# Re-evaluation of Factors Affecting Manual or Automatic Control of Camera Exposure

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**The sophistication of exposure controls in cameras has demanded more thorough analysis of the predetermination of exposure. The film exposure level maintained by an automatic control in a camera depends primarily on the film speed but several other variables can manifest substantial influence. The effects of field-luminance distribution and spectral sensitivity, as well as the sensitometric, optical and photometric relations are expressed analytically and the equations for camera exposure are derived. The resulting constant relates the ASA standard film speed to the preferred exposure for an area in an average scene having the average luminance indicated by the meter. This constant, when combined with nine variables which are a function of camera design, meter design and scene structure, provides an equation that is simplified by substituting empirical values for all but three parameters. The exposure constant is expressed as a function of the lens transmission, spectral characteristics of the detector and the discrimination of the field luminance measurement.**

CERTAIN mathematical relationships exist between the camera exposure indicated by the exposure meter and the sensitometric exposure used to determine film speed. The most critical films are the color reversal types. Film speed is reciprocally related to the exposure required to properly reproduce the scene on the photographic film. USA Standard PH2.21–1961 gives the following definition of ASA standard film speed $S_z$ in terms of the sensitometric test exposure:

$$S_z = n/E_m \tag{1}$$

where

$n = 8$

and

$$E_m = \sqrt{E_s E_h}$$

where

$E_h$ = exposure required to produce a density of 0.20 above minimum density.
$E_s$ = exposure required for a density of 2.0 above minimum density or the exposure at the tangent point of the curve with the straight line drawn from $E_h$. The lesser of these exposures is chosen as the value of $E_s$.
$E_m$ = geometric mean of $E_s$ and $E_h$.

Exposures are expressed in meter-candle seconds.

The exposure as determined by the exposure meter is

$$E_g = I_o T \tag{2}$$

where

$T$ = effective time of the shutter in seconds.
$I_o$ = illuminance of the film, by the part of the scene having the luminance measured by the exposure meter, in meter-candelas (lux).

In order for a meter to be used to set a camera to the proper exposure, the following relationship[2] is assumed to exist.

$$(E_g/E_m) = \text{constant} \tag{3}$$

To write this relationship in a usable form, Eq. (1) is substituted in Eq. (3) to obtain:

$$E_g = K_1/S_z \text{ (camera exposure)} \tag{4}$$

This factor $K_1$ has been determined experimentally by psychometrically selecting the "preferred exposure"[3,4] for scene types, light levels, camera and meter types covering the ranges normally encountered. Its value for the purpose of designing exposure controls is dependent upon three variables; viz: the spectral characteristics of the photodetector, the photographic effectiveness of the scene illuminant, and the distribution of luminance levels in the scene as measured by the detector.

### Relationship of Field Luminance and Cell Illuminance

It should be noted that the value for the measured field luminance ($B_a$) is the *arithmetic* average of the illuminance incident on the cell times the cell acceptance[7] given by the equation:

$$B_a = \frac{C_a \int I_c \, da}{a} \tag{5}$$

where

$B_a$ = field luminance as measured by the control system.
$C_a$ = cell acceptance or G-number[5] = the ratio of the luminance of the field measured by the system to the illuminance on the bare cell when both result in the same scale indication.
$a$ = area of scene.
$I_c$ = cell illuminance.

Since the cell illuminance $I_c$ due to any particular part of the field is a function of the directional system, $I_c$ is not a constant, but varies with each part of the scene. Therefore, $I_c$ may be replaced by the following relation.

$$I_c = (B_s/C_s) \tag{6}$$

where

$B_s$ = brightness of any particular point in the scene.
$C_s$ = cell acceptance for light from the same particular point.

