


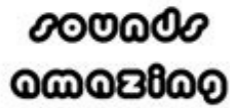
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# Wave equation worksheet pdf

## Wave equation example. Wave equation worksheet answers. Wave equation formula. What is the basic wave equation.

In 1924, Louis de Broglie presented his research thesis, in which he proposed electrons have properties of both waves and particles, like light. He rearranged the terms of the Plank-Einstein relation to apply to all types of matter. The de Broglie equation is an equation used to describe the wave properties of matter, specifically, the wave nature of the electron.  $\lambda = h/mv$ , where  $\lambda$  is wavelength,  $h$  is Planck's constant,  $m$  is the mass of a particle, moving at a velocity  $v$ . de Broglie suggested that particles can exhibit properties of waves. The de Broglie hypothesis was verified when matter waves were observed in George Paget Thomson's cathode ray diffraction experiment and the Davisson-Germer experiment, which specifically applied to electrons. Since then, the de Broglie equation has been shown to apply to elementary particles, neutral atoms, and molecules. Differential wave equation important in physics Not to be confused with wave function.



<http://www.acoustics.salford.ac.uk/schools>

### TEACHERS LESSON PLAN: Lesson One – Sound Waves

This lesson plan accompanies the WHITEBOARD version of the site, and can perhaps be used as a 'script' to accompany the lesson. The guide script is shown in *italics*.

#### 1) SOUND WAVES

*In this lesson you will learn about sound and waves. You will find out exactly how waves work. And you will be able to identify and label the following properties of sound...*

#### 2) KEYWORDS

The keywords we will cover in this lesson are:

- Speed = distance travelled in unit time (m/s)
- Frequency = number of complete waves in one second (Hz)
- Wavelength = distance between matching points on the wave (m)
- Longitudinal = vibration parallel to direction of travel
- Transverse = vibration at right angle to direction of travel

At the beginning of the class, you could write the AIM and the KEYWORDS on the board.

*3) This is a Mexican wave. A group of people jump up and sit back down. People nearby see them and do the same, then some people further away do the same. The wave is the disturbance (people jumping up and sitting back down), and it travels across the crowd. None of the people in the crowd travel with the wave, they all remain in their seats.*

*Assuming the class have no prior knowledge, you could spend 5 minutes asking open questions, such as 'what is a wave?' and 'what travels in waves?' You could either do this with the whole class, or for larger classes, split into groups of 3 or 4. If splitting the class into groups, you will probably need another 5 minutes to get feedback from the questions. You could collate the correct answers, and then write the definition on the board and ask them to write it down in their book.*

#### 4) WAVE TYPES

*Waves carry energy from one place to another. Sound, light and radio signals all travel in the form of waves. There are two main types of wave. Who wants to come up and click on a type of wave to see an example of how it 'behaves'?*

*Next, you could show the class the animation/video of ripple tank, and also a slinky (use a real one for this – ideally a few). Ask two people to hold it; one person sends a wave down it.*



A pulse traveling through a string with fixed endpoints as modeled by the wave equation Spherical waves coming from a point source A solution to the 2D wave equation The (two-way) wave equation is a second-order linear partial differential equation for the description of waves or standing wave fields - as they occur in classical physics - such as mechanical waves (e.g. water waves, sound waves and seismic waves) or electromagnetic waves (including light waves).

It arises in fields like acoustics, electromagnetism, and fluid dynamics. Single mechanical or electromagnetic waves propagating in a pre-defined direction can also be described with the first-order one-way wave equation, which is much easier to solve and also valid for inhomogeneous media. Introduction The (two-way) wave equation is a second-order partial differential equation describing waves, including traveling and standing waves; the latter can be considered as linear superpositions of waves traveling in opposite directions. This article mostly focuses on the scalar wave equation describing waves in scalars by scalar functions  $u = u(x_1, x_2, \dots, x_n; t)$  of a time variable  $t$  (a variable representing time) and one or more spatial variables  $x_1, x_2, \dots, x_n$  (variables representing a position in a space under discussion), while there are vector wave equations describing waves in vectors such as waves for electrical field, magnetic field, and magnetic vector potential and elastic waves. By comparison with vector wave equations, the scalar wave equation can be seen as a special case of the vector wave equations; in the Cartesian coordinate system, the scalar wave equation is the equation to be satisfied by each component (for each coordinate axis, such as the  $x$  component for the  $x$  axis) of a vector wave without sources of waves in the considered domain (i.e., a space and time). For example, in the Cartesian coordinate system, for  $(E_x, E_y, E_z) \in \mathbb{R}^3$  as the representation of an electric vector field wave  $E \rightarrow (\text{vec } E)$  in the absence of wave sources, each coordinate axis component  $E_i$  ( $i = x, y, z$ ) must satisfy the scalar wave equation. Other scalar wave equation solutions  $u$  are for physical quantities in scalars such as pressure in a liquid or gas, or the displacement along some specific direction of particles of a vibrating solid away from their resting (equilibrium) positions. The scalar wave equation is  $\partial^2 u / \partial t^2 = c^2 (\partial^2 u / \partial x^2 + \partial^2 u / \partial y^2 + \dots + \partial^2 u / \partial x_n^2)$ , where  $c$  is a fixed non-negative real coefficient.

