CO–MAT IC

Research Document / Procces Report

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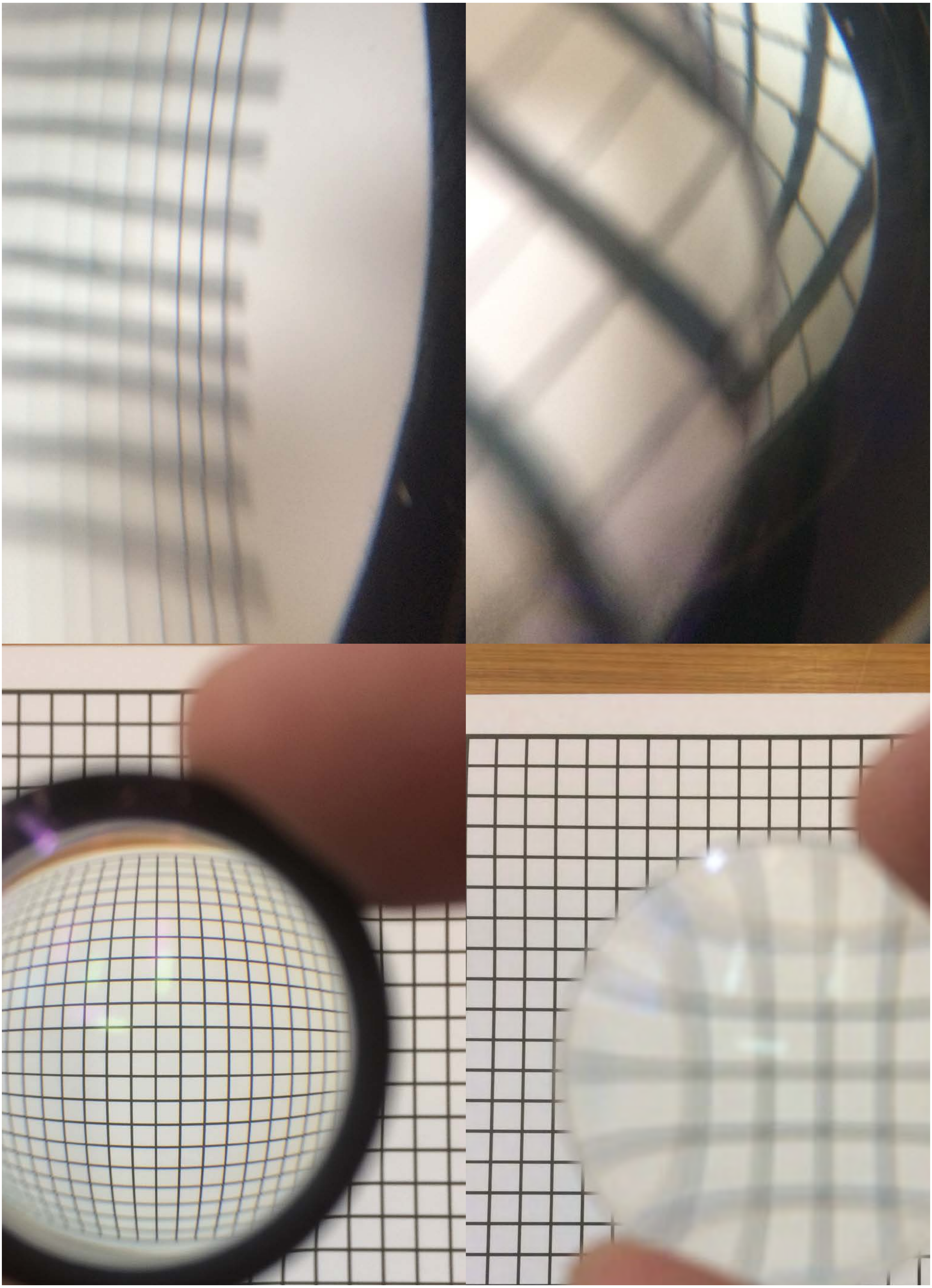
Practice: Digital Craft



FIRST LENS TEST.

HOW DO LENSES WORK?

