THE CAMERA LENS

JOHN TAYLOR

The camera lens is probably the most important item in your photography kit after the camera. It is through the lens that light from your subject is focused on the film or sensor to create an image. Let's start by remembering what the camera is aimed at is a three-dimensional scene, but the film or sensor, and indeed the final image is a flat plane.

FOCAL LENGTH

The most important descriptor of a lens is its **focal length**. If we use a simple magnifying glass or reading glass lens, we can focus the image of a distant subject on a piece of paper by moving the lens back and forth until a sharp image is produced. The distance between the lens and the sharp distant image (focal plane) is the Focal Length.

The distance between the lens and the focal plane is the ***focal length*** *when the lens is focused at infinity.*

The **focal point** is a point at the centre of the lens from where the focal length is measured. Light from the subject will pass straight through the focal point. Light through any other part of the lens is bent as it passes through the lens. On a modern multi-element camera lens, the focal point is an imaginary position inside the lens. Knowing where the focal point or node is, enables the photographer to optimise taking multiple images for a panorama. Rotating the camera around this point for each image prevents parallax error, and better stitching to combine the multiple images.

A lens with a long focal length, being further away from the image, produces a larger image, magnifies the subject and has a narrow field of view. Conversely a lens with a short focal length, has a wide angle of view and gets more in, but the image is reduced in size. The perspective is exaggerated.

LENS MOUNT

When purchasing a lens, the most obvious factor is that it fits your camera. Best advice if you have any doubts, is to purchase lenses from a photographic supplier. Buying privately could be a problem, if you do not know exactly what you need. Not only does the lens fitting have to match the camera, but lenses designed specifically for crop sensor cameras do not suit full frame cameras, even though the bayonet mount may be identical.

FOCUSING A LENS

If we lengthen the distance between the lens and the sensor or film, the image of a distant subject will become blurred (out of focus). However closer subjects will come into focus. This is how we adjust the camera's focus. Old lenses had a screw mechanism and you turned a focus ring. You focused even older bellows cameras by sliding the lens along a rail. New lenses have internal motors to focus.

The focal length is the minimum distance between the focal point and the sensor that a sharp image can be produced. At shorter distances the image of all subjects, whatever the distance, is blurred. Lenses just don't focus at shorter distances than the focal length.

Modern camera lenses have multiple elements. Focusing is often by moving elements inside the lens, but the principal is the same. Remember lenses which lengthen or shorten when focused, pump air and dust into the lens and camera body.

LENS APERTURE

The amount of light that will pass through a lens and illuminate the sensor is directly related to the *area* of the lens. Doubling the area allows twice as much light and is a one stop increase in exposure. A large aperture lens is desirable to let through plenty of light, but the cost is higher, because it has much more glass, requires higher precision and is more difficult to design. A large aperture lens is also heavy.

Lens aperture is expressed as the ratio of the lens diameter to the focal length, f. On the front of the barrel, you will see this expressed in the following way: f = 100mm 1:2.8. This means that the focal length of the lens is 100mm and the maximum aperture diameter is 100mm divided by 2.8, or 35.7mm.

Lenses have a variable aperture or iris to adjust the amount of light that reaches the sensor. Rather than expressing aperture in some understandable units, such as diameter, they are expressed in f/ numbers. The exposure at a particular f/number, is the same irrespective of the focal length. This means that lens focal length does not need to be considered in exposure determination.

There is a tendency for some writers and publications to omit the divisor sign (f8 not f/8), which shows a lamentable lack of technical literacy. In any fraction the larger the divisor, the smaller the value – ¼ is smaller than ½. As the f/number gets larger, the aperture gets smaller: f/11 is smaller than f/2.8. This is the same for exposure times: 1/1000 second is a shorter time than 1/25 second.

