APEX—The Additive System of Photographic Exposure

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Issue 7
August 4, 2007

ABSTRACT

The Additive System of Photographic Exposure (APEX) provides for stating several factors involved in photographic exposure in logarithmic form. In this way, calculation of the "proper exposure" for a given situation may be done manually using only addition. Although the importance of that has largely faded since the time the system was developed, the scheme is still widely used in technical work relating to photographic exposure, especially the quantity "exposure value" (E_V). This article explains the APEX system, and gives cautions about irregularities in its usage that are often encountered.

INTRODUCTION

APEX— The Additive System of Photographic Exposure

The Additive System of Photographic Exposure (APEX) provides for stating several factors involved in photographic exposure in logarithmic form. In this way, calculation of the "proper exposure" for a given situation may be done manually using only simple addition.

This convenience was a principal motivation for the development of the system (first completely promulgated in 1961), which took place when the use of photographic light meters was not universal and cameras with internal exposure metering systems were almost nonexistent.

Although changes in practice and technology have diminished the importance of this objective, it is today still common and convenient to express certain exposure-related factors in APEX terms.

The factors represented in this system are:

- Exposure time (shutter speed)
- Aperture (in the f/number sense)
- Exposure (the joint effect of the two above factors)
- ISO speed (film or digital imager "sensitivity")
- Metered scene luminance (brightness)
- Metered incident light illuminance (illumination)

Base 2 logarithms

The APEX definitions of exposure factors utilize "base 2" logarithms. As a result, a change of one unit in an APEX value corresponds to a 2:1 change in the actual factor, a change that photographers call "one stop".[1] Thus, experienced photographers can readily appreciate the significance of changes in factors expressed in APEX terms.

The base 2 logarithm of a number can be calculated by taking the common (base 10) logarithm ("log") of the number and dividing that by the common logarithm of 2 (which is approximately 0.3010).

"Correct exposure"

There is of course no unique way to calculate the appropriate exposure for a particular photograph, especially if we consider the diverse artistic and technical objectives that may be involved and the range of properties that the scene might exhibit.

By "correct exposure" in this article we mean the exposure that would be arbitrarily dictated by a widely-accepted mathematical relationship, the exposure we would expect to have "recommended" by a properly-performing photographic exposure meter.

Terminology and notation

The various exposure factors in their APEX forms are all spoken of as "values", as for example "aperture value". The word "value" is thus an arbitrary cue that the APEX (logarithmic) form of the factor is meant.

Formally, the symbols for the APEX values all have a "v" subscript, as A_v (subscript lower-case "V"). In documents where subscripts cannot be rendered, the symbols are presented this way: Av (lower-case "V"). And in fact, we will use this convention here, since it is what is most often seen.

We will be speaking of two distinct factors having the unfortunately-similar formal names *luminance* and *illuminance*. To avoid confusion between these terms, we will often state, parenthetically, the less

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[1] The term most directly relates to *aperture*. It goes back to the time when cameras were first equipped for control of aperture. Commonly, a metal plate carrying a number of holes of different diameter passed through a transverse slot in the lens barrel. It was said to "stop down" the lens aperture, and the different holes were said to be "stops". The photographer moved the plate to put into place the appropriate stop for a particular exposure. Commonly, successive holes had areas that differed by 2:1. Thus a 2:1 change in aperture area came to be known as a "one stop" change.

precise but more recognizable terms *brightness* and *illumination*, respectively. (Brightness is the term used in APEX anyway.)

It is customary for the tables showing the APEX forms of the various factors to cover the range of integer values from 0 through 10 or so. Values outside that range may of course occur. Negative and fractional values are also perfectly meaningful.

THE APEX EXPOSURE FACTORS

The numbers

The numbers stated for each value step are the mathematically-ideal ones under the formal definition of the value. Where another number is shown in square brackets, it is the one customarily used in APEX tables. It is a number near the ideal one but chosen from the numbers usually available for that factor in a camera's settings, or the precise number rounded to an integer.

Reference materials

See Appendix A for the underlying equations defining all APEX values. Also attached is a sheet repeating all the value tables for convenient reference.