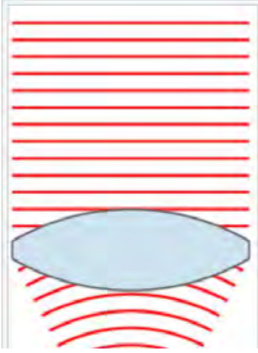
Lens (optics)

From Wikipedia, the free encyclopedia

For other uses, see Lens.

A **lens** is a transmissive optical device that focuses or disperses a light beam by means of refraction. A simple lens consists of a single piece of transparent material, while a compound lens consists of several simple lenses (*elements*), usually arranged along a common axis. Lenses are made from materials such as glass or plastic, and are ground and polished or molded to a desired shape. A lens can focus light to form an image, unlike a prism, which refracts light without focusing. Devices that similarly focus or disperse waves and radiation other than visible light are also called lenses, such as microwave lenses, electron lenses, acoustic lenses, or explosive lenses.

A biconvex lens



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History [edit]

See also: History of optics and Camera lens

The word *lens* comes from *lēns* , the Latin name of the lentil, because a double-convex lens is lentil-shaped. The lentil plant also gives its name to a geometric figure.[1]

The Nimrud lens. It is about 38 mm (1.5 in) in diameter

Some scholars argue that the archeological evidence indicates that there was widespread use of lenses in antiquity, spanning several millennia.[2] The so-called Nimrud lens is a rock crystal artifact dated to the 7th century BC which may or may not have been used as a magnifying glass, or a burning glass.[3][4][3][5] Others have suggested that certain Egyptian hieroglyphs depict "simple glass meniscal lenses".[6][*verification needed*]

The oldest certain reference to the use of lenses is from Aristophanes' play *The Clouds* (424 BC) mentioning a burning-glass.[7] Pliny the Elder (1st century) confirms that burning-glasses were known in the Roman period.[8] Pliny also has the earliest known reference to the use of a corrective lens when he mentions that Nero was said to watch the gladiatorial games using an emerald (presumably concave to correct for nearsightedness, though the reference is vague).[9] Both Pliny and Seneca the Younger (3 BC–65 AD) described the magnifying effect of a glass globe filled with water.

Ptolemy (2nd century) wrote a book on *Optics*, which however survives only in the Latin translation of an incomplete and very poor Arabic translation. The book was, however, received, by medieval scholars in the Islamic world, and commented upon by Ibn Sahl (10th century), who was in turn improved upon by Alhazen (*Book of Optics*, 11th century). The Arabic word for "lens", عدسة *'adasa* ("lentil") is a direct loan translation of Latin *lens*, *lenticula*. The Arabic translation of Ptolemy's *Optics* became available in Latin translation in the 12th century (Eugenius of Palermo 1154). Between the 11th and 13th century "reading stones" were invented. These were primitive plano-convex lenses initially made by cutting a glass sphere in half. The medieval (11th or 12th century) rock cystal Visby lenses may or may not have been intended for use as burning glasses.[10]

Spectacles were invented as an improvement of the "reading stones" of the high medieval period in Northern Italy in the second half of the 13th century.[11] This was the start of the optical industry of grinding and polishing lenses for spectacles, first in Venice and Florence in the late 13th century century,[12] and later in the spectacle-making centres in both the Netherlands and Germany.[13] Spectacle makers created improved types of lenses for the correction of vision based more on empirical knowledge gained from observing the effects of the lenses (probably without the knowledge of the rudimentary optical theory of the day).[14][15] The practical development and experimentation with lenses led to the invention of the compound optical microscope around 1595, and the refracting telescope in 1608, both of which appeared in the spectacle-making centres in the Netherlands.[16][17]

Further information: History of the telescope

Construction of simple lenses [edit]

Most lenses are *spherical lenses*: their two surfaces are parts of the surfaces of spheres. Each surface can be *convex* (bulging outwards from the lens), *concave* (depressed into the lens), or *planar* (flat). The line joining the centres of the spheres making up the lens surfaces is called the *axis* of the lens. Typically the lens axis passes through the physical centre of the lens, because of the way they are manufactured. Lenses may be cut or ground after manufacturing to give them a different shape or size. The lens axis may then not pass through the physical centre of the lens.