Substituting (6) in (5) results in the following equation for the measured field luminance.

$$B_a = \frac{C_a \int \frac{B_s}{C_s} \, da}{a} \tag{7}$$

### Relationship Between Field Luminance Range and Film Sensitometry

The film may be considered to respond *logarithmically* to light as shown by Fig. 1. The preferred exposure is obtained when the maximum luminance represented by the brightest area of interest in the scene and the minimum luminance, represented by the darkest area of interest in the scene are desirably spaced on the density-log exposure curve. It has been found by experience that this spacing occurs when the exposure resulting from the minimum luminance ($B_{\min}$) is located some distance $X$ from the shoulder point, and the exposure resulting from the maximum luminance ($B_{\max}$) occurs the same distance $X$ on the other side of the toe point of the curve.[8] In a color reversal film, the shoulder may be said to occur when the value of the gradient ($\Delta d/\Delta \log E$) is approximately $-1.0$ and, the toe, when the gradient is approximately $-0.5$. Figure 1 illustrates the location of these points for a scene whose luminance range exceeds the linear range of the film.

In Fig. 1, the values of the maximum and minimum luminances ($B_{\max}$ and $B_{\min}$), corresponding to the luminances of the lightest and darkest areas of interest in the scene are shown at the top of the figure, and the effect of flare is to make the ratio of the resultant exposures ($E_{\max}/E_{\min}$) less than the ratio of the corresponding luminance values ($B_{\max}/B_{\min}$). These exposures ($E_{\max}$ and $E_{\min}$) are plotted equal distances $X$ from the toe and shoulder points, respectively.

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This placing correlates well with the preferred exposure.[1]

The value of $B_a$ is chosen as the measured value of scene luminance corresponding to an average scene whose range of luminances of interest is from $B_{\min}$ to $B_{\max}$. For the average scene, the exposure resulting from $B_a$ is reasonably close to $E_m$ for color reversal films. If reference is made to Eq. (7), it can be seen that $B_{\max}$ and $B_{\min}$ are only two points among the many points within the scene which establish the value of $B_a$. For example, if a series of theoretical scenes were composed of only luminances of $B_{\max}$ and $B_{\min}$, the value of $B_a$ for any one of these scenes could range from $B_{\max}$ to $B_{\min}$ depending on the percentage of the scene which has a luminance of $B_{\min}$. This general principle also applies to any scene with a full range of luminance levels, and accounts for the variation of $B_s$ in Eq. (7). The second variable that enters into the determination of $B_a$ in Eq. (7) is the cell acceptance for any particular point. The integration of these two variables over the field results in the net response of the detector to a particular scene. The combination of these two effects (scene luminance distribution and cell directional system) causes a distribution of $B_a$ within the range between $B_{\max}$ and $B_{\min}$ for different scenes. For extreme cases such as severely backlighted scenes, $B_a$ may even exceed $B_{\max}$. Since it is assumed in any meter design that the measured value has some fixed relation to $B_{\max}$ and $B_{\min}$, the effect of differences in the measured value of this relation is to shift the exposure along the density-log exposure curve so that the exposures due to $B_{\max}$ and $B_{\min}$ are no longer symmetrically spaced on opposite sides of the toe and shoulder of the curve, respectively.

### Luminance Distribution Factor

To account for the luminance distribution, a factor $R$ is introduced to denote the deviation caused by variation from average luminance distribution in the scene and is defined as:

$$R = (B_a/B_d) \tag{8}$$

where

$B_d$ = value of measured scene luminance which would correspond to an average scene, i.e., average evaluation of Eq. (7), and is called the desired value of measured scene luminance.

### Spectral Considerations

The spectral response of the film and the detector as well as the spectral quality of the light in the scene, and the light used in calibration and sensitometry affect the meter calibration.[12] If one factor ($r$) is chosen to relate cell response between the scene and calibration, and a second factor ($p$) is used to relate the film response between calibration and the scene, these factors can be combined with $R$ into the constant $K_1$ of Eq. (4). These factors are defined as follows:

$r$ = ratio of luminance of uniform surface source used in calibration to luminance of scene when both sources produce the same response of the meter.

