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What is refraction

The spectral colors of the rainbow are caused by dispersive refraction Newton established that refraction causes the dispersion of light into its constituent hues. He named seven colors, in symmetry with the seven distinct notes in the Western musical scale. Rainbows, with their ephemeral quality and gorgeous hues, have fascinated us since the beginning of recorded time. The rainbow is deeply rooted in our history. It appears in the oldest of stories, as well as being ubiquitous in art and music. Newton and the color spectrum: dispersive refraction Isaac Newton established that refraction causes white light to separate into its constituent wavelengths. While he was not the first to demonstrate that a prism produces a spectrum of colored light from incident white light, he showed that a second prism could recombine the colors to create white light again. He also demonstrated that the individual colors remained constant when shone through a prism again. This was in stark contrast to the consensus that the prism itself produced colors. Newton's contribution created a new understanding that white light is a mixture of colored light, and that each color is refracted to a different extent. The different colors correspond to light with different wavelengths, and are refracted to differing degrees. This separation of colors is known as dispersion. Once the colors in sunlight are separated by refraction, we are able to distinguish them in the splendor that is a rainbow. What is refraction? The refractive index (n) of a medium such as air or water tells us how fast light travels in that medium. It is the ratio of the speed of light in a vacuum (c) to the speed of light in this medium (v): n = c / v. The bending of a light as it crosses the boundary into a different medium is determined by its refractive index, or how much the light is slowed down in the new medium. We see objects "breaking" at the boundary between media of different density because of refraction. Light rays are bent, or refracted, because light travels at different speeds in different media. Unless the light ray meets the boundary at exactly 90°, the direction of travel will change and the light ray is "bent." The relationship between the angle of incidence and speed in the first medium and the angle of refraction and the speed of the refracted light in the second medium is given by Snell's law: n1 sin θ1 = n2 sin θ2 (where θ1 = incident angle, n1 is the refractive index of the first medium, θ2 = refracted angle, and n2 is the refractive index of the second medium). The reason that light travels more slowly in a higher density medium is that light interacts with the particles in its path. When light traveling through space to the earth meets the atmosphere, light is absorbed and then re-emitted every time a photon of light collides with an atom of air. Physics: change in direction of a wave For the property of metals, see refraction (metallurgy). Not to be confused with diffraction, the change in direction of a wave around an obstacle.. A ray of light being refracted in a plastic block. In physics, refraction is the change in direction of a wave passing from one medium to another or from a gradual change in the medium.[1] Refraction of light is the most commonly observed phenomenon, but other waves such as sound waves and water waves also experience refraction. How much a wave is refracted is determined by the change in wave speed and the initial direction of wave propagation relative to the direction of change in speed. For light, refraction follows Snell's law, which states that, for a given pair of media, the ratio of the sines of the angle of incidence θ1 and angle of refraction θ2 is equal to the ratio of phase velocities (v1 / v2) in the two media, or equivalently, to the indices of refraction (n2 / n1) of the two media.[2] sin θ1 sin θ2 = v1 v2 = n2 n1

{\displaystyle {\frac {\sin \theta _{1}}{\sin \theta _{2}})={\frac {v_{1}}{v_{2}})}={\frac {n_{2}}{n_{1}}}}

