

A Gaffe in the ISO Standard for Photographic Exposure Meters

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PREFACE

The international standard for photographic exposure meters, ISO 2720-1974, contains a curious situation regarding the exposure meter “calibration constants”, K and C , which seems to the author to have resulted from a gaffe in the standard. This article tells the story.

The matter is essentially inconsequential today, and this article is for historical interest only.

1 INTRODUCTION

As many of my loyal readers know, a little while ago, I wrote a lot to demystify the interrelated matters of film and digital camera speed rating and exposure meter calibration. Doing so required me to review a number of ISO standards in this area.

In ISO 2720-1974, which specifies the performance of free-standing photographic exposure meters, including their “calibration”, I came upon a curious situation regarding the infamous “calibration constants”, K and C . Probing further, I found that this seemed to result from a gaffe apparently committed by the authors of the standard. I’ll describe this situation here. There is a tiny bit of very simple algebra to be seen.

2 BACKGROUND

2.1 Film speed

2.1.1 *Basics*

The “speed” of a certain type of photographic film (or a certain digital camera), refers to its *sensitivity*, by which we mean the inverse of the amount of *photometric exposure* (the product of illuminance on the film or sensor and the time it persists) required to produce a certain benchmark “exposure result” (such as a certain density in the developed film, or a digital output that is a certain fraction of the “full scale” value).

The term originally came from the fact that the greater the sensitivity of the film, then, for a certain scene luminance and f /number of the lens, the shorter will be the needed exposure time—the more sensitive film is “faster” in its response to a given photometric exposure.

Although originally a colloquial term, the term “speed” eventually came to be associated with formal measures of film sensitivity, and I will use that term here.

2.1.2 *Two systems*

The first important industry-standard scheme for assigning a “speed rating” to a film type in the US was developed under the auspices of the American Standards Association (ASA). The rating determined using the ASA test procedures was known as the “ASA speed” of the film, stated this way: “ASA 100”. This was an “arithmetic”¹ (linear) measure: a film with twice the ASA speed required just half the photometric exposure to attain the “benchmark” exposure result.

In Germany, a slightly different film speed rating scheme (based on a different premise of evaluating the film’s response) was standardized by the *Deutsches Institut für Normung* (German Institute for Standardization) (DIN). The rating assigned under their standard was known (in English) as the “DIN index” (often just “DIN”).

It used a logarithmic scale, in which an increase in three units in the speed rating number corresponded almost exactly to a doubling of sensitivity.² Thus, in photographic terms, it worked in “1/3-stop” steps. The DIN indexes were presented this way: “DIN 21°”.

2.1.3 *Harmonization in the ISO standard*

Later, the ASA and DIN systems were harmonized and consolidated in a standard of the International Organization for Standardization (ISO), commonly identified as ISO 6 (now ISO 6-1993).³ The speed rating under this standard was called the “ISO speed”, and was essentially based on almost the same test and analysis procedures as were used for the ASA ratings. (The test and analysis procedures used there did not correspond exactly to those of the DIN standard.)

In the interest of continuity with both these predecessor systems, the ISO standard provided for the speed rating to be presented in both arithmetic and logarithmic forms. The logarithmic form basically followed the scheme used for the DIN speed ratings. An example film

¹ I note that when the word “arithmetic” is used as an adjective (as in this article) the accepted pronunciation is “ar-ith-MET-ic”.

² Precisely, a 10-unit increase in the DIN speed index corresponds to exactly a 10 times increase in sensitivity. We will see more about this later.

³ This standard covers black-and-white negative film, but the relationship between S° and S I cite here is the same in ISO 2240 (covering color reversal film) and ISO 5800 (covering color negative film).

speed rating, giving the rating in both forms, would be "ISO 100/21°".

The two expressions of the ISO speed rating are formally related by this equation:

$$S = 10^{\frac{S^\circ - 1}{10}} \quad (1)$$

where S° is the logarithmic form of the ISO speed and S is the arithmetic form. In the other direction:

$$S^\circ = 1 + 10 \log_{10} S \quad (2)$$

Note that either of these will confirm the exact equivalence between ISO 100 and ISO 21°, an intent of the standard for historical continuity.

