Engineering Physics

Course Code: BPHY101L; Course Type: Theory Only (TH)

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Evolution of Technology

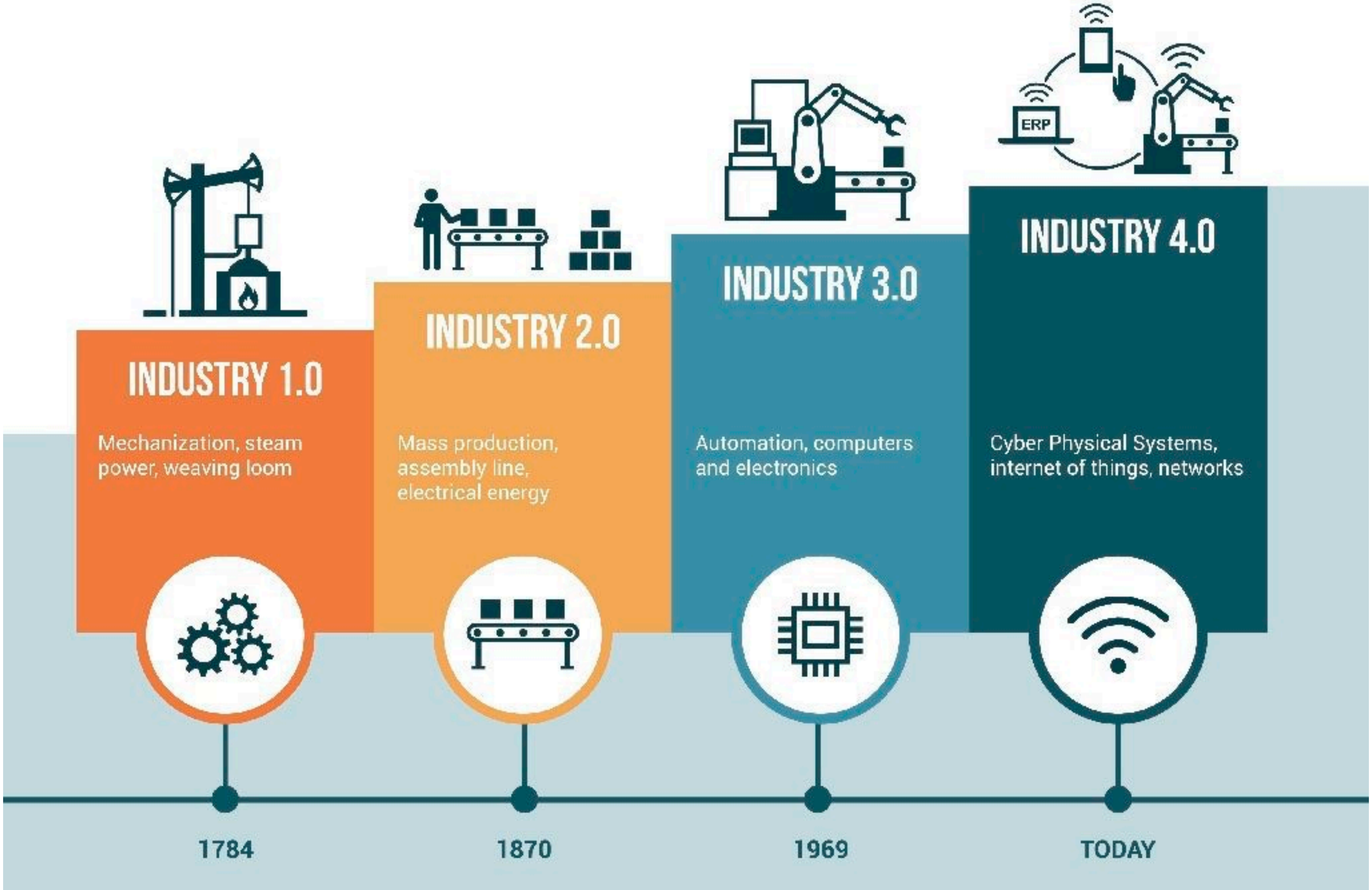
Evolution of Technology

1956, 5 MB

2024, 16 TB

4 TB = 16,777,216 MB

Industrial Revolution



Time Travel from Science to Technology

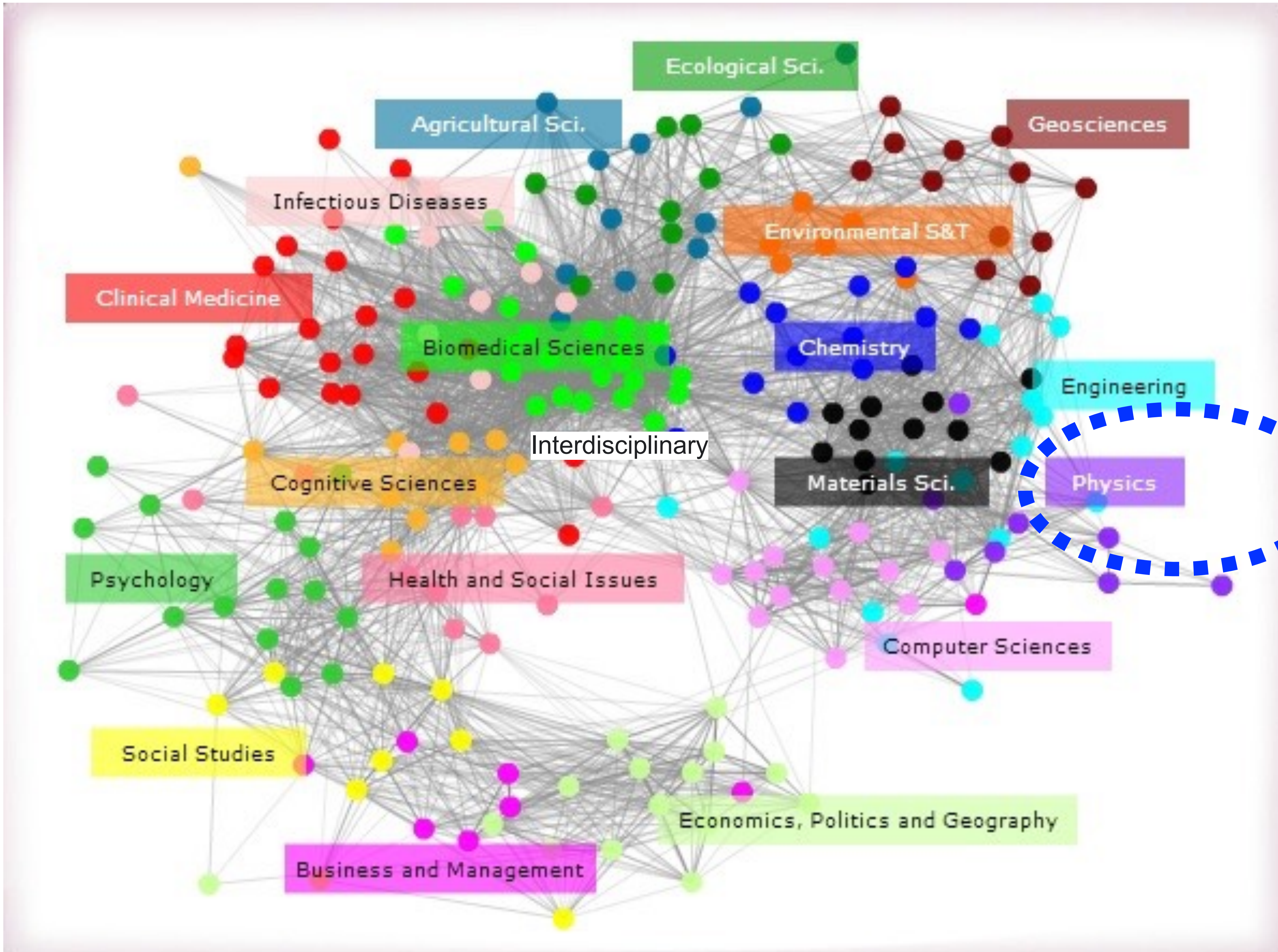
SCIENCE

Science is a methodical way of gaining knowledge on a particular subject, through observation and experiments.

TECHNOLOGY

Technology alludes to the practical application of the scientific knowledge for various purposes.