 Refraction of light at the interface between two media of different refractive indices, with n2 > n1. Since the phase velocity is lower in the second medium (v2 < v1), the angle of refraction θ2 is less than the angle of incidence θ1; that is, the ray in the higher-index medium is closer to the normal. Optical prisms and lenses use refraction to redirect light, as does the human eye. The refractive index of materials varies with the wavelength of light,[3] and thus the angle of the refraction also varies correspondingly. This is called dispersion and causes prisms and rainbows to divide white light into its constituent spectral colors.[4] Light A pen partially submerged in a bowl of water appears bent due to refraction at the water surface. Refraction of light can be seen in many places in our everyday life. It makes objects under a water surface appear closer than they really are. It is what optical lenses are based on, allowing for instruments such as glasses, cameras, binoculars, microscopes, and the human eye. Refraction is also responsible for some natural optical phenomena including rainbows and mirages. General explanation When a wave moves into a slower medium the wavefronts get compressed. For the wavefronts to stay connected at the boundary the wave must change direction. A correct explanation of refraction involves two separate parts, both a result of the wave nature of light. Light slows as it travels through a medium other than vacuum (such as air, glass or water). This is not because of scattering or absorption. Rather it is because, as an electromagnetic oscillation, light itself causes other electrically charged particles such as electrons, to oscillate. The oscillating electrons emit their own electromagnetic waves which interact with the original light. The resulting "combined" wave has wave packets that pass an observer at a slower rate. The light has effectively been slowed. When light returns to a vacuum and there are no electrons nearby, this slowing effect ends and its speed returns to c. When light enters, exits or changes the medium it travels in, at an angle, one side or the other of the wavefront is slowed before the other. This asymmetrical slowing of the light causes it to change the angle of its travel. Once light is within the new medium with constant properties, it travels in a straight line again. Explanation for slowing of light in a medium As described above, the speed of light is slower in a medium other than vacuum. This slowing applies to any medium such as air, water, or glass, and is responsible for phenomena such as refraction. When light leaves the medium and returns to a vacuum, and ignoring any effects of gravity, its speed returns to the usual speed of light in a vacuum, c. Common explanations for this slowing, based upon the idea of light scattering from, or being absorbed and re-emitted by atoms, are both incorrect. Explanations like these would cause a "blurring" effect in the resulting light, as it would no longer be travelling in just one direction. But this effect is not seen in nature. A more correct explanation rests on light's nature as an electromagnetic wave.[5] Because light is an oscillating electrical/magnetic wave, light traveling in a medium causes the electrically charged electrons of the material to also oscillate. (The material's protons also oscillate but as they are around 2000 times more massive, their movement and therefore their effect, is far smaller). A moving electrical charge emits electromagnetic waves of its own. The electromagnetic waves emitted by the oscillating electrons, interact with the electromagnetic waves that make up the original light, similar to water waves on a pond, a process known as constructive interference. When two waves interfere in this way, the resulting "combined" wave may have wave packets that pass an observer at a slower rate. The light has effectively been slowed. When the light leaves the material, this interaction with electrons no longer happens, and therefore the wave packet rate (and therefore its speed) return to normal. Explanation for bending of light as it enters and exits a medium Consider a wave going from one material to another where its speed is slower as in the figure. If it reaches the interface between the materials at an angle one side of the wave will reach the second material first, and therefore slow down earlier. With one side of the wave going slower the whole wave will pivot towards that side. This is why a wave will bend away from the surface or toward the normal when going into a slower material. In the opposite case of a wave reaching a material where the speed is higher, one side of the wave will speed up and the wave will pivot away from that side. Another way of understanding the same thing is to consider the change in wavelength at the interface. When the wave goes from one material to another where the wave has a different speed v, the frequency f of the wave will stay the same, but the distance between wavefronts or wavelength λ=sv/f will change. If the speed is decreased, such as in the figure to the right, the wavelength will also decrease. With an angle between the wave fronts and the interface and change in distance between the wave fronts the angle must change over the interface to keep the wave fronts intact. From these considerations the relationship between the angle of incidence θ1, angle of transmission θ2 and the wave speeds v1 and v2 in the two materials can be derived. This is the law of refraction or Snell's law and can be written as[6] sin θ1 sin θ2 = v 1 v 2

{\displaystyle {\frac {\sin \theta _{1}}{\sin \theta _{2}})={\frac {v_{1}}{v_{2}}}}

. The phenomenon of refraction can in a more fundamental way be derived from the 2 or 3-dimensional wave equation. The boundary condition at the interface will then require the tangential component of the wave vector to be identical on the two sides of the interface.[7] Since the magnitude of the wave vector depend on the wave speed this requires a change in direction of the wave vector. The relevant wave speed in the discussion above is the phase velocity of the wave. This is typically close to the group velocity which can be seen as the truer speed of a wave, but when they differ it is important to use the phase velocity in all calculations relating to refraction. A wave traveling perpendicular to a boundary, i.e. having its wavefronts parallel to the boundary, will not change direction even if the speed of the wave changes. Law of refraction For light, the refractive index n of a material is more often used than the wave phase speed v in the material. They are, however, directly related through the speed of light in vacuum c as n = c v