In other words:  $u$  is the factor representing a displacement from rest situation - it could be gas pressure above or below normal, or the height of water in a pond above or below rest, or something else.  $t$  represents time.  $\partial^2 u / \partial t^2$  is a term for how the displacement accelerates, i.e. not the speed at which the displacement is changing, but in fact the rate at which that displacement's speed is itself changing - its acceleration.  $x$  represents space or position.  $\partial^2 u / \partial x^2$  is a term for how the displacement is varying at the point  $x$  in one of the dimensions (like one of the axes on a graph). It's not the rate at which the displacement is changing across space, but in fact the rate at which the displacement is changing across space - its second derivative. In other words, this term shows how the displacement's changes are squashed up in a tiny surrounding area. The equation states that at any given instance, at any given point, the way the displacement accelerates is proportional to the way the displacement's changes are squashed up in the surrounding area. Or, in even simpler terms, the way displacements get pushed around is proportional to how pointy the displacement is, and conversely. Using the notations of Newtonian mechanics and vector calculus, the wave equation can be written more compactly as  $\ddot{u} = c^2 \nabla^2 u$ , where the double dot on  $u$  denotes double time derivative of  $u$ ,  $\nabla^2$  is the nabla operator, and  $\nabla^2 = \nabla \cdot \nabla$  is the (spatial) Laplacian operator (not vector Laplacian):  $\nabla^2 u = \partial^2 u / \partial t^2$ ,  $\nabla = (\partial / \partial x_1, \partial / \partial x_2, \dots, \partial / \partial x_n)$ ,  $\nabla^2 = \partial^2 u / \partial x_1^2 + \partial^2 u / \partial x_2^2 + \dots + \partial^2 u / \partial x_n^2$ . This equation is typically described as having only one space dimension  $x$ , because the only other independent variable is the time  $t$ . Nevertheless, the dependent variable  $u$  may represent a second space dimension, if, for example, the displacement  $u$  takes place in  $y$  direction, as in the case of a string that is located in the  $xy$  plane. Derivation of the wave equation in one space dimension uses Hooke's law. In the theory of elasticity, Hooke's law is an approximation for certain materials, stating that the amount by which a material body is deformed (the strain) is linearly related to the force causing the deformation (the stress). From Hooke's law The wave equation in the one-dimensional case can be derived from Hooke's law in the following way: imagine an array of little weights of mass  $m$  interconnected with massless springs of length  $h$ . The springs have a spring constant of  $k$ . Here the dependent variable  $u(x)$  measures the distance from the equilibrium of the mass situated at  $x$ , so that  $u(x)$  essentially measures the magnitude of a disturbance (i.e. strain) that is traveling in an elastic material. The resulting force exerted on the mass  $m$  at the location  $x+h$  is:  $F_{\text{Hooke}} = Fx + 2h - Fx = k(u(x+2h, t) - u(x+h, t)) - k(u(x+h, t) - u(x, t))$ . By equating the latter equation with  $F_{\text{Newton}} = ma(t) = m \partial^2 u / \partial t^2$  we obtain:  $\partial^2 u / \partial t^2 = K/L^2 M \partial^2 u / \partial x^2$ , where  $K = k/m$  is the spring constant of the array  $K = k/Nm$ , and the total spring constant of the array  $K = k/Nm$ , we can write the above equation as  $\partial^2 u / \partial t^2 = K/L^2 M \partial^2 u / \partial x^2$ . The speed of a stress wave in a bar is therefore  $E/\rho$ . General solution Algebraic approach The one-dimensional wave equation is unusual for a partial differential equation in that a relatively simple general solution may be found. Defining new variables  $\xi = x - ct$ ,  $\eta = x + ct$  changes the wave equation into  $\partial^2 u / \partial \xi \partial \eta = 0$ , which leads to the