Now, a wonderful coincidence is that although a 10-unit increase in S° corresponds to exactly a 10-fold increase in S , a 3 unit change in S° corresponds to **almost** exactly a doubling of S . The discrepancy is only in the ratio 100000:100008 (to six significant figures).

Especially since the published values of S° are always stated only to the nearest integer, these two relationships can be used almost interchangeably in practical work. For the logarithmic form, most photographers thought in terms of the "three steps of S° is one stop" approximation.

2.1.4 *Standard values*

As noted above, the standard for determining the ISO speed of film prescribes reporting the result in terms of two repertoires of "standard values", one for the arithmetic values and one for the logarithmic values. The precise value (of S actually) determined by measurement and analysis is to be "rounded" to a value on each of those repertoires in accordance with a table.

The standard values for the logarithmic form (S°) are just the integer values of S° (21°, 22°, 23°, etc.), from 12° to 36°.

The standard values for the "arithmetic" form (S) are based on a "decade long" base series, shown here as beginning with the starting value ISO 100. The values in parentheses are not part of this decade, but rather the beginning of the next one, and are shown only for continuity.

100, 125, 160, 200, 250, 320, 400, 500, 640, 800, (1000), (1250)

This sequence is then scaled up or down by integral powers of 10 to produce the entire range of standard values. (The table runs only from ISO 8 to ISO 4000.)

2.1.5 *The fate of S°*

The logarithmic form of expression of ISO speed is no longer in official use. Recent ISO standards (such as ISO 12232, covering the speed rating of digital cameras) do not include that form. It no longer usually appears in the marking of film products.

But it does appear in, and plays a large role in, ISO 2720-1974, covering free-standing exposure meters. That standard's odd treatment of that form is the centerpiece of this article.

3 EXPOSURE METERING

A basic *reflected light*⁴ photographic exposure meter measures the average luminance of the scene and from that, along with knowledge of the supposed sensitivity of the film (the user enters the ISO speed rating into the meter), the meter issues an *exposure recommendation*: a "list" of shutter speed-f/number combinations (any of which would have the same effect on exposure) that will, hopefully, provide a good exposure result. The specific linear equation that defines that process is said to define the *calibration* of the meter.

It is important to note that this type of metering is very subjective; there is no unique "correct" equation that can be derived from physical principles alone. As a result, different exposure meter manufacturers each had its own view of exactly what exposure recommendation, given by the meter in response to its observation of the average scene luminance and the photographer's input of the supposed speed of the film involved, would produce exposure results that were most often considered ideal by the photographer.

An additional complication is that the equation should include consideration of the "transmission factor" of the lens, a value not usually known to the photographer and not taken account of by the f-number specification of lens aperture. (These free-standing meters do not measure "through the camera lens" and thus that matter is not automatically accounted for.)

All that notwithstanding, ISO standard 2720-1974 provides a specification for the behavior of such meters. We would expect it to specify a unique equation that would define the meters' exposure

⁴ The discussions here will mostly assume the *reflected light* technique of exposure metering, as contrasted with the *incident light* technique. I will discuss the latter in due time.

recommendation for any combination of observed scene luminance and supposed film speed.

But the situations mentioned just above precluded industry-wide acceptance of a unique equation defining exposure meter behavior.

To accommodate all this, the ISO equation defining the standard meter behavior includes a constant, K , which may be chosen by the meter manufacturer (over a modest range) to implement its “exposure philosophy” while remaining in conformity with the standard. But not exactly.

4 THE CURIOSITY

4.1 The metering equation(s)

ISO 2720-1074 defines the equation that dictates the meter’s response, but it does not do it directly. Rather (for reflected light metering), it gives the formula in this form:

$$K_1 = \frac{LtS}{A^2} \quad (3)$$

where t is the exposure time (shutter speed), in seconds; N is the f-number of the lens; L is the measured scene luminance, in candelas per square meter; S is the ISO speed (arithmetic form); and K_1 is the calibration constant.

