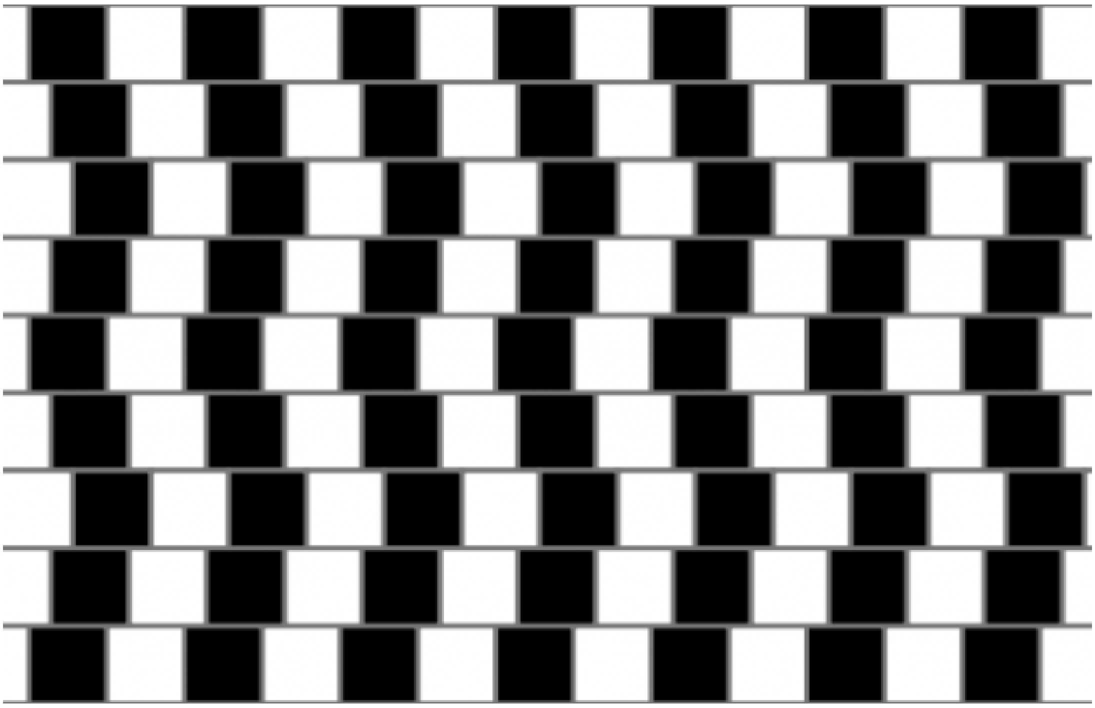
Optics: Light, Reflection, Types of Lenses and Optical Instruments

See online here

Optics is the science of light. Visible light is described as the electromagnetic wave in the sensitivity range of the human eye. Light in the frequency range of $4*10^{14}$ to $8*10^{14}$ Hz is visible to the human eye.

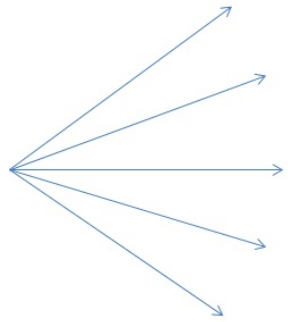
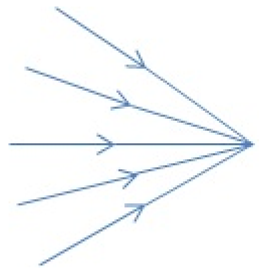
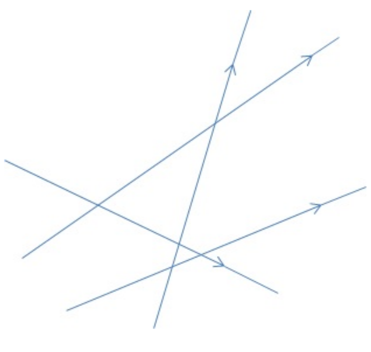


Light Sources and Light Propagation

Bodies that emit light, such as the sun, fixed stars, flames or a light bulb, are known as self-luminous objects or light sources. The distinction is made between artificial light sources (light bulb, arc lamp) and natural light sources (sun, fixed stars).