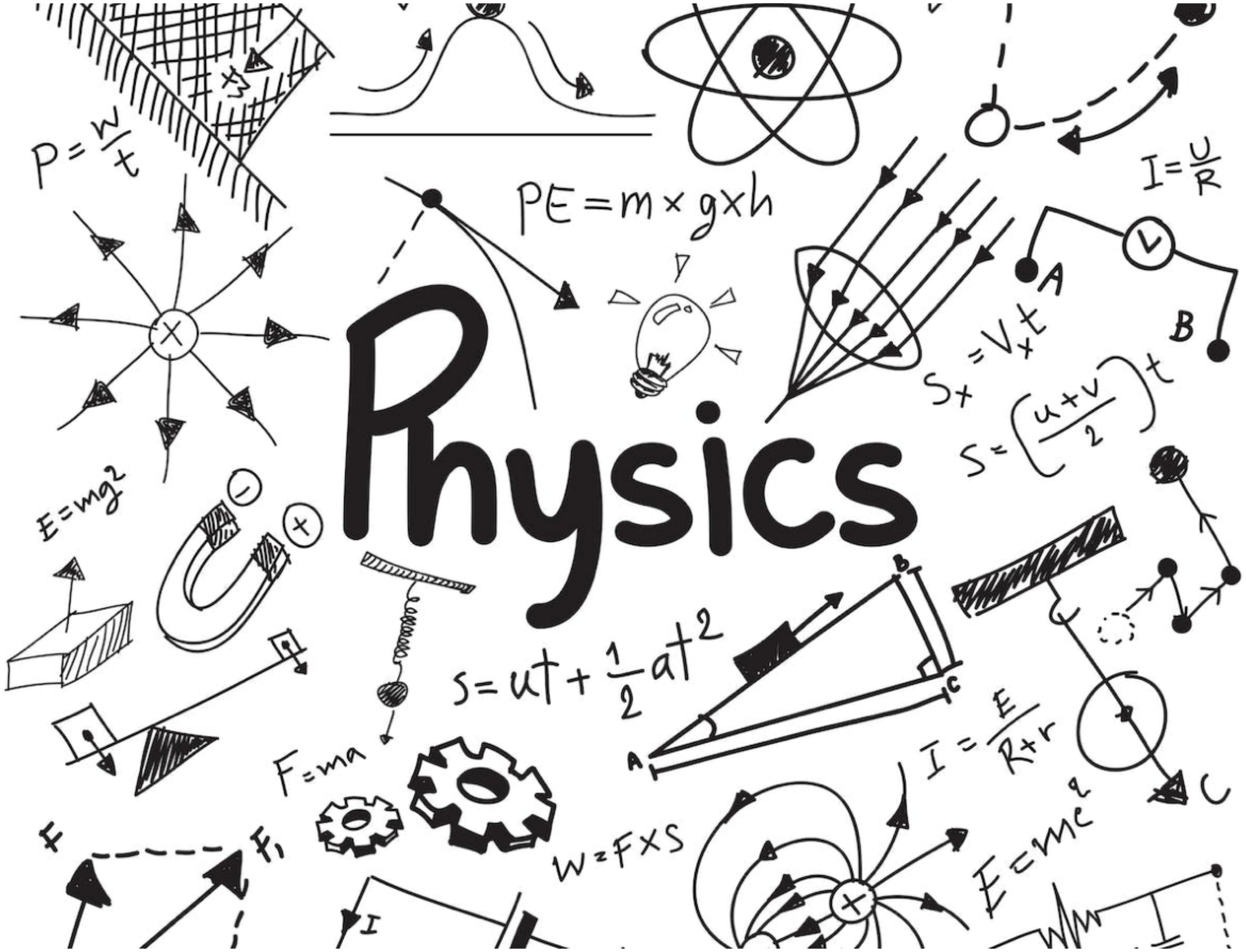
Science is Interdisciplinary



Importance of Physics

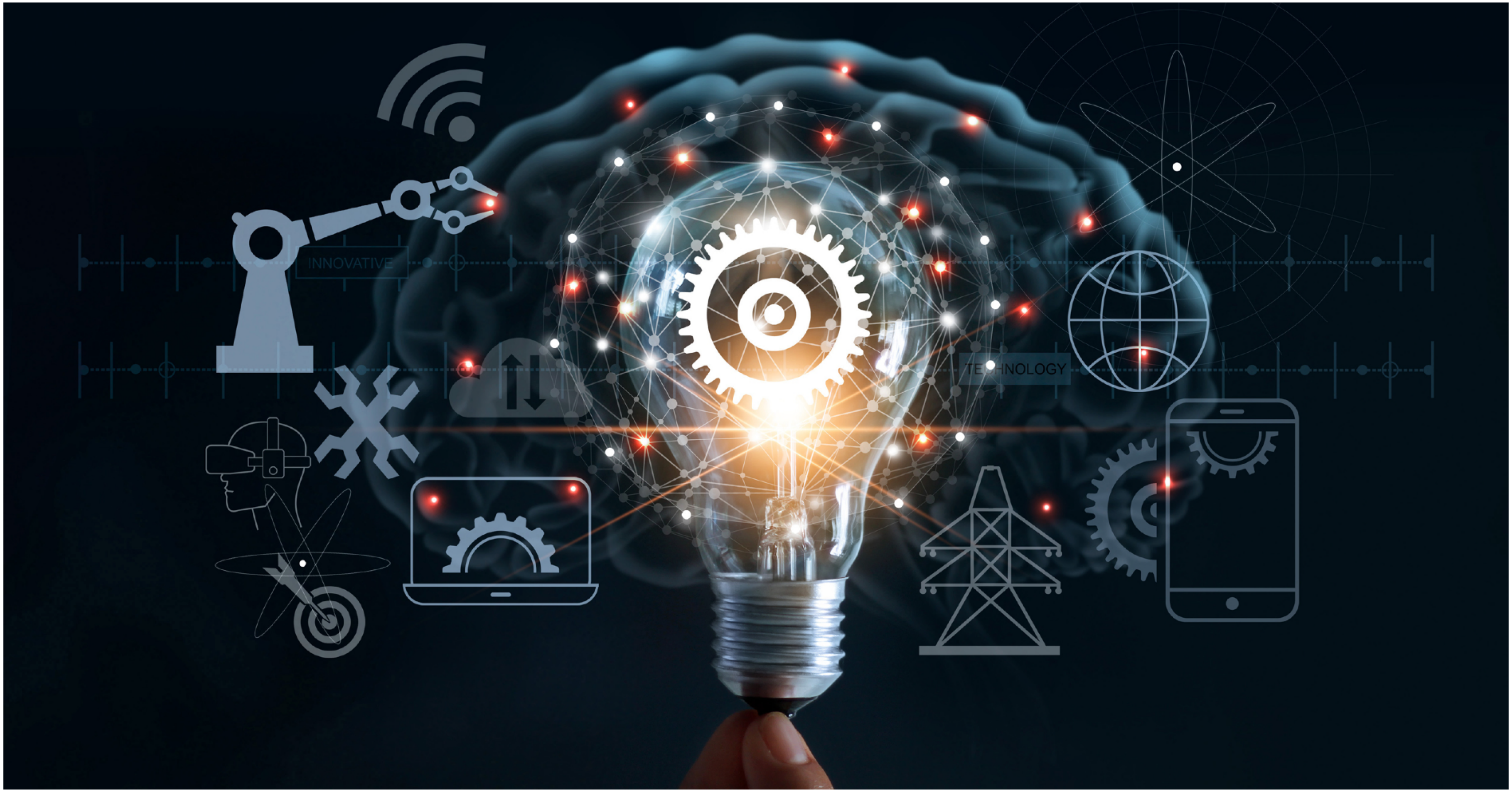
- In Meeting Future Energy Requirements
- In Medical Technologies
- In Modern Engineering
- In the IT Industry
- In the Communication Industry

What is Physics ?



- Physics is one of the most fundamental scientific disciplines, and its main goal is to understand how the universe behaves.
- Physics generates fundamental knowledge needed for the future technological advances.

