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An Interpretation of Current Exposure Meter Technology

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This paper attempts to interpret the changes that have taken place in the past year in exposure meter technology. The 1961 revision of the American Standard for Photographic Exposure Meters[1] includes the first complete array of the new exposure nomenclature, the Additive System. Among other innovations, meters will henceforth be calibrated at 4700°K. instead of 2700°K to make them more accurate in daylight and eliminate the need of different tungsten speeds for most panchromatic materials. This standard not only covers its field thoroughly but prescribes methods of measurement and includes more background technology and educational material than most documents of this character. The ASA subcommittee for exposure meters has kept the standard up-to-date and has agreed on desirable uniform procedures in advance of actual factory practice.

The principal consumer need for a speed rating of a film product is for use with an exposure meter. Photoelectric exposure meters originated in Germany about 1928 and were first made in this country about 1932. By 1937 there were half a dozen types of meters manufactured in the United States and even more imported varieties. Each manufacturer could elect to use any of several film-speed systems, and could select the indicated exposure to produce a negative of whatever density he thought desirable. Reputable exposure meters intentionally differed by as much as one *f*-stop.

The end of this confusion started in 1938 with the organization of Committee Z38 of the American Standards Association under the leadership of L. A. Jones and Paul Arnold. This committee brought together manufacturers, consumers, and other interested groups for the purpose of standardization. The exigencies of World War II forced agreement on methods of measuring and expressing many photographic parameters, including camera exposure. Since then, the war emergency standards have been revised, improved, and expanded to include interchangeability, dimensions, units, nomenclature, testing procedures, and quality relating to all types of photographic materials and apparatus. Photographic measurements have been rationalized almost completely by American Standards. International standardization is progressing. These voluntary standards simplify photography for all.

New Nomenclature

In the latest revision of PH2.12, American Standard for General Purpose Exposure Meters,[1] new symbols and nomenclature appear. The high speeds of new films, for example ASA 1250, require four-digit numbers on exposure meters. The miniature meters of today cannot accommodate a scale of four-digit numbers without a sacrifice of legibility. Accordingly, the exposure meter subcommittee proposed a new scale of film-speed numbers composed of single digits. The new series—0, 1, 2, 3, 4, 5, 6, 7, 8, and 9—is a logarithmic series, base 2, and designates the same film sensitivities as the alternate familiar arithmetic series—3, 6, 12, 25, 50, 100, 200, 400, 800, and 1600—which it is expected to replace. The log series are called film-speed values to distinguish them from the arithmetic film speeds. The two should not be confused, as the series of numbers do not overlap for any commonly used films.

The camera exposure formulas[1,2] (see Table I for nomenclature)

$$SxB/K = 2^{Ev} = A^2/\mathrm{T} \qquad (1)$$

can be written

$$\log_2 Sx + \log_2 B - \log_2 K = Ev = \log_2 A^2 + \log_2 (1/T) \qquad (2)$$

The left side of this equation can be rearranged without changing the equality,

$$\log_2 Sx + \log_2 (B/K) = Ev, \qquad (3)$$

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[*] Members of the ASA Subcommittee PH2/11, Photographic Exposure Meters, who have been concerned with the revision discussed in this paper are: Messrs. A. Boch, T. Briskin, G. Dougan, R. French, M. LaRue, Jr., C. McCamy, D. Merrill, H. Morse, C. Nelson, P. O'Neill, J. Schimoler, A. Stimson (Chairman), M. Townsley, V. Whitman, and A. Williams.

[1] American Standard for General Purpose Photographic Exposure Meters, PH2.12-1961.

[2] Allen Stimson, *Phot. Sci. Eng.*, 4: 203 (1960).

