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Explore our latest gallery of EditorsPicks.Browse Editors' Favorites A wave is a propagating dynamic disturbance (change from equilibrium) of one or more quantities in physics, mathematics, and related subjects, commonly described by a wave equation. At least two field quantities in the wave medium are involved in physical waves. Periodic waves occur when variables oscillate periodically around an equilibrium (resting) value at a specific frequency. A traveling wave occurs when the entire waveform moves in one direction; a standing wave occurs when two superimposed periodic waves move in opposite directions. The amplitude of vibration in a standing wave features nulls at some points when the wave amplitude seems reduced or even zero. WaveA wave is a disturbance in a medium that transports energy without causing net particle movement. Elastic deformation, pressure variations, electric or magnetic intensity, electric potential, or temperature variations are all examples. Pictorial representation of waves.Characteristics of WavesWaves include the following characteristics: The particles of the medium traversed by a wave vibrate only slightly about their mean positions, but they are not permanently displaced in the wave's propagation direction.Along with or perpendicular to the wave's line of travel, each succeeding particle of the medium performs a motion quite identical to its predecessors.During wave motion, only energy is transferred, but not a piece of the medium.Types of WavesThe several forms of waves are listed here: 1. Transverse Waves:Waves in which the medium moves at an angle to the wave's direction. Examples of transverse waves: Water waves (ripples of gravity waves, not sound through water)Light wavesS-wave earthquake wavesStringed instrumentsTorsion waveA crest is the highest point of a transverse wave. It's a trough at the bottom. 2. Longitudinal Wave:The movement of the particles in the medium in a longitudinal wave is in the same dimension as the wave's movement direction. Examples of longitudinal waves: Sound wavesP-type earthquake wavesCompression waveParts of longitudinal waves: Compression-The particles are close together in this case.Rarefaction-Where the particles are dispersed3. Electromagnetic Waves:These are waves that are produced and propagated without the use of a material medium, i.e., they can pass through vacuum and any other material medium. Examples of electromagnetic waves: visible lightultra-violet lightradio wavesmicrowavesElectromagnetic waves.4. Mechanical waves:Only a material medium can produce or propagate mechanical waves. Newton's equations of motion apply to these waves. Examples of mechanical waves: waves on water surfacewaves on stringssound wavesMechanical waves are of two types: Transverse wave motion- The particles of the medium vibrate at right angles to the wave's propagation direction in transverse waves. Transverse waves include string waves, surface water waves, and electromagnetic waves. The disturbance that travels in electromagnetic waves (which include light waves) is caused by the oscillation of electric and magnetic fields at right angles to the wave's travel direction.Longitudinal wave motion- Particles in the medium vibrate back and forth around their mean location along the energy propagation direction in these sorts of waves. They're also known as pressure waves. Longitudinal mechanical waves are what sound waves are.5. Matter waves:These waves are linked to the movement of matter particles. Examples of matter waves: Also, Read- Types of Waves Formula for Speed of Wave It's the entire distance a wave travels in a particular amount of time. The formula for calculating wave speed is as follows: Wave Speed = Distance Covered/Time taken Properties of WavesThe following are the primary characteristics of waves: Amplitude A wave is a form of energy transmission. The amplitude of a wave is its height, which is commonly measured in meters. It is proportional to the quantity of energy transported by a wave.Wavelength A wavelength is a distance between identical locations in adjacent cycles of crests of a wave. In addition, it is measured in meters.Period A wave's period is the amount of time it takes a particle on a medium to complete one complete vibrational cycle. Because the period is a unit of time, it is measured in seconds or minutes.Frequency The number of waves passing a spot in a certain amount of time is referred to as the frequency of a wave. The hertz (Hz) unit of frequency measures one wave every second.The frequency's reciprocal is the period, and vice versa. Period=1 / Frequency OR Frequency = 1 / Period Speed The speed of an object refers to how quickly it moves and is usually stated as the distance traveled divided by the time it takes to travel. The distance traveled by a specific point on the wave (crest) in a given amount of time is referred to as the wave's speed. A wave's speed is thus measured in meters per second or m/s.Check: Properties of Waves Wave BehaviorWaves exhibit several interesting behaviors when they interact with their environment or other waves. Here are some of the common wave behaviors: Reflection: When a wave encounters a barrier, it bounces back in the opposite direction. The angle of incidence (the angle at which the wave strikes the barrier) equals the angle of reflection (the angle at which the wave bounces off). You can see reflection in action when sound waves bounce off a wall