Toric or sphero-cylindrical lenses have surfaces with two different radii of curvature in two orthogonal planes. They have a different focal power in different meridians. This forms an astigmatic lens. An example is eyeglass lenses that are used to correct astigmatism in someone's eye.

More complex are aspheric lenses. These are lenses where one or both surfaces have a shape that is neither spherical nor cylindrical. The more complicated shapes allow such lenses to form images with less aberration than standard simple lenses, but they are more difficult and expensive to produce.

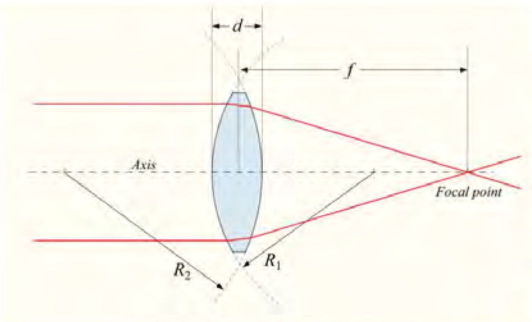
Types of simple lenses [edit]

Lenses are classified by the curvature of the two optical surfaces. A lens is *biconvex* (or *double convex*, or just *convex*) if both surfaces are convex. If both surfaces have the same radius of curvature, the lens is *equiconvex*. A lens with two concave surfaces is *biconcave* (or just *concave*). If one of the surfaces is flat, the lens is *plano-convex* or *plano-concave* depending on the curvature of the other surface. A lens with one convex and one concave side is *convex-concave* or *meniscus*. It is this type of lens that is most commonly used in corrective lenses.

Biconvex | Plano-convex | Positive meniscus | Negative meniscus | Plano-concave | Biconcave

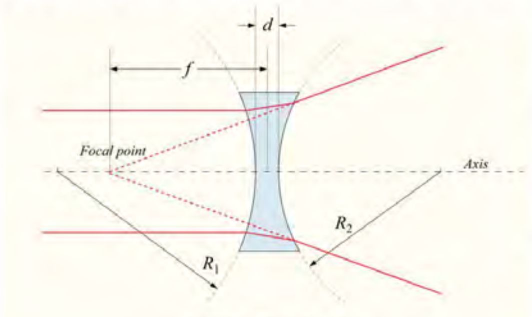
If the lens is biconvex or plano-convex, a collimated beam of light passing through the lens converges to a spot (a *focus*) behind the lens. In this case, the lens is called a *positive* or *converging* lens. The distance from the lens to the spot is the focal length of the lens, which is commonly abbreviated *f* in diagrams and equations. An extended hemispherical lens is a special type of plano-convex lens, in which the lens's curved surface is a full hemisphere and the lens is much thicker than the radius of curvature.

Abborations



Positive (converging) lens

If the lens is biconcave or plano-concave, a collimated beam of light passing through the lens is diverged (spread); the lens is thus called a *negative* or *diverging* lens. The beam, after passing through the lens, appears to emanate from a particular point on the axis in front of the lens. The distance from this point to the lens is also known as the focal length, though it is negative with respect to the focal length of a converging lens.



Negative (diverging) lens

Imaging properties [edit]

As mentioned above, a positive or converging lens in air focuses a collimated beam travelling along the lens axis to a spot (known as the focal point) at a distance *f* from the lens. Conversely, a point source of light placed at the focal point is converted into a collimated beam by the lens. These two cases are examples of image formation in lenses. In the former case, an object at an infinite distance (as represented by a collimated beam of waves) is focused to an image at the focal point of the lens. In the latter, an object at the focal length distance from the lens is imaged at infinity. The plane perpendicular to the lens axis situated at a distance *f* from the lens is called the *focal plane*.