TABLE I. Nomenclature for Exposure Parameters

Arithmetic system[a]		Additive (APEX) system		Relationship
Ev = Exposure value	$2^{Ev} = \frac{A^2}{T}$	Ev = Exposure Value	$Ev = Av + Tv$	
	$= \frac{BSx}{K} = \frac{B_0Sx}{K_0}$		$= Bv + Sv$	
	$= \frac{ISx}{C}$		$= Iv + Sv$	
T = Effective shutter time, sec		Tv = Time value	$2^{Tv} = \frac{1}{T}$	$Tv = 3.32 \log_{10} \frac{1}{T}$
A = Actual *f*-number of lens diaphragm		Av = Aperture value	$2^{Av} = A^2$	$Av = 3.32 \log_{10} A^2$
Sx = ASA speed (of film)[c]		Sv = ASA speed value	$2^{Sv} = NSx$	$Sv = 3.32 \log_{10} NSx$
B = Field luminance, ft-L[d]		Bv = Luminance value[b]	$2^{Bv} = \frac{B}{KN}$	$Bv = 3.32 \log_{10} \frac{B}{KN}$
B_0 = Field luminance, c/sq ft[d]				
K = Exposure constant (reflected light)			$= \frac{B_0}{K_0N}$	$Bv = 3.32 \log_{10} \frac{B_0}{K_0N}$
K_0 = Exposure constant (reflected light)				
C = Exposure constant (incident light)				
I = Incident light (ft-c)[e]		Iv = Incident-light value	$2^{Iv} = \frac{1}{CN}$	$Iv = 3.32 \log_{10} \frac{1}{CN}$

[a] $B = \pi B_0$; $K = \pi K_0 = 3.33 \pm 0.50$; $K_0 = 1.06 \pm 0.16$; $C = 20.8 \pm 5$; $N^b = 0.30$.

[b] The value of N is established in PH2.5-1960.[4] It is a constant which was chosen to establish the relation between Sx and Sv, shown in Table II.

[c] The abbreviated designation of American Standard Speed, Sx, for example, may be written ASA 25, and that for Sv may be written ASA 3°.

[d] The footlambert (ft-L) is the preferred unit to avoid confusion between candles per square foot (c/sq ft) and footcandles (ft-c).

[e] Illuminance. The footcandle (ft-c) is the preferred unit.

and the independent parameter N can be introduced as

$$\log_2 NSx + \log_2 (B/NK) = Ev. \qquad (4)$$

If symbols are substituted,

$$Sv = \log_2 NSx \qquad (5)$$
$$Bv = \log_2 (B/NK) \qquad (6)$$
$$Av = \log_2 A^2 \qquad (7)$$
$$Tv = \log_2 (1/T), \qquad (8)$$

Eq. (2) may be written as

$$Sv + Bv = Ev = Av + Tv \qquad (9)$$

It is obvious the Bv is not an absolute photometric unit of luminance since it involves the parameters N and K. The K was included in Bv for simplicity of Eq. (9). The value $N = 0.30$ was selected in cooperation with Subcommittee PH2/18 to make film speed 3 correspond approximately with film-speed value 0°. (The degree notation (°) was used in the previous standard[3] to distinguish the logarithmic exposure indexes and is now retained[4] to distinguish speed values.)

Fortunately, it was possible to select a value $K = 3.333$ which would make the luminance value $Bv = 0$ correspond exactly to field luminance of 1 ft-L. Thus, the scale of luminance values given in Table II is exact only when the meter is calibrated for the exposure constant $K = 3.333$. The standard permits the manufacturer to select a value for K within the limits $K = 3.333 \pm 0$ 50.

The new value $K = 3.333$ is used when the meters are calibrated at 4700°K. The former value $K = 3.6$, which has been used when the meters[5] were calibrated at 2700°K, is 10% greater because the average cell is about 10% less sensitive at this color temperature. Consequently, no radical change in calibration of reputable American-made meters is anticipated. However, all meters which conform will be more uniform. It is expected that different manufacturers will in the future agree more closely on the value of K, so that the tolerance on $K = 3.333$ of ± 0.50 can be reduced.

The footlambert (ft-L) is now the preferred unit of luminance (brightness) to avoid confusion between the unit, candle per square foot, and the unit of illuminance, the footcandle (ft-c).