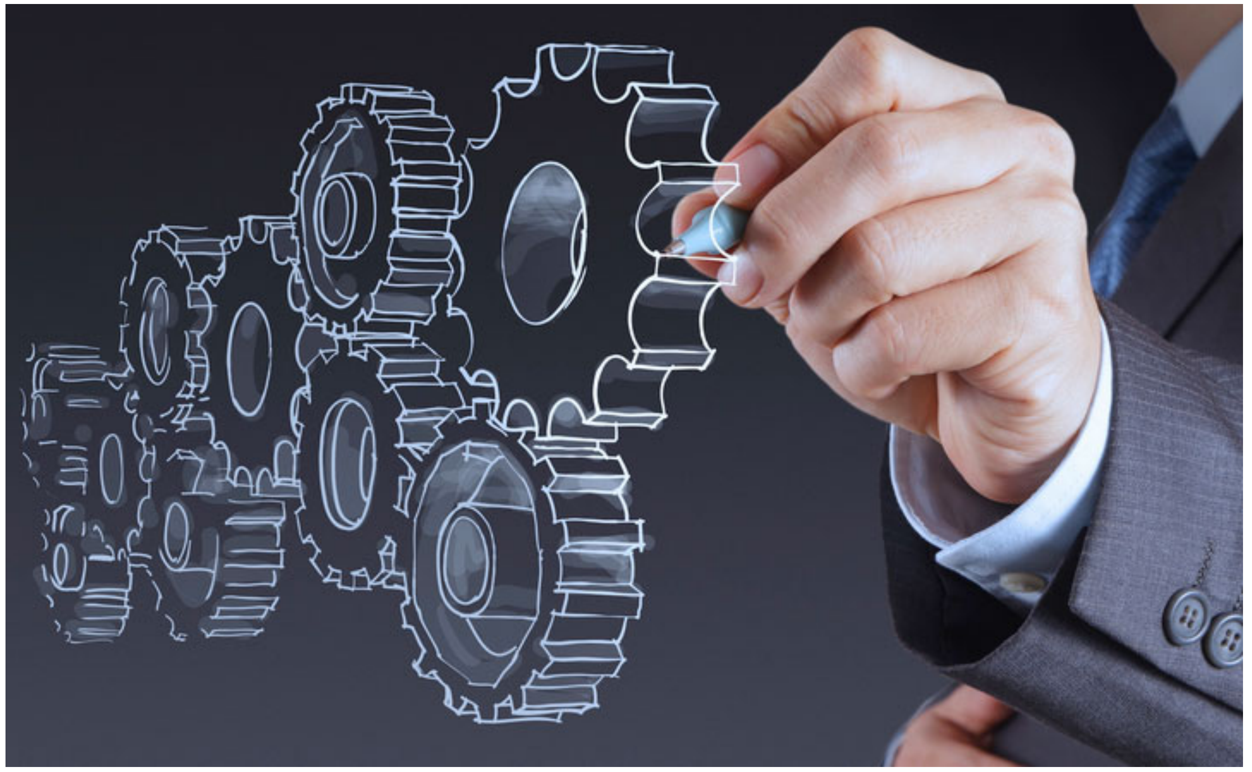
What is Engineering?



Engineering is the mindset to think over the use of scientific principles, to design and build machines, structures, and other items. Engineering enables us to think out of the box

Role of Physics in Engineering

Engineering is a profession in which scientific knowledge and mathematics is used for innovations, to develop new things that benefit mankind, which is important to society and nature, making everything around us easier.



Engineering is basically an application of physics and mathematics to solve everyday problems.

- ➡ Physics is a science that tries to figure out the fundamental laws of the universe in a way that will allow you to make predictions. It tries to boil the universe down into some basic, mathematical laws.
- ➡ Engineering, on the other hand, is concerned with figuring out how to design, build, and use structures and machines. So how are those two things related?