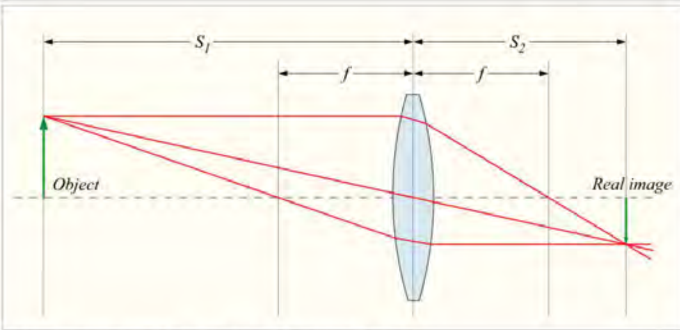
If the distances from the object to the lens and from the lens to the image are S_1 and S_2 respectively, for a lens of negligible thickness, in air, the distances are related by the **thin lens formula**:[21][22][23]

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f} \, .$$

This can also be put into the "Newtonian" form:

$$x_1 x_2 = f^2 ,$$ [24]

where $x_1 = S_1 - f$ and $x_2 = S_2 - f$.



A camera lens forms a *real image* of a distant object.

demagnified virtual image.

path) into a magnified real image (green rays at focus)

For a thin lens, the distances S_1 and S_2 are measured from the object and image to the position of the lens, as described above. When the thickness of the lens is not much smaller than S_1 and S_2 or there are multiple lens elements (a compound lens), one must instead measure from the object and image to the principal planes of the lens. If distances S_1 or S_2 pass through a medium other than air or vacuum a more complicated analysis is required.

Magnification [edit]

The linear *magnification* of an imaging system using a single lens is given by

$$M = -\frac{S_2}{S_1} = \frac{f}{f - S_1} \, ,$$

where *M* is the magnification factor defined as the ratio of the size of an image compared to the size of the object. The sign convention here dictates that if *M* is negative, as it is for real images, the image is upside-down with respect to the object. For virtual images *M* is positive, so the image is upright.

Real image of a lamp is projected onto a screen (inverted). Reflections of the lamp from both surfaces of the biconvex lens are visible.

A convex lens ($f \ll S_1$) forming a real, inverted image rather than the upright, virtual image as seen in a magnifying glass

Linear magnification *M* is not always the most useful measure of magnifying power. For instance, when characterizing a visual telescope or binoculars that produce only a virtual image, one would be more concerned with the angular magnification—which expresses how much larger a distant object appears through the telescope compared to the naked eye. In the case of a camera one would quote the plate scale, which compares the apparent (angular) size of a distant object to the size of the real image produced at the focus. The plate scale is the reciprocal of the focal length of the camera lens; lenses are categorized as long-focus lenses or wide-angle lenses according to their focal lengths.

Using an inappropriate measurement of magnification can be formally correct but yield a meaningless number. For instance, using a magnifying glass of 5 cm focal length, held 20 cm from the eye and 5 cm from the object, produces a virtual image at infinity of infinite linear size: $M = \infty$. But the *angular magnification* is 5, meaning that the object appears 5 times larger to the eye than without the lens. When taking a picture of the moon using a camera with a 50 mm lens, one is not concerned with the linear magnification $M \approx -50\text{ mm} / 380\,000\text{ km} = -1.3 \times 10^{-10}$. Rather, the plate scale of the camera is about 1°/mm, from which one can conclude that the 0.5 mm image on the film corresponds to an angular size of the moon seen from earth of about 0.5°.

In the extreme case where an object is an infinite distance away, $S_1 = \infty$, $S_2 = f$ and $M = -f/\infty = 0$, indicating that the object would be imaged to a single point in the focal plane. In fact, the diameter of the projected spot is not actually zero, since diffraction places a lower limit on the size of the point spread function. This is called the diffraction limit.

History of the telescope

From Wikipedia, the free encyclopedia

Early depiction of a "Dutch telescope" from 1624.

The earliest known telescope appeared in 1608 in the Netherlands when an eyeglass maker named Hans Lippershey tried to obtain a patent on one. Although Lippershey did not receive his patent, news of the new invention soon spread across Europe. The design of these early refracting telescopes consisted of a convex objective lens and a concave eyepiece. Galileo improved on this design the following year and applied it to astronomy. In 1611, Johannes Kepler described how a far more useful telescope could be made with a convex objective lens and a convex eyepiece lens and by 1655 astronomers such as Christiaan Huygens were building powerful but unwieldy Keplerian telescopes with compound eyepieces.[1]

Isaac Newton is credited with building the first reflector in 1668 with a design that incorporated a small flat diagonal mirror to reflect the light to an eyepiece mounted on the side of the telescope. Laurent Cassegrain in 1672 described the design of a reflector with a small convex secondary mirror to reflect light through a central hole in the main mirror.