The light that is emitted into the surrounding space propagates in a straight line as long as it encounters no obstacle. Light beams are used for the presentation of light in an imaginary straight line along which the light is thought to propagate. Light beams do not exist in reality, because the light emitted by a light source fans out in so-called bundles of light. The light beams are demarcated by boundary or marginal rays. The linear propagation of light is based on a shadowing effect.

Type	Definition	Appearance

Divergent	Rays emanating radially from a common point form a divergent light beam, which increases the cross-section of the light beam.	 Image by Lecturio
Convergent	Rays converging at a mutual point form a convergent light beam, which decreases the cross-section of the light beam.	 Image by Lecturio
Parallel	Parallel rays extend equally spaced, and the beam cross-section remains the same.	 Image by Lecturio
Diffuse	Diffuse rays have neither a common starting point nor a common destination, and the cross-sections are not determinable.	 Image by Lecturio

Reflection of Light

Things are only visible to us when the light originating from them reaches our eye. Illuminated bodies reflect light from their surface into our eyes. There are 2 types of reflection: regular and diffuse.

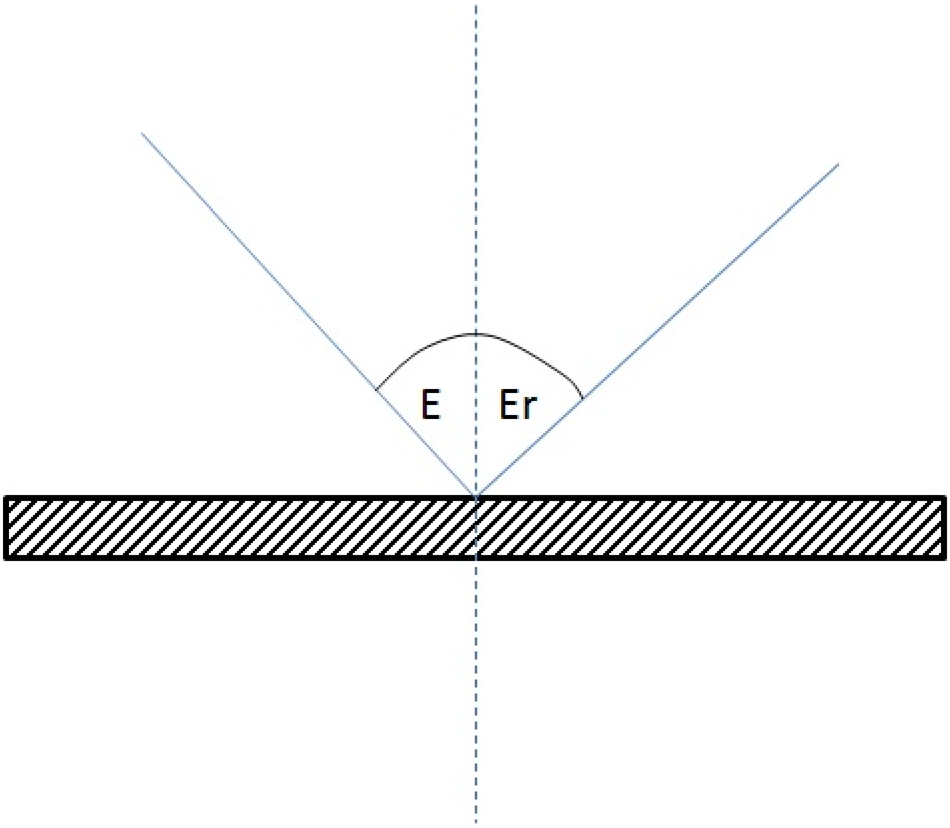


Image: Reflection. By Lecturio

Regular reflection

Smooth surfaces reflect light regularly, and the angle of incidence is equal to the angle of reflection.

Diffuse reflection (Scattering)

Rough surfaces scatter light in all directions and thereby produce a diffuse reflection. Such a reflection is visible from any side. Examples are room walls, the moon, and the clouds. The indirect lighting produced by diffuse reflection is characterized by reduced glare and reduced shadows.

Mirrors and Reflection

Plane mirrors

Plane mirror is common in everyday life. In a plane mirror, the objects and images are symmetrical with respect to the mirror plane. The mirror image is virtual and appears as far behind the mirror as the object in front.

