APEX—The Additive System of Photographic Exposure

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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 simple addition. Although the importance of that has largely faded since the time the system was developed, it is still widely used in technical work relating to photographic exposure, especially the APEX quantity "exposure value" (E_V). This article explains the APEX system, and gives cautions about various irregularities in its usage that are often encountered.

INTRODUCTION

The role of APEX

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, 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 sensitivity (film "speed")
- Metered scene luminance (brightness)
- Incident light illuminance

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 on 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 a cue that the APEX (logarithmic) form of the factor is meant.

The symbols for the APEX values all have a "V" subscript, as A_V (subscript upper-case "V"). In documents where subscripts cannot be rendered, the symbols are presented this way: Av (lower-case "V").

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 generally use instead the alternative, if less precise, terms *brightness* and *illumination*, respectively. (Brightness is in fact the term used in APEX anyway.)

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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.

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

THE APEX EXPOSURE FACTORS

The numbers

The numbers stated for each value step are the mathematically-ideal ones. 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 (A_V)

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

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

Aperture Value (A_V)	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 (T_V)

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

Time Value (T_V)	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 (S_V)

Speed Value (S_V) reflects the "speed" (sensitivity) of the film or equivalent, usually expressed as an "ISO number". A larger Speed Value represents a greater film sensitivity (speed).

Speed Value (S_V)	Film speed (ISO)
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 (B_V)

Brightness Value indicates the metered brightness (luminance) of the scene. A larger Brightness Value represents greater scene brightness.

The table shows the values of B_V on the basis of two different units.

Brightness Value (B_V)	Scene brightness (luminance)	
	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 that formally the scale of this table should depend on the value of the so-called "reflected light meter calibration constant", usually indicated as *K*. This is a value that is chosen by the manufacturer of an exposure meter (or an automatic exposure camera) to reflect their view of what constitutes "correct exposure" for any scene brightness. The table above is predicated on a *K* of 11.4 (for luminance in candelas/m^2). We'll learn more about this in the next section.

THE EXPOSURE EQUATION

The basic equation for determining the "correct exposure" (in the sense discussed earlier) is:

$$\frac{N_f^{\,2}}{T_s} = \frac{L_s S_f}{K} \tag{1}$$

where N_f is the aperture, as an f/number; T_s is the shutter time in seconds; L_s is the average scene luminance (brightness), in some appropriate unit; S_f is the speed (sensitivity) of the film, as an ISO 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:

$$A_V + T_V = B_V + S_V \qquad (2)$$

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 B_V. The value of *K* (for *B* 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 12.5 is generally used by manufacturers. (This change represents a very small increase in exposure.) Nevertheless, the table in the earlier section, based on the original 11.4 value, is most commonly cited for general reference.

Exposure value (E_V)

The typical "reflected light" photographic exposure meter (the most common form) measures (average) scene brightness (B_V, as an APEX value). That finding goes into some type of exposure calculator, typically a circular "slide rule", into which the photographer has set the ISO sensitivity (film speed) of interest. The calculator then displays a scale of aperture versus shutter speed, any matching 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 $A_V + T_V$, a number that we may say defines "exposure".[4]

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

$$E_V = A_V + T_V \qquad (3)$$

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[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".

[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 that 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 (illumination times time) as the result of the exposure.

We can then rewrite the fundamental exposure equation as:

$$E_V = B_V + S_V \quad (4)$$

A larger value of E_V represents less exposure.

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

Incident Light Value (I_V)

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 illumination on the scene (with an "incident light" exposure meter) and from it determine an appropriate exposure.[5]

To recognize this, an additional value, for illumination, has been added to APEX: Incident Light Value (I_V). A larger Incident Light Value represents greater illuminance.[6]

Some incident light meters (all too few, unfortunately) report their luminance reading in terms of I_V.

The table shows the values of I_V on the basis of two different units.

Light Value (I_V)	Illumination (illuminance)	
	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 that formally the scaling of this table should depend on the value of the so-called "incident light exposure meter calibration constant", usually indicated as *C*. This is a value that is chosen by the

[5] Still based on an assumption about the range of scene reflectance!

[6] This is sometimes called "Light Value" and given the symbol L_V.

manufacturer of an exposure meter (or an automatic exposure camera) to reflect their view of what constitutes "correct exposure" for any scene brightness. The table above is predicated on a *C* of 224 (for illuminance in lux). We'll hear more about that shortly.

The (average) brightness of a scene (in foot-lamberts) is the product of the illumination (in foot-candles) and the (average) scene reflectance[7] (which would be 1.0 for a "diffuse" surface which reflected all the incident light).