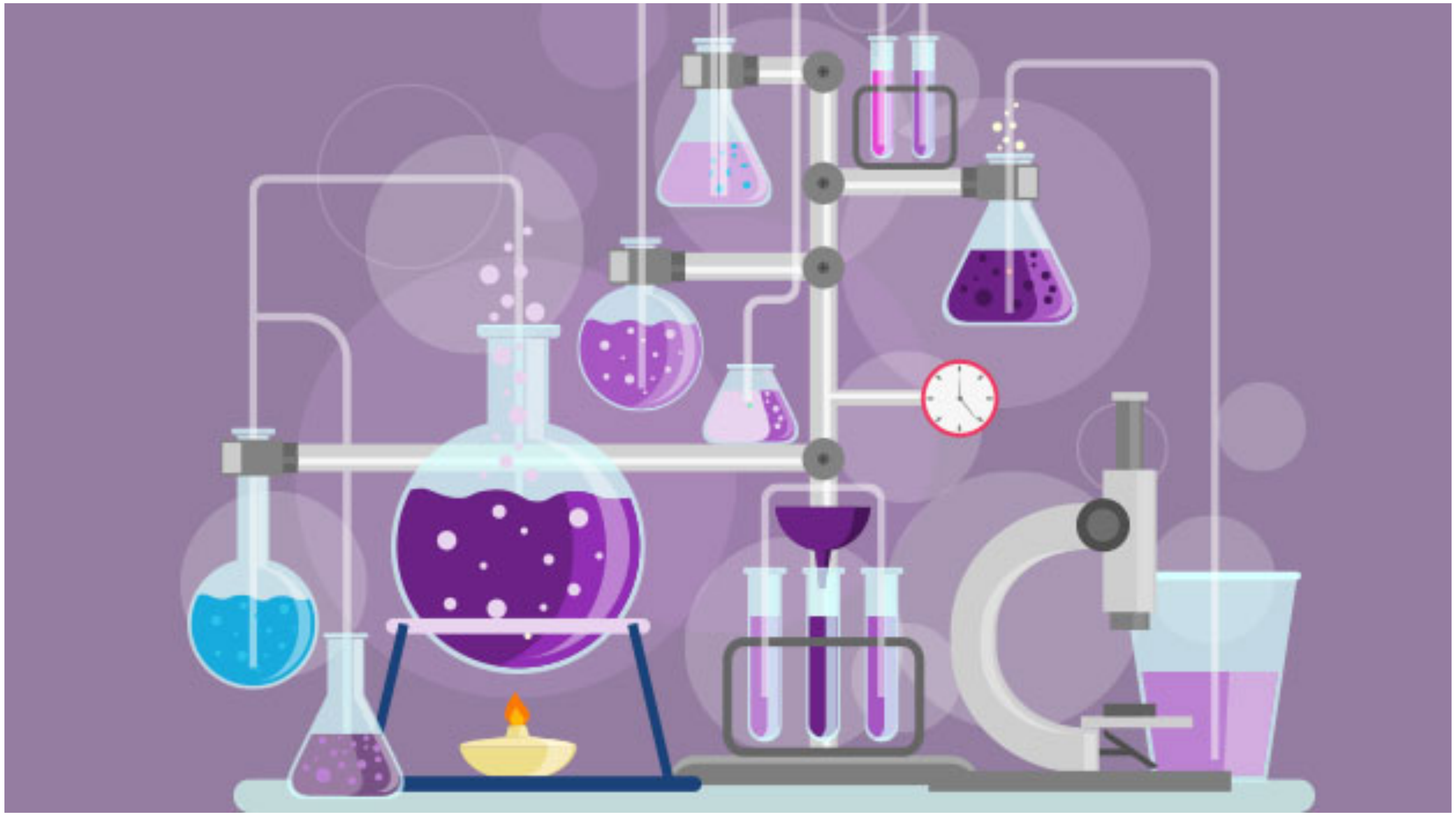
Role of Physics in Engineering

Civil engineering involves designing and building bridges, dams, skyscrapers, roads, and railways using our physics knowledge of forces, fluid pressure, and gravity.

Role of Physics in Engineering

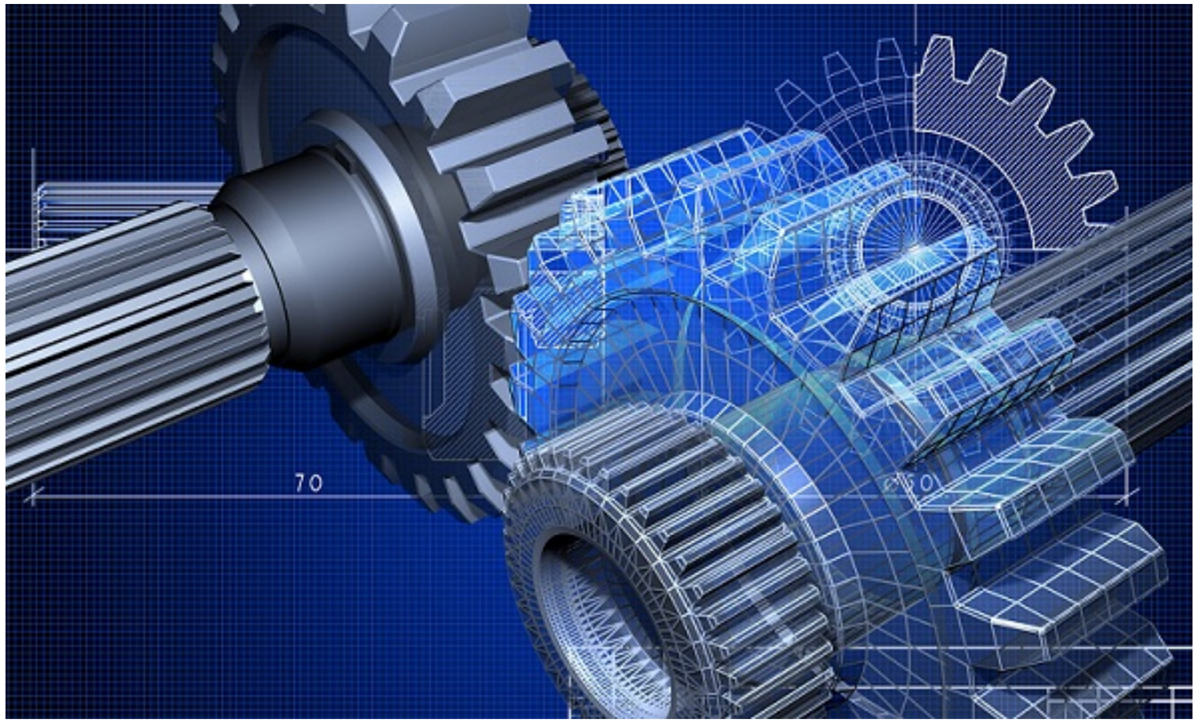
Electrical and electronics engineering involves designing electrical circuits, including motors, electronic