A Gaffe in the ISO Standard for Photographic Exposure Meters

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ABSTRACT

The international standard for photographic exposure meters, ISO 2720-1974, contains an inexplicable gaffe, leading to a curious situation regarding the exposure meter calibration constants, *K* and *C*. This article tells the story.

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 (this is, by the way, at this writing, the latest version), which specifies the performance of free-standing photographic exposure meters, including their "calibration", I came upon a curious inconsistency regarding the infamous "calibration constants", *K* and *C*. Probing further, I found that this resulted from a gaffe apparently committed by the authors of the standard. I'll describe this situation here. Of course, it will take some algebra (like all good stories).

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 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.

Although originally a colloquial term, the term "speed" eventually came to be associated with formal measures of film sensitivity.

2.1.2 *Two systems*

The first standardized scheme for assigning a "speed rating" to a film type in the US was done 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: "ISO 100". This was an "arithmetic" 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. Thus, in photographic terms, it worked in "1/3-stop" steps. The DIN indexes were presented this way: "DIN 21°".

2.1.3 *Harmonization into the ISO standards*

Later, the ASA and DIN systems were harmonized and consolidated in standards of the International Organization for Standardization (ISO). The speed ratings under those standards was called the "ISO speed", and were essentially based on almost the same definitions as the ASA ratings. (They did not correspond exactly to the DIN ratings.)

In the interest of continuity, these ISO standards provided for the rating to be presented in both linear and logarithmic forms. The logarithmic form basically followed the DIN scheme. An example film rating would be: "ISO 100/21°".

The two expressions of the ISO speed rating are formally related by this equation (as had been the case with the DIN system):

$$S = 10^{\frac{S^\circ - 1}{10}} \tag{1}$$

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

$$S^\circ = 10 \log S + 1 \tag{2}$$

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

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 is one stop" approximation.

2.1.4 *Standard values*

As noted above, the standards for determining the ISO speed of film provide for reporting the result in terms of two repertoires of "standard values", one in an "arithmetic" scale and one on a logarithmic scale. The precise value determined by measurement is to be "rounded" to a value on each of those scales in accordance with a table.

The standard values when expressed in "logarithmic" form (S°) are just the integer values of S° (21°, 22°, 23°, etc.).

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 powers of 10 to produce the entire range of standard values. (The actual 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 does appears in, and plays a large role in, the current issue of ISO 2720 (issued in 1974), covering free standing exposure meters. That standard's peculiar treatment of this factor is the centerpiece of this article.

3. Exposure metering

A basic reflected light 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 governs that process is said to define the *calibration* of the meter.

ISO standard 2720 provides specifications for such meters, including a standard exposure equation. Well, it's not quite standard. The exposure equation defining the meter's behavior includes a constant, *K*, which may be chosen (by the meter manufacturer) over a modest range while remaining in conformity with the standard. This flexibility caters to:

- The manufacturer's view of what lens transmission factor should be anticipated (these meters do not measure "through the lens" and thus that matter is not automatically accounted for)
- The manufacturer's view of the optimal "exposure strategy" (since this type of metering is very pragmatic, no single best approach is derivable from physical principles alone).

4. THE "GAFFE"

4.1 The reflected light metering equation

In ISO 2720, the basic calibration equation for reflected light exposure meters is given essentially as this:

$$\frac{t}{N^2} = \frac{K}{LS} \qquad (3)$$

where t is the shutter speed, in seconds; N is the f-number of the lens; L is the measured scene luminance; S is the ISO sensitivity (linear form); and K is the calibration constant. The left side can be thought of as the "exposure recommendation". (It is this quantity that is expressed, in logarithmic form, as *exposure value*, Ev, under the APEX system.)