Aperture value (Av)

Aperture value (Av) represents the aperture in its "relative aperture" (f/number), form (*e.g.*, f/3.5). A larger Av represents a smaller aperture (larger f/number) and thus less exposure.

The table shows integer values of A_v. As is customary, the f/numbers are shown to two significant figures.

Aperture value (Av)	Aperture
0	f/1.0
1	f/1.4
2	f/2.0
3	f/2.8
4	f/4.0
5	f/5.6
6	f/8.0
7	f/11
8	f/16
9	f/22
10	f/32

Time value (Tv)

Time value (Tv) represents the exposure time (shutter speed) in seconds. A larger Tv represents a "faster" shutter speed and thus less exposure (it works in the same direction as the denominator of shutter speed).

Time value (Tv)	Exposure time
0	1
1	1/2
2	1/4
3	1/8
4	1/16 [1/15]
5	1/32 [1/30]
6	1/64 [1/60]
7	1/128 (1/125]
8	1/256 (1/250)
9	1/512 [1/500]
10	1/1024 [1/1000]

The numbers in square brackets are the precise numbers rounded to a number in the standard series of shutter speeds.

Speed value (Sv)

Speed value (Sv) reflects the sensitivity of the film or equivalent, expressed as an "ISO speed". A larger Sv represents a greater sensitivity (speed).

Speed value (Sv)	Sensitivity (ISO speed)
0	3.125 [3]
1	6.25 [6]
2	12.5 [12]
3	25
4	50
5	100
6	200
7	400
8	800
9	1600
10	3200

(Actually, in the original definition of APEX, the precise speeds at the different Sv points were "1/12 stop" higher (1.06x) than those shown here, for a peculiar reason relating to the origin of the underlying definitions. This curiosity has basically been discarded in current practice, and we will not reflect it here.)

Brightness value (Bv)

Brightness value (Bv) indicates the metered luminance (brightness) of the scene. A larger Bv represents greater scene luminance. The table shows the values of Bv on the basis of two different luminance units.

Brightness value (Bv)	Scene luminance (brightness)	
	foot-lamberts	candelas/m^2
0	1	3.4
1	2	6.9
2	4	14
3	8	27
4	16	55
5	32	109
6	64	219
7	128	439
8	256	877
9	512	1754
10	1024	3508

Note: formally, the scaling of this table should depend on the value of the "reflected light exposure meter calibration constant", usually indicated as *K*. This is a value that is chosen by the manufacturer of an exposure meter to reflect its view of what constitutes "correct exposure". The table above is predicated on a *K* of 11.4 (for luminance in candelas/m^2). We'll hear more about this shortly.

Incident light value (Iv)

Incident light value (Iv) indicates the (metered) illuminance (illumination) on the scene. A larger incident light value represents a greater illuminance. The table shows the values of Iv on the basis of two different units for illuminance.

Incident light value (Iv)	Illuminance (illumination)	
	foot-candles	lux
0	6.25 [6]	67
1	12.5 [12]	135
2	25	269
3	50	538
4	100	1076
5	200	2152
6	400	4304
7	800	8608
8	1600	17260
9	3200	34432
10	6400	68864

Note: formally the scaling of this table should depend on the value of the "incident light exposure meter calibration constant", usually indicated as *C*. This is a value that is chosen by the manufacturer of an exposure meter to reflect their view of what constitutes "correct exposure". The table above is predicated on a *C* of 224 (for illuminance in lux). We'll hear more about this shortly.

THE EXPOSURE EQUATION

Reflected light metering

The basic equation for determining the "correct exposure" (in the sense discussed earlier), based on "reflected light metering" (that is, based on measurement of the average luminance of the scene, is:

$$\frac{t}{N^2} = \frac{K}{L_s S} \qquad (1)$$

where t is the exposure time in seconds; N is the aperture, as an f/number; L_s is the metered average scene luminance (brightness), in some appropriate unit; S is the sensitivity (speed) of the film or digital imager, as an ISO speed number; and K is an arbitrary constant, which accommodates the units involved and reflects a particular manufacturer's concept of "proper exposure". K is often spoken of as the "reflected light exposure meter calibration constant".