general solution  $u(\xi, \eta) = F(\xi) + G(\eta)$ , or equivalently,  $u(x, t) = F(x - ct) + G(x + ct)$ . In other words, solutions of the 1D wave equation are sums of a right-traveling function  $F$  and a left-traveling function  $G$ . "Traveling" means that the shape of these individual arbitrary functions with respect to  $x$  stays constant, however, the functions are translated left and right with time at the speed  $c$ . This was derived by Jean le Rond d'Alembert. Another way to arrive at this result is to factor the wave equation into two one-way wave equations:  $(\partial / \partial t - c \partial / \partial x)(\partial / \partial t + c \partial / \partial x)u = 0$ . As a result, if we define  $v = \partial u / \partial t + c \partial u / \partial x$ , then  $\partial v / \partial t - c \partial v / \partial x = 0$ . From this,  $v$  must have the form  $G(x + ct)$ , and from this the correct form of the full solution  $u$  can be deduced. The usual second-order wave equation is sometimes called the "two-way wave equation" (superposition of two waves) to distinguish it from the first-order one-way wave equation describing the wave propagation of a single wave in a pre-defined direction. For an initial-value problem, the arbitrary functions  $F$  and  $G$  can be determined to satisfy initial conditions:  $u(x, 0) = f(x)$ ,  $u_t(x, 0) = g(x)$ . The result is d'Alembert's formula:  $u(x, t) = f(x - ct) + f(x + ct) / 2 + 1/2c \int_{x-ct}^{x+ct} g(s) ds$ . In the classical sense, if  $f(x) \in C^k$ , and  $g(x) \in C^{k-1}$ , then  $u(x, t) \in C^k$ . However, the waveforms  $F$  and  $G$  may also be generalized functions, such as the delta-function. In that case, the solution may be interpreted as an impulse that travels to the right or the left. The basic wave equation is a linear differential equation, and so it will adhere to the superposition principle. This means that the net displacement caused by two or more waves is the sum of the displacements which would have been caused by each wave individually. In addition, the behavior of a wave can be analyzed by breaking up the wave into components, e.g. the Fourier transform breaks up a wave into sinusoidal components. Plane-wave eigenmodes Main article: Helmholtz equation Another way to solve the one-dimensional wave equation is to first analyze its frequency eigenmodes. A so-called eigenmode is a solution that oscillates in time with a well-defined constant angular frequency  $\omega$ , so that the temporal part of the wave function takes the form  $e^{-i\omega t} = \cos(\omega t) - i \sin(\omega t)$ , and the amplitude is a function  $f(x)$  of the spatial variable  $x$ , giving a separation of variables for the wave function:  $u(x, t) = e^{-i\omega t} f(x)$ . This produces an ordinary differential equation for the spatial part  $f(x)$ :  $\partial^2 u / \partial x^2 = -\omega^2 u / \partial t^2 = -\omega^2 e^{-i\omega t} f(x) = -\omega^2 e^{-i\omega t} f(x)$ . Therefore,  $d^2 f(x) / dx^2 = -(\omega/c)^2 f(x)$ . This is precisely an eigenvalue equation for  $f(x)$ , hence the name eigenmode. Known as the Helmholtz equation, it has the well-known plane-wave solutions  $f(x) = A e^{\pm i k x} = A e^{\pm i(kx + \omega t)} + B e^{i(kx - \omega t)}$ , where complex numbers  $A, B$  depend in general on any initial and boundary conditions of the problem. Eigenmodes are useful in constructing a full solution to the wave equation, because each of them evolves in time trivially with the phase factor  $e^{-i\omega t}$ , so that a full solution can be decomposed into an eigenmode expansion:  $u(x, t) = \int_{-\infty}^{\infty} s(\omega) u(x, t) d\omega = \int_{-\infty}^{\infty} s(\omega) e^{i(kx + \omega t)} d\omega + \int_{-\infty}^{\infty} s(-\omega) e^{i(kx - \omega t)} d\omega = F(x - ct) + G(x + ct)$ , which is exactly the same form as in the algebraic approach. Functions  $s(\omega)$  are known as the Fourier component and are determined by initial and boundary conditions.