The achromatic lens, which greatly reduced color aberrations in objective lenses and allowed for shorter and more functional telescopes, first appeared in a 1733 telescope made by Chester Moore Hall, who did not publicize it. John Dollond learned of Hall's invention[2][3] and began producing telescopes using it in commercial quantities, starting in 1758.

Important developments in reflecting telescopes were John Hadley's production of larger paraboloidal mirrors in 1721; the process of silvering glass mirrors introduced by Léon Foucault in 1857;[4] and the adoption of long-lasting aluminized coatings on reflector mirrors in 1932.[5] The Ritchey-Chretien variant of Cassegrain reflector was invented around 1910, but not widely adopted until after 1950; many modern telescopes including the Hubble Space Telescope use this design, which gives a wider field of view than a classic Cassegrain.

During the period 1850–1900, reflectors suffered from problems with speculum metal mirrors, and a considerable number of "Great Refractors" were built from 60 cm to 1 metre aperture, culminating in the Yerkes Observatory refractor in 1897; however, starting from the early 1900s a series of ever-larger reflectors with glass mirrors were built, including the Mount Wilson 60-inch (1.5 metre), the 100-inch (2.5 metre) Hooker Telescope (1917) and the 200-inch (5 metre) Hale telescope (1948); essentially all major research telescopes since 1900 have been reflectors. A number of 4-metre class (160 inch) telescopes were built on superior higher altitude sites including Hawaii and the Chilean desert in the 1975–1985 era. The development of the computer-controlled alt-azimuth mount in the 1970s and active optics in the 1980s enabled a new generation of even larger telescopes, starting with the 10-metre (400 inch) Keck telescopes in 1993/1996, and a number of 8-metre telescopes including the ESO Very Large Telescope, Gemini Observatory and Subaru Telescope.

"Defocus" redirects here. For the intentional use of defocusing, see shallow focus.

A photograph of Christmas lights with significant defocus aberration.

In optics, **defocus** is the aberration in which an image is simply out of focus. This aberration is familiar to anyone who has used a camera, videocamera, microscope, telescope, or binoculars. Optically, defocus refers to a translation of the focus along the optical axis away from the detection surface. In general, defocus reduces the sharpness and contrast of the image. What should be sharp, high-contrast edges in a scene become gradual transitions. Fine detail in the scene is blurred or even becomes invisible. Nearly all image-forming optical devices incorporate some form of focus adjustment to minimize defocus and maximize image quality.

Contents [hide]

V·T·E **Optical aberration**

Defocus

Tilt
Spherical aberration
Astigmatism
Coma
Distortion
Petzval field curvature
Chromatic aberration

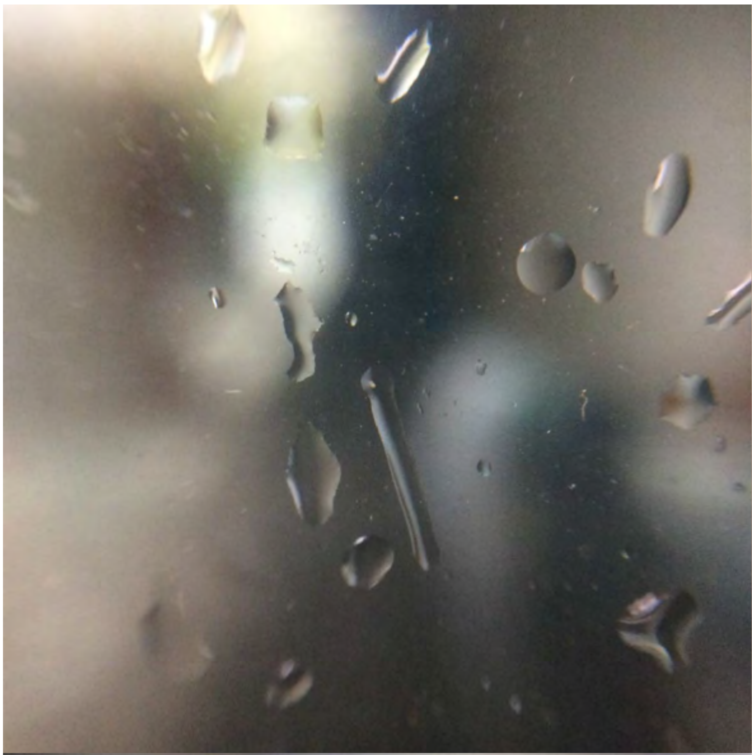
In optics and photography [edit]