When we use APEX values, this becomes:

$$\mathrm{Av} + \mathrm{Tv} = \mathrm{Bv} + \mathrm{Sv} \qquad (2)$$

We see how the use of the APEX "logarithmic" values simplifies the work of making a calculation of exposure factors.

Note that no constant is visible. The value of K has been "built in" to the definition of the reference point for the scale for Bv. The value of K (for L in candelas/m^2) was originally 11.4, selected from the range recommended by the standard for exposure meters at the time.[2] Today a value of about 12.5 is widely used by manufacturers. (This change represents a very small increase in exposure.) Nevertheless, the table above, based on the original 11.4 value, is most commonly cited for general reference.

Exposure value (Ev)

The typical "reflected light" photographic exposure meter (the most common form) measures (average) scene luminance (B_V, as an APEX value). This finding goes into some type of exposure calculator, typically a circular "slide rule", into which the photographer has set the sensitivity of the film or imager (as an ISO speed). The calculator then presents a scale of aperture versus shutter speed, any matching

[2] The particular value was chosen from that range so that the table (for luminance in foot-lamberts, as was common usage at the time) came out "tidy".

pair of which produce the exposure the meter "recommends" for the combination of scene brightness and film sensitivity.[3] The photographer makes a choice of a pair in order to suit the particular photographic task. The state of this calculator constitutes a value of Av + Tv, a number that we may say defines "exposure".[4]

To facilitate discussions of this, APEX defines a composite value, Exposure Value (Ev), as:

$$Ev = Av + Tv \tag{3}$$

A larger value of Ev represents less exposure.

We can then rewrite the fundamental reflected-light metering exposure equation as:

$$Ev = Bv + Sv \tag{4}$$

Many light meters will in fact report their recommended exposure in terms of Ev as well as in aperture-shutter speed pairs.

Incident light metering

In one approach to determining the appropriate exposure for a photographic scene (one which avoids dependence on an assumption of average scene reflectance), we measure the illuminance (illumination) on the scene (with an "incident light" exposure meter) and from it determine an appropriate exposure.[5]

Some incident light meters (all too few, unfortunately) report their luminance reading in terms of the APEX Incident Light Value, Iv.

The (average) brightness of a scene (in foot-lamberts) is the product of the illumination (in foot-candles) and the (average) scene reflectance (which would be 1.0 for a "diffuse" surface which reflected all the incident light, in a certain ideal way).

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[3] This approach is based on an assumption of (a) average scene reflectance and (b) the range of reflectance from the darkest to the lightest object in the scene.

[4] Note that this meaning of "exposure" does not relate to the amount of light hitting the film (although this is of course influenced by the exposure)—it merely describes the impact of a pair of camera parameters. This is a different, equally-legitimate meaning of the term "exposure" than that found in discussions of film exposure curves (such as the "D log E" curve), where *exposure* means the total amount of "light energy" per unit area of the film (illuminance times time) as the result of the exposure.

[5] Still based on an assumption about the range of scene reflectance, just no longer on an assumption about average scene reflectance.

The fundamental equation for "correct" exposure based on incident illuminance is:

$$\frac{t}{N^2} = \frac{C}{E_i S} \qquad (5)$$

where t is the exposure time in seconds; N is the aperture, as an F-number; E_i is the average illuminance incident on the scene (in some appropriate unit); S is the speed (sensitivity) of the film, as an ISO number; and C is the arbitrary constant spoken of in connection with the table.

The value of C originally suggested by the standard for exposure meters was a range centered about 241 (for illuminance in lux), but for APEX purposes a value of 224 was chosen.[6] The current commonly-used value of C is 250. However, for general reference work the table above (with a C of 224) is usually cited.