Now, in order to accommodate all practices, the authors also restated this equation to use the ISO speed expressed in the logarithmic form ($S°$). That would be easily (and correctly) done by substituting equation 1 into equation 3, giving:

$$\frac{t}{N^2} = \frac{K}{L \bullet 10^{\frac{S°-1}{10}}} \qquad (4)$$

But it appears that the authors believed (erroneously) that the underlying relationship between S and $S°$ was:

$$S = 10^{\frac{S°}{10}} \qquad (5)$$

Thus, when they substituted, they got:

$$\frac{t}{N^2} = \frac{K}{10^{\frac{S^\circ}{10}}} \qquad (6)$$

Presumably they tested their logarithmic form equation against their linear form for such well-known exact equivalents as ISO 100 and ISO 21°, and found that it gave inconsistent values of t/N^2 for any given K. (No kidding!) The discrepancy was, as we could see by comparison of the two equations above, precisely in the ratio $10^{\frac{1}{10}}$.

So to get around this, they said that the two equations needed different kinds of K, which they called K_1 for the one suitable for the linear form equation and K_2 for the logarithmic form. Then they defined the relationship between the two Ks as:

$$K_2 = 1.26 K_1 \qquad (7)$$

This factor is $10^{\frac{1}{10}}$ (rounded to 2 decimal places), just what is needed to "plug" the gaffe.

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 [1]
- For K_2 (for use with ISO speed as S°): 13.1 to 16.9

Of course there is no legitimate reason why different values of K would be appropriate depending on whether the calculations are made with the linear or logarithmic expressions of ISO speed.

Imagine that we have a photographic exposure meter in which the "exposure calculator" (the circular slide rule used to work the exposure equation) allowed the film sensitivity to be set in either S or S° form (usually in one of two little windows that allowed views of scales on the S and S° basis). Once the "film sensitivity" dial was set (regardless of how), it is absurd to think that the calculator should practice one of two different exposure equations depending on which way the user had set that dial. (More on this in section 4.3 of this article.)

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[1] These values of K are in units of candela-seconds (rarely mentioned), as is appropriate when the calibration equation uses luminance in candelas, as in all the ISO documents. You will often see other numerical values of K, which are in other units, for use in calibration equations where different units (such as foot-lamberts) are used for luminance.

Ironically, the standard, in another area, includes a table giving the (correct) relationship between film sensitivities in S and S° forms, and this table is referenced in the passage where the incorrect relationship is used.

Although the table, as prescribed by the original ISO standards for film speed, gives S° rounded to integer values, and S rounded to a value in the list of "preferred ISO speeds", it clearly shows that the relationship of equation 5 does not work out.

4.2 The incident light metering equation

The standard also covers the calibration of "incident light" exposure meters. This also involves a calibration constant, C. The very same gaffe is committed, leading to the notion that there are two kinds of C: C_1 and C_2, each with its own range of permissible values.

4.3 Effect on exposure meter design

So, which range of "K" is "correct"? The calibration adopted by a manufacturer is actually arbitrary, and the ranges specified by the standard are chosen based more on the realities of the era than any definitive mathematical determination. So we cannot really say that any range is "correct".

Given the nature of the "gaffe", one would be tempted to assume that the "K_1" range (based on S) might be the more appropriate. But not knowing the history of the work, we cannot be sure.

How might the manufacturer of an exposure meter, attempting to hew to the guidelines of this standard (which is, after all, its supposed purpose in life), proceed? In the "analog" meters, with a dial to set the film sensitivity, they ordinarily have two scales, one for S and one for S° (often on opposite sides of the dial, or with "stacked" labeling).

Invariably, they are lined up to reflect the accepted equivalence between the two scales: the settings for ISO 21° and ISO 100 are the same, as are the settings for ISO 24° and ISO 200. We see this arrangement on the figure above, which shows the exposure calculator dials on a Sekonic Model L-398 exposure meter.

In this case, the setting windows for the two forms are labeled ASA and DIN respectively, as this was before the harmonization of those two definitions for film speed (with their different approaches to expressing the value) into the ISO standards for film speed (with two different form of expression).[2]

Of course there is no opportunity for the meter to issue a different exposure recommendation depending on which of those scales was used to set the exposure index. The meter has no idea which scale was used.

This well illuminates the fact that having different recommended values of "K" for operation with the linear and logarithmic expressions of ISO speed makes no sense, and could not even be followed in practice.

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[2] In fact, when the ISO standard did emerge, there was little real point in using the S° form, and so the next model of this meter only had provision for setting the film sensitivity in terms of the linear ISO speed (S).