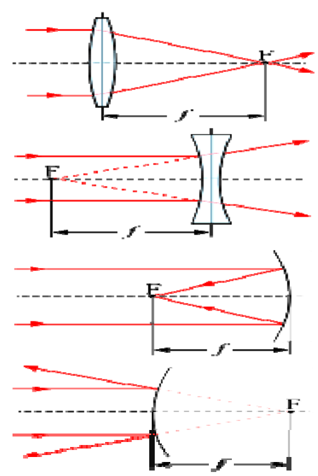
THE OPTICAL SYSTEM CHARACTERISTICS

BASIC TERMS

Film/sensor Plane: the plane in the camera where lies the surface of the film/sensor onto which the image is exposed

Focal Length: the distance from the optical centre of the lens to the film/sensor plane when focus is set at infinity. Focal length of an optical system is a measure of how strongly the system converges or diverges light. For an optical system in air, it is the distance over which initially collimated rays are brought to a focus. A system with a shorter focal length has greater optical power than one with a long focal length; that is, it bends the rays more strongly, bringing them to a focus in a shorter distance.



f-focal length of the optical system

Angle Of View: the angle inside a conical shape extending from the camera into the viewed scene. This cone is the limit of what can be seen through the lens

Aperture: opening of the lens through which light enters the camera. This can be modified by an expandable/contractable iris diaphragm

F - Stop: a numeric indication of the size of the aperture

Depth Of Field: the zone of sharp focus in a scene, extending from the nearest element that is sharp to the farthest

Circle Of Confusion: circular area (rather than a point) of light at the film/sensor plane caused by images that are out of focus. Their true focus point being in front of or behind the film/sensor plane

Hyperfocal Distance: The distance that when focused upon provides the greatest depth of field

Resolution Limit: The size an object has to be before it can be considered as sharply resolved in an image

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In most photography and all telescopy, where the subject is essentially infinitely far away, longer focal length (lower optical power) leads to higher magnification and a narrower angle of view; conversely, shorter focal length or higher optical power is associated with a wider angle of view. On the other hand, in applications such as microscopy in which magnification is achieved by bringing the object close to the lens, a shorter focal length (higher optical power) leads to higher magnification because the subject can be brought closer to the center of projection

Optimal Focusing Distance

Focusing distance is the measure that defines how far is the targeted object (i.e. its focused point) from the lens (i.e. lens` focal point).

Have you ever wondered what factors cause an image to be in or out of focus, why come parts of an image can seem sharp while others are fuzzy and blurred? Why taking a photograph of apparently the same subject with different cameras or lenses may give differing ranges of focus?

There are many considerations when deciding how to compose an image and then setting the camera to achieve the desired result. Here we will discuss how to achieve a sharp image over the desired range within the scene, whether this is a deep area providing a clear representation of much of the scene or a very shallow section highlighting a particular element. The range of this sharp area within an image is referred to as the Depth Of Field (DOF). There are three main components that affect the DOF:

- the Focal Length of the lens in use
- the distance at which the lens is focused and
- the Aperture setting on the lens

When considering the focal length of a lens, the larger this value is, the shallower will be the depth of field, i.e. less of the entire image will be in focus. This indicates that, assuming all other factors are the same, a wide angle lens, e.g. with a focal length of 20mm, will have much more of the scene in focus than a 300mm telephoto lens.

The further away from the camera that a lens is focused upon, the larger will be the DOF.

The aperture of a lens is the opening through which light enters the camera. This aperture can be increased or decreased to let more or less light respectively into the camera. The settings of the aperture and hence the amount of light reaching the film are indicated by the term f-Stop. The f-Stop is a relative measure and is designed such that whatever lens is in use the same f-Stop will pass the same amount of light onto the film/sensor. A typical range of f-Stops is 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, and 45. The lower a number, the wider the aperture (d=FL/f), and hence the more light that reaches the film/sensor. Each higher f-Stop in this sequence lets in exactly half the light of the previous number. Some cameras may be able to set intermediate f- Stops. In reality the f-Stop is the ratio of the focal length of the lens to the actual diameter of the aperture. Thus an f-stop of f/4 gives an iris opening equal to one quarter of the focal length of the lens.

f: f-Stop
FL: focal length
d: diameter of aperture

$$f = FL/d$$

or

$$d = FL/f$$

These aperture diameters on their respective lens allow the same amount of light onto the film/sensor.

