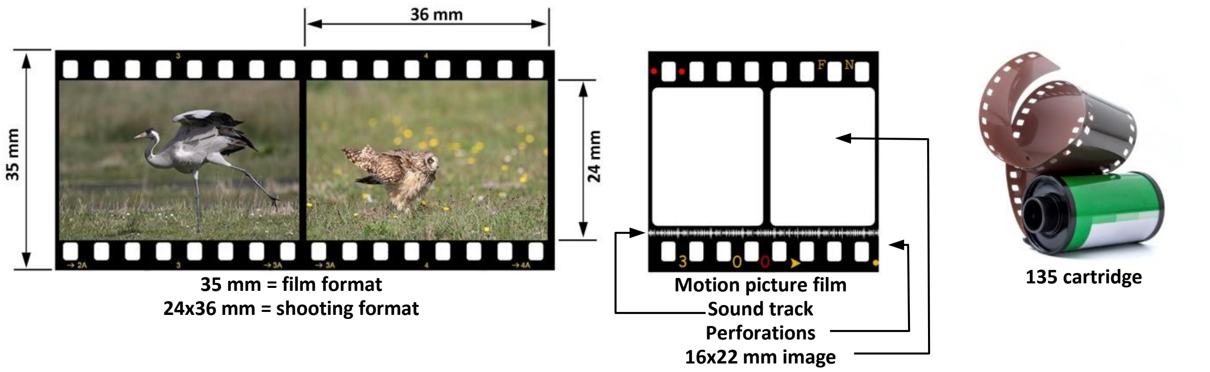
Equivalent focal length

Considerations on this sometimes misunderstood notion that is the equivalent focal length 35 mm or 24x36

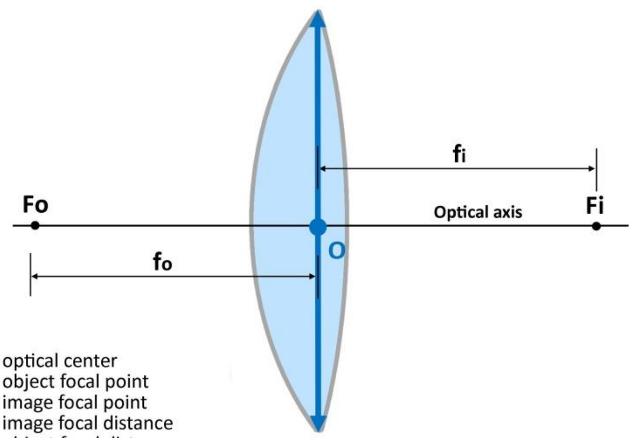
In photography, the focal distance equivalent to 35 mm (see box) or 24x36 is a measurement that indicates the particular angle of view of a camera lens combined with a specific type of film or sensor. The term comes from the time when the vast majority of photos were made with 35 mm films

Now that digital cameras have almost completely replaced film cameras, there is no longer a single relationship between the focal distance of a lens and the angle of view, since it also depends on the size of the sensor, which is not standardized as the film size was. The equivalent focal distance of 35 mm of a given lens-sensor combination is the focal length that would be required on a 35mm film camera to get the same angle of view.



The "film format" must be differentiated from the "shooting format." For example, a 135 film can be used to take classic images of 24-36 mm, 18x 24 mm (also called half-format) and panoramic images of 24-65 mm. Launched by Oskar Barnack (the inventor of the Leica) in1924, it is originally used for motion pictures. The two strips of film on either side of the image are used to punch the perforations and contain a magnetic strip for soundtrack. In photography, they will only be used to punch the perforations used to carry the film on the camera's drums. The 35 mm format will give the 135 cartridge, a packaging marketed by Kodak from 1934 allowing the loading and handling of the roll in broad daylight.

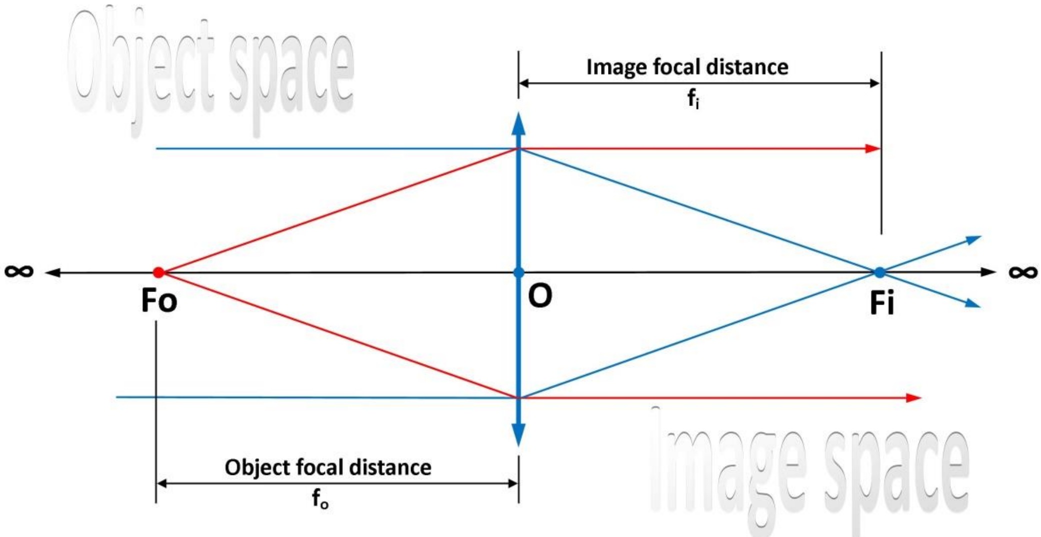
Reminders of optics principles



O = optical center
Fo = object focal point
Fi = image focal point
fi = image focal distance
fo = object focal distance

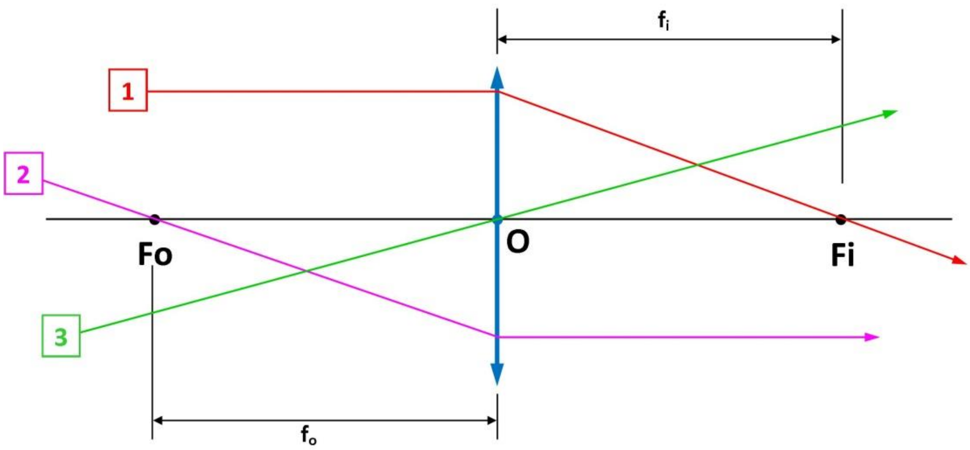
A convex lens is the intersection of two spheres. In optical diagrams, it will generally be represented not by the design of its actual cut but by its symbol (a double arrow of length equal to the larger size of the lens cut).

The *optical axis* is an imaginary line that crosses the lens by penetrating it perpendicular to the center of its entrance face. It could be materialized by joining the centers of the two constituent spheres of the lens. Schematically, the *optical center* is the point at the intersection of the optical axis and the lens symbol. Its exact determination is complex; let's just say that any light beam passing through the lens via the optical center is not deflected, does not experience any refraction.

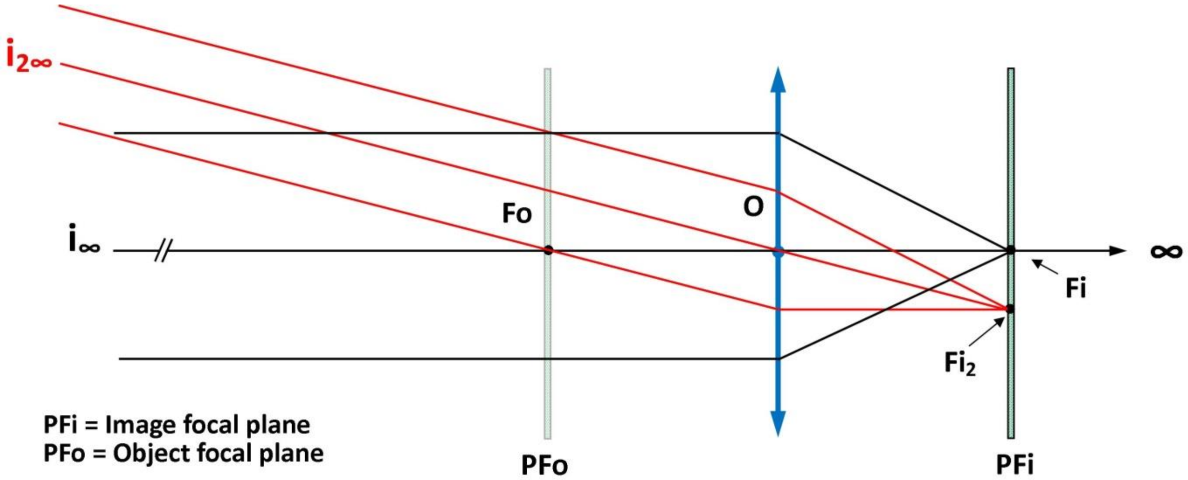


The *image focal point* is where the image of an object located at infinity is formed. It is therefore the point of the optical axis where all the light rays parallel to it converge; these light rays are considered to be coming from infinity. All rays are deflected except the one that is identical to the optical axis. The *focal distance* or commonly called focal length is the distance that separates the optical centre of the lens from its image focal point. In optics, the path of the light rays is perfectly symmetrical. Therefore there is also an *object focal point* and an object focal distance symmetrical in relation to the optical centre of the lens. Any light ray from the lens object focal point is deflected and comes out parallel to the lens's optical axis.