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

$$\frac{N_f^2}{T_S} = \frac{I_S S_F}{C} \qquad (5)$$

where N_f is the aperture, as an F-number; T_s is the shutter time in seconds; I_s is the average scene illumination (in some appropriate unit); S_f 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.[8] The current commonly-used value of *C* (for illumination in lux) is 250. However, for general reference work the table we saw above (with a C of 224) is usually cited.

The equivalent in APEX terms becomes:

$$A_V + T_V = I_V + S_V \qquad (6)$$

or

$$E_V = I_V + S_V \qquad (7)$$

If we compare the equations for the reflective and incident light meters, using either the original suggested values or the current common values for *K* and *C*, we find that they jointly imply that the reflective light meter operates on the basis of an assumed average scene reflectance of about 16%.

Relating this to the "12.5%" and "18%" average scene reflectance values involved in the theory of exposure metering is a complex issue beyond the scope of this article.

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[7] The actual "physicist's" equation has the factor $1/\pi$ in it. However, the definition of the foot-lambert was chosen to make that factor disappear!

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

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 illuminated by full sunlight[9], an aperture of f/16 and a shutter speed of one over the ISO sensitivity 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 L_V 9.6, about 5000 foot-candles (or about 50,000 lux).

Exposure compensation – the "E_V" 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 would be 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 would cause these 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 effect, the use of this feature makes the basic exposure equation followed by the camera become:

$$A_V + T_V = B_V + S_V - C_V \qquad (8)$$

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

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

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

The amount of exposure compensation is quite properly described in the same units as E_v. As a result, the exposure compensation setting is often called the "E_v setting". That's not a good description. It in fact does not set E_v; it forces E_v to be different from what would ordinarily be put into effect by the metering system. "E_v offset" would be a better description. In technical contexts, exposure compensation is in fact often called "exposure bias".

Scene brightness in E_v?

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

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

Of course, if we know the E_v that a camera's metering system has recommended for a scene, we could in fact equate that to scene brightness if we also knew the ISO sensitivity (S_v) in effect.[10]

It turns out that, when a manufacturer states some critical scene brightness in E_v units, and nothing to the contrary is stated, it is most often based on the assumption that the ISO sensitivity is ISO 100 (S_v 5). (Canon, for example, so states explicitly.) That is, the brightness being described is that which, if the ISO sensitivity of the camera were ISO 100, would lead to camera arranging for an exposure of the stated E_v.

The relationship between this irregular description of scene luminance in "E_v" and the description of that luminance in the proper value, B_v, is as follows:

$$B_v = E_v' - 5 \qquad (9)$$

where E_v' is the so-called "E_v" used to describe the luminance.

I discourage this usage.

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

E_v 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 E_v steps". Of course, aperture is defined in terms of A_v, not E_v. But, in defense of the practice, a 1/3 unit change in A_v does give a 1/3 unit change in E_v. As with the use of E_v units for brightness, I'm sure the motive for the practice is that many photographic enthusiasts have heard of E_v but not A_v.

Still, a better practice would be so say, ". . . in 1/3 stop steps").

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 I_v table, labeled "B_v", or vice-versa. Sometimes discussions of brightness (*luminance*) will mention the units which are applicable to illumination (*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, "A_v was f/5.6" or "T_v was 1/60 sec". In fact, those APEX designations should only be used in connection with those exposure factors expressed in APEX form.

A related problem occurs in connection with many 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 then is then set by the metering system to achieve the E_v the system thinks appropriate, based on measurement of scene brightness. The two modes are labeled "Av" and "Tv", respectively. Yet the factors are set not in terms of APEX units but in conventional form ("f/3.5" or "1/125 sec"). What gives here?

Here's my guess: initially, on the Canon models offering those 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.

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APPENDIX A

Formulas defining the APEX values

For aperture value, A_V:

$$A_v = 2\log_2 N \quad (10)$$

where N is the f/number.

For time value, T_V:

$$T_v = \log_2 D_T \quad (11)$$

where D_T is the denominator of the shutter speed.

For speed value, S_V:

$$S_v = \log_2 \frac{S}{3.125} \quad (12)$$

where S is the ISO speed rating.

For brightness value, B_V:

$$B_v = \log_2 \frac{L}{0.3K} \quad (13)$$

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, use $K = 3.33$.)

For incident light value, I_V:

$$I_v = \log_2 \frac{E}{0.3C} \quad (14)$$

where E is the illumination (illuminance) in lux and C is the incident light metering constant, usually taken to be 224.

(For illumination in foot-candles, use C = 20.8.)

This value is sometimes called “light value” and symbolized L_V.

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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 (A_V)	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 (T_V)	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 (S_V)	Film speed (ISO)
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 (B_V)	Brightness (luminance)	
	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

Light Value (L_V)	Illumination (illuminance)	
	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 illumination 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 and ISO sensitivity.