.10 density	Speed = 1/E	Kodak booklet, "Kodak Materials for Geophysical Exploration"
	where last complete trace envelope is visible	Writing Speed = πaf (a is peak to peak amplitude; f is frequency) example: Writing Speed = 15,000 in. sec.	Du Pont (private comm.), *Kodak Techbit* No. 1, 1964
(b) reversal	detectable density below max. density	Speed = 1/E	*Kodak Techbit* No. 4, 1963
Information Recording			
(a) detective speed	first distinguishable exposure level above fog		Milne & Eyer (Ref. 28)
(b) informational speed	10th distinguishable density level (arbitrary)		*Ibid.*
(c) information sensitivity	". gradient $g = dD/dE$ divided by the product of Selwyn granularity (G) and the square root of the area (s) of the spread function."		Perrin (Ref. 27)
Spectroscopy and Astronomy	0.60 density		T. Dunham, Jr. (Ref. 11, p. 908)
Infrared	practical test implied		Manufacturer's data sheet
Microphotography			
(a) negative materials	Minimum Brightness: best rendition of detail in darker parts of subject		Kodak booklet, "Kodak Films & Plates for Photography Through the Microscope"
(b) reversal materials	Maximum Brightness: best rendition of brightest parts of subject		*Ibid.*
Microfilm	1.20 density	Relative Sens. = 45/E	Federal Standard No. 170 Method D
Photomechanical Reproduction	2.50 density	Relative Sens. = 10/E	*Ibid.*, Method C
Process Control	fixed density	Relative Speed (between two curves having the same gamma) = antilog {(D1-D2)/gamma}	SMPTE, op. cit., p. 99
Relative Comparisons of Various Films	0.60 density	Relative Sens. (SA) = 1/E	Kodak booklet, "Kodak Plates for Science & Industry," p. 6

TABLE II. Obsolete Film Speeds

Most of the earlier methods for specifying film speeds were based either on an inertia point or on a threshold density)

Speed designation	Criterion (speed point)	Calculation
1881 Warnerke	threshold density	
1890 Hurter and Driffield	inertia (where extension of st. line of H and D curve intersects base + fog level)	Speed = $34/i$
1890 Watkins	inertia	Speed = $68/i$
1893 Wynne	inertia	Speed = $6.4(68/i)^{1/2}$
1894 Scheiner	Schwellenwert (threshold) (Exposure modulator consisted of continuous logarithmic aperture instead of a wedge)	
1901 Chapman-Jones	threshold density based on stepped wedge	
1919 Eder-Hecht	threshold density based on continuous wedge	
1932 Weston	inertia (density of gamma + fog)	Speed = $4/E$
1934 DIN 4512	0.1 density	Speed = $\log_{10} 0.36/E$
1939 Eastman Kodak Co.	fractional gradient ($0.30\bar{G}$)	Speed = $1/E$
1943 ASA	" " "	"
1947 BSI	" " "	"

Such a definition of exposure appears in PH2.5-1960,[3] PH2.21-1961,[7] and in PH2.20-1960, "Sensitometric Exposure of Artificial-Light-Type Color Films," which uses the phrase "absolute photometric units."

To define exposure solely in terms of light seems reasonable for pictorial photography. The appropriateness of this definition for photographic papers is not so clear, since radiation other than light is effective in causing a response of the printing material.

For narrow-band radiation (monochromatic) sensitometry, exposure is usually defined as the quantity of energy received per unit area of the receiving surface, measured in ergs/cm^2 or other physical units. No weighting function is involved in this definition.

For direct photography with x-rays, the unit of exposure is the roentgen, which is defined in terms of the effects of the x-rays in ionizing a specific absorber, i.e., air. Thus a weighting function is involved as for light.

For the study of the fundamental properties of photographic emulsions, such as latent-image formation, exposure is often expressed as the average number of incident (or preferably, absorbed) photons per grain.[17] To be meaningful, a count of photons should specify the nature of the photons being considered.

Many definitions of exposure have been devised for special situations; these involve different wavelength limits and weighting functions. For example, in PH2.9-1956,[5] screened x-ray exposure for blue-sensitive films is defined as ergs/cm^2, with integration between 300 and 540 mμ; a similar definition for green-sensitive films specifies a different energy distribution from 300–700 mμ. Thus the exposure is related to the spectral sensitivity of the photographic material being tested.

For the comparison of sources of quite different spectral energy distributions, the definition of exposure on an absolute basis has been suggested, based on the response of an ideal blackbody detector. In practice, however, more or less arbitrary limits of the wavelength range are necessary in order to avoid the inclusion of inappropriate radiation. For tungsten lamps, for example, the infrared content is usually not included because it is large in comparison with the radiation that is effective for most emulsions.

That the listing above includes many definitions of exposure attests to the difficulty of specifying, in meaningful terms, the amount of energy available to the photographic emulsion. If an error is made in defining exposure, the calculated values of speed, and the relationships among the speeds of different emulsions, will be in error.

Criteria of Image Quality

The specification of film speed requires that a criterion be found that correlates well with independent estimates of image excellence. Such estimates are necessarily subjective, inasmuch as an observer must make the final judgment of quality.

When an observer examines an image, his visual impression is based on quantitative and qualitative differences in illuminance on the retinal mosaic. Therefore, a criterion related to some measure of difference in the image should show good correlation with subjective estimates of image quality. If a conventional $D \log E$ curve is thought to describe the response of the photographic material, the criterion may be defined as a gradient.

Considerable evidence[19–21] supports the view that in pictorial black-and-white photography (negative-positive system) an excellent criterion is a fixed relationship between the minimum useful negative gradient for the shadows and the average gradient of that part of the $D \log E$ curve used in making the negative. There is evidence[22] to indicate that for a black-and-white pictorial print a similar gradient relationship holds. A gradient criterion would also be expected to correlate with the readability of an oscillograph trace, the legibility of microfilm images, and the detectability of star images. Even for materials intended for lithographic use, the edges of dots and lines are describable by a curve similar to the $D \log E$ curve. For such a curve the gradients should supply a significant criterion. The special problems presented by lithographic films are discussed in Ref. 16.

In the speed methods summarized in Tables I and II, gradient criteria are few; fixed densities more popular, supposedly, because they are easily determined. The change in 1960 of the American Standard method for the speed of pictorial black-and-white negatives from a gradient method to a fixed density method was based on evidence of a good correlation between the two techniques. The correlation holds only when conditions of development are specified so as to yield negatives of fixed contrast.

Practically all the speed methods now in use are derived from density measurements of large sample areas. Speeds could be based on microdensity measurements, such as acutance or resolution. Howlett,[18] Kardas,[23] and Levy[24] suggest such methods. Perrin[25] proposes informational sensitivity as a more nearly basic characteristic of a negative material, dependent upon gradient, granularity, and point spread function.

Any characteristic of the image which is affected by exposure level and which can be shown to correlate with image quality may serve as the basis of a speed method. Only for pictorial photography has extensive experimental work led to well-accepted methods.

Tables I and II give the essentials of the speed methods which have acquired the status of standards or are generally accepted as useful. The tables should enable one to discover whether or not a method is available for the intended application. The variety of methods now in use suggests that efforts are needed to clarify the situation.

Bibliography

American Standards

1. *Sensitometry and Grading of Photographic Papers*, PH2.2-1953.
2. *Photographic Speed and Exposure Index*, PH2.5-1954.