{\displaystyle n={\frac {c}{v}}}

. In optics, therefore, the law of refraction is typically written as n 1 sin θ 1 = n 2 sin θ 2

{\displaystyle n_{1}\sin \theta _{1}=n_{2}\sin \theta _{2}}

. Refractio in a water surface A pencil part immersed in water looks bent due to refraction: the light waves from X change direction and so seem to originate at Y. Refraction occurs when light goes through a water surface since water has a refractive index of 1.33 and air has a refractive index of about 1. Looking at a straight object, such as a pencil in the figure here, which is placed at a slant, partially in the water, the object appears to bend at the water's surface. This is due to the bending of light rays as they move from the water to the air. Once the rays reach the eye, the eye traces them back as straight lines (lines of sight). The lines of sight (shown as dashed lines) intersect at a higher position than where the actual rays originated. This causes the pencil to appear higher and the water to appear shallower than it really is. The depth that the water appears to be when viewed from above is known as the apparent depth. This is an important consideration for spearfishing from the surface because it will make the target fish appear to be in a different place, and the fisher must aim lower to catch the fish. Conversely, an object above the water has a higher apparent height when viewed from below the water. The opposite correction must be made by an archer fish.[8] For small angles of incidence (measured from the normal, when sin θ is approximately the same as tan θ), the ratio of apparent to real depth is the ratio of the refractive indexes of air to that of water. But, as the angle of incidence approaches 90o, the apparent depth approaches zero, albeit reflection increases, which limits observation at high angles of incidence. Conversely, the apparent height approaches infinity as the angle of incidence (from below) increases, but even earlier, as the angle of total internal reflection is approached, albeit the image also fades from view as this limit is approached. An image of the Golden Gate Bridge is refracted and bent by many differing three-dimensional drops of water. Dispersion Refraction is also responsible for rainbows and for the splitting of white light into a rainbow-spectrum as it passes through a glass prism. Glass has a higher refractive index than air. When a beam of white light passes from air into a material having an index of refraction that varies with frequency, a phenomenon known as dispersion occurs, in which different coloured components of the white light are refracted at different angles, i.e., they bend by different amounts at the interface, so that they become separated. The different colors correspond to different frequencies. Atmospheric refraction Main article: Atmospheric refraction The sun appears slightly flattened when close to the horizon due to refraction in the atmosphere. The refractive index of air depends on the air density and thus vary with air temperature and pressure. Since the pressure is lower at higher altitudes, the refractive index is also lower, causing light rays to refract towards the earth surface when traveling long distances through the atmosphere. This shifts the apparent positions of stars slightly when they are close to the horizon and makes the sun visible before it geometricly rises above the horizon during a sunrise. Heat haze in the engine exhaust above a diesel locomotive. Temperature variations in the air can also cause refraction of light. This can be seen as a heat haze when hot and cold air is mixed e.g. over a fire, in engine exhaust, or when opening a window on a cold day. This makes objects viewed through the mixed air appear to shimmer or move around randomly as the hot and cold air moves. This effect is also visible from normal variations in air temperature during a sunny day when using high magnification telephoto lenses and is often limiting the image quality in these cases. [9] In a similar way, atmospheric turbulence gives rapidly varying distortions in the images of astronomical telescopes limiting the resolution of terrestrial telescopes not using adaptive optics or other techniques for overcoming these atmospheric distortions. Mirage over a hot road. Air temperature variations close to the surface can give rise to other optical phenomena, such as mirages and Fata Morgana. Most commonly, air heated by a hot road on a sunny day deflects light approaching at a shallow angle towards a viewer. This makes the road appear reflecting, giving an illusion of water covering the road. Clinical significance In medicine, particularly optometry, ophthalmology and orthoptics, refraction (also known as refractometry) is a clinical test in which a phoropter may be used by the appropriate eye care professional to determine the eye's refractive error and the best corrective lenses to be prescribed. A series of test lenses in graded optical powers or focal lengths are presented to determine which provides the sharpest, clearest vision.