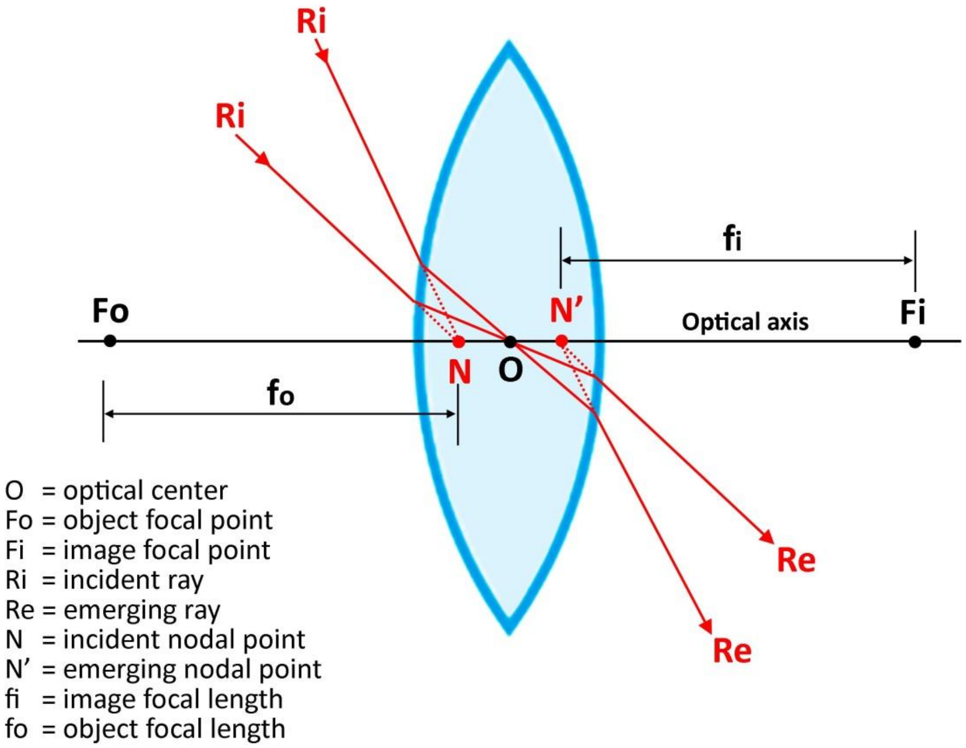
From what has been said above, three important light rays can be deduced. They behave invariably regardless of the position or shape of the object from which they originate. We'll call them special light rays.



1. Any incident light ray parallel to the optical axis is deflected towards the image focal point of the lens.
2. Any incident light ray passing through the lens object focal point is deflected and emerges from the lens parallel to the optical axis.
3. Any incident light ray passing through the optical center of the lens is not deflected and emerges from the lens in its extension.



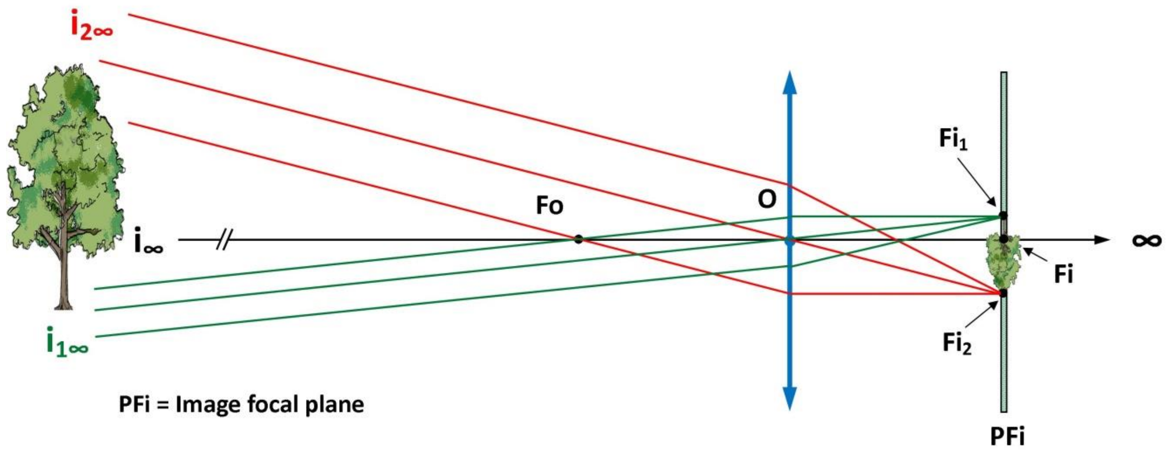
The *image focal plane* (PFi) is perpendicular to the optical axis and passes through the image focal point (Fi) on which images of objects located to infinity are formed. The Fi_2 point is a secondary image focal point of the lens for all light rays coming from direction $I_2\infty$. If a ground glass, film or digital sensor is placed on this focal plane, the objects seen by the lens can be viewed or recorded. This is the very principle of the camera. The *object focal plane* (PFo) is the plane perpendicular to the optical axis passing through the object focal point (Fo) of the lens. An object placed on the object focal plane can not to be viewed as it forms at an infinite distance since the light rays coming from it emerge from the lens parallel to each other.



Any incident light ray (Ri) is refracted, passes through the optical center of the lens and comes out parallel to itself. If the incident ray is extended, it cuts the optical axis to a point N. The same can be done with the emerging ray (Re). These points N and N' are called nodal points of the lens. Their location does not vary and depends on the thickness of the lens. The thinner it is, the closer the nodal points are to the optical center. The focal distance is actually measured from these points. They are of great importance in the construction and optical calculations of lenses. The diaphragm will be located at one of the nodal points or at the optical center of the lens, which is not always technically possible.

Image of an object located at infinity.

Under the behavior of the special light rays and admitting that all of them come from infinity, one can build the following graph. We can see that the image of this object located at infinity is built on the image focal plane.



Photographic infinity has nothing to do with mathematical infinity. In photography, it is considered that all objects located at 1000 times the focal length of the lens used are at infinity. Thus, with a lens of 50 mm focal length all objects located at 50,000 mm (or 50 m to be clearer) are at infinity. Let's be careful, however, this notion is indeed variable because the photographic infinity also called hyperfocal distance (if you focus at infinity, the hyperfocal distance is the distance beyond which all objects have an acceptable sharpness) is function of the focal length of the lens and the aperture.

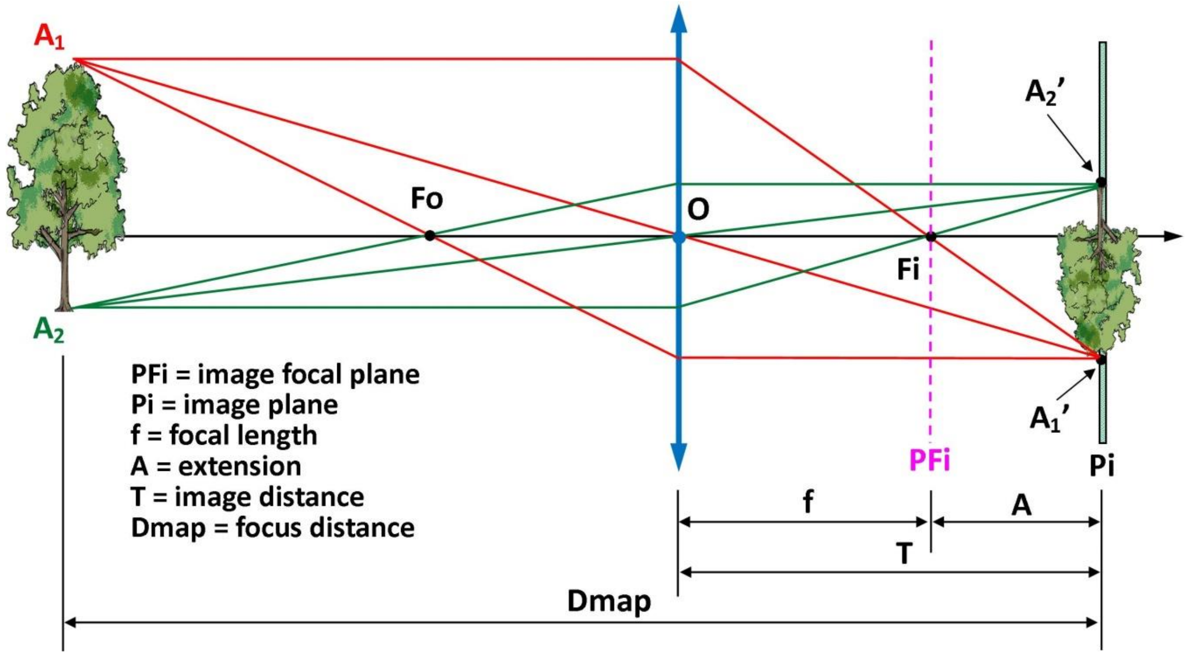
Image of an object located at a finite distance.

To form the image of a point at a distance less than infinity, we need to form the image of all the points that compose it. To this end, let's isolate a particular point of this object (A_1). This point emits rays in all directions. However, there are three of them whose particular behaviour is known:

- The ray parallel to the optical axis converges at the image focal point.
- The ray passing through the object focal point emerges parallel to the optical axis
- The ray passing through the optical centre is not deflected.