Curved mirrors

Mirrors with curved surfaces are also common, e.g., car headlights.

Concave mirrors

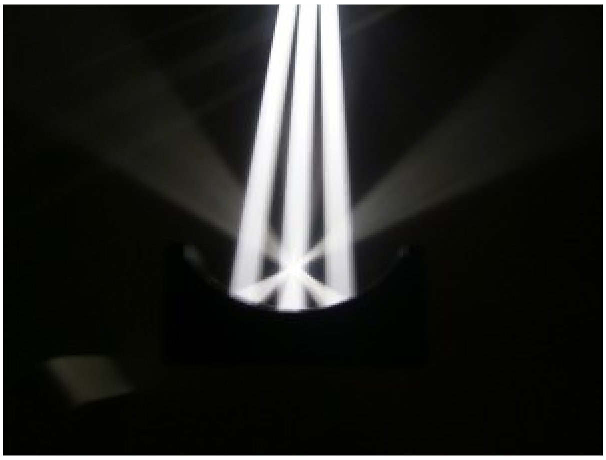


Image: Beam path in a concave mirror. By Johannes S., License: CC BY-SA 3.0

The concave mirrors are curved inward, and the mirror surface correlates with a portion of the inside of a spherical surface. The line from the center of the sphere to the center of the mirror is known as the optical axis.

If a parallel beam of light reaches a curved mirror, the rays unite at the focal point. The distance of the focal point from the center of the mirror is called the focal distance. The focal distance is interpreted as half of the radius of the curvature by the viewer.

$$f = r / 2$$

Incident beam parallel to the axis passes through the focal point after reflection. The parallel ray becomes the focal ray.

Incident beam through the focal point travels, after reflection, parallel to the axis. The focal ray becomes the parallel ray.

Incident beam through the spherical center returns after reflection and the central ray remains unchanged.

Convex mirrors

Image: Convex mirror for an overview of road traffic. By Gerard Hogervorst, License: CC BY-SA 3.0

With convex mirrors, the mirror surface correlates with part of the spherical surface. The outward curved portion of the spherical surface reflects light. The images of the convex mirror are always upright and down-scaled.

The closer the object is to the mirror, the greater the image size approaches the object size. An incident parallel beam is reflected as though it originates at a point **f** behind the mirror—the so-called virtual focal point. An incident divergent beam is divergent after reflection, and its opening angle is greater than that of the incident beam. The peripheral rays can be constructed using the law of reflection.

The relationship between object distance, image distance and focal lengths of concave mirrors are also valid. However, the focal length and the image distance carry a negative sign, since they are behind the mirror.

Parabolic mirror

Image: Focusing of light through parabolic mirrors. By Jean-Michel Courty, License: CC BY 2.5

The reflecting surface of parabolic mirrors resembles the section of a parabola. All incident light beams parallel to the axis, and even off-axis, run through the focal point after reflection. Parabolic mirrors are used to reflect light in car headlights.

Absorption of Light

White walls reflect light better than grey or black. With black walls, almost no reflection of the incident light occurs. The part of the light, which is not reflected by a surface is absorbed. Absorbed light radiation is usually converted into heat energy.

Refraction of Light

When a light beam crosses the boundary of two transparent media with different light velocities a part of the light is reflected, while another part is refracted. During the passage from an optically-thinner medium to an optically-denser medium, the light beam is refracted towards the perpendicular plane, and vice versa. A ray traveling perpendicular to the boundary between the 2 media is not refracted and does not change direction.

Incident ray refracted ray, and the normal is in the same plane.

The refractive ratio depends only on the nature of the 2 media. The angle of incidence of the light beam does not affect the refraction ratio. According to Snell’s law, it is possible to construct the ray path between 2 media when the refractive index is known.

Total Internal Reflection

When light travels from an optically-thicker medium to the boundary with an angle of incidence greater than the critical angle, the light is completely reflected. The critical angle is reached when the angle of reflection is 90°, e.g., refraction at the critical angle when light crosses from water to air.