Since the calibration color temperature of 4700K was chosen to minimize the spectral effect of indicated luminance in daylight compared to the indicated luminance at 3200K (tungsten), the spectral response ratio determined between 4700K and 2850K is a reasonable measure of the effect of difference in spectral sensitivity between daylight and the 4700K calibration sources.

$p$ = ratio of the photographic effectiveness (actinity)[6] of scene illuminance to the photographic effectiveness of illuminance used in determining film speed.

It is now possible to define a basic constant $K_1$ which excludes all variables except film speed $S_x$ and camera exposure $E_g$ due to measured field luminance. $K_1'$ is defined as the value of $K_1$ when:

$r = 1.0 \quad p = 1.0 \quad R = 1.0$

Equation (4) may be modified by substituting the above parameters to obtain:

$$E_g = \frac{K_1' r}{p\, S_x\, R} \tag{10}$$

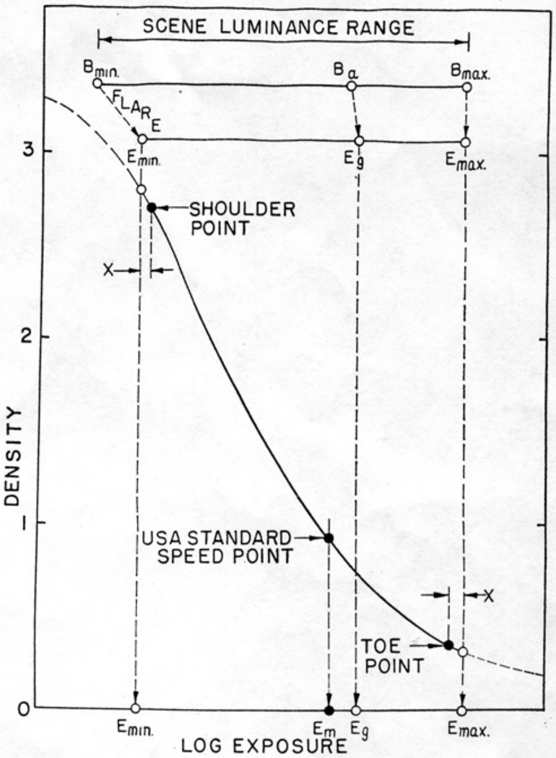

**Fig. 1. Relationship between field luminance range and film sensitometry.**

### Relation Between Basic Exposure Parameters

Equation (10) may then be modified by substituting Eq. (2) for $E_g$ in order to present it in terms of the basic exposure parameters.

$$I_o\, T = \frac{K_1' r}{p\, S_x\, R} \tag{11}$$

The classical camera image illuminance formula[2] is:

$$I_o = \frac{B\,(U - F)^2\, t\, CH\, \mathrm{Cos}^4\,\Theta}{4 \quad A^2 \quad U^2} \tag{12}$$

where:

$B$ = field luminance measured by the meter based on luminance of calibration source, lumens/square meter.
$U$ = distance from lens to object.
$F$ = focal length of lens.
$t$ = lens transmittance.
$C$ = camera flare correction factor.
$H$ = vignetting factor.
$\Theta$ = angle of image point from axis of lens.
$A$ = geometric $f$-number of lens.[10]

Substituting Eq. (12) into Eq. (11) and rearranging in a form compatible with the exposure meter equation:

$$\frac{T S_x\, B}{A^2} = \frac{4\, K_1'\, U^2 r}{(U - F)^2\, t\, CH\, \mathrm{Cos}^4\,\Theta\, p\, R} \tag{13}$$

The exposure meter equation is:

