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.

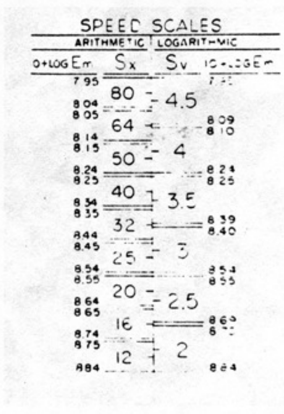

Fig. 1. Graphical conversion chart between typical ASA film speeds and ASA film-speed values showing that the centers of the prescribed[4] $\log_{10}E_m$ intervals do not exactly coincide. The formulas for determining S_x and S_v from sensitometric measurements are $S_x = 0.8/E_m$ and $2^{S_v} = 0.24/E_m$

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

* 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.

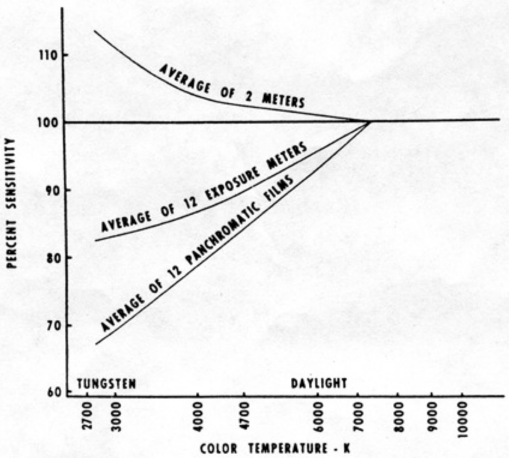

Fig. 2. Change in average spectral sensitivity with color temperature of 12 panchromatic films and 14 exposure meters.

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

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

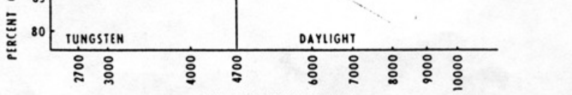

Fig. 3. Meters which are calibrated at 4700°K are more accurate over the entire range than those calibrated at tungsten or daylight color temperatures.

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.

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

---

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.