These three rays converge towards point A_1' which is the image of point A_1. The same can be done with point A_2, which forms its image at point A_2'as well as with all the points of the object. We notice that the image forms behind the image focal plane, on a new plane that will be called the *image plane (Pi).* Again, if you place a ground glass, film or digital sensor on this image plane, you can view or record this image.

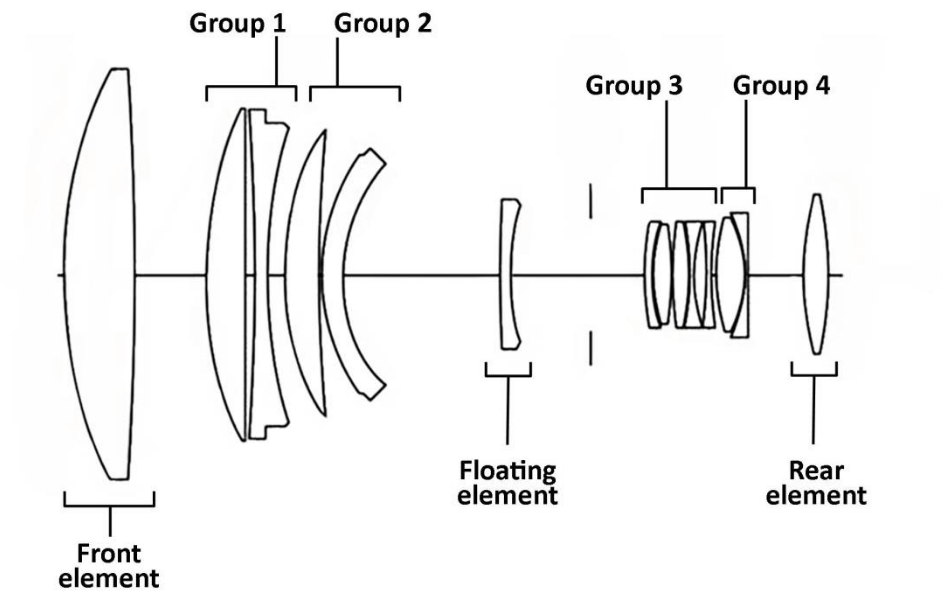
The distance between the optical center of the lens and the image plane is the *image distance (T),* the distance between the image focal plane and the image plane is *the extension (A)*. The *focus distance (Dmap)* is always the distance between the subject and its image (image focal plane or image plane).



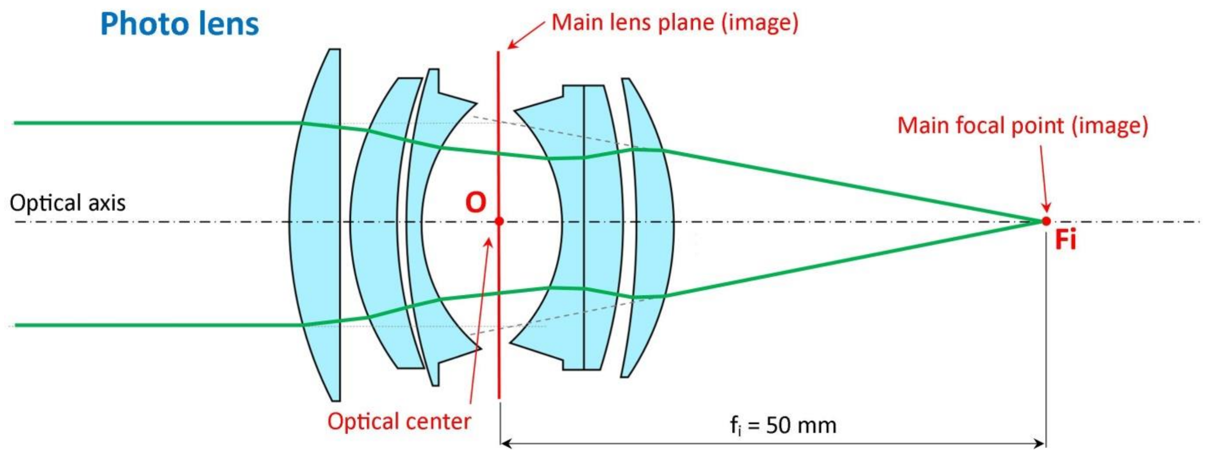
Lenses.

Elements and groups.

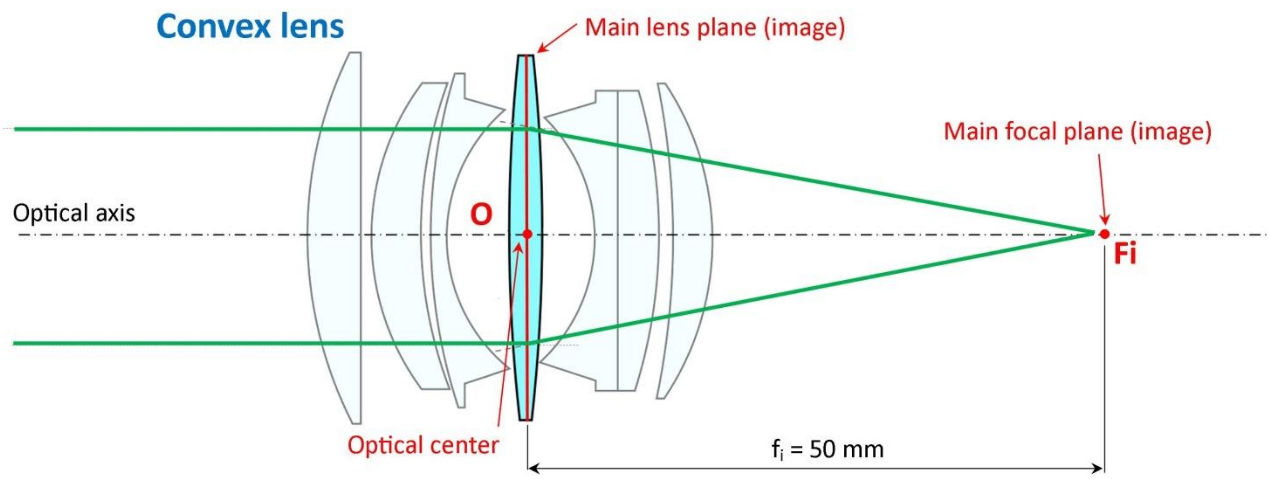
If you want to get images of photographic quality, you need more than a single convex lens. To build a photo lens, it will be necessary to assemble several lenses to ensure the formation of a suitable image on the sensor or film plane. Two or more lenses joined together by bonding on their entire surface or not make up a ***group.*** An isolated lens (the entire surface of which is in contact with air) is an ***element.*** The different groups and elements are separated by air.



The axes of all lenses must be aligned with the optical axis of the lens to achieve a centered system (unlike tilt-shift lenses for example). The main plane of the lens is perpendicular to its optical axis. It is in this plan that manufacturers will try to place the diaphragm. It is easy to understand that in such more or less complex optical systems, light rays are refracted in various ways by the different lenses that make up the groups and elements; they do not follow a straight path.

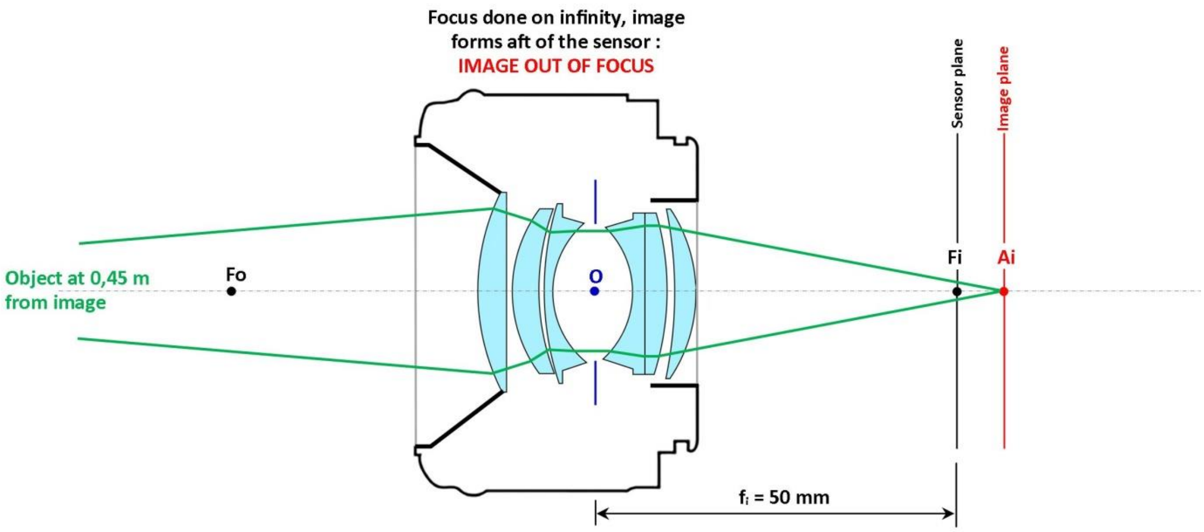


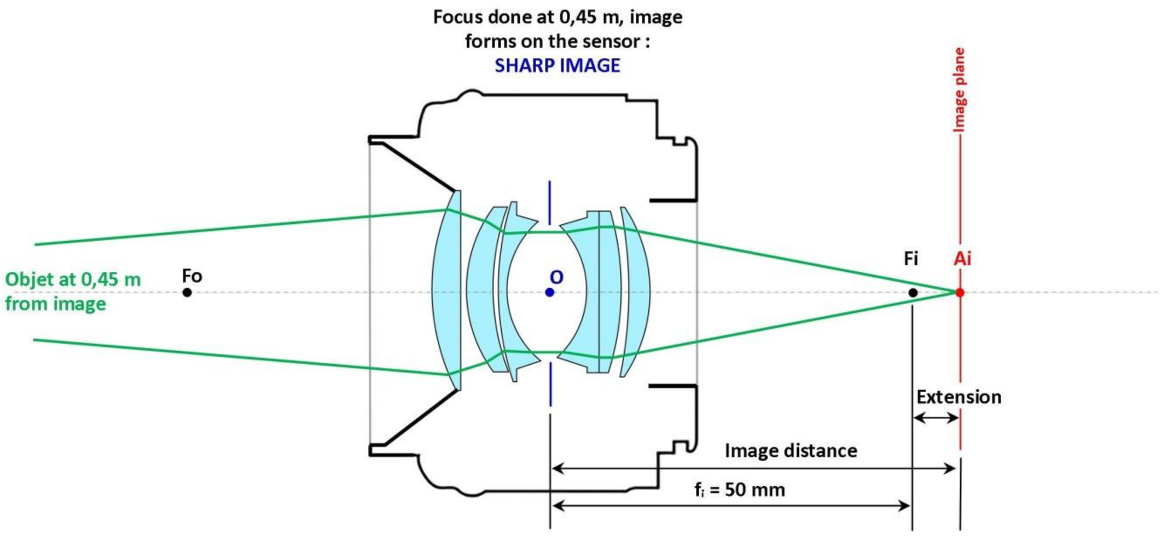
However, for the simplicity of the reasoning, we will continue to equate a lens (regardless of the number of groups and elements that make it up) with a thin converging lens of equivalent focal distance.