The incident-light value Iv involves the constant C which can vary ± 24% within the limits of the standard and at the option of the meter designer. Incident light, as defined in the Standard for Photographic Exposure,[1] is measured at the subject position in a plane normal to the direction of the camera. However, illumination for visual purposes is ordinarily measured in a horizontal plane. For these reasons, photographic incident-light data may

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[3] American Standard Method for Determining Photographic Speed and Exposure Index, PH2.5-1954. American Standards Association, 10 E. 40 St., New York 16, N. Y.

[4] American Standard Method for Determining Speed of Photographic Negative Materials, PH2.5-1960.

[5] American Standard for General Purpose Photographic Exposure Meters, PH2.12-1957.

TABLE II. Conversion Tables[a] for Arithmetic and Additive (Logarithmic) Systems of Exposure Units

Time T (sec)	Tv	Aperture A ($f/$)	Av	Film Speed Sx	Sv	Luminance[b] B (ft-L)	B_0 (c/sq ft)	Bv	Incident Light[c] I (ft-c)	Iv	Exposure A^2/T	Ev
1	0	1	0	3	0°	1	0.32	0	6	0	1	0
1/2	1	1.4	1	6	1°	2	0.64	1	12	1	2	1
1/4	2	2	2	12	2°	4	1.25	2	25	2	4	2
[d] 1/8	3	2.8	3	25	3°	8	2.50	3	50	3	8	3
1/15	4	4	4	50	4°	16	5.00	4	100	4	16	4
1/30	5	5.6	5	100	5°	32	10.0	5	200	5	32	5
1/60	6	8	6	200	6°	64	20.0	6	400	6	64	6
1/125	7	11	7	400	7°	125	40.0	7	800	7	125	7
1/250	8	16	8	800	8°	250	80.0	8	1600	8	250	8
1/500	9	22	9	1600	9°	500	160	9	3200	9	500	9
1/1000	10	32	10	3200	10°	1000	320	10	6400	10	1000	10
				6400	11°	2000	640	11	12500	11	2000	11
				12500	12°	4000	1250	12	25000	12	4000	12
											8000	13
											16000	14
											32000	15
											64000	16
											125000	17
											250000	18

[a] For nomenclature see Table I.

[b] Luminance for $K = 3.3333$ and $K_0 = 1.061$.

[c] Illuminance for $C = 20.83$. Incident light is measured in the plane of the subject, perpendicular to the direction of the camera.

[d] The tabular values of T, A, Sx, B, B_0, and I are rounded off to a uniform series of numbers which are easy to remember. However, the actual numbers to be used in designing and calibrating equipment are in a power-of-two geometric progression, starting with the precise values of the figures on the fourth line. The precise value of f 2.8 is $8^{1/2}$. $B_0 = B/\pi$. The precise value of $Sx\ 25 = 32/2^{1/3} = 25.4$. According to the formulas in Table I, the precise equivalent of Sv 3 is $Sx\ 25 = 26.7$. Since APEX values are intended to be precise, the tabular luminance figures are based on $Sx\ 25 = 26.7$ and $K = 3.333$. The center points of the Em intervals (Fig. 1) which define Sx and Sv differ by a twelfth-root-of-two step because the relations given in Table I were used to establish common boundaries and not common midpoints. Tables of precise values of all exposure parameters will be published in another American standard.

[e] If intermediate subdivisions are used, square-root-of-two steps are preferred for all parameters except Sx. Cube-root-of-two steps are preferred for these arithmetic speeds in accordance with PH2.5-1960.[4]

not agree with those of illuminating engineers. The tolerance on the value of the exposure constant K for reflected-light meters is less than that on the value of C for incident-light meters, because of the greater variations in the acceptance angles and directions of aiming the incident-light receivers.

The ratio of K to C is the average scene reflectance for which the meter is calibrated. The mean value is now $R = 3.333/20.83 = 16\%$. This value of reflectance is indicated when the reflected-light meter is aimed from the camera toward the subject, and the incident-light meter is aimed from the subject toward the camera. However, it is close to the reflectance of the "gray card" used with reflected-light meters. Kodak's "Neutral Gray Card" had a reflectance of 18%. The difference is due to the angle at which the card is held.