appliances, optical fiber networks, computers, and communication links. Circuits use physics principles like voltage, current, and resistance.

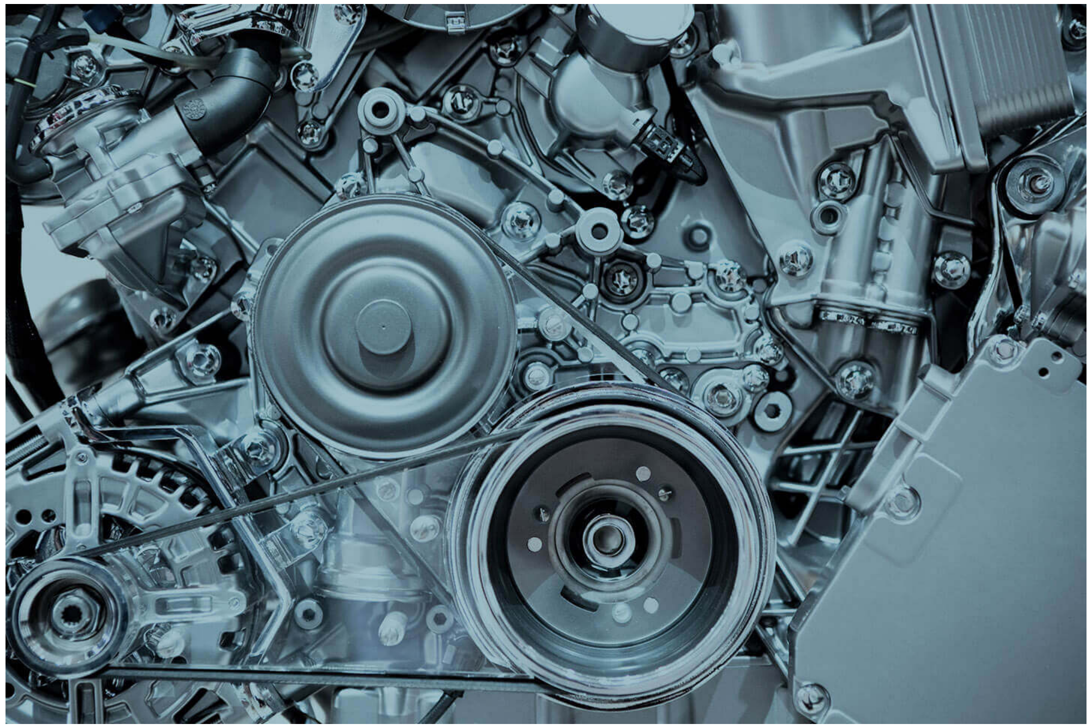
Role of Physics in Engineering



Chemical engineering involves designing systems for oil refining, the creation of industrial chemicals, and man-made fibers and products, which requires an understanding of molecular forces