Focusing in photo lenses.

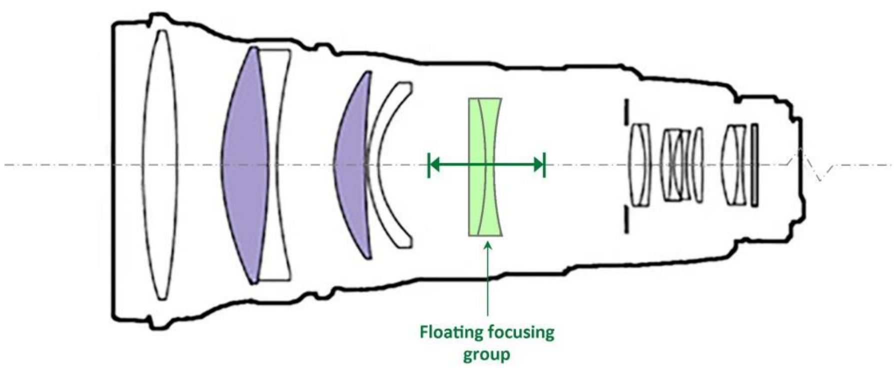
We have seen above that if the focus of a lens is done on infinity, a sharp image of the object forms on the image focal plane (located in the image focal point of the lens and where the photographic sensor is). The image plane is therefore confused with the image focal plane. On the other hand, if the subject is at a finite distance from the camera and the lens is still set to infinity, this image will form aft of the image focal plane (the image plane is no longer confused with the image focal plane) and the image formed on the sensor is not sharp. In order to sharpen it, we will have to move the optical center of the lens forward a distance equal to that separating the image plane from the image focal plane: the extension. This actually increases the image distance.





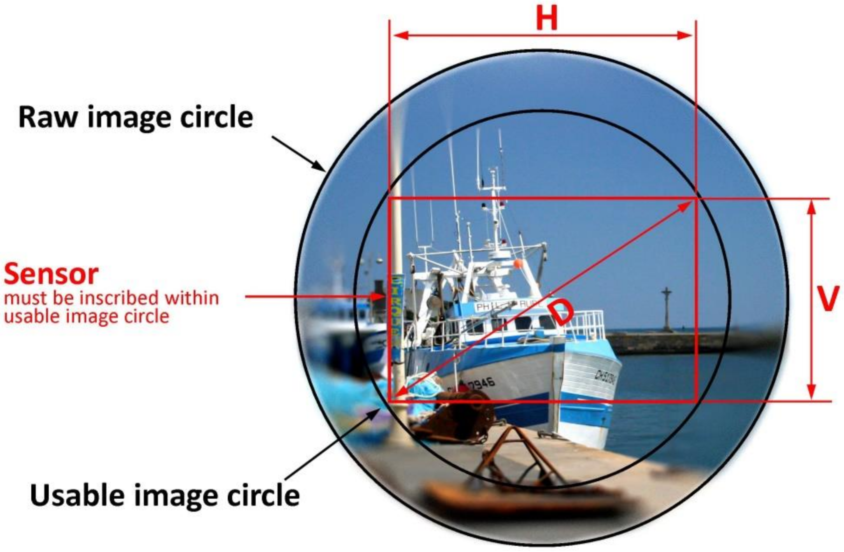
In a camera, the focus is done by moving all the lenses (groups and elements) that make up the lens or only a part of them (groups or floating focus elements). It is optimal when the photosensitive surface (film or sensor) coincides with the plane where the image of the object to be photographed is formed.

Canon EF 400 mm f/2.8 L IS USM



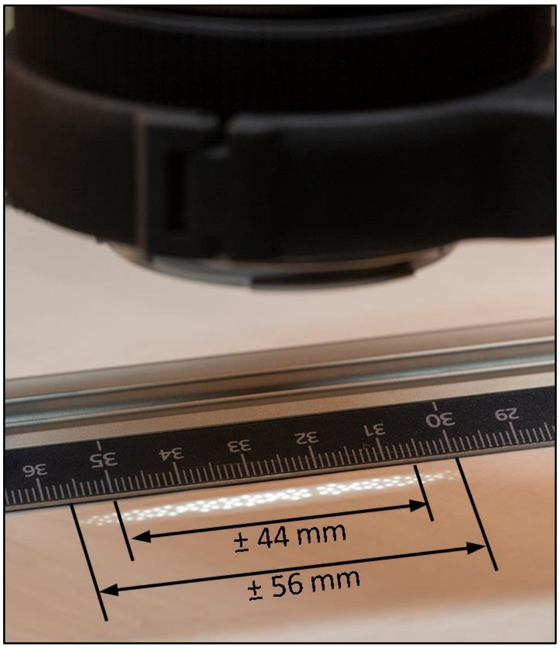
Field of view and image circle

Every lens has a "field of view" limited to a certain angle. Objects outside this *angle of field* are not "seen" by the lens and therefore do not appear in the image. The lens has a circular section; the image it forms is obviously rounded: it is the *raw image circle* characterized by its diameter. It is known that the quality of the image decreases on the periphery of this raw image circle due to the aberrations and distortions that appear on the edges of the image. There is, therefore, within this raw image circle, in which the whole image is clear and devoid of any drop in luminance, aberration, distortion or loss of quality; the *usable image circle*. The entire rectangle formed by the sensor must be inscribed in this useful image circle whose diameter must be at least equal to the diagonal of the format to be covered. Otherwise, the corners of the image will darken. The lens does not cover the shooting format and that there is vignetting.



It is easy to calculate this diagonal using the Pythagorean formula $D = \sqrt{V^2 + H^2}$
So we find : 43 mm for the 24x36 full frame
28.6 mm for APS-C
27 mm for Canon APS-C
In practical, the lenses have a rough image circle whose diameter is slightly larger than the diagonal of the shooting format to be covered.

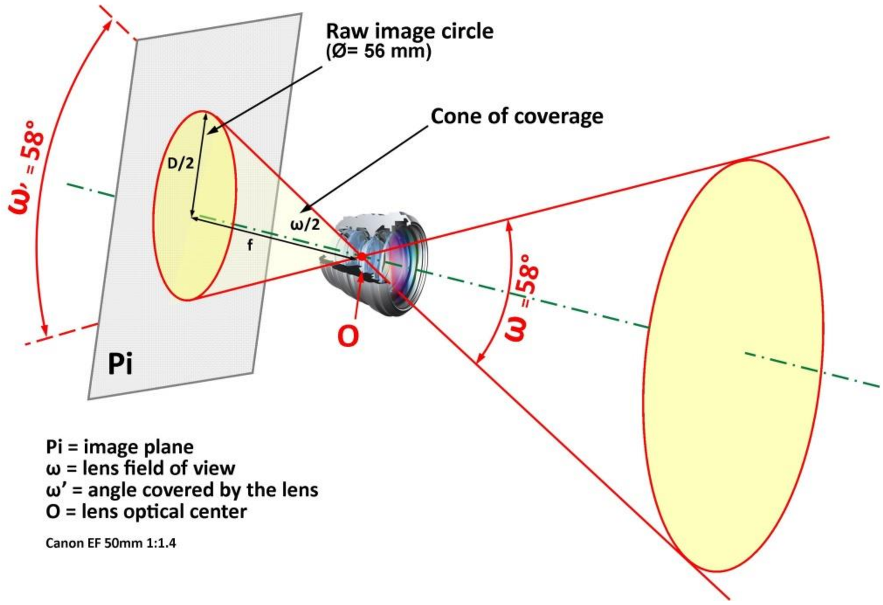
Although empirical and subjective, there is a method to measure the field view of a lens. Let's install this lens on top of a sheet of paper at a distance more or less equal to its focal length. Beforehand, we will have closed its diaphragm to f/16 and set the focus to infinity. Let's light it up with a LED light fixture, for example, and fine-tune the distance from the sheet of paper until the image of the fixture is clear. Now the sheet of paper is located on the focal image plane of the lens. Now all we have to do is measure the formed image.



Canon EF 50mm f/1.4

I made the measurements for two different lenses: Canon EF 50mm f/1.4 (designed for full format) and Canon EF-S 18-135mm f/3.5-5.6 (designed for the APS-C Canon format). The figure above shows that the diameter of the raw image circle is 56 mm while that of the usable image circle is 44 mm. For the APS-C lens, I measured 36 and 28 mm respectively.

Now let's calculate the field of view of this lens.