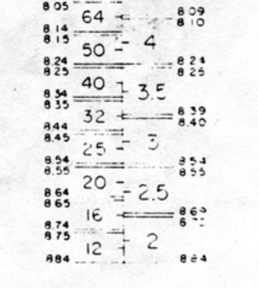

Fig. 1. Graphical conversion chart between typical ASA film speeds and ASA film-speed values showing that the centers of the prescribed[1] $\log_{10}E_m$ intervals do not exactly coincide. The formulas for determining S_x and S_v from sensitometric measurements are $S_x = 0.8/E_m$ and $2^{S_v} = 0.24/E_m$

The luminance value and incident-light value scales on exposure meters are exact photometric quantities for a particular meter. The values are related to established photometric units by the selected exposure constant.

The definitions of aperture value[6] Av, Eq. (7) and time value[7] Tv, Eq. (8) were originated by ASA Sectional Committee PH3 and published in 1959.

The logarithmic system of nomenclature in Table I and the units involved are compatible with the exposure-value* system introduced by Deckel on the Compur shutter in 1954. The original purpose of the Ev system was to simplify the exposure meter by eliminating the need for aperture and time scales on the exposure computer. This made the built-in meter more practical. The cross coupling of the diaphragm and shutter also simplified the use of the camera. With the introduction of automatic exposure-controlled cameras the need for exposure-value

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* At the 1955 International Standards Organization meeting in Stockholm the exposure meter subcommittee of the ISO agreed that the English translation of the German "Lichtwerte" would be exposure-value instead of light-value. The new terminology became the American Standard[5] in 1957.

6. American Standard for Aperture Markings for Still Camera Lenses, PH3.33-1959.
7. American Standard for Exposure Time Markings for Shutters used in Still Cameras, PH3.32-1959.

markings has diminished. However, the industry is indebted to Deckel for naming a quantitative unit of camera exposure which had hitherto been nameless.

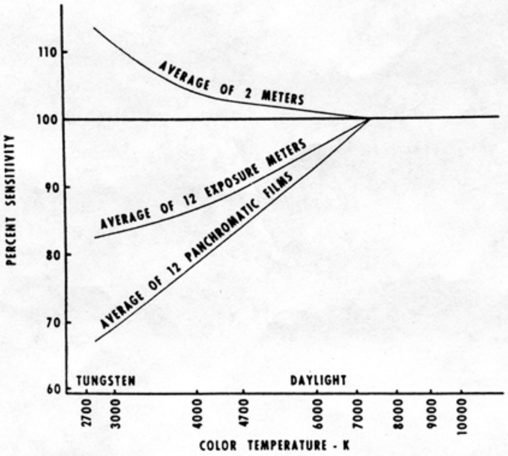

Fig. 2. Change in average spectral sensitivity with color temperature of 12 panchromatic films and 14 exposure meters.

When Subcommittee PH2.18, under the chairmanship of J. L. Tupper, established[4] the exposure intervals corresponding to speed numbers and speed values, the divisions were at the boundaries and not the centers of the intervals. The relations are shown graphically in Fig. 1 for a typical portion of the range. The center points of the speed intervals on the two scales are spaced approximately a twelfth-root-of-two step apart. They can never correspond exactly because the arithmetic scale has three subdivisions and the log scale has only two. However, the conversion is sufficiently accurate for the intended use of the film products in question.

Calibration at 4700°K

With changes in color temperature, the sensitivity of selenium cells of American manufacture changes in the same direction, although somewhat less in magnitude, as panchromatic negative materials. Hence, meter makers have urged film manufacturers to eliminate tungsten film ratings for several years. K. S. Weaver of the Kodak Research Laboratories made extensive tests on a dozen of each of fourteen makes of meters to determine the feasibility of this elimination. His tests showed that two of the fourteen changed sensitivity with color temperature in the opposite direction from the majority. This confirmed other observations that some meters, which manifested perfect calibration in the laboratory (at 2700°K), differed markedly when used in daylight. The results are illustrated in Fig. 2. A. L. Sorem showed (Fig. 3) that the errors could be equally divided between daylight and tungsten if all meters were calibrated at 4700°K rather than 2700°K. This calibration is now included in the standard. It will assure closer agreement between meters in daylight and eliminate the need for tungsten film speeds for most panchromatic negative materials.