But for this equation to most clearly define the meter’s “result”, we can rearrange it thus:

$$\frac{t}{A^2} = \frac{K_1}{LS} \quad (4)$$

The left side can be thought of as the “recommended” *photographic exposure*—the photographic exposure⁵ the meter “recommends” we use for this shot.

Now, in order to accommodate both official forms for the expression of film speed, the authors also provided an alternate form of this equation that uses the ISO speed expressed in logarithmic form (S°).

We might expect that to be done by just taking into account the formal relationship between S° and S in equation 1; that is, by

⁵ *Photographic exposure* is a value that reflects the joint effect on exposure of the aperture (A) and the time of exposure (t). It is this quantity that, in the logarithmic APEX system, is reflected by the value E_v .

substituting equation 1 into equation 4, which would give (rearranged as before):

$$\frac{t}{N^2} = \frac{K_1}{L \cdot 10^{\frac{S^\circ-1}{10}}} \quad (5)$$

But instead the standard gives this for that alternate equation (rearranged in the same way):

$$\frac{t}{N^2} = \frac{K_2}{L \cdot 10^{\frac{S^\circ}{10}}} \quad (6)$$

We can see that for the same values of L and S, and for the same value of K, the results of these two equations (t/N^2) would differ exactly by the ratio $10^{0.1}$ (about 1.26)

Now the standard goes on to say:

$$K_2 = 10^{0.1} K_1 \text{ or } K_2 = 1.26 K_1 \quad (7)$$

That being the case, then for any given values of L and S, and a given choice of either K_1 or K_2 , both forms of the equation will give the same result (as we might well expect).

5 THE STORY

5.1 The curiosity

Why might equation 6 have been chosen with the need to use a different value of K than in equation 4 for a given "exposure philosophy"? There seems to me no reason for that.

It is my theory that this came about in essentially the following way.

5.2 The "gaffe"

It is my theory that this came from the authors of the standard believing (erroneously) that the underlying relationship between S and S° was:

$$S = 10^{\frac{S^\circ}{10}} \quad (8)$$

Substituting this into equation 4 would give equation 6, as presented in the standard.

It is this that I consider to be the "gaffe" in the standard, as reflected in the title of this article.

5.3 The discrepancy

Presumably the developers of the standard tested their logarithmic form equation against their arithmetic form for such well-known exact equivalents as ISO 100 and ISO 21⁰, and found that, not surprisingly, they gave inconsistent values of t/N^2 for any given K . The discrepancy would have been, as we could see by comparison of the two equations above, precisely in the ratio $10^{0.1}$ (about 1.26).

5.4 The “plug”

So to get around this, I believe, the authors said that the two forms of the equation needed different values of K , which they called K_1 for the one suitable for the arithmetic form equation and K_2 for that suitable for the logarithmic form. This in effect required the relationship between the two K s to be:

$$K_2 = 10^{0.1} K_1 \quad (9)$$

or very nearly:

$$K_2 = 1.26 K_1 \quad (10)$$

as is in fact defined in the standard.

This difference is just what is needed to “plug” the discrepancy in result resulting from what I consider to be the incorrect relationship between the two forms of the equation.

5.5 Allowable ranges of K_1 and K^2

Having thus papered over their basic gaffe, they then stated that the acceptable values of “ K ” were:

- For K_1 (for use with ISO speed as S): 10.6 to 13.4 ⁶
- For K_2 (for use with ISO speed as S^0): 13.1 to 16.9

Again, this is essentially consistent with the ratio between the “two kinds of K ” I have discussed.

6 FOR INCIDENT LIGHT EXPOSURE METERS

I have so far discussed the situation for “reflected light” exposure meters, which work by observing the average luminance of the scene.