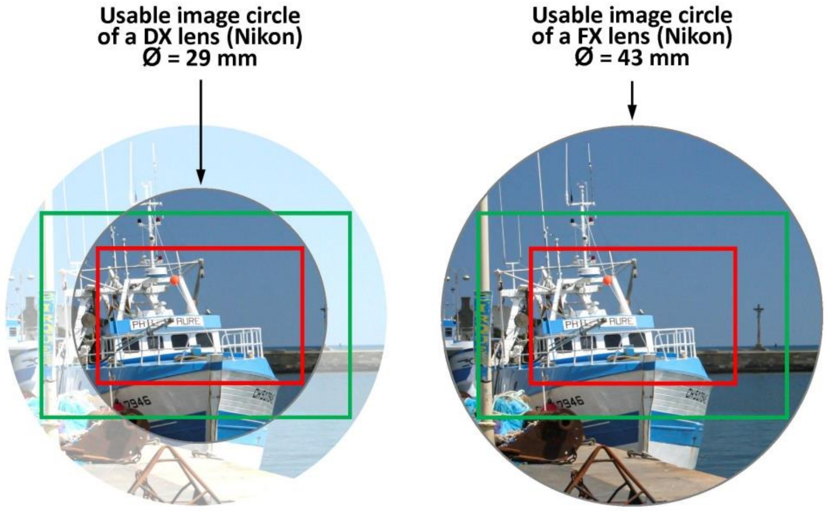


$\frac{D}{2} = f\ tan\frac{\omega}{2}$ or $D = 2\ f \tan\frac{\omega}{2}$ thus $\tan\frac{\omega}{2} = \frac{D}{2f}$

$$\frac{\omega}{2} = arctan\frac{D}{2f}$$

$$\omega = 2\ arctan\frac{D}{2f}$$

For the full frame lens there is therefore a 58-degree field angle corresponding to the raw image circle. A 47-degree field angle will match the useful image circle. We see that the angle of field of view varies with the focal length of the lens and with the diameter of the usable image circle that corresponds to the format used. It is also understandable that the construction and optical formula of the so-called full frame and APS-C lenses is not the same. Indeed, the usable image circle of an APS-C lens does not necessarily have to be as large as that of a full frame format.

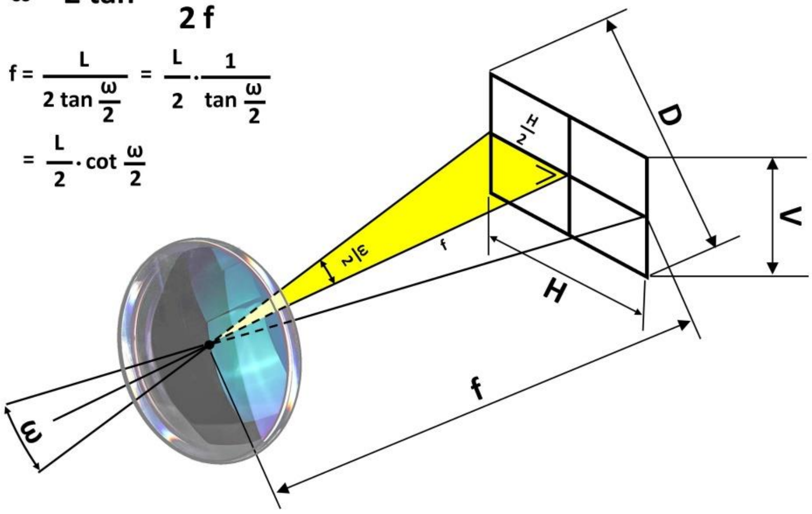


Framing obtained with a DX sensor (16 x 24 mm)
Framing obtained with a FX sensor (24 x 36 mm)

This is why most manufacturers produce two types of lenses adapted to the two major types of sensors, 24x36 or APS-C. When it comes to making a choice, let's not forget that a full-size lens will be usable with both a full-size sensor and APS-C. The reverse is not true. Indeed, a 24x36 sensor will be larger than the field covered by an APS-C lens and there will be vignetting (as can be seen in the figure above). For Canon lenses, an EF lens can be used on a full frame body (EOS 1D, 6D and 5D) as well as on an APS-C body. On the other hand, it will be mechanically impossible to mount an EF-S lens on a full frame body and it can therefore only be used in an APS-C camera. With Nikon both types of lenses can be mounted on both types of body; FX cameras correct the fact that the DX circular image is smaller than the full-size sensor by activating only pixels fitted in the size of a DX sensor.

$$\omega = 2 \tan^{-1} \frac{L}{2f}$$

$$f = \frac{L}{2 \tan \frac{\omega}{2}} = \frac{L}{2} \cdot \frac{1}{\tan \frac{\omega}{2}} = \frac{L}{2} \cdot \cot \frac{\omega}{2}$$



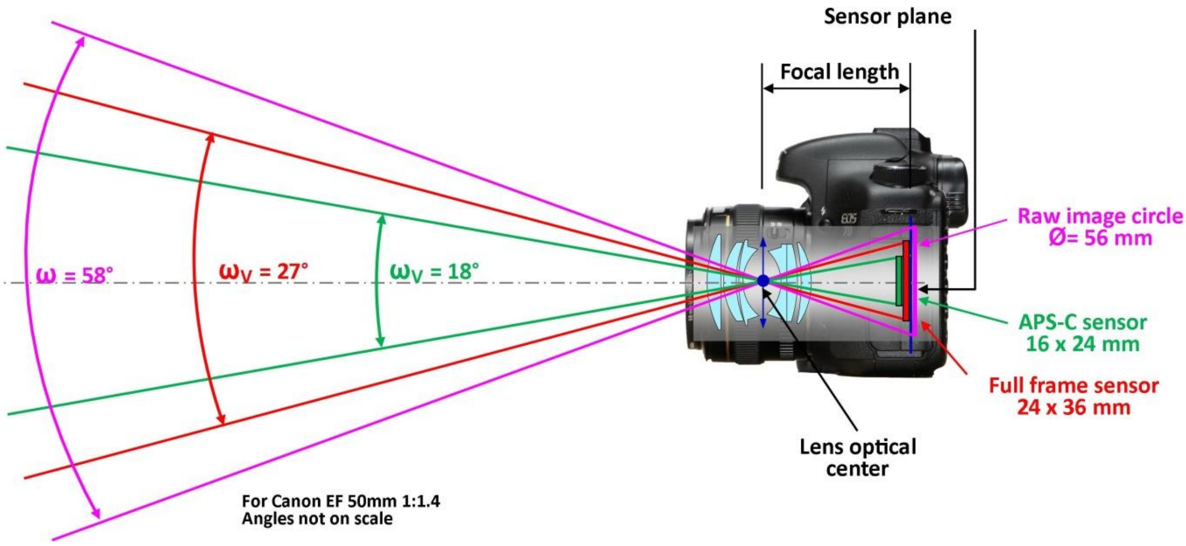
Vertical, horizontal and diagonal field angles can be calculated based on sensor size and lens focal length.

The demonstration of this formula has already been done above, so I will not return to it.

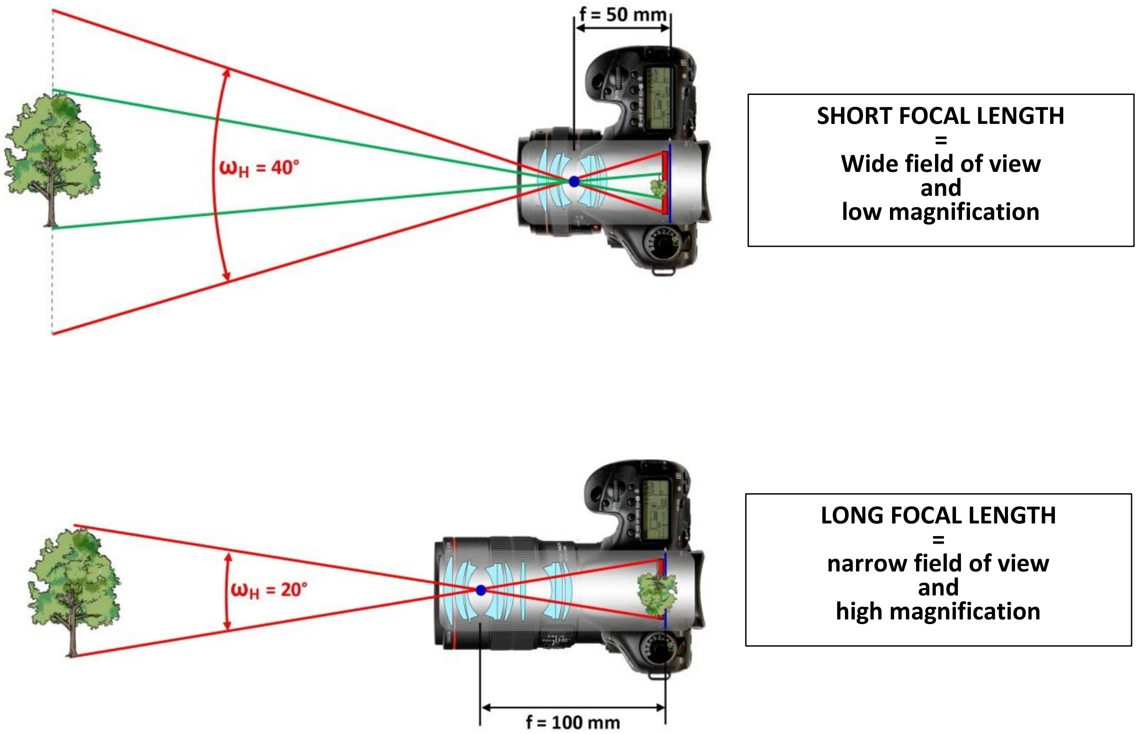
Here, L shows the width of the format used (H for "horizontal"), its height (V for "vertical") or its diagonal (D).