and you hear an echo, or when light waves bounce off a mirror and create a reflection. Refraction: When a wave travels from one medium to another where its speed is different, it bends. This bending is called refraction. The amount of bending depends on the difference in speed between the two mediums. Refraction is why a straw appears bent when inserted in a glass of water, and why light bends as it enters the atmosphere from space, causing objects to appear slightly displaced. Diffraction: When a wave encounters an opening or a small obstacle, it bends around the edges and spreads out. Diffraction is why sound waves can bend around corners, and why light waves can spread out from a narrow slit. Interference: When two waves meet, their crests and troughs can interact with each other, producing either constructive or destructive interference. Constructive interference occurs when the crests of two waves line up, creating a wave with a larger amplitude. Destructive interference occurs when the crest of one wave lines up with the trough of another wave, partially or completely canceling out the waves. Doppler effectThe Doppler Effect is the change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source. It occurs for any type of wave, but it is commonly observed with sound waves. Source approaching: Waves compressed, higher perceived frequency (e.g., ambulance siren). Source moving away: Waves stretched, lower perceived frequency (e.g., ambulance siren moving away). Applies to all waves: Sound waves (common experience). Light waves (astronomical study of stars and galaxies). Standing Wave Standing waves result from the interference of two waves traveling in opposite directions with the same frequency and amplitude.Instead of propagating, the energy of these waves becomes confined within a specific region, forming a stationary pattern of oscillation.Standing waves have points of minimal displacement called nodes and points of maximal displacement called antinodes.They are observed in various physical systems, including vibrating strings, acoustic resonance in pipes, and electromagnetic waves in transmission lines.Standing waves play a crucial role in phenomena such as musical instrument vibrations, sound resonance, and the behavior of electromagnetic fields in antennas.Related Article: Wave MotionRadio WavesDifference between Reflection and RefractionSample ProblemsProblem 1: In a specific medium, a wave travels at 900 meters per second. Calculate the wavelength of a specific point in the medium if 3000 waves pass through it in 2 minutes. Solution: The speed of a wave in medium v = 900 ms-1 Freq. of wave = no. of waves passing per sec (n) = 3000 waves/2 min = 3000 / 2 60 = 25 s Wave length () = ? v = n () = v/n = 900/25 = 36 m Problem 2: What distinguishes the roar of our national animal from that of a mosquito? Solution: The buzzing of a mosquito creates a sound of high pitch and low intensity or loudness, but the roaring of a national animal (tiger) produces a sound of low pitch and high intensity or loudness. Problem 3: Is it feasible to tell when a vessel maintained beneath the faucet is going to overflow? Solution: The length of an air column is inversely related to the frequency of the note it produces. The length of the air column above the vessel reduces as the level of water in the vessel rises. It generates a sound with a decreasing frequency, i.e. the sound gets shorter. It is possible to determine whether the vessel is filled with water based on the shrillness of the sound. Problem 4: The bottom of a ship in the sea shoots SONAR waves straight down into the saltwater. After 3.5 s, the signal reflects off the deep bottom bedrock and returns to the ship. When the ship reaches 100 km, it transmits another signal, which is received after 2 s. Calculate the depth of the sea in each example, as well as the height difference between the two. Solution: Velocity of SONAR waves in water C = 1500 ms-1 Time taken by be wave after reflection from the bottom of sea 2t = 3.5s t =1.75s Distance covered (d) = ? C = d/t => d = c.t = 1500 1.75 - 2625 m After moving 100km The time taken by the wave = 2t = 2s T = 2/2 = 1s d =? d = 1500 l = 1500 The difference between these two heights = 2625 - 1500 = 1125m Problem 5: Why does a tone sound louder in an empty room than in a room with furniture and other objects? Solution: Sound is an energy form. The majority of the energy is absorbed by the furniture that acts as an obstruction. As a result, the strength of sound decreases, yet in an empty room, the intensity of sound remains relatively constant due to the absence of impediments, and we perceive it as louder. Share copy and redistribute the material in any medium or format for any purpose, even commercially. Adapt remix, transform, and build upon the material for any purpose, even commercially. The licensor cannot revoke these freedoms as long as you follow the license terms. Attribution You must give appropriate credit , provide a link to the license, and indicate if changes were made . You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. ShareAlike If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original. No additional restrictions You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits. You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation . No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material. Repeated oscillation around equilibriumThis article is about waves in the scientific sense. For waves on