[10] Gallery Play media 2D simulation: refraction of a quantum particle.The black half of the background is zero potential, the gray half is a higher potential. White blur represents the probability distribution of finding a particle in a given place if measured. Water waves Main article: Water wave refraction Water waves are almost parallel to the beach when they hit it because they gradually refract towards land as the water gets shallower. Water waves travel slower in shallower water. This can be used to demonstrate refraction in ripple tanks and also explains why waves on a shoreline tend to strike the shore close to a perpendicular angle. As the waves travel from deep water into shallower water near the shore, they are refracted from their original direction of travel to an angle more normal to the shoreline.[11] Acoustics Main article: Refraction (sound) In underwater acoustics, refraction is the bending or curving of a sound ray that results when the ray passes through a sound speed gradient from a region of one sound speed to a region of a different speed. The amount of ray bending is dependent on the amount of difference between sound speeds, that is, the variation in temperature, salinity, and pressure of the water.[12] Similar acoustics effects are also found in the Earth's atmosphere. The phenomenon of refraction of sound in the atmosphere has been known for centuries.[13] however, beginning in the early 1970s, widespread analysis of this effect came into vogue through the designing of urban highways and noise barriers to address the meteorological effects of bending of sound rays in the lower atmosphere.[14] See also Birefringence (double refraction) Geometrical optics Huygens-Fresnel principle List of indices of refraction Negative refraction Reflection Schlieren photography Seismic refraction Super refraction References ↑ The Editors of Encyclopaedia Britannica. "Refraction". Encyclopaedia Britannica. Retrieved 2018-10-16. ↑ Born and Wolf (1959). Principles of Optics. New York, NY: Pergamon Press INC. p. 37. ↑ R. Paschotta, article on chromatic dispersion Archived 2015-06-29 at the Wayback Machine in the Encyclopedia of Laser Physics and Technology Archived 2015-08-13 at the Wayback Machine, accessed on 2014-09-08 ↑ Carl R. Nave, page on Dispersion Archived 2014-09-24 at the Wayback Machine in HyperPhysics Archived 2007-10-28 at the Wayback Machine, Department of Physics and Astronomy, Georgia State University, accessed on 2014-09-08 ↑ Why does light slow down in water? - Fermilab ↑ Hecht, Eugene (2002). Optics. Addison-Wesley, p. 101. ISBN 0-321-18878-0. ↑ "Refraction". RP Photonics Encyclopedia. RP Photonics Consulting GmbH, Dr. Rüdiger Paschotta. Retrieved 2018-10-23. It results from the boundary conditions which the incoming and the transmitted wave need to fulfill at the boundary between the two media. Essentially, the tangential components of the wave vectors need to be identical, as otherwise the phase difference between the waves at the boundary would be position-dependent, and the wavefronts could not be continuous. As the magnitude of the wave vector depends on the refractive index of the medium, the said condition can in general only be fulfilled with different propagation directions. ↑ Dill, Lawrence M. (1977). "Refraction and the spitting behavior of the archerfish (*Toxotes chatareus*)". Behavioral Ecology and Sociobiology. 2 (2): 169-184. doi:10.1007/BF00361900. JSTOR 4599128. S2CID 14111919. ↑ "The effect of heat haze on image quality". Nikon. 2016-07-10. Retrieved 2018-11-04. ↑ "Refraction". eyeglossary.net. Archived from the original on 2006-05-26. Retrieved 2006-05-23. ↑ "Shoaling, Refraction, and Diffraction of Waves". University of Delaware Center for Applied Coastal Research. Archived from the original on 2009-04-14. Retrieved 2009-07-23. ↑ Navy Supplement to the DOD Dictionary of Military and Associated Terms (PDF). Department Of The Navy. August 2006. NTRP 1-02.[permanent dead link] ↑ Mary Somerville (1840), On the Connexion of the Physical Sciences, J. 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