To ***increase*** the DOF:

- use a shorter focal length
- lens move further back from the subject
- use a smaller aperture/iris opening (larger f-Stop number)

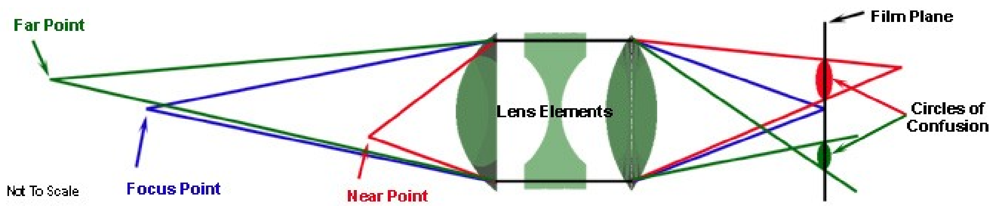
To ***decrease*** the DOF:

- use a longer focal length
- lens move closer to the subject
- use a wider aperture/iris opening (smaller f-Stop number)

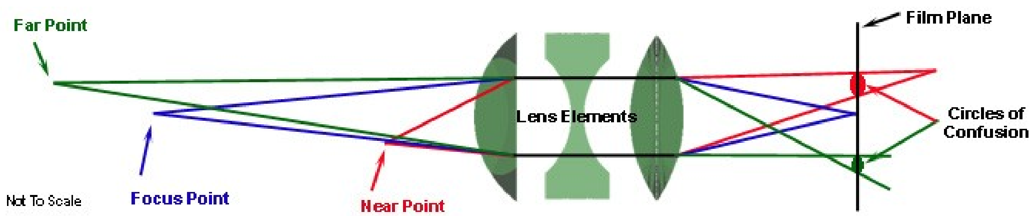
Light Behaviour Through A Lens

Light does not travel in a straight line through a camera lens. It is the purpose of the lens to bend the light so that a large image can be condensed onto a small piece of film/sensor. Thus the lens elements within a camera lens change the angle of the light as it passes through.

A lens focuses at only one distance at any one time. Light reflected from objects at this distance is brought to a sharp point on the film/sensor. These images are thus 'in focus'. All light is sharply focused at some point. The light from objects not at the same distance from the lens as its current focus distance will be brought to a sharp point either in front of or behind the film/sensor plane. Therefore, as this light crosses the film/sensor plane it is not a sharp point but rather a circle. The wider this circle the more out of focus the object will appear. These circles are referred to as 'Circles Of Confusion'.



Primarily, to achieve a maximum depth of field, the objective is to minimise the size of the circles of confusion. As the aperture of a lens is narrowed (a higher number f-Stop) the passage of light through the lens is narrowed. This leads to smaller circles of confusion and a sharper appearing image.



Unfortunately, however, light bends around sharp edges (e.g. in this case the aperture iris) at different rates depending on its colour. This causes a limit of sharpness depending on the diffraction of the light. Thus to achieve the desirable DOF use an aperture small enough but no smaller.

The Circle Of Confusion needs a touch more explanation. Traditionally a tolerable CofC equates to what the human eye deems to be a sharp image on an 8"x10" print when viewed from a standard reading distance of say 10 inches (254mm). This is generally accepted to be approximately 1/100 of an inch, or .254 millimetres. Thus the circle of confusion for an 8x10 format will be 0.254mm. To calculate the CofC for other formats the ratio of the size of the film/sensor to this 8x10 format must be applied to the CofC for the 8x10 format.

<u>Different CofC values can be taken from the following table:</u>

Format	Dimensions	Diagonal Length	Short Side CofC	Diagonal CofC
35mm	24mm x 36mm	43.27mm	.254 / (200 / 24) = 0.030mm	.254 / (320.16 / 43.27) = 0.034mm
456	41.5mm x 56mm	69.70mm	.254 / (200 / 41.5) = 0.053mm	.254 / (320.16 / 69.70) = 0.055mm
6x6	56mm x 56mm	79.20mm	.254 / (200 / 56) = 0.071mm	.254 / (320.16 / 79.20) = 0.063mm
6x7 b	56mm x 69.5mm	89.25mm	.254 / (200 / 56) = 0.071mm	.254 / (320.16 / 89.25) = 0.071mm
6x9	56mm x 84mm	100.96mm	.254 / (200 / 56) = 0.071mm	.254 / (320.16 / 100.96) = 0.080mm
4x5	96mm x 120mm	153.67mm	.254 / (200 / 96) = 0.122mm	.254 / (320.16 / 153.67) = 0.122mm
8x10	200mm x 250mm	320.16mm	.254 / (200 / 200) = 0.254mm	.254 / (320.16 / 320.16) = 0.254m