seas and lakes, see Wind wave. For the human hand gesture, see Waving. For other uses, see Wave (disambiguation) and Wave motion (disambiguation).Surface waves in water showing water ripplesIn physics, mathematics, engineering, and related fields, a wave is a propagating dynamic disturbance (change from equilibrium) of one or more quantities. Periodic waves oscillate repeatedly about an equilibrium (resting) value at some frequency. When the entire waveform moves in one direction, it is said to be a travelling wave; by contrast, a pair of superimposed periodic waves traveling in opposite directions makes a standing wave. In a standing wave, the amplitude of vibration has nulls at some positions where the wave amplitude appears smaller or even zero.There are two types of waves that are most commonly studied in classical physics: mechanical waves and electromagnetic waves. In a mechanical wave, stress and strain fields oscillate about a mechanical equilibrium. A mechanical wave is a local deformation (strain) in some physical medium that propagates from particle to particle by creating local stresses that cause strain in neighboring particles too. For example, sound waves are variations of the local pressure and particle motion that propagate through the medium. Other examples of mechanical waves are seismic waves, gravity waves, surface waves and string vibrations. In an electromagnetic wave (such as light), coupling between the electric and magnetic fields sustains propagation of waves involving these fields according to Maxwell's equations. Electromagnetic waves can travel through a vacuum and through some dielectric media (at wavelengths where they are considered transparent). Electromagnetic waves, as determined by their frequencies (or wavelengths), have more specific designations including radio waves, infrared radiation, terahertz waves, visible light, ultraviolet radiation, X-rays and gamma rays.Other types of waves include gravitational waves, which are disturbances in spacetime that propagate according to general relativity; heat diffusion waves; plasma waves that combine mechanical deformations and electromagnetic fields; reactiondiffusion waves, such as in the BelousovZhabotinsky reaction; and many more. Mechanical and electromagnetic waves transfer energy,[1] momentum, and information, but they do not transfer particles in the medium. In mathematics and electronics waves are studied as signals.[2] On the other hand, some waves have envelopes which do not move at all such as standing waves (which are fundamental to music) and hydraulic jumps.Example of biological waves expanding over the brain cortex, an example of spreading depolarizations.[3]A physical wave field is almost always confined to some finite region of space, called its domain. For example, the seismic waves generated by earthquakes are significant only in the interior and surface of the planet, so they can be ignored outside it. However, waves with infinite domain, that extend over the whole space, are commonly studied in mathematics, and are very valuable tools for understanding physical waves in finite domains.A plane wave is an important mathematical idealization where the disturbance is identical along any (infinite) plane normal to a specific direction of travel. Mathematically, the simplest wave is a sinusoidal plane wave in which at any point the field experiences simple harmonic motion at one frequency. In linear media, complicated waves can generally be decomposed as the sum of many sinusoidal plane waves having different directions of propagation and/or different frequencies. A plane wave is classified as a transverse wave if the field disturbance at each point is described by a vector perpendicular to the direction of propagation (also the direction of energy transfer); or longitudinal wave if those vectors are aligned with the propagation direction. Mechanical waves include both transverse and longitudinal waves; on the other hand electromagnetic plane waves are strictly transverse while sound waves in fluids (such as air) can only be longitudinal. That physical direction of an oscillating field relative to the propagation direction is also referred to as the wave's polarization, which can be an important attribute.Modern physics H ^ | n (t) = i d d t | n (t) {\displaystyle {\hat {H}}|\psi _{n}(t)\rangle =i\hbar {\frac {d}{dt}}|\psi _{n}(t)\rangle } G + g = T {\displaystyle G_{\mu u }+\Lambda g_{\mu u }={\kappa }T_{\mu u }} Schrdinger and Einstein field equationsFoundersMax PlanckAlbert EinsteinNiels BohrMax BornErwin SchrdingerWerner HeisenbergPascual JordanWolfgang PauliPaul DiracErnest RutherfordLouis de BroglieSatyendra Nath BoseConceptsTopologySpaceTimeEnergyMatterWorkRandomnessInformationEntropyLightParticleWaveBranchesAppliedExperimentalTheoreticalMathematicalPhilosophy of physicsQuantum mechanicsQuantum field theoryQuantum informationQuantum computationElectromagnetismWeak interactionElectroweak interactionStrong interactionAtomicParticleNuclearAtomic, molecular, and opticalCondensed matterStatisticalComplex systemsNon-linear dynamicsBiophysicsNeurophysicsPlasma physicsSpecial relativityGeneral relativityAstrophysicsCosmologyTheories of gravitationQuantum gravityTheory of everythingScientistsRntgenWittenBecquerelLorentzPlanckCurieWienSkodowska-CurieSommerfeldRutherfordSoddyOnnesEinsteinWilczekBornWeylBohrKramersSchrdingerde BroglieLaueBoseComptonPauliWaltonFermivan der