**Table I. Units and Values of Parameters Used in Equation $\frac{A^2}{T} = \frac{BS}{K}$ where $K = \frac{K_o r}{tR}$**

| Symbol | Parameter | Unit | Name | Values of parameters PH2.12-1961 | Values of parameters Proposed revision* |
|---|---|---|---|---|---|
| $A$ | Relative aperture | $f$-number | — | Geometric $f$-number[10] | Geometric $f$-number |
| $T$ | Exposure time | Seconds | — | Actual value | Actual effective value |
| $S$ | Film sensitivity | ASA speed | — | Actual value | Actual value |
| $t$ | Lens transmittance | — | — | .95 | Actual value† |
| $r$ | Spectral response factor | — | — | 1.05 | Actual value† |
| $R$ | Scene luminance distribution factor | — | — | 1.0 | Actual value† |
| $B$ | Field luminance | (see below) | | Actual value | Actual value |
| $K$ | Exposure constant | *Units of Field Luminance* ($B$) | | | |
| | | lm/m$^2$ | apostilb (abs) | 35.8 | 38.7 |
| | | cd/m$^2$ | nit | 11.4 | 12.4 |
| | | lm/ft$^2$ | footlambert (fL) | 3.33 | 3.64 |
| | | cd/ft$^2$ | — | 1.06 | 1.16 |

* The differences from the 1961 values do not represent a change in exposure level for average scenes. The values include different parameters.

† See text for representative values in paragraph on historical background.

$$K = \frac{TS_x B}{A^2} \qquad (14)$$

where

$K$ = exposure meter calibration constant.

Substituting Eq. (13) into Eq. (14), results in an equation containing all the factors influencing the value of the exposure constant.

$$K = \frac{4 K_1' U^2 r}{(U - F)^2 t CH \operatorname{Cos}^4 \Theta p R} \qquad (15)$$

## Historical Background

Since it is obviously very cumbersome to use all of the parameters indicated in Eq. (15), $K$ has been assumed to have a constant value, and a tolerance has been applied to it to cover these effects. In PH2.12–1961 the following assumptions were made:

$U = 80F$  $C = 1.03$
$r = 1.05$  $H = 1.0$
$R = 1.0$  $\Theta = 12°$ $(\operatorname{Cos}^4 \Theta = 0.916)$
$t = .95$  $p = 1.1$

$K$ was taken to be 3.33 when $B$ was in footlamberts. When this value is converted to the basic units of the above equations, it becomes 3.33 × 10.76 = 35.8. This corresponds to a value of 8.2 for the basic constant $K_1'$. Recent information indicates that more representative values are:

$t = .90$  $p = 1.0$  $r = 1.0$

(For selenium cells, $r$ is normally between 1.0 and 1.2 while for cadmium sulfide cells $r$ is usually between 0.8 and 1.0.)

Substituting these values into Eq. (15) gives 3.64 as the value of the exposure constant $K$.

Since there are several variables included in the determination of $K$ which are subject to change, it is desirable to establish a constant $K_o$ which is not likely to be changed greatly as these variables change. Therefore, $K$ is defined as follows:

$$K = \frac{K_o r}{t R} \qquad (16)$$

Using the above values for $K$, $r$, $t$ and $R$, $K_o$ becomes 3.3.

Therefore

$$K = \frac{3.3 r}{t R} \text{ (for 16mm and larger films)} \qquad (17)$$

Since the screen luminance is lower for 8mm films, it has been found that the preferred exposure should be increased by approximately $\frac{1}{3}$ $E_v$. When this factor is taken into account, Eq. (17) becomes:

$$K = \frac{4.15 r}{t R} \text{ (for 8mm and super 8 films)} \qquad (18)$$

## Summary

Equations (17) and (18) provide a better foundation for establishing different values of the constant $K$ used to calibrate meters under a wide variety of applications. In particular, the loss in transmission due to the many elements in a zoom lens, and the effects of highly red or blue sensitive detectors are taken into account. The factor $R$ is more difficult to evaluate. It is a measure of the discrimination of the detector and directional system in measuring the luminance of the important parts of the scene. Its actual value should be determined in meter designs for special applications where unusual scene luminance distributions may be encountered.

## References

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