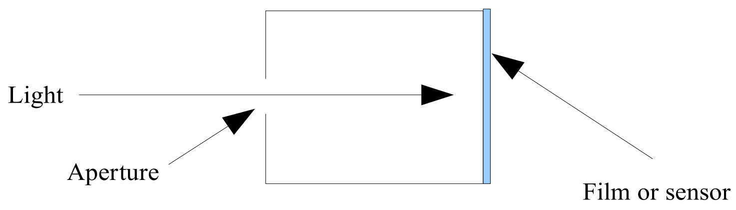
Aperture and Time values – V1.0

PhotoClub European Commission – Brussels 17-02-2009

1. Introduction[1]



In photography, the light reaches a film or a sensor through a hole, characterised by an aperture, during some time, associated to the shutter speed.

The exposure value (EV) denotes all combinations of camera shutter speed and relative aperture that give the same exposure. Although all camera settings with the same exposure value nominally give the same exposure, they do not necessarily give the same picture. The exposure time ("shutter speed") determines the amount of motion blur and the relative aperture determines the depth of field, as illustrated by the four images below. The aperture and shutter speed need to be chosen such that the resulting exposure is "correct".

Slow shutter speed

High shutter speed

Large aperture f/5

Small aperture f/32

Exposure value is a base-2 logarithmic scale defined by:

where

[1] From Wikipedia: http://en.wikipedia.org/wiki/Exposure_value

- N is the relative aperture (f-number)
- t is the exposure time ("shutter speed") in seconds

EV 0 corresponds to an exposure time of 1 s and a relative aperture of f/1.0. If the EV is known, it can be used to select combinations of exposure time and f-number.

Each increment of 1 in exposure value corresponds to a change of one "step" (or, more commonly, one "stop") in exposure, i.e., half as much exposure, either by halving the exposure time or halving the aperture area, or a combination of such changes.

2. Time value (Tv) or Shutter speed[2]

2.1. Description

In photography, shutter speed is a common term used to discuss exposure time, the effective length of time a shutter is open; the total exposure is proportional to this exposure time, or duration of light reaching the film or image sensor.

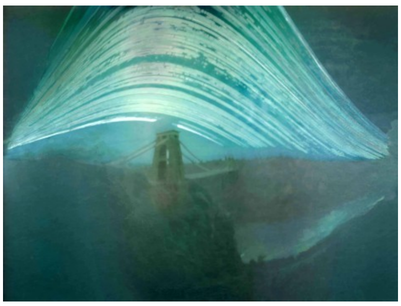
Each standard increment either doubles the amount of light (longer time) or halves the amount of light (shorter time). For example, if you move from 1 s to 1/2 s, you have effectively halved the amount of light entering the shutter.

The term "speed" is used in reference to short exposure times as fast, and long exposure times as slow. Shutter speeds are often designated by the reciprocal time, for example 60 for 1/60 s.

Camera shutters often include one or two other settings for making very long exposures:

- B (for bulb): keep the shutter open as long as the shutter release is held
- T (for time): keep the shutter open until the shutter release is pressed again

2.2. Examples



If every picture tells a story, this one might make a novel. The six month long exposure compresses the time from December 17, 2007 to June 21, 2008 into a single point of view. Dubbed a solargraph, the remarkable image was recorded with a simple pinhole camera made from a drink can lined with a piece of photographic paper. The Clifton Suspension Bridge over the Avon River Gorge in Bristol, UK emerges from the foreground, but rising and setting each day the Sun arcs overhead, tracing a glowing path through the sky. Cloud cover causes dark gaps in the daily Sun trails. In December, the Sun trails begin lower down and are short, corresponding to a time near the northern hemisphere's winter solstice date. They grow longer and climb higher in the sky as the June 21st summer solstice approaches. A detailed description is available at the URI http://www.pinhole-photography.org/Solargraph%20instructions.htm

[2] From Wikipedia: http://en.wikipedia.org/wiki/Shutter_speed

An extended exposure can also allow photographers to catch brief flashes of light, as seen here. Exposure time 15 seconds.

A photo of sparks coming from coals (exposure time 15 seconds)

A photo of street at night (exposure time 30 seconds)

Sparklers moved in a circular motion with a exposure time of 4 seconds

Slow shutter speed combined with panning the camera can achieve a motion blur for moving objects.

3. Aperture value (Av)[3]

The aperture stop of a photographic lens can be adjusted to control the amount of light reaching the film or image sensor. In combination with variation of shutter speed, the aperture size will regulate the film's degree of exposure to light. Typically, a fast shutter speed will require a larger aperture to ensure sufficient light exposure, and a slow shutter speed will require a smaller aperture to avoid excessive exposure.