WaalsHeisenbergDysonZeemanMoseleyHilbertGdelJordanDiracWignerHawkingP. W. AndersonLematreThomsonPoincarWheelerPenroseMillikanNambuvon NeumannHiggsHahnFeynmanYangLeeLenardSalam't HooftVeltmanBellGell-MannJ. J. ThomsonRamanBraggBardeenShockleyChadwickLawrenceZeilingerGoudsmitUhlenbeckCategories Modern physicsvteSee also: Solitary waveA wave can be described just like a field, namely as a function F (x , t) {\displaystyle F(x,t)} where x {\displaystyle x} is a position and t {\displaystyle t} is a time.The value of x {\displaystyle x} is a point of space, specifically in the region where the wave is defined. In mathematical terms, it is usually a vector in the Cartesian three-dimensional space R 3 {\displaystyle \mathbb {R} ^{3}} . However, in many cases one can ignore one dimension, and let x {\displaystyle x} be a point of the Cartesian plane R 2 {\displaystyle \mathbb {R} ^{2}} . This is the case, for example, when studying vibrations of a drum skin. One may even restrict x {\displaystyle x} to a point of the Cartesian line R {\displaystyle \mathbb {R} } that is, the set of real numbers. This is the case, for example, when studying vibrations in a violin string or recorder. The time t {\displaystyle t} , on the other hand, is always assumed to be a scalar; that is, a real number.The value of F (x , t) {\displaystyle F(x,t)} can be any physical quantity of interest assigned to the point x {\displaystyle x} that may vary with time. For example, if F {\displaystyle F} represents the vibrations inside an elastic solid, the value of F (x , t) {\displaystyle F(x,t)} is usually a vector that gives the current displacement from x {\displaystyle x} of the material particles that would be at the point x {\displaystyle x} in the absence of vibration. For an electromagnetic wave, the value of F {\displaystyle F} can be the electric field vector E {\displaystyle E} , or the magnetic field vector H {\displaystyle H} , or any related quantity, such as the Poynting vector E H {\displaystyle E\times H} . In fluid dynamics, the value of F (x , t) {\displaystyle F(x,t)} could be the velocity vector of the fluid at the point x {\displaystyle x} , or any scalar property like pressure, temperature, or density. In a chemical reaction, F (x , t) {\displaystyle F(x,t)} could be the concentration of some substance in the neighborhood of point x {\displaystyle x} of the reaction medium.For any dimension d {\displaystyle d} (1, 2, or 3), the wave's domain is then a subset D {\displaystyle D} of R d {\displaystyle \mathbb {R} ^{d}} , such that the function value F (x , t) {\displaystyle F(x,t)} is defined for any point x {\displaystyle x} in D {\displaystyle D} . For example, when describing the motion of a drum skin, one can consider D {\displaystyle D} to be a disk (circle) on the plane R 2 {\displaystyle \mathbb {R} ^{2}} with center at the origin (0 , 0) {\displaystyle (0,0)} , and let F (x , t) {\displaystyle F(x,t)} be the vertical displacement of the skin at the point x {\displaystyle x} of D {\displaystyle D} and at time t {\displaystyle t} .Main article: Superposition principleWaves of the same type are often superposed and encountered simultaneously at a given point in space and time. The properties at that point are the sum of the properties of each component wave at that point. In general, the velocities are not the same, so the wave form will change over time and space.See also: Wind wave Spectrum, Electromagnetic spectrum, and Spectrum (physical sciences)This section needs expansion with: concept summary. You can help by adding to it. (May 2023)Sometimes one is interested in a single specific wave. More often, however, one needs to understand large set of possible waves; like all the ways that a drum skin can vibrate after being struck once with a drum stick, or all the possible radar echoes one could get from an airplane that may be approaching an airport.In some of those situations, one may describe such a family of waves by a function F (A , B , ; x , t) {\displaystyle F(A,B,\ldots ;x,t)} that depends on certain parameters A , B , {\displaystyle A,B,\ldots } , besides x {\displaystyle x} and t {\displaystyle t} . Then one can obtain different waves that is, different functions of x {\displaystyle x} and t {\displaystyle t} by choosing different values for those parameters.Sound pressure standing wave in a half-open pipe playing the 7th harmonic of the fundamental (n = 4)For example, the sound pressure inside a recorder that is playing a "pure" note is typically a standing wave, that can be written as F (A , L , n , c ; x , t) = A (cos 2 x 2 n 1 4 L) (cos 2 c t 2 n 1 4 L) {\displaystyle F(A,L,n,c;x,t)=A\left(\cos 2\pi x{\frac {2n-1}{4L}}\right)\left(\cos 2\pi ct{\frac {2n-1}{4L}}\right)} The parameter A {\displaystyle A} defines the amplitude of the wave (that is, the maximum sound pressure in the bore, which is related to the loudness of the note); c {\displaystyle c} is the speed of sound; L {\displaystyle L} is the length of the bore; and n {\displaystyle n} is a positive integer (1,2,3,...) that specifies the number of nodes in the standing wave. (The position x {\displaystyle x} should be measured from the mouthpiece, and the time t {\displaystyle t} from any moment at which the pressure at the mouthpiece is maximum. The quantity = 4 L / (2 n 1) {\displaystyle \lambda =4L/(2n-1)} is the wavelength of the emitted note, and f = c / {\displaystyle f=c/\lambda } is its frequency.) Many general properties of these waves can be inferred from this general equation, without choosing specific values for