The equivalent in APEX terms becomes:

$$\mathrm{Av} + \mathrm{Tv} = \mathrm{Iv} + \mathrm{Sv} \qquad (6)$$

or

$$\mathrm{Ev} = \mathrm{Iv} + \mathrm{Sv} \qquad (7)$$

If we compare the equations for reflected and incident light metering, using the original suggested values for K and C, we might conclude that they jointly imply that the reflective light meter operates on the basis of an assumed average scene reflectance of about 16%. But this matter is not that simple (owing to such matters as the inclusion of "overexposure headroom" in the reflected light metering strategy but not the incident light strategy).

In any case, interpreting this relationship, and relating it to the "12.8%" and "18%" average scene reflectance values often mentioned in the theory of exposure metering standards, is a complex issue beyond the scope of this article.

ODDS AND ENDS

Sunny 16

Experienced photographers often use a "rule of thumb", sometimes referred to as the "sunny 16" rule, to estimate outdoor exposure when no meter is available. This rule suggests, for exposure on a scene

[6] Again so that the table (for luminance in foot-candles) came out "tidy".

illuminated by full sunlight[7], an aperture of f/16 and a shutter speed of one over the ISO speed number of the film (such as f/16 and 1/200 sec for ISO 200 film).

If we work backwards through the APEX exposure equation, we find that this rule is essentially predicated on a scene illumination of about Iv 9.6, about 5000 foot-candles (or about 50,000 lux).

Exposure compensation – the "Ev" setting

This topic is not really part of APEX, but it's a matter that is usually described in terms of an APEX value, so we will lightly treat it here.

Many cameras have provision for forcing the camera to use an exposure that is greater or less, by a user-determined amount, than the exposure the metering system would normally choose. This is often useful for cases in which certain properties of the scene would frustrate the metering system's ability to secure the effect desired by the photographer.

An example is a scene where a large percentage of the image area has a very low brightness, or a scene where a large percentage of the image area has a very high brightness. The camera's metering system, left to its own devices, would call for an exposure that will cause these majority areas to be recorded as a nice middle gray for either scene.

The amount of this "exposure compensation" is often adjustable in steps of 1/2 or 1/3 "stop", often up to a maximum of 2 or 3 stops in either direction.

In effect, the use of this feature makes the basic exposure equation followed by the camera become:

$$Av + Tv = Bv + Sv - Cv \qquad (8)$$

where Cv is the exposure compensation setting in APEX-like units. (Note that Cv is not a term defined in APEX—it is my own notation.)

Thus, a "plus" setting of the exposure compensation control increases the exposure given for any given measured scene brightness (smaller values of Av and/or Tv produce greater exposure.)

The amount of exposure compensation is quite properly described in the same "units" as Ev. As a result, the exposure compensation setting is often called the "Ev setting". This is not a good description.

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[7] At some time of day, during some season, at some latitude—this isn't scientific, just handy!

It in fact does not set Ev, but rather forces Ev to be different from what would ordinarily be put into effect by the metering system. “Ev offset” is a better description. In technical contexts, exposure compensation is often called “exposure bias”.

Scene brightness in Ev?

We often see, especially in camera specifications, a factor that seems to be scene luminance (brightness) described in terms of an Ev number. Such a factor might be, for example, the lowest scene luminance for which the exposure metering system of the camera is able to function reliably.

This usage is unfortunate and technically inappropriate, as Ev is a measure of exposure, not luminance. There is a perfectly good APEX quantity for luminance: Bv. I suspect the motive for the practice is that many photographic enthusiasts have heard of Ev but not Bv.

Of course, if we know the Ev that a camera’s metering system recommends for a scene, we can in fact equate that to scene luminance if we also know the ISO sensitivity (Sv) in effect.[8]

It turns out that, when a manufacturer states some critical scene luminance in terms of “Ev”, and nothing to the contrary is stated, it is most often based on the assumption that the ISO sensitivity is ISO 100 (Sv 5). (Canon, for example, so states explicitly.) In other words, the luminance being described is that which, if the ISO sensitivity of the camera were ISO 100, would lead to the camera arranging for an exposure of the stated Ev.

The relationship between this irregular description of scene luminance in “Ev” and the description of that luminance in the proper value, Bv, is as follows:

$$Bv = Ev' - 5 \qquad (9)$$

where Ev′ is the so-called “Ev” used to describe the luminance.