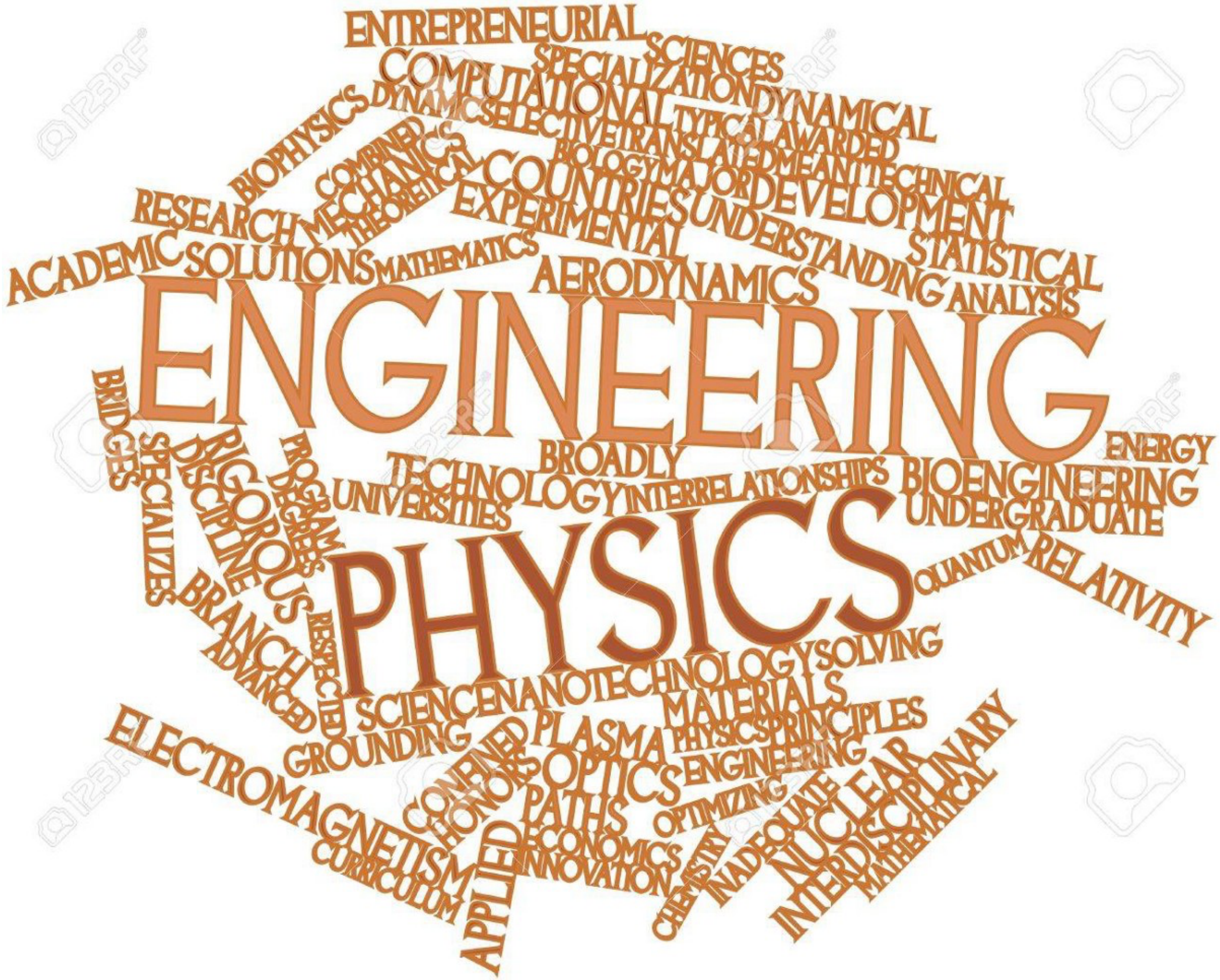
Role of Physics in Engineering





Mechanical engineering deals with aircraft, engines, weapons, cars, pneumatics, and hydraulics. For these, we have to understand forces and complex fluid motions, like air flow across an aircraft or water flow through tubes

Role of Physics in Engineering



An engineer might design the product itself, or just figure out a way to build it. But either way, success is impossible without an understanding of the physics behind each of them.

BPHY101L: Course Objective

Course Objectives

- To explain the dual nature of radiation and matter.
- To apply Schrödinger's equation to solve finite and infinite potential problems and apply quantum ideas at the nanoscale.
- To understand Maxwell's equations for electromagnetic waves and apply the concepts to semiconductors for engineering applications.

Course Outcomes

At the end of the course, the student will be able to

- Comprehend the phenomenon of waves and electromagnetic waves.
- Understand the principles of quantum mechanics.
- Apply quantum mechanical ideas to a subatomic domain.
- Appreciate the fundamental principles of a laser and its types.
- Design a typical optical fiber communication system using optoelectronic devices.