the parameters.As another example, it may be that the vibrations of a drum skin after a single strike depend only on the distance r {\displaystyle r} from the center of the skin to the strike point, and on the strength s {\displaystyle s} of the strike. Then the vibration for all possible strikes can be described by a function F (r , s ; x , t) {\displaystyle F(r,s;x,t)} .Sometimes the family of waves of interest has infinitely many parameters. For example, one may want to describe what happens to the temperature in a metal bar when it is initially heated at various temperatures at different points along its length, and then allowed to cool by itself in vacuum. In that case, instead of a scalar or vector, the parameter would have to be a function h {\displaystyle h} such that h (x) {\displaystyle h(x)} is the initial temperature at each point x {\displaystyle x} of the bar. Then the temperatures at later times can be expressed by a function F {\displaystyle F} that depends on the function h {\displaystyle h} (that is, a functional operator), so that the temperature at a later time is F (h ; x , t) {\displaystyle F(h;x,t)} Another way to describe and study a family of waves is to give a mathematical equation that, instead of explicitly giving the value of F (x , t) {\displaystyle F(x,t)} , only constrains how those values can change with time. Then the family of waves in question consists of all functions F {\displaystyle F} that satisfy those constraints that is, all solutions of the equation.This approach is extremely important in physics, because the constraints usually are a consequence of the physical processes that cause the wave to evolve. For example, if F (x , t) {\displaystyle F(x,t)} is the temperature inside a block of some homogeneous and isotropic solid material, its evolution is constrained by the partial differential equation F t (x , t) = (2 F x 1 2 (x , t) + 2 F x 2 2 (x , t) + 2 F x 3 2 (x , t)) + Q (x , t) {\displaystyle {\frac {\partial F}{\partial t}}(x,t)=\alpha \left({\frac {\partial ^{2}F}{\partial x_{1}^{2}}}(x,t)+{\frac {\partial ^{2}F}{\partial x_{2}^{2}}}(x,t)+{\frac {\partial ^{2}F}{\partial x_{3}^{2}}}(x,t)\right)+\beta Q(x,t)} where Q (p , f) {\displaystyle Q(p,f)} is the heat that is being generated per unit of volume and time in the neighborhood of x {\displaystyle x} at time t {\displaystyle t} (for example, by chemical reactions happening there); x 1 , x 2 , x 3 {\displaystyle x_{1},x_{2},x_{3}} are the Cartesian coordinates of the point x {\displaystyle x} ; F / t {\displaystyle \partial F/\partial t} is the (first) derivative of F {\displaystyle F} with respect to t {\displaystyle t} ; and 2 F / x i 2 {\displaystyle \partial ^{2}F/\partial x_{i}^{2}} is the second derivative of F {\displaystyle F} relative to x i {\displaystyle x_{i}} . (The symbol " {\displaystyle \partial } " is meant to signify that, in the derivative with respect to some variable, all other variables must be considered fixed.)This equation can be derived from the laws of physics that govern the diffusion of heat in solid media. For that reason, it is called the heat equation in mathematics, even though it applies to many other physical quantities besides temperatures.For another example, we can describe all possible sounds echoing within a container of gas by a function F (x , t) {\displaystyle F(x,t)} that gives the pressure at a point x {\displaystyle x} and time t {\displaystyle t} within that container. If the gas was initially at uniform temperature and composition, the evolution of F {\displaystyle F} is constrained by the formula 2 F t 2 (x , t) = (2 F x 1 2 (x , t) + 2 F x 2 2 (x , t) + 2 F x 3 2 (x , t)) + P (x , t) {\displaystyle {\frac {\partial ^{2}F}{\partial t^{2}}}(x,t)=\alpha \left({\frac {\partial ^{2}F}{\partial x_{1}^{2}}}(x,t)+{\frac {\partial ^{2}F}{\partial x_{2}^{2}}}(x,t)+{\frac {\partial ^{2}F}{\partial x_{3}^{2}}}(x,t)\right)+\beta P(x,t)} Here P (x , t) {\displaystyle P(x,t)} is some extra compression force that is being applied to the gas near x {\displaystyle x} by some external process, such as a loudspeaker or piston right next to p {\displaystyle p} .This same differential equation describes the behavior of mechanical vibrations and electromagnetic fields in a homogeneous isotropic non-conducting solid. Note that this equation differs from that of heat flow only in that the left-hand side is 2 F / t 2 {\displaystyle \partial ^{2}F/\partial t^{2}} , the second derivative of F {\displaystyle F} with respect to time, rather than the first derivative F / t {\displaystyle \partial F/\partial t} . Yet this small change makes a huge difference on the set of solutions F {\displaystyle F} . This differential equation is called "the" wave equation in mathematics, even though it describes only one very special kind of waves.Main articles: Wave equation and d'Alembert's formulaConsider a traveling transverse wave (which may be a pulse) on a string (the medium). Consider the string to have a single spatial dimension. Consider this wave as travelingWavelength can be measured between any two corresponding points on a waveform.Animation of two waves, the green wave moves to the right while blue wave moves to the left, the net red wave amplitude at each point is the sum of the amplitudes of the individual waves. Note that f(x, t) + g(x, t) = u(x, t). in the x {\displaystyle x} direction in space. For example, let the positive x {\displaystyle x} direction be to the right, and the negative x {\displaystyle x} direction be to the left.with constant amplitude u {\displaystyle u} with constant velocity v {\displaystyle v} , where v {\displaystyle v} isindependent of wavelength (no dispersion)independent of amplitude (linear media, not nonlinear).