A device called a diaphragm usually serves as the aperture stop, and controls the aperture. The diaphragm functions much like the iris of the eye. It controls the effective diameter of the lens opening. Reducing the aperture size increases the depth of field, which describes the extent to which subject matter lying closer than or farther from the actual plane of focus appears to be in focus. In general, the smaller the aperture (the larger the number), the greater the distance from the plane of focus the subject matter may be while still appearing in focus.

The lens aperture is usually specified as an f-number, the ratio of focal length to effective aperture diameter. A lens typically has a set of marked “f-stops” that the f-number can be set to. A lower f-number denotes a greater aperture opening which allows more light to reach the film or image sensor. The photography term "one f-stop” refers to a factor of √2 (approx. 1.414) change in f-number, which in turn corresponds to a factor of 2 change in light intensity.

In optics, the f-number (sometimes called focal ratio, f-ratio, or relative aperture[1]) of an optical system expresses the diameter of the entrance pupil in terms of the focal length of the lens; in simpler terms, the f-number is the focal length divided by the "effective" aperture diameter. It is a dimensionless number that is a quantitative measure of lens speed, an important concept in photography.

The f-number f/#, often notated as N, is given by f/#=N=f/D where f is the focal length, and D is the diameter of the entrance pupil. By convention, “f/#” is treated as a single symbol, and specific values of f/# are written by replacing the number sign with the value. For example, if the focal length is 16 times the pupil diameter, the f-number is f/16, or N=16. The greater the f-number, the less light per unit area reaches the image plane of the system; the amount of light transmitted to the film (or sensor) decreases with the f-number squared. Doubling the f-number increases the necessary exposure time by a factor of four.

The literal interpretation of the f/N notation for f-number N is as an arithmetic expression for the effective aperture diameter (entrance pupil diameter), which is equal to the focal length divided by the f-number: D = f / N. The notation is commonly read aloud as “eff” followed by the number: f/8, for example, is usually pronounced “eff eight”.

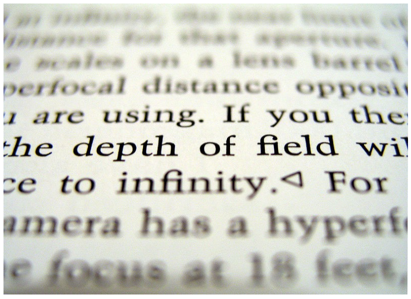
[3] From Wikipedia: http://en.wikipedia.org/wiki/Aperture and http://en.wikipedia.org/wiki/F-number

The pupil diameter is proportional to the diameter of the aperture stop of the system. In a camera, this is typically the diaphragm aperture, which can be adjusted to vary the size of the pupil, and hence the amount of light that reaches the film or image sensor. The common assumption in photography that the pupil diameter is equal to the aperture diameter is not correct for many types of camera lens, because of the magnifying effect of lens elements in front of the aperture.

A 100 mm lens with an aperture setting of f/4 will have a pupil diameter of 25 mm. A 135 mm lens with a setting of f/4 will have a pupil diameter of about 33.8 mm. The 135 mm lens' f/4 opening is larger than that of the 100 mm lens but both will transmit the same amount of light to the film or sensor.

4. Depth of Field[4]

4.1. Introduction



In optics, particularly as it relates to film and photography, the depth of field (DoF) is the portion of a scene that appears sharp in the image. Although a lens can precisely focus at only one distance, the decrease in sharpness is gradual on either side of the focused distance, so that within the DoF, the unsharpness is imperceptible under normal viewing conditions.

For some images, such as landscapes, a large DoF may be appropriate, while for others, such as portraits, a small DoF may be more effective.

The DoF is determined by the subject distance (that is, the distance to the plane that is perfectly in focus), the lens focal length, and the lens f-number (relative aperture). Except at close-up distances, DoF is approximately determined by the subject magnification and the lens f-number. For a given f-number, increasing the magnification, either by moving closer to the subject or using a lens of greater focal length, decreases the DoF; decreasing magnification increases DoF. For a given subject magnification, increasing the f-number (decreasing the aperture diameter) increases the DoF; decreasing f-number decreases DoF.

When focus is set to the hyper-focal distance, the DoF extends from half the hyper-focal distance to infinity, and is the largest DoF possible for a given f-number.

4.2. Hyper-focal distance

The hyper-focal distance is the nearest focus distance at which the DoF extends to infinity; focusing the camera at the hyper-focal distance results in the largest possible depth of field for a given f-number, from D/2 to infinity. Focusing beyond the hyper-focal distance does not increase the far DoF (which already extends to infinity), but it does decrease the DoF in front of the subject, decreasing the total DoF.