Course Structure

Module 1	Introduction to waves	7 Hours
Waves on a string - Wave equation on a string (derivation) - Harmonic waves- reflection and transmission of waves at a boundary (Qualitative) - Standing waves and their eigenfrequencies.		
Module 2	**Electromagnetic waves**	**7 Hours**
Physics of divergence - gradient and curl - Qualitative understanding of surface and volume integral - Maxwell Equations (Qualitative) - Displacement current - Electromagnetic wave equation in free space - Plane electromagnetic waves in free space - Hertz's experiment.		
Module 3	**Elements of quantum mechanics**	**6 Hours**
Need for Quantum Mechanics: Idea of Quantization (Planck and Einstein) - Compton effect (Qualitative) – de Broglie hypothesis - - Davisson-Germer experiment - Wave function and probability interpretation - Heisenberg uncertainty principle - Schrödinger wave equation (time dependent and time independent)		
Module 4	**Aplications of quantum mechanics**	**5 Hours**
Eigenvalues and eigenfunction of particle confined in one dimensional box - Basics of nanophysics - Quantum confinement and nanostructures - Tunnel effect (qualitative) and scanning tunneling microscope.		
Module 5	**Lasers**	**6 Hours**
Laser characteristics - spatial and temporal coherence - Einstein coefficients and their significance - Population inversion - two, three and four level systems - Pumping schemes - threshold gain coefficient - Components of a laser - He-Ne, Nd:YAG and CO_2 lasers and their engineering applications.		
Module 6	**Propagation of EMW in optical fibers**	**6 Hours**
Introduction to optical fiber communication system - light propagation through fibers - Acceptance angle - Numerical aperture - V-parameter - Types of fibers – Attenuation - Dispersion-intermodal and intramodal. Application of fiber in medicine - Endoscopy.		
Module 7	**Optoelectronic devices**	**6 Hours**
Introduction to semiconductors - direct and indirect bandgap – Sources: LED and laser diode, Photodetectors: PN and PIN.		
Module 8	**Contemporary issues**	**2 Hours**

Total Lecture hours : 45 Hours

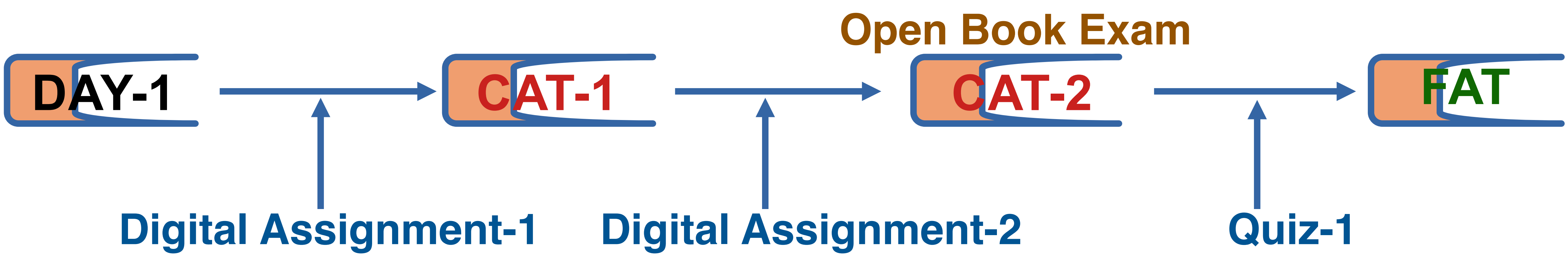
Reference Books

Textbook(s)	
1.	H. D. Young and R. A. Freedman, University Physics with Modern Physics, 2020, 15th Edition, Pearson, USA.
2.	D. K. Mynbaev and Lowell L. Scheiner, Fiber Optic Communication Technology, 2011, 1st Edition, Pearson, USA
Reference Books	
1.	H. J. Pain, The Physics of vibrations and waves, 2013, 6th Edition, Wiley Publications, India.
2.	R. A. Serway, J. W. Jewett, Jr, Physics for Scientists and Engineers with Modern Physics, 2019, 10th Edition, Cengage Learning, USA.
3.	K. Krane, Modern Physics, 2020, 4th Edition, Wiley Edition, India.
4.	M.N.O. Sadiku, Principles of Electromagnetics, 2015, 6th Edition, Oxford University Press, India.
5.	W. Silfvast, Laser Fundamentals, 2012, 2nd Edition, Cambridge University Press, India.
Mode of Evaluation: Written assignment, Quiz, CAT and FAT	