way wave equation (resulting from factorization of the vectorial two-way wave equation), and an analytical solution can be derived.[9] Other coordinate systems In three dimensions, the wave equation, when written in elliptic cylindrical coordinates, may be solved by separation of variables, leading to the Mathieu differential equation. Further generalizations Elastic waves The elastic wave equation (also known as the Navier–Cauchy equation) in three dimensions describes the propagation of waves in an isotropic homogeneous elastic medium. Most solid materials are elastic, so this equation describes such phenomena as seismic waves in the Earth and ultrasonic waves used to detect flaws in materials.

While linear, this equation has a more complex form than the equations given above, as it must account for both longitudinal and transverse motion: 



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{\displaystyle \rho \ddot {\mathbf {u} }=\mathbf {f} +(\lambda +2\mu )\nabla (\nabla \cdot \mathbf {u} )-\mu \nabla \times (\nabla \times \mathbf {u} ),}

 where: λ and μ are the so-called Lamé parameters describing the elastic properties of the medium, ρ is the density, f is the source function (driving force), u is the displacement vector. By using 



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{\displaystyle \nabla \times (\nabla \times u)=\nabla (\nabla \cdot u)-\nabla \cdot \nabla u=\nabla (\nabla \cdot u)-\Delta u,}

 the elastic wave equation can be rewritten into the more common form of the Navier–Cauchy equation. Note that in the elastic wave equation, both force and displacement are vector quantities. Thus, this equation is sometimes known as the vector wave equation. As an aid to understanding, the reader will observe that if f and ∇ · u are set to zero, this becomes (effectively) Maxwell's equation for the propagation of the electric field E, which has only transverse waves. Dispersion relation In dispersive wave phenomena, the speed of wave propagation varies with the wavelength of the wave, which is reflected by a dispersion relation 



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 where ω is the angular frequency, and k is the wavevector describing plane-wave solutions. For light waves, the dispersion relation is 



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 but in general, the constant speed c gets replaced by a variable phase velocity: 



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{\displaystyle v\_{\text{p}}={\frac {\omega (k)}{k}}.}

 See also Acoustic attenuation Acoustic wave equation Bateman transform Electromagnetic wave equation Helmholtz equation Inhomogeneous electromagnetic wave equation Laplace operator Mathematics of oscillation Maxwell's equations One-way wave equation Schrödinger equation Standing wave Vibrations of a circular membrane Wheeler–Feynman absorber theory Notes ^ a b Speiser, David.

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doi:10.4249/scholarpedia.4308 Retrieved from " Wave Velocity is one of the common topics of all the exams that test students on the parameters of physics.

Students normally find it hard to deal with this topic as it is a little complex in nature.

Although, if studied well, the same topic could be very scoring for the students from exam point of view. To bridge the gap between students and their learning Vedantu has come up with an article prepared by a team of dedicated teachers on wave velocity. Wave Velocity - Formula, Properties, Examples could also be found in the PDF format from the website. The students can download it on their devices and study from the comfort of their homes. The resource is free of cost and doesn't require any prior registration fee. A wave is a result of external perturbation in a plane surface. We can define a wave as - a wave is a disturbance propagating in space with transportation of energy and momentum from one point to another without transfer of the matter. The most commonly used examples for waves are the ripples in a pond, Sound that reaches us propagates through wave motion, TV signals, etc. The waves are classified into different types depending upon the type of medium, propagation energy, dimensions, and the vibration of particles.What is Wave Velocity?Now, we are constantly talking about the term wave velocity. To understand the wave velocity first, let us look at the meaning and define wave velocity.The wave velocity definition is given as the velocity associated with the disturbance propagating in the given medium or in other words, wave velocity is the distance traveled by waves per unit time.The wave velocity depends upon the nature of the medium used.The wave velocity is also known as phase velocity. (Image will be Uploaded soon)Now the formula of wave velocity is given as follows.