If the lens includes a DoF scale, the hyper-focal distance can be set by aligning the infinity mark on the distance scale with the mark on the DoF scale corresponding to the f-number to which the lens is set. For example, with the 35 mm lens set to f/11, aligning the infinity mark with the "11" to the left of the index mark on the DoF scale would set the focus to the hyper-focal distance. Focusing on the hyper-focal distance is a special case of zone focusing in which the far limit of DoF is at infinity.

The formula $H = f^2/Nc + f$ where

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4 From Wikipedia: http://en.wikipedia.org/wiki/Depth_of_field

- H is the hyper-focal distance
- f is the focal length
- N is the f-number (f/D for aperture diameter D)
- c is the circle of confusion

provides the hyper-focal distance.

As an example, let's compute the hyper-focal distance for a 50 mm lens at *f*/16 using a circle of confusion of 0.03 mm (which is a value typically used in 35 mm photography):

$$H=(50\text{mm})^2/((16)(0.03\text{mm}))+(50\text{mm})=5258\text{mm}$$

If we focus the lens at a distance of 5.2 m, then everything from half that distance (2.6 m) to infinity will be acceptably sharp in our photograph.

Limited DoF: selective focus

Depth of field can be anywhere from a fraction of a millimeter to virtually infinite. In some cases, such as landscapes, it may be desirable to have the entire image in focus, and a large DoF is appropriate. In other cases, artistic considerations may dictate that only a part of the image be in focus, emphasizing the subject whilst de-emphasizing the background, perhaps giving only a suggestion of the environment. A portrait or closeup still photograph might use a small DoF to isolate the subject from a distracting background. The use of limited DoF to emphasize one part of an image is known as selective focus or differential focus.

For a given scene and subject magnification, the background blur increases with lens focal length. If it is not important that background objects be unrecognizable, background de-emphasis can be increased by using a lens of longer focal length and increasing the subject distance to maintain the same magnification. This technique requires that sufficient space in front of the subject be available; moreover, the perspective of the scene changes because of the different camera position, and this may or may not be acceptable.

Near vs. far distribution

The DoF beyond the subject is always greater than the DoF in front of the subject. When the subject is at the hyper-focal distance or beyond, the far DoF is infinite; as the subject distance decreases, near:far DoF ratio increases, approaching unity at high magnification. The oft-cited "rule" that 1/3 of the DoF is in front of the subject and 2/3 is beyond is true only when the subject distance is 1/3 the hyper-focal distance.

4.3. DoF summary

The Depth of Field (DoF) depends on the 4 following parameters:

- Aperture (URI: http://en.wikipedia.org/wiki/Aperture): The smallest the aperture is (e.g. f/11), the biggest the DoF is; The larger the aperture is (e.g. f/2.8) the smallest the DoF is.
- Focal length of the lens (URI: http://en.wikipedia.org/wiki/Focal_length): A short focal length (e.g. 35 mm) leads to a a big DoF; A long focal length (e.g. 300 mm) leads to a small DoF.
- Focus distance: A far focus plan leads to a big DoF; A close focus plan leads to a small DoF
- Circle of confusion[5] (URI: http://en.wikipedia.org/wiki/Circle_of_confusion): A small circle of confusion leads to a small DoF.

[5] This parameter depends on the sensor for a digital camera and on the film format for an analogue camera. It is therefore not possible in general to use it to influence the Depth of Field.

In optics, a circle of confusion, is an optical spot caused by a cone of light rays from a lens not coming to a perfect focus when imaging a point source. The DoF is the region where the size of the circle of confusion is less than the resolution of the human eye. Circles with a diameter less than the circle of confusion will appear to be in focus.

Small DoF		***Big DoF***	
Large aperture	e.g. f/2.8	Small aperture	e.g. f/11
Long focal length	e.g. 300 mm	Short focal length	e.g. 35 mm
Close focus plan	e.g. 0.3 m	Far focus plan	e.g. 100 m
Small circle of confusion		Large circle of confusion	

5. Exercises

5.1. Aperture: Depth of Field

Indoor, take several pictures of a specific setting (e.g. playing cards) at various aperture (left column), at various focal length and focus distance and compare the results.

It is likely that for some aperture value, the exposure time becomes too slow (e.g. more then 1/30s). The use of a tripod or of a flash will help to take the pictures without introducing a moving blur.

Focal length:	***F1=28mm***			***F2=50mm***			***F3=100mm***			***F4=200mm***		
Focus distance:	***0.3m***	***1.5m***	***5.0m***	0.3m	1.5m	5.0m	0.3m	1.5m	5.0m	0.3m	1.5m	5.0m
f/1.0												
f/1.4												
f/2.0												
f/2.8												
f/4.0												
f/5.6												
f/8												
f/11												
f/16												
f/22												
f/32												
f/45												
f/64												

5.2. Aperture: 3 cases

1. Everything sharp
2. Sharp foreground and blurred background
3. Blurred foreground and sharp background