- ω = Angle of view
- L = The sensor's size
- f = focal length

The field of view (here the vertical field of view ω_V) varies with the size of the sensor



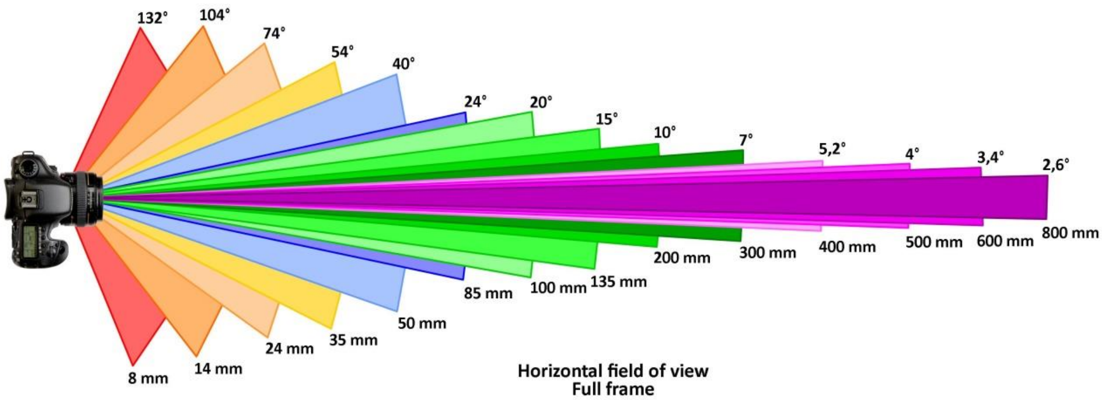
The field of view (here the horizontal field of view ω_H) varies with the focal length



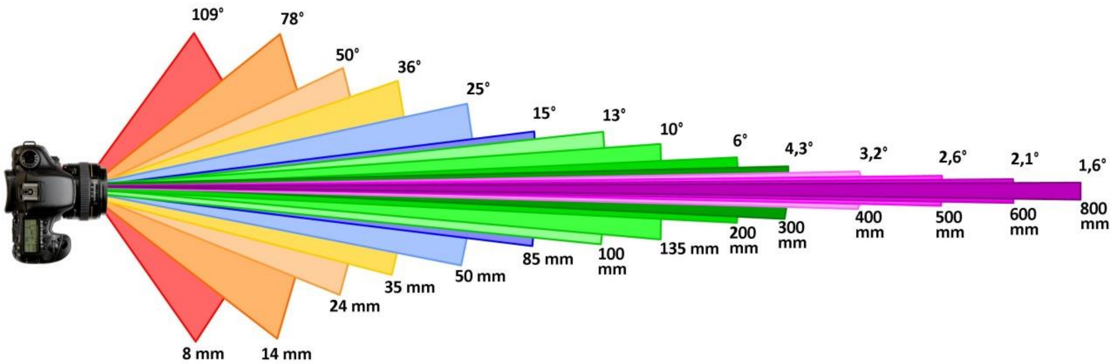
Below is a summary of diagonal, horizontal and vertical field of view for full format sensors (FF), Canon APS-C and 1/1.3' sensor (Nikon Coolpix A1000).

Fields of view for Canon EF lenses in degrees

	Full frame (in mm)			APS-C Canon (in mm)		
Focal	D	H	V	D	H	V
mm	43	36	24	27	22,5	15
8	139	132	113	119	109	86
14	114	104	81	88	78	56
24	84	74	53	59	50	35
35	63	54	38	42	36	24
50	47	40	27	30	25	17
85	28	24	16	18	15	10
100	24	20	14	15	13	9
135	18	15	10	11	10	6
200	12	10	7	8	6	4
300	8,2	6,9	4,6	5,2	4,3	2,9
400	6,2	5,2	3,4	3,9	3,2	2,1
500	4,9	4,1	2,7	3,1	2,6	1,7
600	4,1	3,4	2,3	2,6	2,1	1,4
800	3,1	2,6	1,7	1,9	1,6	1,1



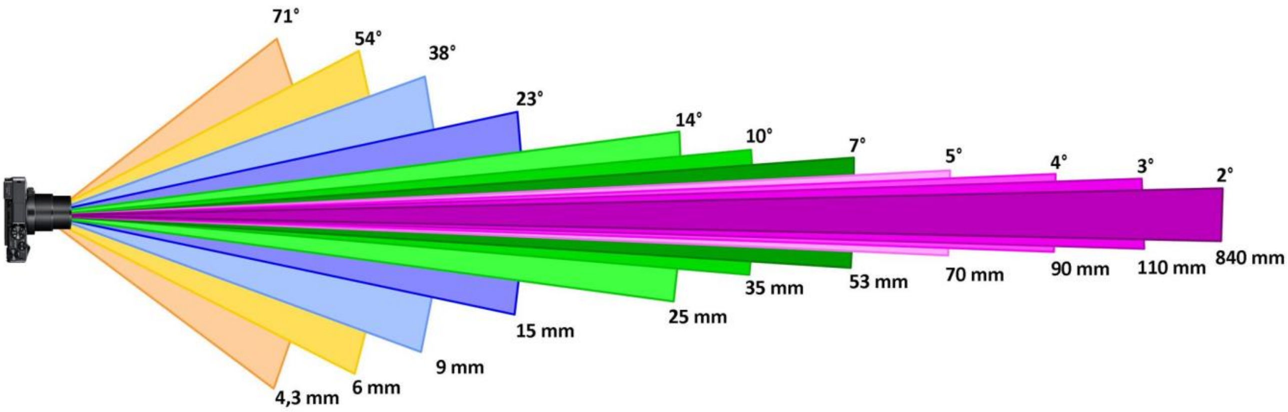
Horizontal field of view
Full frame



Horizontal field of view
APS-C Canon

Fields of view compact cameras

Nikon Coolpix A1000 35x optical zoom - Focal lengths from 4,3 to 150 mm 1/2,3" sensor (6,16 x 4,62 mm)											
f (mm)	4,3	6	9	15	25	35	53	70	90	110	150
ω (°)	71	54	38	23	14	10	7	5	4	3	2
f (24x36)	*24*	*34*	*50*	*84*	*140*	*196*	*297*	*392*	*504*	*616*	*840*

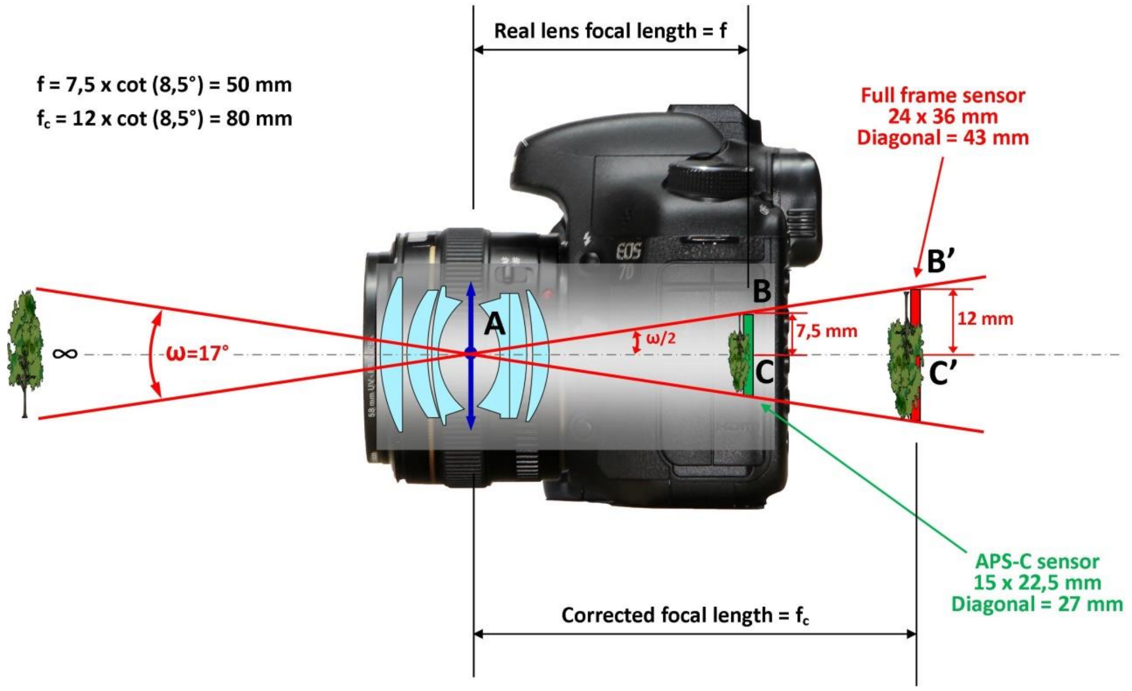


Equivalent or corrected focal length.

As we said at the beginning of this article, in photography, the equivalent or corrected focal length in 35 mm or 24x36 is a measurement that indicates the particular angle of view of a camera lens combined with a specific type of film or sensor that would produce the same framing on a 24x36sensor. The equivalent focal length to 35 mm of a given lens-sensor combination is the focal length that would be required on a 35mm film camera to get the same angle of view. In other words, starting from a lens/APS-C body combination (for example), what should be the focal length of a lens that I would mounted on a camera body equipped with a full frame sensor so that it has the same angle of field? In the following figure, I consider the case of an APS-C body equipped with a 50 mm focal length lens. So under the formula of the field angle depending on the focal length and the size of the sensor we can calculate the vertical field angle (landscape framing) of the set at 17 degrees.