Remember the amount of light through the lens is dependent directly on the **Area** of the aperture, or its **diameter squared.** So, at f/8, a lens will allow only a quarter of the light as a lens at f/4. So, to double the amount of light passing an aperture, you have to increase its diameter by a factor of the square root of two, or 1.414. This means if I want to halve the light at f/4, I need to change the aperture to f/ (4 x 1.414) = f/5.6. This is why the standard aperture series numbers appear like they do. Each number is 1.4 x the previous one, and each step up the series is one stop or EV.

f/1 f/1.4 f/2 f/2.8 f/4 f/5.6 f/8 f/11 f/16

Notice how every other f/number in the series is doubled – 1.4 doubled is 2.8, 2.8 doubled is 5.6, 5,6 doubled is rounded to 11, and so on.

DEPTH OF FOCUS

Focusing is used to sharpen the most important part of the subject, for example the eyes. How much is acceptably sharp in front of and behind the point of focus is known as the **DEPTH OF FOCUS - DoF**. If the DoF is large, then focusing is not critical. Subjects over a wide range in front of and behind the main subject will be acceptably sharp. However, when the DoF is narrow, accurate focusing is required or the image will not be acceptable.

Depth of focus is dependent on three important factors – Lens aperture, focal length and distance the lens is focused to. A long focal length lens has less Dof than a short one. Dof is more at smaller apertures. Subjects closer to the camera have much less DoF. Those very close, as macro shots, can have a DoF of millimetre dimensions.

The photographer can select lens focal length and aperture to give the desired Dof. With any lens, selecting a smaller aperture increases DoF significantly. A large DoF is usually chosen for general shots of scenes, such as landscapes or buildings. It is possible to get acceptable sharpness across the whole image. A narrow DoF is great for isolating a subject from the background, and is favoured for portraits, wildlife and still life images. The out-of-focus parts of the image can have an abstract quality.

HYPERFOCAL DISTANCE

The **HYPERFOCAL DISTANCE** is the distance the lens is focused at to make subjects at infinite distance sharp and give maximum depth of focus. Use the manual focus setting. With this focus setting, distances from half the hyperfocal length to infinity will be sharp. For any focal length, it depends on the aperture. There are two ways it can be set. Many prime lenses have a distance scale which has aperture marks indicated. These show the depth of focus for a particular aperture setting. With the lens on manual focus, set the far aperture mark on the infinity mark. The lens is then set at the hyperfocal distance.

In the example above the 14mm lens is focused at the hyperfocal distance for f/11, which is 0.6m. With one f/11 mark aligned with the infinity mark (∞). The other f/11 mark is at 0.4m, which tells me that everything from 0.4m to infinite distance will be sharp if I use an aperture of f/11. This is the quickest and simplest way of focusing a prime wide angle lens for landscape and similar subjects.

Not all lenses have depth of focus scales on them. Zoom lenses and long focus lenses probably will not have them. Some cameras with advanced electronics, can display the depth of focus as a bar against a distance scale on the live view image.

However, there are alternatives. The hyperfocal distance can be found in tables, or from a phone app. Photo Pills has a DoF function that also determines hyperfocal distance. For the above lens at f/11, Photo Pills determines that the hyperfocal distance is 0.59m and the hyperfocal near limit 0.3m

THE SWEET SPOT

Generally, a lens used at its maximum aperture will not produce the sharpest possible image. The best and most expensive lenses have great performance at maximum aperture, but generally the lens will be its sharpest at 2 to 3 stops smaller than the maximum aperture. A f/2.8 lens will be best at f/5.6.

As the aperture is reduced below this value the image will be degraded slightly. This is due to a diffraction. This effect will probably not be noticeable until the smallest apertures are chosen - f/16 or smaller.