⁶ These values of K are appropriate when the calibration equation uses luminance, L , in the SI unit *candelas per square meter*. You will often see other numerical values of K , intended for use in calibration equations where different units (such as the foot-lambert) are used for luminance.

An alternative meter approach, with various benefits, has the meter observe the *illuminance* upon the scene. This is spoken of as “incident light” exposure metering.

For much the same reasons for reflected light metering, there is no equation governing the response of the meter that is inherently “correct” and derivable from physical principles.

Thus, comparable to the situation for reflected light metering, the equations include a constant C , whose value can be chosen (over a modest range specified in the standard) by the meter manufacturer to implement its “exposure philosophy” for this type of metering.

And just as for reflected light meters, the equation in ISO 2720-1974 that defines the behavior of incident light exposure meters is given in two forms, one working with the film presumed ISO speed to be input in the arithmetic form and the other with the speed to be input in the logarithmic form.

And, wholly parallel to the situation for reflected light meters, the two forms of the equation have different values of C , called C_1 and C_2 . The ratio between C_2 and C_1 is fixed, equal to $10^{0.1}$ (about 1.26:1). And the story there, as I see it, is entirely parallel to that for K in the reflected metering case.

7 SUMMARY

If, as is defined in the standard, we use $K_2 = 10^{0.1}K_1$, then equations 4 and 6 become exactly equivalent. So what then is the motivation for constructing equation 6 so that it requires a different value of K than equation 4?

I think there is no legitimate reason why different values of K (or C) would be appropriate depending on whether the calculations are based on the arithmetic or logarithmic expressions of the ISO speed of the film. We would expect that a meter manufacturer would choose a value of K (or C) based on its “exposure philosophy”, and this value would be part of either form of the equation.

In any case, I consider the curious situation in ISO 2720-1974 as almost certainly resulting from a “gaffe” by the authors of the standard.

8 THE APPENDIX

In the body of this article I presented the various “meter calibration” equations without noting the units of S (or S°) and K .

But for the truly fastidious reader, I will look into that in Appendix A.

Appendix A On the units of S and K

In the body of this article I presented the various “meter calibration” equations without noting the units of S (or S°) and K.

But for the truly fastidious reader, I will look into that here.

ISO 6 defines S thus:

$$S = \frac{0.80}{H_m} \quad (11)$$

where H_m is a certain *photometric exposure* determined, by testing, as causing a certain prescribed exposure result on the film of interest (we need not here be concerned with the details of that).

In the SI (International System of Units), the unit of photometric exposure is the lux-second ($\text{lx}\cdot\text{s}$).

That being the case, from equation 11 the unit of S should be $\text{lx}^{-1}\text{s}^{-1}$. But in the algebra used in the standard, for the sake of simplicity, S is treated as dimensionless and unitless, and I will follow that conceit here.

Now in ISO-2720-1974, the meter calibration equation (for use with the film speed being in the arithmetic form, symbolized S) is:

$$K_1 = \frac{LtS}{A^2} \quad (12)$$

The unit of L is the candela per square meter ($\text{cd}\cdot\text{m}^{-2}$). The unit of t is the second (s). A is a dimensionless number. Recall that we treat S as dimensionless and unitless.

If we put all that together, we find that the unit of K_1 must be:

$\text{cd}\cdot\text{s}\cdot\text{m}^{-2}$ (candela-seconds per square meter).

Now ISO 6 also defines the logarithmic expression of film speed, S° , as:

$$S^\circ = 1 + 10\log_{10} S \quad (13)$$

That is by the way only workable if S is dimensionless. Since a logarithm is a dimensionless, unitless number (as is “1”), S° is truly dimensionless and unitless.

Now the corresponding equation in ISO 2729-1974 is:

$$K_2 = \frac{Lt \cdot 10^{\frac{S^\circ}{10}}}{A^2} \quad (14)$$

That would seem to suggest that the unit of K_1 must be:

$\text{cd} \cdot \text{s} \cdot \text{m}^{-2}$ (candela-seconds per square meter).

just as for K_1 .

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