In the right triangles ABC et AB’C’, respectively AC=BC cot αA and AC’=B’C’ cot αA. Thus :

- AC = 7.5 mm x cot(8.5°) = 50 mm = focal length of the lens/sensor combination
- AC’ = 12 mm x cot(8.5°) = 80 mm = equivalent or corrected focal length to 35 mm



If we start from the last formula of the box above, we can make the following reasoning:

$$\frac{f}{f_c} = \frac{\frac{V_{FF}}{2} \cdot \cot\frac{\omega}{2}}{\frac{V_{APS\text{-}C}}{2} \cdot \cot\frac{\omega}{2}} = \frac{\frac{V_{FF}}{2}}{\frac{V_{APS\text{-}C}}{2}} = \frac{V_{FF}}{2} \cdot \frac{2}{V_{APS\text{-}C}} = \frac{V_{FF}}{V_{APS\text{-}C}}$$

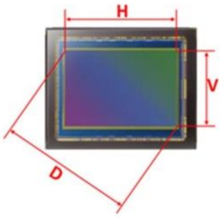
With : f = real land focal length
f_c = 24x36 corrected focal length
V_{FF} = vertical dimension of the full frame format = 12 mm
$V_{APS\text{-}C}$ = vertical dimension of the Canon APS-C sensor = 7.5 mm
ω = angle of view of the lens/sensor combination

The same development can be done with the other dimensions of the sensor (H or D)
This gives us a correction factor only based on the size of the sensor. So:

- The correction factor for APS-C Canon is 24/15 or 36/22.5 or 43/27 = 1.6
- The correction factor for APS-C Nikon is 24/15.8 or 36/23.8 or 43/28.6 = 1.5
- The corrected focal length of the figure example is 50 x 1.6 = 80 mm.

It is now possible to assign a correction factor to each type of sensor based on its physical dimensions.

Summary of the mostly used sensors



Sensor dimensions

Sensor	Dimensions in mm			Image ratio	Conversion factor	Examples
	H	V	D			
1/3"	4,8	3,6	6,0	4/3	7,2	Nikon Coolpix W150
1/2,5"	5,76	4,29	7,2	4/3	6,0	Smatphone Iphones - Samsung série S Huawei P9 …
1/2,3"	6,16	4,62	7,7	4/3	5,6	Canon SX70HS, SX700HS, 540 HS… Canon Ixus, Powershot… Nikon Coolpix A10, A1000, B600, P1000… Sony HX60, HX99, H400V, WX 500/350/830… Olympus TG5/6… Panasonic Lumix FT30, TZ96, FZ82…
1/1,7"	7,6	5,7	9,5	4/3	4,6	Canon Powershot G16, S200, S120, N100… Fujifilm LX7, LF1… Nikon Coolpix P340 …
1"	13,2	8,8	15,9	3/2	2,7	Canon G3X, G5X, G7X, G9X. Nikon 1 J3… Sony RX100 , RX10 , AX100 … Panas Lumix FZ1000, TZ202, TZ101
4/3	17,3	13	21,6	4,3	2,0	Fujifilm Lumix Série G, LX100… Olympus Pen EPL 8/9/10, PEN-F, OMD E-M1X, E-M5, E-M10…
APS-C Canon	22,5	15	27,0	3/2	1,6	Canon 76D, 77D, 80D, 90D, 7D, 7D Mk ii, 250D, 800D, 2000D, 4000D, EOS M, G1X Mk iii… Fujifilm XPro3, X-T2, G-T20, X-A3,5,7, XF-10
APS-C autres	23,8	15,8	28,6	3/2	1,5	Nikon D300, D3200, D3300, D5200, D5300, D5500, D7100, D7200, D7500, D500, Z50… Sony série α6000, α58/68/77…
APS-H	27,9	18,6	33,5	3/2	1,3	Canon 1D (plus produit
Plein format	36	24	43,3	3/2	1,0	Canon 1D, 1DX, série 5D, 6D, EOS R… Nikon D3S, D4, D5, D700, D800, D810, D850, Df, Z6, Z7… Sony α7, α9, RX1… Panasonic Lumix série S...
Moyen format	43,8	32,9	54,8	4/3	0,8	Fujifilm GFX50S, GFX50R,GFX100… Haselblad X1D II 50C, H6D 50C
	53,4	40	66,7	4/3	0,6	Haselblad H6D 100C

Conclusion.

Consider the following points of comparison:

Magnification.

Although rarely used in normal photography, the magnification is the ratio between the size of the image recorded on the camera sensor and the actual dimension of the subject photographed. The magnification G=the size of the image on the sensor/the real size of the object. For example :

- If you are photographing a 2 cm object and the image of that same object measures 1 cm on the sensor, then we have a magnification of 1/2 (often rated 1:2), or a magnification factor of 0.5x.
- If the image of the same object measures 2 cm on the sensor, the magnification will be 1/1 (1:1), the magnification factor 1x

Perspective

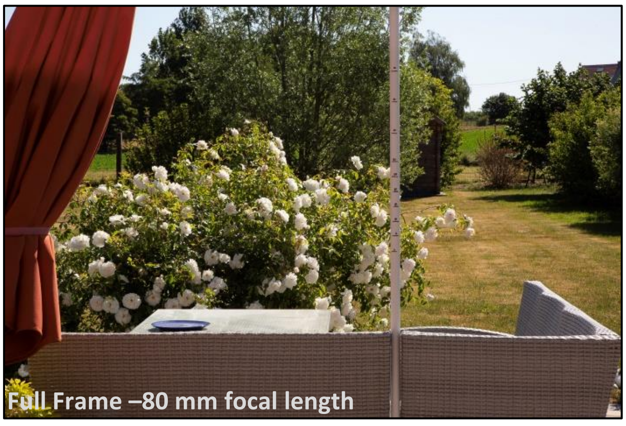
The perspective, as I hear it here, refers to the size of the objects as well as the distance between them.

The wide angle allows you to include more elements in your photo. On the other hand, it tends to stretch the perspective, that is to say give the impression that the different elements of the image look further from each other. On the contrary, the telephoto lens allows you to get closer to your subject and give the impression that the different elements are closer to each other.

The following photos are made up of four separate shots. Away from the shooting point: the garden lounge and parasol, the white rose, the willow and finally the garden shed. We realize that, by increasing the focal length, these different elements seem closer and closer to each other. The perspective is therefore changed by the change of focal length, the image "flattens" by increasing the focal length.


Full Frame –30 mm focal length

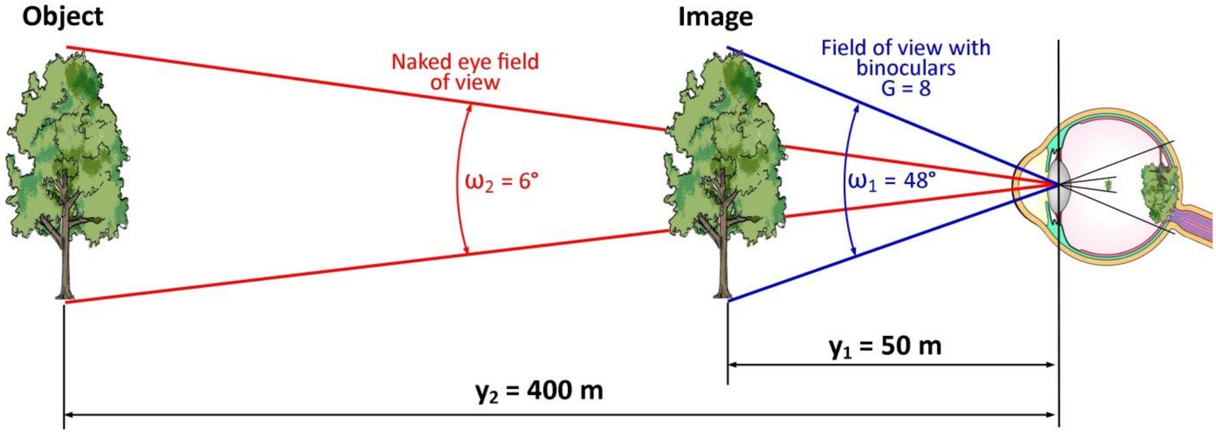

Full Frame –50 mm focal length


Full Frame –80 mm focal length


Full Frame –130 mm focal length

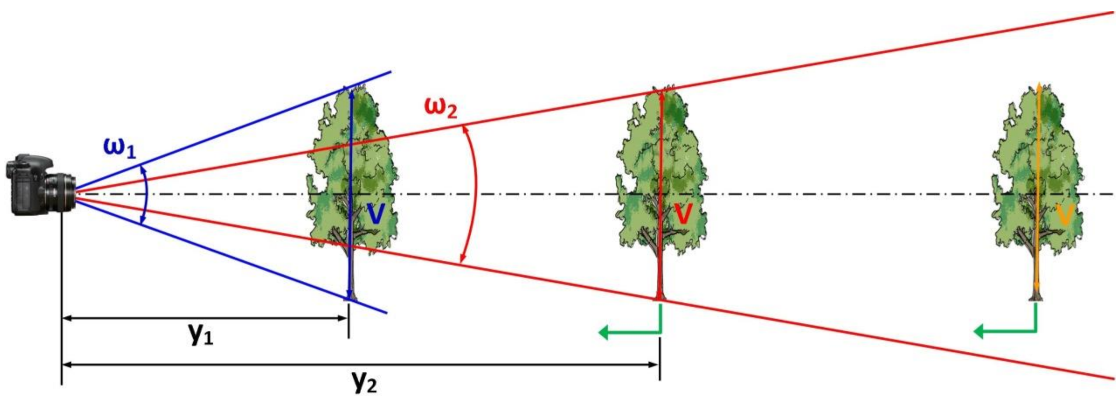
Magnifying power

The concept of magnification used for observation using an instrument (such as telescopes or binoculars) can be considered in a number of ways:



- To the naked eye, the image that forms on our retina is a certain size. Observation of the same object using an observation instrument produces an image on the retina of a different size, usually larger. The relationship between these two dimensions of the image is magnifying power. This concept is theoretical since it is impossible to directly measure the image at the retina.
- With an observation instrument, the object is seen as if it were located at another distance from the observer, usually a smaller distance. The magnifying power is the ratio between these two distances. Thus, binoculars magnifying 8 times will give me the impression that the subject is 8 times closer to me. This notion of closeness or bigger proximity is the one that is most often associated with magnification by the greatest number of us.
- In fact, this is all a matter of angles. The angular dimension of an object is the angle formed by the extreme points of the object and the eye of the observer. Through an optical instrument, this angle is different, usually larger, and the relationship between these two angular dimensions represents magnification. $G = \omega_1/\omega_2 = 48/6 = 8$

Can we draw a parallel between magnifying power and focal length of a lens?



$$y_1 = \frac{V}{2} \cot \frac{\omega_1}{2} = \cot \frac{\omega_1}{2} \qquad \text{donc} \qquad \frac{y_1}{y_2} = \frac{\cot \frac{\omega_1}{2}}{\cot \frac{\omega_2}{2}} = \frac{\cot 13{,}5°}{\cot 7°} = \frac{1}{2}$$

$$y_2 = \frac{V}{2} \cot \frac{\omega_2}{2} = \cot \frac{\omega_2}{2}$$

Let's first accept the following notion (which I will not develop here but which is accepted by many photographers): a 50 mm focal length on a full frame sensor more or less corresponds to human vision, and produces a magnifying power of 1X.