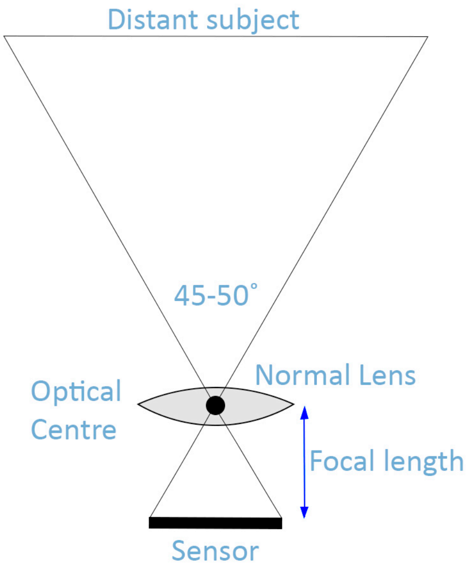
Test this out for your camera. With it on a tripod, photograph a newspaper sheet so it fills the frame, at different apertures. Compare the images at 100%, and find which is the best aperture for your camera/lens combination. Look at the centre and the edges of the image.

THE STANDARD OR NORMAL LENS

The most useful lens is one that covers an angle of 45 to 50 degrees, and this is given the name Normal lens or Standard lens. This lens has an ideal perspective and is the one all others are compared to.

The focal length of a normal lens is approximately the same as the diagonal length of the sensor or film frame.

As you can see in the diagram and table below, what constitutes a normal or standard lens depends on the size of the film or sensor the camera uses.



Sensor Type	Sensor Size	Focal length of Normal Lens approx.
Medium format (Phase One)	56 x 56mm	85mm
Full frame 35mm	36 x 24 mm	50mm
APS-C sensor (Canon)	22.3 x 14.9mm	28mm
APS-C sensor (Other brands)	23.6 x 15.6mm	30mm
Micro Four thirds	17.3 x 13mm	25mm
iPhone	5.79 x 4mm	7mm

Suppliers of SLR cameras provide lenses that will fit both full frame and APS-C cameras. They use the term **Crop Factor** to show the effect of lenses designed for full frame cameras on APS-C cameras, where they will have a narrower angle of view. So, a 50mm lens on a full frame camera is considered a normal lens. But on an APS-C camera it will have a narrower angle of view and will be a long focus lens. If you are considering extra lenses, don't worry about crop factor. Just remember what the focal length of a normal lens is for your camera from the above table. Wide angle lenses will have shorter focal length and long focus lenses longer focal length.

The standard lens produces the most desirable combination of depth and perspective for most circumstances. Wider angle and long focus lenses provide a more distorted view of typical subjects or scenes.

The DoF for a normal lens depends mostly on aperture. In most cases a small aperture f/8 or smaller is selected for maximum DoF and an image that is sharp all over. A large aperture f/4 or larger can be used to isolate a subject and give a spectacular blurred background (high bokeh). The Depth of Focus for a standard lens depends on the sensor size. Those for larger format cameras (larger sensors) have less depth of focus than small sensor cameras. Whereas focusing is critical for medium format cameras, cameras with tiny sensors, such as Smartphone or consumer cameras, do not need a focusing mechanism for acceptably sharp images.

It is often desirable to have the background or foreground out of focus, so as to highlight the focused main subject. This is easier with larger format cameras – full frame or medium format cameras, than APS-C or four thirds cameras. Smartphone cameras can only give an out-of-focus background effect by electronic simulation.

WIDE ANGLE LENS

If the focal length is shorter than for a standard lens, it will have a wider field of view. Short focal length lenses are usually known as **Wide Angle Lenses**. Subjects make smaller images than for a standard lens.

As the view angle gets wider, the lens designer has to consider that the real spherical world is producing an image on a flat sensor or film. It will look unreal in that straight lines at the edges of the subject will be curved when projected on the image. This does not look natural, and we consider this to be barrel distortion. Our eyes suffer barrel distortion at the periphery of vision, but our brains compensate firstly by applying a correction, and secondly by our eyes turning to look at the points of interest. If this distortion is not corrected, the lens is known as a **Fish-eye lens**.