I discourage this usage.

Ev “units” for everything

There is another practice which is not technically appropriate but doesn’t actually give “wrong” information. Sometimes a camera manufacturer, stating the range of aperture available on a certain model, will say, for example: “f/2.8 through f/11, in 1/3 Ev steps”. Of course, aperture is defined in terms of Av, not Ev. And APEX values

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[8] And, to be precise, the metering constant, K, employed in the calibration of that camera.

are dimensionless and unitless, so a change in any one of them in the mentioned increment is just in steps of "1/3" (we might say, "1/3 unit").

But, in defense of the practice, a 1/3 unit change in Av does give a 1/3 unit change in Ev. Perhaps the motive for the practice is that many photographic enthusiasts have heard of Ev but not Av.

Still, a better practice would be so say, if we feel we must state a "unit", "f/2.8 through f/11, in 1/3 stop steps". (*Stop* is almost always acceptable in photographic photometry as the "unit" of a change in a factor affecting, or relating to, exposure.)

Another caution

The author has seen a number of monographs and charts explaining APEX in which the concepts of *luminance* (brightness) and *illuminance* (illumination) were confused. Sometimes there will be a perfectly good Iv table labeled "Bv", or vice-versa. Sometimes discussions of *luminance* will mention the units that are applicable to *illuminance*, or vice-versa. Please be cautious before undertaking any strenuous intellectual exercise in this area where there is a risk of such misinformation.

APEX notation for non-APEX quantities

Sometimes we will see it stated that in a particular situation, "Av was f/5.6" or "Tv was 1/60 sec". In fact, these APEX designations should only be used for the expression of these exposure factors in APEX (logarithmic) form.

A related problem occurs in connection with Canon cameras. Many of these have "aperture priority" and "shutter priority" exposure modes, in which the mentioned exposure factor is set directly by the user and the mating one is then set by the metering system to achieve the exposure (Ev) the system thinks appropriate. The two modes are labeled "Av" and "Tv", respectively. Yet the factors are set not in terms of APEX values but in conventional form ("f/3.5" or "1/125 sec"). What gives here?

Here's my guess: initially, on the Canon models offering these modes, the factors were indeed set in terms of the APEX units (in vogue at the time), and the modes were named correspondingly. Later, when awareness of APEX among photographers faded (or actually, didn't really flourish), Canon reverted to labeling the scales for setting aperture and shutter speed in the traditional units, but opted (for continuity) to retain the Av and Tv designations for the modes. Just a guess.

LIGHT VALUE, LV

Sometimes we encounter what sounds like a related concept involving the quantity *light value* (LV). What's with that?

Today we mostly encounter this term as used by some authors as a replacement for "Ev" to unambiguously designate a logarithmic measure of scene luminance (the "Ev assuming ISO 100" convention). It's certainly better than calling the measure "Ev", but there is no need for this coinage, as a perfectly appropriate logarithmic measure of scene luminance exists: Bv.

There was an earlier use of the term "light value" (again symbolized as "LV"). On the first Polaroid Land camera, the Model 95, and the first "smaller film" Land camera, the Model 80, exposure was set with a single dial marked in terms of a number Polaroid called *light value*, symbolized LV. This is a logarithmic measure of exposure conceptually identical to exposure value (Ev) but with the scale starting at a different point (such that LV=Ev -9).

The Polaroid exposure meter was set for the sensitivity (ISO speed) of the film in use, and then issued its exposure "recommendation" as an LV number. The user set this on the camera.

There was no provision for setting shutter speed and aperture separately. Each LV setting called up a preordained combination of shutter speed and aperture (an early example of "programmed exposure).

As the APEX system neared completion, Polaroid switched (in the successor models 95B and 80A) to the use of an Ev scale for exposure setting. This allowed consistency with other APEX-aware exposure meters, and the later Polaroid meters had Ev scales as well as LV scales (Ev scales only after a while).

Light value (LV), in either sense, is not part of APEX.