The wave velocity formula says it is the product of wavelength and the frequency of the wave. I.e.,Wave velocity (v) mathematically is given by,\(\Rightarrow v = \frac{w}{k} \)......(1) Where, w - The angular velocity k - the angular wavenumber or propagation constantWe know that,The value of the angular velocity = w = \(\frac{2\pi}{T}\) where \(\frac{2\pi}{T}\) - Frequency of the waveThe value of the wavenumber = k = \(\frac{2\pi}{\lambda}\) where \(\lambda\) - The wavelength Substituting these value in equation (1) we get, \(\Rightarrow v = \frac{2\pi w}{2\pi k} = \frac{w}{k}\)Therefore, we have,\(\Rightarrow v = \frac{w}{k}\).....(2)Where,\(\lambda\) - The wavelength\(\nu\) - Frequency of the waveEquation (2) is known as the equation of wave velocity or wave velocity formula.Wave Velocity Formula:In wave motion, the perturbations travel through the medium due to repeated periodic oscillations of the particles. The velocity of the wave will be different from the velocity of the particles with which they vibrate about their mean positions.

The wave velocity will always be constant but the particle velocity will be changing with time periods.Properties of Wave Velocity:The wave velocity in a given medium is always constant.The wave velocity is independent of the time and source of the wave, but the wave velocity depends on the wavelength of the propagating wave in a given medium.The wave velocity depends on the medium used.Examples:1. How to Calculate Wave Velocity for a Given Periodic Wave with a Wavelength of 3m Has a Frequency 6Hz?Sol: Given,The wavelength of the periodic wave = \(\lambda\) = 3mThe frequency of the given periodic wave = \(\nu\) = 6HzWe have to calculate the wave velocity of the given periodic wave. From the equation of wave velocity we have,\(\Rightarrow v = \lambda \nu\)Where, \(\lambda\) - The wavelength \(\nu\) - Frequency of the waveSubstituting the corresponding values in equation (1) we get, \(\Rightarrow v = 3(6) = 18\text{ m/s.2. How Do You Find the Velocity of a Wave with a Wavelength of 20m has a Frequency 70Hz?Sol: Given, The wavelength of the periodic wave = \(\lambda\) = 20mThe frequency of the given periodic wave = \(\nu\) = 70HzWe have to calculate the wave velocity of the given periodic wave.

From the equation of wave velocity we have,\(\Rightarrow v = \lambda \nu\)Where, \(\lambda\) - The wavelength \(\nu\) - Frequency of the waveSubstituting the corresponding values in equation (1) we get, = v = (20)(70) = 1400 m/sTherefore, the wave velocity of a given periodic wave is 1400 m/s.3. The Velocity of Wave 70m/s. If the Wavelength of the Wave is 1m then Calculate the Frequency of the Given Wave.Sol: The wavelength of the wave = \(\lambda\) = 1mThe wave velocity of the given wave = v = 70m/sWe have to calculate the Frequency of the given wave. From the equation of wave velocity we have,\(\Rightarrow v = \lambda \nu\)..... 1Where, \(\lambda\) - The wavelength \(\nu\) - Frequency of the waveOn rearranging the equation (1) for the frequency of the wave, \(\Rightarrow \nu = \frac{v}{\lambda}\) \)......(2) Substituting the given values, \(\Rightarrow \nu = \frac{70}{1}\) \)......(2) = 70 HzTherefore, the frequency of the given wave is 70Hz 4. A Wave with a Frequency 450Hz is Traveling at a Speed of 200m/s. Then Calculate the Wavelength of the Wave. Sol: The frequency of the wave = \(\nu\) = 450HzThe wave velocity of the given wave = v = 200m/s We have to calculate the wavelength of the given wave. From the equation of wave velocity we have,\(\Rightarrow v = \lambda \nu\)..... 1Where, \(\lambda\) - The wavelength \(\nu\) - Frequency of the waveOn rearranging the equation (1) for the wavelength of the wave, \(\Rightarrow \lambda = \frac{v}{\nu}\) \)......(2) Substituting the corresponding values in (2) we get, \(\Rightarrow \lambda = \frac{200}{450}\) \)......(2) = 0.44m Therefore, the wavelength of the given wave is 0.44m.Revision remedyThe Wave Velocity - Formula, Properties, Examples article developed by Vedantu is a perfect tool for revision for the students. It is advised that when the exams are near, you should choose to revise from the wave velocity PDF. The article precisely mentions all the details with complete clarity to the students. One may even choose to make notes from the above content and enhance her chances to score well in the exams. On the other hand, just underlining the keywords would suffice too. All one has to do is look at the keywords. If feasible, taking a printout is also a convenient idea.Making the Notes and Underlining As it is common knowledge, having good revision notes is the best policy for scoring well in exams. One can use the wave velocity article to make the revision notes. Note down all the keywords and important definitions that are relevant from the exam point of view.