The lens designer, by using multiple lens elements can design lenses with rectilinear correction, so that images of straight lines at the edges of the frame are straightened. This adds to the complexity of design, and the cost. Extreme wide angle lenses have a complicated design, just to ensure light from a wide angle is covers to the corners of the image. In the case of some fish eye lenses, the image is a circle that does not fill the frame. For SLR lenses, the design also has to account for the short focal length effectively putting the focal point inside the mirror box. The focal point of a 14mm lens is 14mm in front of the sensor. This means that wide angle lenses are heavier and more expensive than normal lenses. They are more likely to suffer lens aberrations that degrade the image.

Wide angle lenses tend to give an unusual view of a scene. It gives exaggerated perspective, in that subjects close to the camera appear large and those far away appear small. If the subject has his feet close to the camera and his face further away, it appears as though he has huge feet and a tiny head. In landscape photography, a small puddle close to the camera can be made to look like a lake, compared to distant mountains, which can look like unimpressive rock lumps. If used in an urban street or indoors environment, a wide-angle lens exaggerates converging lines and the sense of perspective.

Wide angle lenses have a large depth of focus. Focusing is rarely critical and they will be sharp all over.

LONG FOCUS AND TELEPHOTO LENSES

If the focal length is longer than for a standard lens, it will have a narrower angle of view. It will image a smaller part of the subject and magnify it.

Long lenses exaggerate the size of distant subjects, making mountains more impressive. Converging lines are flattened, minimising the impression of perspective. A nearby subject can appear unnaturally close to a distant one, a phenomenon known as foreshortening. A long parallel road or railway line, or atmospheric mist is necessary to give an impression of depth.

Because of their narrow angle, long lenses are preferred for photographing fauna. A distant bird or animal can be made to fill the frame.

As the focal length gets longer, so does the lens barrel, and the physical size of a given lens aperture. This means more glass so these lenses can be heavy. The longer lenses have a telephoto design incorporating a convex lens element, which saves weight. So, a 1600mm lens is much shorter than 1600mm. These lenses have maximum apertures of f/4 or smaller. The other issue that seems evident is that the more the image is magnified, higher precision is required to make a sharp image. Cheap long or telephoto lenses can have disappointingly soft images, especially at maximum aperture.

Long focus lenses have narrow depth of focus, even with small apertures. Focus is therefore always critical.

ZOOM LENSES

Zoom lenses are designed to have a variable focal length, so that the magnification can be changed (zoom-in or zoom-out). These first appeared in the 1960's, firstly for cinema and television, but soon became popular for still photography. Now they are extremely popular, and most photographers will start with a zoom lens that spans the range of the standard lens. So, for a full frame camera, the 24 to 70mm or 24 to 105mm focal length lens is usually the one sold with the camera. An equivalent zoom lens for an APS-C camera is 18 to 56mm.

Zoom lenses are more difficult to design and therefore have more compromises. Lens faults (aberrations) that degrade the image are more evident, particularly for the low-cost kit lenses supplied with low price cameras. They are heavy, because they require more lens elements. They are not available in wide aperture. They are expensive, particularly those with large aperture and that are made to the highest image quality. The wider the zoom range the more extreme these issues become. A 24 to 400mm zoom might seem a useful lens, particularly for travel, but the reduced quality of the image, weight, small maximum aperture, and the price, all reduce its popularity.

As you change the focal length, then the physical size of the aperture changes. So, an aperture of f/4 at 70mm has a diameter of 70/4 = 17.5mm, whereas at 24 mm it is only 6mm. This requires the aperture to be mechanically or electronically linked to the focal length. Some of the cheaper or lighter designed lenses have a variable maximum aperture. The lens below has a maximum aperture of f/3.5 at 18mm focal length but when zoomed to 55mm the maximum aperture is reduced to f/5.6. This is shown on the lens name as 1:3.5-5.6/18-56.

These days, lenses with a fixed focal length are known as prime lenses, because the zoom lens is much more popular. For real quality, choose prime lenses, and zoom with your feet by moving towards and away from your subject. The 50mm standard lens with a fairly large aperture of f/1.4 is the best value lens for Canon and

Nikon SLR cameras. It produces an image as good as a much higher priced standard zoom lens, has two stops larger aperture and is much lighter.