[4][5]with constant waveform, or shapeThis wave can then be described by the two-dimensional functions u (x , t) = F (x v t) {\displaystyle u(x,t)=F(x-vt)} (waveform F {\displaystyle F} traveling to the right) u (x , t) = G (x + v t) {\displaystyle u(x,t)=G(x+vt)} (waveform G {\displaystyle G} traveling to the left)or, more generally, by d'Alembert's formula:[6] u (x , t) = F (x v t) + G (x + v t) . {\displaystyle u(x,t)=F(x-vt)+G(x+vt).} representing two component waveforms F {\displaystyle F} and G {\displaystyle G} traveling through the medium in opposite directions. A generalized representation of this wave can be obtained[7] as the partial differential equation 1 v 2 2 u t 2 = 2 u x 2 . {\displaystyle {\frac {1}{v^{2}}}{\frac {\partial ^{2}u}{\partial t^{2}}}={\frac {\partial ^{2}u}{\partial x^{2}}}.} General solutions are based upon Duhamel's principle.[8]Main article: WaveformSine, square, triangle and sawtooth waveformsThe form or shape of F in d'Alembert's formula involves the argument x vt. Constant values of this argument correspond to constant values of F, and these constant values occur if x increases at the same rate that vt increases. That is, the wave shaped like the function F will move in the positive x-direction at velocity v (and G will propagate at the same speed in the negative x-direction).[9]In the case of a periodic function F with period , that is, F(x + vt) = F(x vt), the periodicity of F in space means that a snapshot of the wave at a given time t finds the wave varying periodically in space with period (the wavelength of the wave). In a similar fashion, this periodicity of F implies a periodicity in time as well: F(x v(t + T)) = F(x vt) provided vT = , so an observation of the wave at a fixed location x finds the wave undulating periodically in time with period T = /v.[10]Main article: Amplitude modulationSee also: Frequency modulation and Phase modulationAmplitude modulation can be achieved through f(x,t) = 1.00sin(2/0.10(x1.00t)) and g(x,t) = 1.00sin(2/0.11(x1.00t)) only the resultant is visible to improve clarity of waveform.Illustration of the envelope (the slowly varying red curve) of an amplitude-modulated wave. The fast varying blue curve is the carrier wave, which is being modulated.The amplitude of a wave may be constant (in which case the wave is a c.w. or continuous wave), or may be modulated so as to vary with time and/or position. The outline of the variation in amplitude is called the envelope of the wave. Mathematically, the modulated wave can be written in the form:[11][12][13] u (x , t) = A (x , t) sin (k x t +) , {\displaystyle u(x,t)=A(x,t)\sin \left(kx-\omega t+\phi \right),} where A (x , t) {\displaystyle A(x,\ t)} is the amplitude envelope of the wave, k {\displaystyle k} is the wavenumber and {\displaystyle \phi } is the phase. If the group velocity v g {\displaystyle v_{g}} (see below) is wavelength-independent, this equation can be simplified as:[14] u (x , t) = A (x v g t) sin (k x t +) , {\displaystyle u(x,t)=A(x-v_{g}t)\sin \left(kx-\omega t+\phi \right),} showing that the envelope moves with the group velocity and retains its shape. Otherwise, in cases where the group velocity varies with wavelength, the pulse shape changes in a manner often described using an envelope equation.[14][15]Main articles: Phase velocity and Group velocitySee also: Envelope (waves) Phase and group velocityThe red square moves with the phase velocity, while the green circles propagate with the group velocity.There are two velocities that are associated with waves, the phase velocity and the group velocity.Phase velocity is the rate at which the phase of the wave propagates in space: any given phase of the wave (for example, the crest) will appear to travel at the phase velocity. The phase velocity is given in terms of the wavelength (lambda) and period T as v p = T . {\displaystyle v_{\mathrm {p} }={\frac {\lambda }{T}}.} A wave with the group and phase velocities going in different directionsGroup velocity is a property of waves that have a defined envelope, measuring propagation through space (that is, phase velocity) of the overall shape of the waves' amplitudesmodulation or envelope of the wave.This section is an excerpt from Sine wave.[edit]Tracing the y component of a circle while going around the circle results in a sine wave (red). Tracing the x component results in a cosine wave (blue). Both waves are sinusoids of the same frequency but different phases.A sine wave, sinusoidal wave, or sinusoid (symbol:) is a periodic wave whose waveform (shape) is the trigonometric sine function. In mechanics, as a linear motion over time, this is simple harmonic motion; as rotation, it corresponds to uniform circular motion. Sine waves occur often in physics, including wind waves, sound waves, and light waves, such as monochromatic radiation. In engineering, signal processing, and mathematics, Fourier analysis decomposes general functions into a sum of sine waves of various frequencies, relative phases, and magnitudes.When any two sine waves of the same frequency (but arbitrary phase) are linearly combined, the result is another sine wave of the same frequency; this property is unique among periodic waves. Conversely, if some phase is chosen as a zero reference, a