Let's imagine a full frame SLR that we first equip with a 50 mm focal length lens with a vertical field of view of 27 degrees. In order for an object of vertical size = V to occupy the full height of the sensor, we must be at a distance from the object equal to Y_1. Now let's change the lens for a 100 mm with a vertical field of view of 14 degrees. If we want this same size = V object to occupy the full height of our sensor, we must move at a distance of Y_2 equal to twice Y_1. Therefore, with a 100 mm, an object seems twice as close as it actually is (magnifying power of 2X). Let's increase the focal length to 200 mm and we see that Y2 is now equal to four times Y_1 magnifying power of 4X).

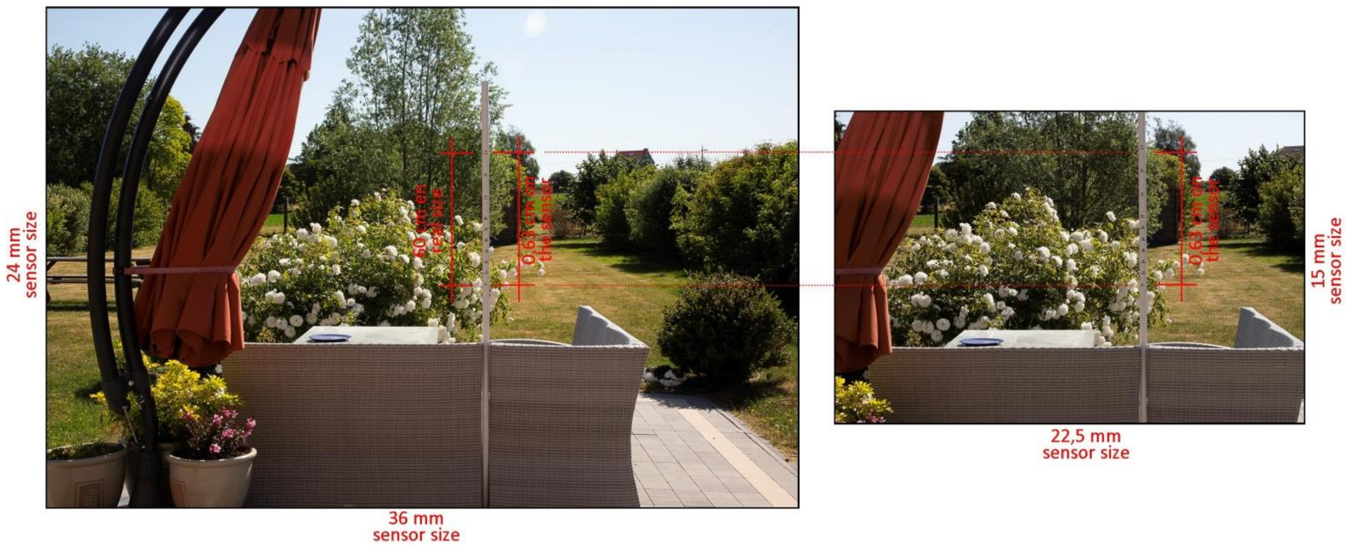
In addition, the summary of fields of view above shows a ratio of 1/2 for each doubling of the focal length meaning a doubling of magnifying power.

For example: 50 mm –= 27° and G = 27/27 = 1
100 mm = 14° and G = 27/14 = 2
200 mm = 7° and G = 27/7 = 4
400 mm = 3.4° and G = 27/3.4 = 8
800 mm = 1.7° and G = 27/1.7 = 16

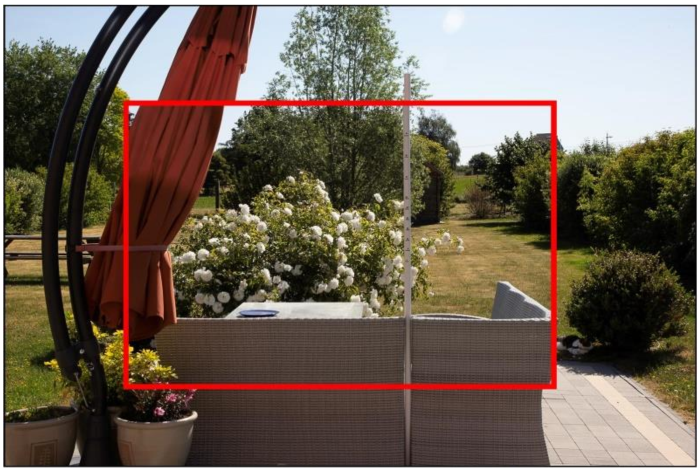
So we can consider that the magnifying power produced by a lens is worth its focal length divided by 50.

Let's compare two raw images.

Let's look at the next two images. The one on the left was made using a camera equipped with a full frame sensor with a 50 mm focal length lens; the one on the right with the same lens but this time with a body fitted with an APS-C sensor. The size of these two photos is proportional to that of the respective sensors



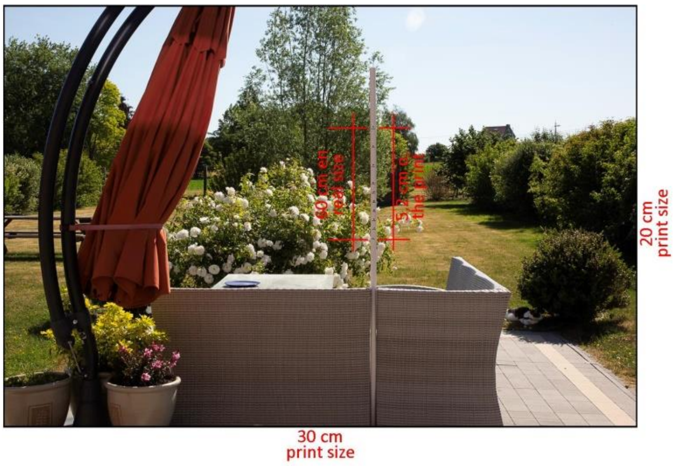
1. The size of the 60 cm segment on the front plane bar is the same size on both images (or sensors): the magnification does not change.
2. The perspective on the two photos remains the same: the perspective is not affected.
3. The size of the objects in the two photos and the angle at which they are shown do not vary: the magnifying power does not change

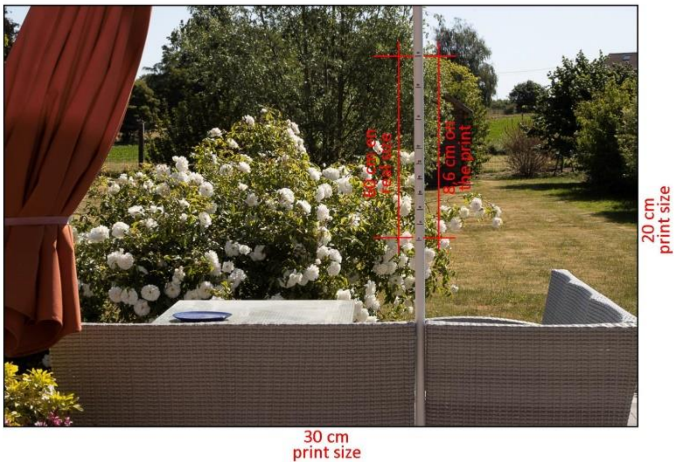


Only the framing of the shot changes. Both sensors "see" exactly the same scene. The full frame image is simply trimmed to be limited to what the APS-C sensor covers.

Let's compare two prints of the same size.

Let's look at the next two images. The top one was made with a camera again equipped with a full frame sensor with a 50 mm focal length lens; the bottom one with the same lens but this time with a body fitted with an APS-C sensor. We made a print o these two photos 30 X 20 cm in size.





1. The size of the 60 cm segment on the front-plane bar is no longer the same size on the two images (or prints): the reproduction ratio (or print ratio) varies from 1/12 on the top draw to 1/7 on the bottom.
2. The perspective on the two prints changes: the perspective on the bottom photo seems more flat.
3. The objects in the two photos and the angle at which they are shown are different this time. The size of the 60 cm segment on the bar at the foreground is no longer the same size on the two images (or prints), 5.2 cm versus 8.6 cm. If, again, we accept that a 50mm focal length on a full frame has a magnifying power of 1X (on the top picture). On the bottom picture it becomes equal to 8.6/ 5.2 = 1.6X. We can therefore say that the equivalent focal length on the bottom print is 50 x 1.6 - 80 mm

These same differences will also be visible through the viewfinder or on the camera screen in "Life View" shooting mode.