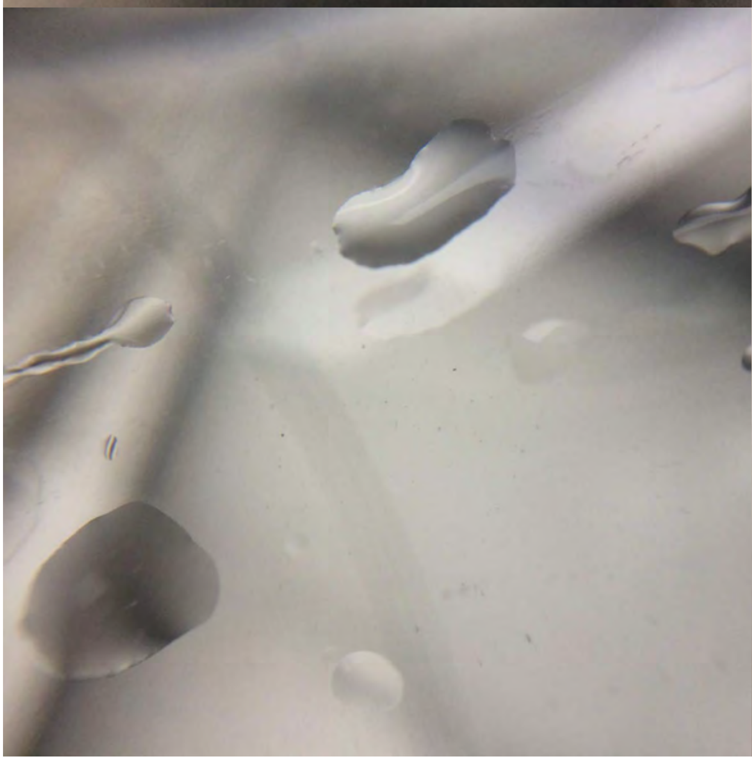
The degree of image blurring for a given amount of focus shift depends inversely on the lens f-number. Low f-numbers, such as $f/1.4$ to $f/2.8$, are very sensitive to defocus and have very shallow depths of focus. High f-numbers, in the $f/16$ to $f/32$ range, are highly tolerant of defocus, and consequently have large depths of focus. The limiting case in f-number is the pinhole camera, operating at perhaps $f/100$ to $f/1000$, in which case all objects are in focus almost regardless of their distance from the pinhole aperture. The penalty for achieving this extreme depth of focus is very dim illumination at the imaging film or sensor, limited resolution due to diffraction, and very long exposure time, which introduces the potential for image degradation due to motion blur.

The amount of allowable defocus is related to the resolution of the imaging medium. A lower-resolution imaging chip or film is more tolerant of defocus and other aberrations. To take full advantage of a higher resolution medium, defocus and other aberrations must be minimized.

Defocus is modeled in Zernike polynomial format as $a(2\rho^2 - 1)$, where a is the defocus coefficient in wavelengths of light. This corresponds to the parabola-shaped optical path difference between two spherical wavefronts that are tangent at their vertices and have different radii of curvature.