sine wave of arbitrary phase can be written as the linear combination of two sine waves with phases of zero and a quarter cycle, the sine and cosine components, respectively.Main article: Plane waveA plane wave is a kind of wave whose value varies only in one spatial direction. That is, its value is constant on a plane that is perpendicular to that direction. Plane waves can be specified by a vector of unit length n ^ {\displaystyle {\hat {n}}} indicating the direction that the wave varies in, and a wave profile describing how the wave varies as a function of the displacement along that direction (n ^ x {\displaystyle {\hat {n}}\cdot {\vec {x}}}) and time (t {\displaystyle t}). Since the wave profile only depends on the position x {\displaystyle {\vec {x}}} in the combination n ^ x {\displaystyle {\hat {n}}\cdot {\vec {x}}} , any displacement in directions perpendicular to n ^ {\displaystyle {\hat {n}}} cannot affect the value of the field.Plane waves are often used to model electromagnetic waves far from a source. For electromagnetic plane waves, the electric and magnetic fields themselves are transverse to the direction of propagation, and also perpendicular to each other.Main articles: Standing wave, Acoustic resonance, Helmholtz resonance, and Organ pipeStanding wave. The red dots represent the wave nodes.A standing wave, also known as a stationary wave, is a wave whose envelope remains in a constant position. This phenomenon arises as a result of interference between two waves traveling in opposite directions.The sum of two counter-propagating waves (of equal amplitude and frequency) creates a standing wave. Standing waves commonly arise when a boundary blocks further propagation of the wave, thus causing wave reflection, and therefore introducing a counter-propagating wave. For example, when a violin string is displaced, transverse waves propagate out to where the string is held in place at the bridge and the nut, where the waves are reflected back. At the bridge and nut, the two opposed waves are in antiphase and cancel each other, producing a node. Halfway between two nodes there is an antinode, where the two counter-propagating waves enhance each other maximally. There is no net propagation of energy over time.One-dimensional standing waves; the fundamental mode and the first 5 overtonesA two-dimensional standing wave on a disk; this is the fundamental mode.A standing wave on a disk with two nodal lines crossing at the center; this is an overtone.Main article: SolitonSolitary wave in a laboratory wave channelA soliton or solitary wave is a self-reinforcing wave packet that maintains its shape while it propagates at a constant velocity. Solitons are caused by a cancellation of nonlinear and dispersive effects in the medium. (Dispersive effects are a property of certain systems where the speed of a wave depends on its frequency.) Solitons are the solutions of a widespread class of weakly nonlinear dispersive partial differential equations describing physical systems.Wave propagation is any of the ways in which waves travel. With respect to the direction of the oscillation relative to the propagation direction, we can distinguish between longitudinal wave and transverse waves.Electromagnetic waves propagate in vacuum as well as in material media. Propagation of other wave types such as sound may occur only in a transmission medium.Further information: Reflection coefficientThe propagation and reflection of plane wavese.g. Pressure waves (P wave) or Shear waves (SH or SV-waves) are phenomena that were first characterized within the field of classical seismology, and are now considered fundamental concepts in modern seismic tomography. The analytical solution to this problem exists and is well known. The frequency domain solution can be obtained by first finding the Helmholtz decomposition of the displacement field, which is then substituted into the wave equation. From here, the plane wave eigenmodes can be calculated.[citation needed][clarification needed]The propagation of SV-wave in a homogeneous half-space (the horizontal displacement field)The propagation of SV-wave in a homogeneous half-space (The vertical displacement field)[clarification needed]The analytical solution of SV-wave in a half-space indicates that the plane SV wave reflects back to the domain as a P and SV waves, leaving out special cases. The angle of the reflected SV wave is identical to the incidence wave, while the angle of the reflected P wave is greater than the SV wave. For the same wave frequency, the SV wavelength is smaller than the P wavelength. This fact has been depicted in this animated picture.[16]Similar to the SV wave, the P incidence, in general, reflects as the P and SV wave. There are some special cases where the regime is different.[clarification needed]Further information: Phase velocity, Group velocity, and Signal velocitySeismic wave propagation in 2D modelled using FDTD method in the presence of a landmineWave velocity is a general concept, of various kinds of wave velocities, for a wave's phase and speed concerning energy (and information) propagation. The phase velocity is given as: v p = k , {\displaystyle v_{\rm {p}}={\frac {\omega }{k}},} where:vp is the phase velocity (with SI unit m/s), is the angular frequency (with SI unit rad/s),k is the wavenumber (with SI unit rad/m).The phase speed gives you the speed at which a point of constant phase of the wave will travel for a discrete frequency. The angular frequency cannot be chosen independently from the wavenumber k, but both are related through the dispersion relationship: = (k) . {\displaystyle \omega =\Omega (k).