Example: refraction at the critical angle when crossing from water to air

$$\frac{n_2}{n_1} = \frac{\sin \varepsilon_1}{\sin \varepsilon_2}$$

$$\frac{n_{Luft}}{n_{Wasser}} = \frac{3}{4}$$

$$\frac{3}{4} = \frac{\sin \varepsilon_1}{\sin 90°} = \frac{\sin \varepsilon_1}{1}$$

$$\sin \varepsilon_1 = \frac{3}{4}$$

$$\varepsilon_1 = 48{,}6°$$

Optical Lenses

Translucent bodies that are bound by curved surfaces, usually spherical surfaces, are called optical lenses. The connection line of the center points M and M’ of the curved surface forms the optical axis of the lens. The points of intersection S1 and S2 of the 2 lens surfaces and the optical axis are known as the vertices of the lens. The midpoint of the segment S1S2 is called the optical midpoint 0. The plane perpendicular to the optical axis through 0 is called the plane of the lens or refraction.

Rays traveling through the focal point of the lens are called focal rays.

Rays traveling through the optical midpoint are called midpoint rays.

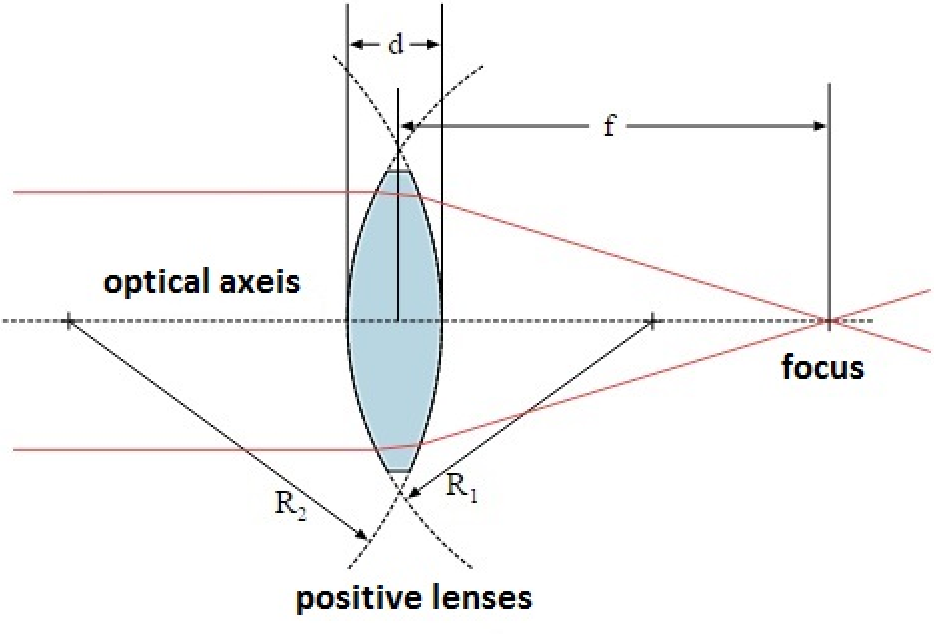
Rays entering parallel to the optical axis are known as parallel rays.

Types of Lenses

The most common lenses are spherical. They are translucent and bound by 2 spherical surfaces. The 2 types of spherical lenses are convex and concave.

Convex lenses

Convex lenses are thicker in the middle than on the edges. The refract lighted from a convex lens converges parallel or moderately divergent light beams so that the rays meet at a point.



[Image](): Radii of a converging lens: +R1 (R1>0) ; −R2 (R2<0). By Max Mustermann, License: CC BY 2.0

It is possible to converge divergent beam bundles with converging lenses if the divergence is not too large.

Concave lenses

Concave lenses are thinner in the middle than on the edges. The refracted light diverges the incident beam. The incident light beam parallel to the optical axis is refracted as if the individual rays arise from a focal point in front of the lens. The distance of this point is the focal length (also known as the dispersal distance).