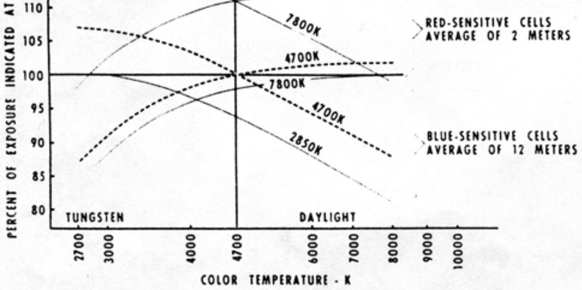

Fig. 3. Meters which are calibrated at 4700°K are more accurate over the entire range than those calibrated at tungsten or daylight color temperatures.

The only luminous standard[8] available for purchase is the tungsten "standard lamp." A variety of sizes and shapes may be procured from the National Bureau of Standards or from a few recognized standardizing laboratories. For use on a bar photometer such lamps are ordinarily rated in horizontal candlepower in the marked direction at the stated voltage or current and the given color temperature. Lamps for use in the Ulbricht sphere are rated in terms of total lumens. The accuracy of these ratings has been found to be within ± 2%, which is sufficient for most photometry. Some laboratories purchase several lamps at a time and preserve the one having the average candlepower as their reference standard. These standard lamps are used as a source for producing known illuminance, usually expressed in footcandles or metercandles. Different laboratories have agreed rather closely on the magnitude of the units of illuminance.

Measurements of brightness or luminance are more difficult, and disagreements between laboratories by as much as 50% have been encountered. In the past, it was not possible to buy a standard of brightness suitable for calibrating exposure meters. (In recent years the National Bureau of Standards did make available a small piece of opal glass calibrated for luminous directional transmittance[1] at tungsten color temperatures.)

Photometric measurements in photography are complicated because of the differing spectral sensitivities of the eye, the exposure meters, and the films. Scientists have agreed on the spectral sensitivity of the Standard Observer, and all photometric measurements are based on the corresponding luminous efficiency of radiant energy.[9] For instance, the 100% sensitivity level in Fig. 2 is the sensitivity of the eye to

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[8] Allen Stimson Chap. 12., *Applied Electrical Measurements*, I. F. Kinnard, ed., John Wiley & Sons, New York, 1956, p. 387.

[9] American Standard Method of Spectrophotometric Measurement of Color, Z58.7.1.

light of the different color temperatures. The corresponding total radiation of a blackbody at each point would be markedly different. A method for determining the sensitivity of a given film to different colored illuminants is described in an American standard;[10] the relationship is called the *actinity* of the source. For these reasons, it is especially important in standards for photographic measurements to specify in considerable detail the light sources and the filters used with them.

One of the two manufacturers of meters having red-sensitive cells has found it necessary to assign a higher speed to certain color films than the film manufacturer. It is obvious that the red-sensitivity of the cells causes the meter to read relatively lower in daylight resulting in overexposure. A higher film speed was assigned to compensate for the discrepancy.

The revised standard[1] completely specifies a suitable blue glass filter for converting 2850°K tungsten light to 4700°K light. It also specifies a diffusing sandwich composed of blue glass and diffusing filter which in combination with a 2850°K lamp provides a 4700°K surface source of uniform luminance. These filters and sandwiches are to be made available and calibrated by the National Bureau of Standards for luminous directional transmittance per unit of incident light at 2850°K. Thus, the luminance of the calibration source at 4700°K can be easily computed from the candlepower of the 2850°K lamp, its distance from the sandwich, and the luminous directional transmittance of the sandwich.

The blue-glass conversion filter will probably absorb 75% or more of the light, making it difficult to achieve a large-area source of daylight brightness levels without excessive heating and power consumption. For this reason it is expected that the 4700°K surface source will be used as the primary laboratory reference for luminance and that factory calibration will continue at 2700°K. It is important that the cells used to transfer the luminance calibration from the 4700°K reference source to the 2700°K factory equipment be identical in manufacture, mounting, enclosure, and directional characteristics with those of the products to be tested.