} In the special case (k) = ck, with c a constant, the waves are called non-dispersive, since all frequencies travel at the same phase speed c. For instance electromagnetic waves in vacuum are non-dispersive. In case of other forms of the dispersion relation, we have dispersive waves. The dispersion relationship depends on the medium through which the waves propagate and on the type of waves (for instance electromagnetic, sound or water waves).The speed at which a resultant wave packet from a narrow range of frequencies will travel is called the group velocity and is determined from the gradient of the dispersion relation: v g = k {\displaystyle v_{\rm {g}}={\frac {\partial \omega }{\partial k}}} In almost all cases, a wave is mainly a movement of energy through a medium. Most often, the group velocity is the velocity at which the energy moves through this medium.Light beam exhibiting reflection, refraction, transmission and dispersion when encountering a prismWaves exhibit common behaviors under a number of standard situations, for example:Main articles: Rectilinear propagation, Transmittance, and Transmission mediumWaves normally move in a straight line (that is, rectilinearly) through a transmission medium. Such media can be classified into one or more of the following categories:A bounded medium if it is finite in extent, otherwise an unbounded mediumA linear medium if the amplitudes of different waves at any particular point in the medium can be addedA uniform medium or homogeneous medium if its physical properties are unchanged at different locations in spaceAn anisotropic medium if one or more of its physical properties differ in one or more directionsAn isotropic medium if its physical properties are the same in all directionsMain articles: Absorption (acoustics) and Absorption (electromagnetic radiation)Waves are usually defined in media which allow most or all of a wave's energy to propagate without loss. However materials may be characterized as "lossy" if they remove energy from a wave, usually converting it into heat. This is termed "absorption." A material which absorbs a wave's energy, either in transmission or reflection, is characterized by a refractive index which is complex. The amount of absorption will generally depend on the frequency (wavelength) of the wave, which, for instance, explains why objects may appear colored.Main article: Reflection (physics)When a wave strikes a reflective surface, it changes direction, such that the angle made by the incident wave and line normal to the surface equals the angle made by the reflected wave and the same normal line.Main article: RefractionSinusoidal traveling plane wave entering a region of lower wave velocity at an angle, illustrating the decrease in wavelength and change of direction (refraction) that resultsRefraction is the phenomenon of a wave changing its speed. Mathematically, this means that the size of the phase velocity changes. Typically, refraction occurs when a wave passes from one medium into another. The amount by which a wave is refracted by a material is given by the refractive index of the material. The directions of incidence and refraction are related to the refractive indices of the two materials by Snell's law.Main article: DiffractionA wave exhibits diffraction when it encounters an obstacle that bends the wave or when it spreads after emerging from an opening. Diffraction effects are more pronounced when the size of the obstacle or opening is comparable to the wavelength of the wave.Main article: Wave interferenceIdentical waves from two sources undergoing interference. Observed at the bottom one sees 5 positions where the waves add in phase, but in between which they are out of phase and cancel.When waves in a linear medium (the usual case) cross each other in a region of space, they do not actually interact with each other, but continue on as if the other one were not present. However at any point in that region the field quantities describing those waves add according to the superposition principle. If the waves are of the same frequency in a fixed phase relationship, then there will generally be positions at which the two waves are in phase and their amplitudes add, and other positions where they are out of phase and their amplitudes (partially or fully) cancel. This is called an interference pattern.Main article: Polarization (waves)The phenomenon of polarization arises when wave motion can occur simultaneously in two orthogonal directions. Transverse waves can be polarized, for instance. When polarization is used as a descriptor without qualification, it usually refers to the special, simple case of linear polarization. A transverse wave is linearly polarized if it oscillates in only one direction or plane. In the case of linear polarization, it is often useful to add the relative orientation of that plane, perpendicular to the direction of travel, in which the oscillation occurs, such as "horizontal" for instance, if the plane of polarization is parallel to the ground. Electromagnetic waves propagating in free space, for instance, are transverse; they can be polarized by the use of a polarizing filter.Longitudinal waves, such as sound waves, do not exhibit polarization. For these waves there is only one direction of oscillation, that is, along the direction of travel.Schematic of light