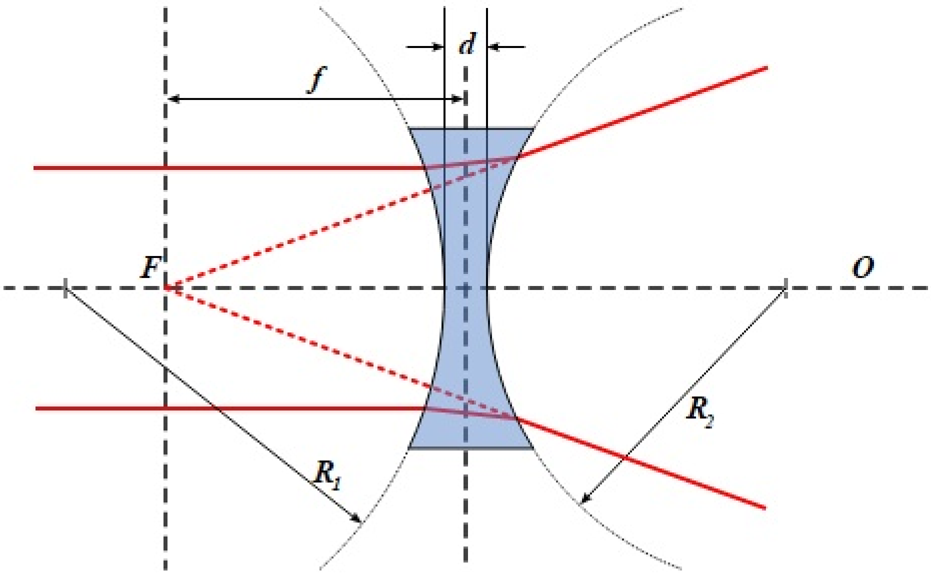


Image: Radii of a diverging lens: -R1 (R1<0) ; +R2 (R2>0). By Max Mustermann, License: CC BY-SA 3.0

An incident light beam parallel to the optical axis is refracted as if the individual rays originate from a focal point F in front of the lens. The distance of this pint is the focal length f, which is negative and is also known as dispersal distance.

Optical Instruments

The human eye is essentially an optical instrument.

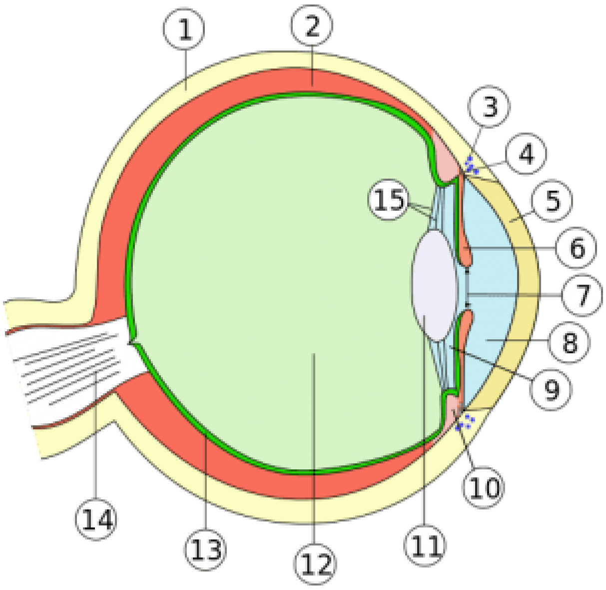


Image: Structure of the vertebrate eye. By Talos, colorized by Jakov, License: CC BY-SA 3.0

Almost spherical, the eye can be rotated by six muscles acting on it from all sides. The sclera (1) forms the outer shell and is continuous with the cornea (5). The iris (6) contains a small hole in the middle. The light rays penetrate into the interior of the eye through the pupil (7).

The refracting system of the eye consists of the cornea (5) and the lens (11), which act approximately like a convex lens refracting light onto the retina (13). The images of observed objects are real inverted images on the retina. A normal eye can see near objects as sharply as distant ones, due to the eye's ability to change its curvature and focal length, and thus it's refracting power. This adaptability is called accommodation.

The Microscope

The microscope consists of 2 lenses—the prime lens and the ocular system. The prime lens is the one facing the observed object whereas the ocular or eyepiece system is in front of the eye.

The prime lens can be replaced with lenses of other focal lengths, and the object distance can be adjusted.

Enlarged and inverted virtual images of the observed object can be observed microscopically. The total magnification of the microscope **v** is the product of the object magnification $\mathbf{v_a}$ and the magnification of the eyepiece $\mathbf{v_g}$.

$$\mathbf{v = v_a * v_g}$$

Notes