These CofC values will give the same sharpness for each format when that negative is used to enlarge the print to 8"x10".

Depth Of Field Calculations

To achieve the maximum depth of field the camera should be focused at the Hyperfocal Distance for the lens in use.

Examining this formula reveals that different focal length and aperture combinations will have a different hyperfocal distance. The range of the depth of field for any distance can be calculated using the formulas here. Objects positioned outside of these boundaries will begin to appear fuzzy and out of focus. Remember, using the CofC from the table will give a "standard acceptable" reproduction of print.

H: hyperfocal distance
CofC: circle of confusion
FL: focal length
f: f-Stop of lens

$$H = \frac{FL * FL}{CofC * f}$$

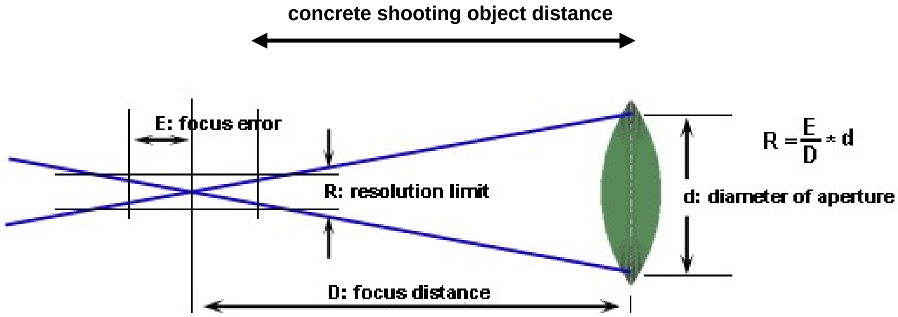
nl: near limit
fl: far limit
H: hyperfocal distance
D: focus distance
FL: focal length

$$nl = \frac{H * D}{H + (D - FL)} \qquad fl = \frac{H * D}{H - (D - FL)}$$

Many people do not believe this standard is good enough and prefer to use smaller values. This will give a narrower band of acceptable depth of field. It will not make objects within this range sharper than the same distances as before but if the whole image is kept within the range then the whole image will appear sharper than if the whole image were within the wider depth of field range.

Web-site: *www. dofmaster.com/doftable.html* can be used for on-line calculation depth of field ranges (WARNING: Obtained values are calculated from generalized formulas. Wherever possible, use manufacturer supplied tables!!!)

An Alternate DOF Philosophy



When the hyperfocal distance is used as the concrete focus distance, it will provide no more than average image quality in all but a few specific cases. This is simply due to the fact that not every scene is optimally covered by the hyperfocal DOF range. Using the formula for resolution limit (i.e. the estimated size of the shot object which would appear sharp for chosen hyperfocal distance and concrete object-to-camera distance), the photographer can decide which segments of the image will be the sharpest. For example with a 70mm lens with an f-Stop of f/5.6 we have an aperture diameter of 12.5mm and a hyperfocal distance of 29.167 metres. When shooting at the hyperfocal distance an object which is two meters away from the camera, such object would have a resolution limit (R) of 12.5 * (29167 - 2000)/29167 = 11.64mm.

Preserving the hyperfocal distance (29.167m), some other object located farther away in the scene (say 1km from the fixed camera station), would have resolution limit of 12.5 * (1000000 - 29167)/29167 = 416.07mm. Although at larger object-to-camera distance (as in the last case), object`s R value will resolve as sharp relatively small entities (approx. 416mm) – regardless the fact that they are distant ones, this R value will fail to sharpen any other one with the same dimension if it is located much closer to camera.

Source: http://www.conent.com/ConAdv/Encyclopaedia/Photography/CNQ_CAPhotographyOOI.asp