MACRO AND CLOSE-UP PHOTOGRAPHY

Macro photography is classically defined as photography where the image on the sensor is life size and up to ten-times life size. Most close-up photography is colloquially known as macro, but in reality, the image is smaller than life size. The macro setting on many prosumer zoom lenses gives magnifications much less than life size. Very few lenses can extend into the macro range: most of the Nikon and Canon Macro lenses only go to 1:1 magnification at their closest focus distance. I use the term close-up photography to cover photographing a subject less than 50mm in size. This seams the most simple-to-understand term, given that sensor sizes can vary from Micro Four Thirds to medium format, and it is the size of the final image on a print or screen that is the most relevant one, not the size on a sensor.

To focus on a subject that is close to the camera, the lens is moved further away from the sensor. If the focal point to sensor distance is increased to twice the focal length, the size of the image is equal to the size of the subject. Normally lens design limits the amount of focus movement available.

Traditionally there were two ways of undertaking close-up photography. The simplest is to use a supplementary lens or dioptre, which effectively is a reading or magnifying glass for your camera. It screws to the filter holder in front of the lens. With it on, the camera no longer focuses at distant objects (it becomes short sighted). Supplementary lenses are still available (if you can find them) and are a low-cost way of getting into close-up photography. The other option for interchangeable lenses was to use an extension tube or bellows between the lens and the camera body to effectively increase the focal plane to focal point distance. Extension tubes are still available and are a useful accessory.

If you move the lens further from the camera, the effective aperture is less than the selected aperture. This is a problem if you are determining exposure with a separate exposure meter. You have to apply a correction to increase exposure. However, modern cameras with their through-the-lens metering compensate for this effect. It is sometimes worth remembering the light level is reduced a lot for close-up images. Effectively if you are focused at 1:1 magnification, the light level received by the sensor is two stops less than if you were shooting with the lens focused at infinity. For those interested, the magnification is calculated by subject height divided by the image height. Add one to the magnification and square the result. This is the factor you must multiply the exposure time by to determine the correct exposure.

In the 1980’s special prime lenses were designed for close-up and macro photography, and these have become the most usual accessory to get into this genre. Not only can these lenses produce an image of life size on the sensor, but they can focus on infinity. They make a useful prime lens. They are designed for working at close distances, but are good focused at infinity. These can focus to around 1:1 magnification (the subject and image sizes are the same). They are available to focus down to 5:1, where the image is 5-times the subject size. As they work by moving elements within the lens, the above calculation may not apply, but there is certainly a considerable reduction in light level at the sensor when focused at close distances.

Working at close distances reduces the depth of focus considerably, so focusing becomes critical. A 100mm macro lens focused at its closest distance (magnification of 1), with an aperture of f/2.8 has a depth of focus of only 0.34mm, and is only 1.92mm at f/16. If you are chasing insects around it is essential to set the autofocus to servo mode to keep the subject sharp.

SOME LENS VOCABLIARY

TILT-SHIFT LENS

This lens has two extra adjustments.

The tilt function allows the lens to be tilted so the lens plane is not parallel to the focus plane. This allows adjustment so that a distant subject at the top of the image, and a near subject at the bottom of the image, and all points on the same flat plane between these is sharply focused. It's cool to see this, but focus stacking can achieve a better result. It can also be used to narrow the depth of focus.

The shift function is of more use. The lens can be slid up or down so as to move the image across the focus plane. This has two uses. Firstly, it can be used to correct converging verticals. Normally to photograph a tall building the photographer has to point the lens upwards to get the top in and avoid excessive foreground. This results in converging verticals. With a shift lens, the camera back is set vertical and the lens slid upward so the image of the top of the building is included in the frame. The second use is for panorama shots. The lens is adjusted with the shift movement horizontal. Taking two shots at the extremes of the shift0 mechanism give two images that can be easily stitched into a panorama.