The new standard source of luminance at 4700°K should bring all manufacturers into closer agreement and result in better-satisfied customers.

Spectral Sensitivity

The existence and availability of two standard light sources at 2850°K and 4700°K provides a convenient means for checking the relative spectral response of different meters. A method for determining relative spectral sensitivity by this means may be included in the next revision of the standard. The response to the 4700°K source is between .75 and 1.30 of that to the 2850°K source for most selenium cells. The standard[1] states that the responses to wavelengths over 7000 A or under 3500 A shall each be less than 5% of the total response to an equal energy source.

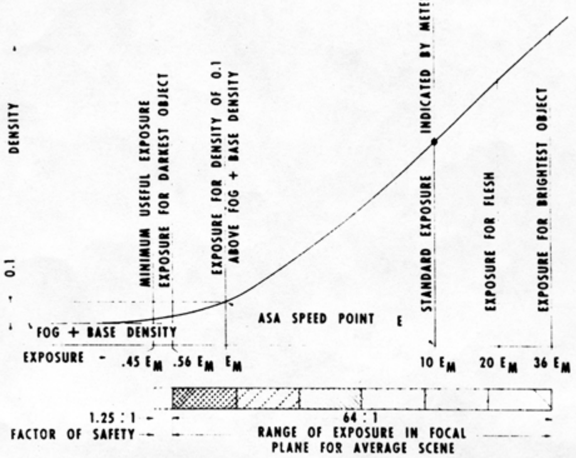

Fig. 4. Characteristic curve of a negative film product showing the relations between exposure meter readings of a typical subject and the ASA speed point of the film.

Performance

The standard[1] gives precise instructions for measuring important performance characteristics of exposure meters so that different laboratories can duplicate results. The method of calibration is described in detail and test methods for determining the accuracy of calibration are outlined. It is prescribed that the accuracy shall be within a cube-root-of-two factor in the center angular half of the scale and within a square-root-of-two factor in the end quarters.

The position or balance error is checked in each of three positions, and the total error is limited to 2% of the calibrated scale length.

The directional system is evaluated in terms of the angle from the axis of the receiver, at which the cutoff is 50%. This is called the specific acceptance angle in the observed direction.

Background Theory

In an appendix of the standard[1] a learned discourse is given by C. N. Nelson on the relations between field luminance, lens and camera characteristics, and illuminance in the focal plane. He compares the exposure meter reading with the sensitometric criterion used in determining speeds. This section is an up-to-date revision of important parts of his article,[11] "Safety Factors in Camera Exposures."

The latest standard on sensitometry of films[4] bases the ASA speed on the exposure required to produce a density of the negative of 0.1 above the fog-plus-base densities, provided other stipulations in the sensitometric procedure are followed. Thus,

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[10] American Standard Method for Determining the Actinity or the Relative Photographic Effectiveness of Illuminants, PH2.3-1956.

[11] C. N. Nelson, *Phot. Sci. Eng.*, **4:** 48 (1960).

in Fig. 4, the designated ASA speed point corresponds to an exposure E_m. An exposure meter designed in accordance with PH2.12–1961[1] will indicate the standard meter exposure[12] E, which for average conditions is equal to $10E_m$. Using Jones and Condit's data for image illuminance,[13] the brightest object in the average scene will produce a film exposure of 36 E_m, and the darkest object, 0.56 E_m. This provides a safety factor[4] of approximately 1.25 compared with 2.5 used prior to 1960.[3] The smaller safety factor is desirable today because the widespread use of exposure meters and the uniformity of commercial processing has largely eliminated a source of uncertainty in the computation of camera exposure. The lesser exposures permit higher shutter speeds or smaller apertures, or better pictures in darker surroundings, and result in more printable negatives of lower graininess.

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[12] Allen Stimson, Chap. 8, *Photography, Its Materials and Processes*, 6th ed. C. B. Neblette, ed., Van Nostrand, New York, 1962.

[13] L. A. Jones and H. R. Condit, *J. Opt. Soc. Am.*, **31**: 651 (1941).