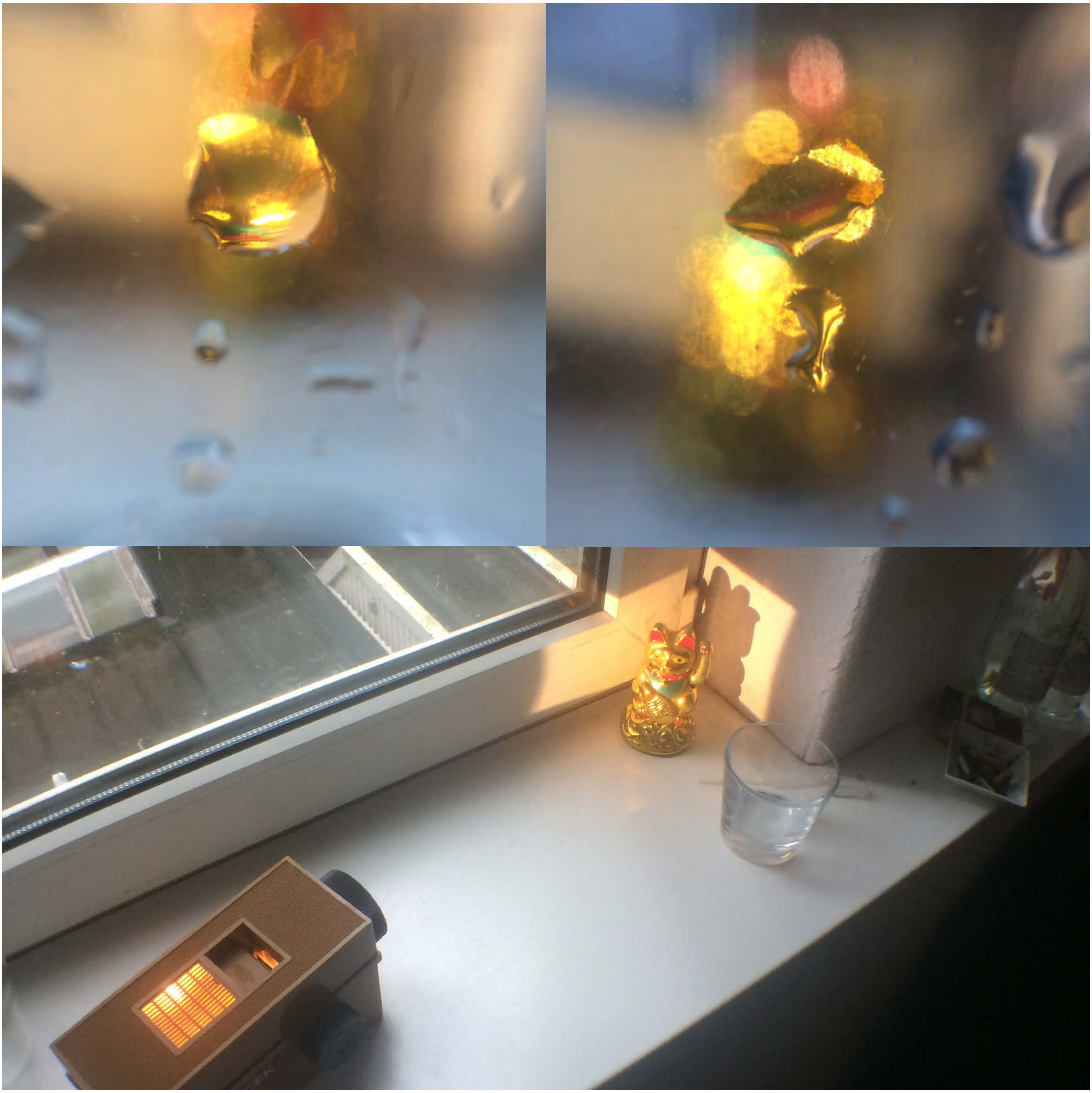
For some applications, such as phase contrast electron microscopy, defocused images can contain useful information. Multiple images recorded with various values of defocus can be used to examine how the intensity of the electron wave varies in three-dimensional space, and from this information the phase of the wave can be inferred. This is the basis of non-interferometric phase retrieval. Examples of phase retrieval algorithms that use defocused images include the Gerchberg–Saxton algorithm and various methods based on the transport of intensity equation.






Waterdruppled fasination

Waterdruplets were the first lenses use. They bend light and create a magnifing effect.



Setup waterdruplet with light + effect

Using a waterdrupplet and a clip on lens to record light and movement.