ORIGIN AND STATUS

The APEX system of notation was first promulgated by American Standard ASA PH2.12-1961, *American Standard General-Purpose Photographic Exposure Meters (Photoelectric Type)*.

That standard was superseded by American National Standard ANSI PH3.49-1971, *American National Standard for general-purpose photographic exposure meters (photoelectric type)*. In this new standard, it is mentioned that the APEX system has not been used on consumer products and accordingly it is not included in the standard proper; however, because it has been found useful in engineering, it is included in an appendix.

That standard was superseded by ISO Standard ISO 2720-1974, *Photography—General purpose photographic exposure meters (photoelectric type)—Guide to product specification*. The APEX system of notation is not covered by (or even mentioned by) this standard, nor is it covered by any other contemporary standard.

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APPENDIX A

Formulas defining the APEX values

In this appendix, we will use the formal notation for APEX values, with a subscript of lower-case "v".

<u>For aperture value, A_v:</u>

$$A_n = 2\log_2 N \tag{10}$$

where N is the f/number.

<u>For time value, T_v:</u>

$$t_v = -\log_2 t \tag{11}$$

where t is the exposure time (shutter speed) in seconds, or, alternatively, by:

$$t_v = \log_2 D_t \tag{12}$$

where D_t is the denominator of the shutter speed in seconds.

<u>For speed value, S_v:</u>

$$S_v = \log_2 \frac{S}{3.125} \tag{13}$$

where S is the ISO speed rating.

<u>For brightness value, B_v:</u>

$$B_v = \log_2 \frac{L}{0.3K} \tag{14}$$

where L is the luminance (brightness) in candelas/m^2 and K is the reflected light metering constant, usually taken to be 11.4. (For brightness in foot-lamberts, the equivalent is $K = 3.33$.)

<u>For incident light value, I_v:</u>

$$I_v = \log_2 \frac{E}{0.3C} \tag{15}$$

where E is the incident illuminance (illumination) in lux and C is the incident light metering constant, usually taken to be 224. (For illumination in foot-candles, the equivalent is $C = 20.8$.)

For exposure value, E_V:

$$E_v = T_v + A_v \tag{16}$$

therefore:

$$E_v = -\log_2 \frac{t}{N^2} \tag{17}$$

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Summary of APEX values for exposure factors

The numbers shown in square brackets (and the f-numbers for aperture) are the customary ones for practical use. The others are the theoretically-precise ones.

Aperture Value (Av)	Aperture
0	f/1.0
1	f/1.4
2	f/2.0
3	f/2.8
4	f/4.0
5	f/5.6
6	f/8.0
7	f/11
8	f/16
9	f/22
10	f/32

Time Value (Tv)	Exposure time
0	1
1	1/2
2	1/4
3	1/8
4	1/16 [1/15]
5	1/32 [1/30]
6	1/64 [1/60]
7	1/128 (1/125]
8	1/256 (1/250)
9	1/512 [1/500]
10	1/1024 [1/1000]

Speed Value (Sv)	Sensitivity (ISO speed)
0	3.125 [3]
1	6.25 [6]
2	12.5 [12]
3	25
4	50
5	100
6	200
7	400
8	800
9	1600
10	3200

Brightness Value (Bv)	Luminance (rightness)	
	foot-lamberts	candelas/m^2
0	1	3.4
1	2	6.9
2	4	14
3	8	27
4	16	55
5	32	109
6	64	219
7	128	439
8	256	877
9	512	1754
10	1024	3508

Incident Light Value (Iv)	Illuminance (illumination)	
	foot-candles	lux
0	6.25 [6]	67
1	12.5 [12]	135
2	25	269
3	50	538
4	100	1076
5	200	2152
6	400	4304
7	800	8608
8	1600	17260
9	3200	34432
10	6400	68864

These brightness and illuminance value tables are based on the nominal values of the respective meter calibration constants (*K* and *C*) suggested for use when the APEX system was first defined. The actual tables would depend on a particular manufacturer's choice of those constants, which reflects that manufacturer's opinion of the "proper exposure" for a given scene brightness or illuminance with a given ISO sensitivity of the film or digital imager.