LENS VIGNETTING

This is an aberration that is common with wide angle lenses. The edges of the image are noticeably darker than the centre. The designer can do much to lessen the effect, but at a cost. This vignetting can be corrected using software. Some modern cameras will do this if the feature is turned on. Development software (Lightroom and Adobe Camera RAW) can also correct it if the camera and lens profile exists.

BARREL AND PINCUSHION DISTORTION

Normally if an image is projected on a flat plane, straight lines at the edge of the frame will be curved outwards, which looks unnatural. This is considered to be barrel distortion. Our eyes would show similar effect at the periphery of our vision, but our brains compensate for it. In addition, we turn our eyes to see detail and don't notice the effect.

Lens designers put in considerable effort with multi-element designs to make the edges straight for rectilinear lenses. Sometimes they over-correct and end up with the opposite distortion, which is pincushion distortion. Cheaper zoom lenses can have barrel distortion at one end of the zoom and pincushion distortion at the other. Fisheye lenses do not correct barrel distortion.

This distortion can be corrected in some modern cameras by built-in software, if the function is turned on. It can also be corrected during development if the development software (eg Lightroom or Photoshop) has a lens profile available for the lens-camera combination. Lens profiles are available for most camera – lens combinations from one manufacturer (e.g. Canon cameras and lenses), but may not be available for third party lenses.

CHROMATIC ABERRATION

The edges of a lens are in effect a prism, so they will disperse white light into a rainbow. An image of a white spot at the corner of the frame becomes a tiny rainbow. On digital images, the tiny rainbow is captured as yellow, blue, purple or green fringes.

Again, good lens design can minimise this (apochromatic lenses). It can also be reduced by software in-camera or during development provided a camera – lens profile is available.

SOME OTHER LENS ABERRATIONS

Coma – results in distortion of the image at the edges and corners. A spot or circle will be rendered correctly in the centre of the image, but at the edge may be stretched radially, like a comet. It can also be stretched circumferentially. Usually only evident at maximum aperture.

Spherical aberration – The centre of the image can be focused sharply, but the edges of the image are always soft. Modern apochromatic lenses, and those with more expensive parabolic surfaces can correct these distortions.

Un-flat field – the centre of the image can be focused but the edges are unsharp, but also the edge can be focused, when the centre will be unsharp. The focus plane is not a flat but is spherical. This aberration is rare with modern lenses. Can be corrected by stopping the lens down to increase depth of focus.

Flare – a degradation of the image due to internal reflections when the lens is pointed towards a strong light source. Reduced by special lens coatings (multicoated lenses).

LENS QUALITY AND VALUE

Camera lenses like many other things are variable in quality. I hope I have in the previous sections explained how difficult it is to design a high-quality lens.

Quality can vary from the kit lenses priced at $200 supplied with prosumer cameras to the beautiful lenses supplied by Leica, Schneider and Zeiss which can cost over $10,000.

Probably the best value lenses are those supplied by the camera manufacturer. The Canon L-series lenses and their Nikon equivalents are designed for professional photographers. They integrate with the camera well as they are designed together. Aberrations such as vignetting, barrel distortion and chromatic aberration can be corrected by software in-camera or with Lightroom or Photoshop. Whereas third party lenses may not have this ability.

High quality requires precision manufacture and the ability to hand-adjust during assembly. It requires the use of expensive parabolic rather than spherical elements. Glasses of different strengths are required – flint glass and crown glass for example. Quality lenses are better sealed against the ingress of dust and moisture, and are rugged in design and construction. High quality means exceptional sharpness at all apertures, and minimal lens aberrations. It also means they can handle the knocks of a hard life. I and other club members have had cheap lenses fail when a small plastic part breaks internally as a result of a fall.

You get what you pay for unfortunately. But remember a good lens should be your friend and retain its value for many years if you care for it. They don’t go obsolete like cameras.

> *REMEMBER - DATE YOUR CAMERA, BUT MARRY YOUR LENSES – ANNON*

JST April 2019