Assessment

CAT – Continuous Assessment Test

FAT – Final Assessment Test



Relative weight

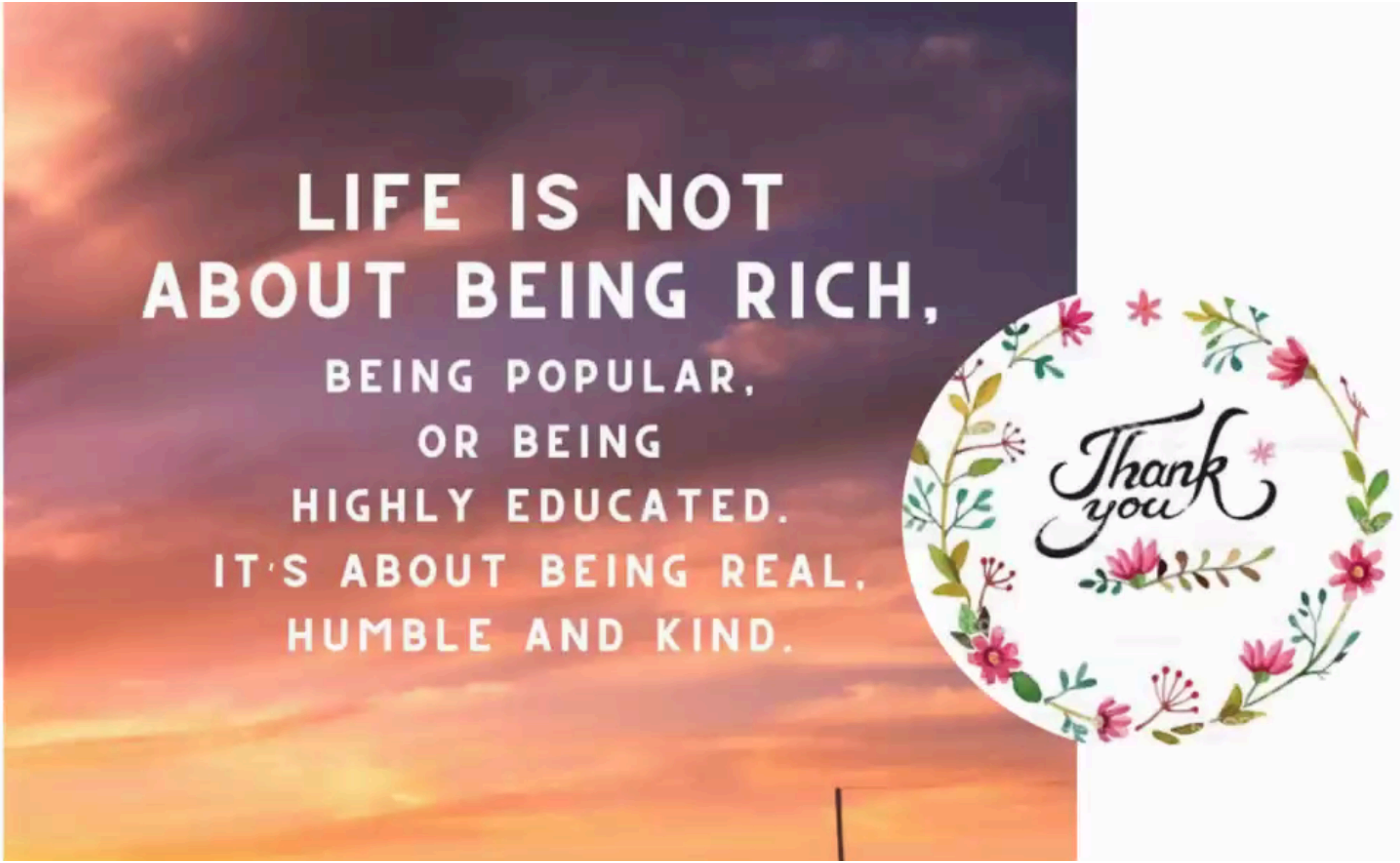
CAT-1 + CAT-2:	30%
FAT :	40%
Assignments+Quiz:	30%

Engineering Physics Exam Pattern

Exam	Marks	Weightage	Weightage Mark	Schedule
Continuous Assessment Test (CAT)-1	50	15%	**15**	Refer VTOP
Continuous Assessment Test (CAT)-2	50	15%	**15**	Refer VTOP
Digital Assignment (DA)-1	10	100%	**10**	Refer VTOP
Digital Assignment (DA)-2	10	100%	**10**	Refer VTOP
Quiz -1	10	100%	**10**	Refer VTOP
Final Assessment Test (FAT)	100	40%	**40**	To be announced
Total		**100**	**100**	

Important Points

- A Whatsaap Group link will be send to you, joining that group is mandatory
- Keep visiting VTOP/Whatsapp Group for class notes and materials.
- Make separate a notebook for BPHY101L and take regular notes of the classes.
- Use of mobile phones; coming late in class are not allowed during lecture hours.
- Spend time in Library for reading through the reference book.
- Active participation during discussion and timely submission of the assignments is expected.


LIFE IS NOT
ABOUT BEING RICH,
BEING POPULAR,
OR BEING
HIGHLY EDUCATED.
IT'S ABOUT BEING REAL,
HUMBLE AND KIND.
Thank you

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Module-1: Introduction to Waves

Major aim to understand:

Classification of waves based on their broad physical properties (mechanical waves, water waves, EM waves, sound waves and matter waves).

Discussion based on other criteria: longitudinal, transverse and mixed waves.

Further classification based on dimensionality: 1-D, 2-D and 3-D waves)
waves on a string, derivation of wave equations, Harmonic waves- reflection and transmission of waves at a boundary (Qualitative) - Standing waves and their eigenfrequencies.

Reference: Chapter 5, Section 5.2 from 'The Physics of Vibrations and Waves', 1st Edition, H J Pain and P Rankin, John Wiley and Sons Ltd, 2015

Waves: The concept

What is a wave ?

A wave is a disturbance which propagates in a medium and transfers energy from one location to another **without a net transfer of medium particles**.

A wave is a disturbance in a medium that carries energy without a net movement of particles. It may take the form of elastic deformation, a variation of pressure, electric or magnetic intensity, electric potential, or temperature

sound wave

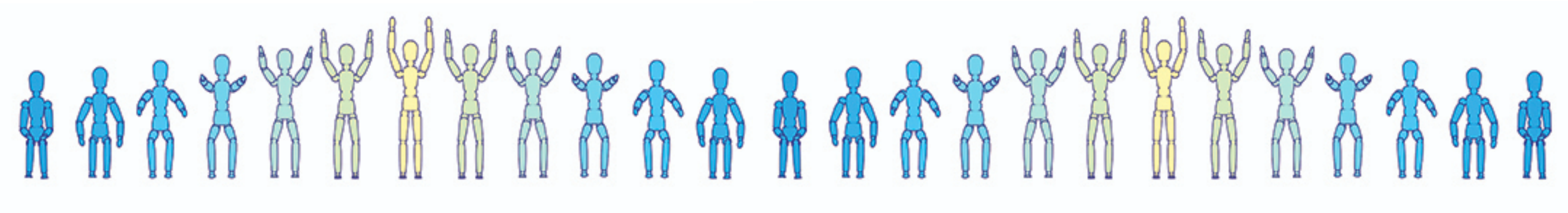
water wave

seismic wave

Radio, light and microwave

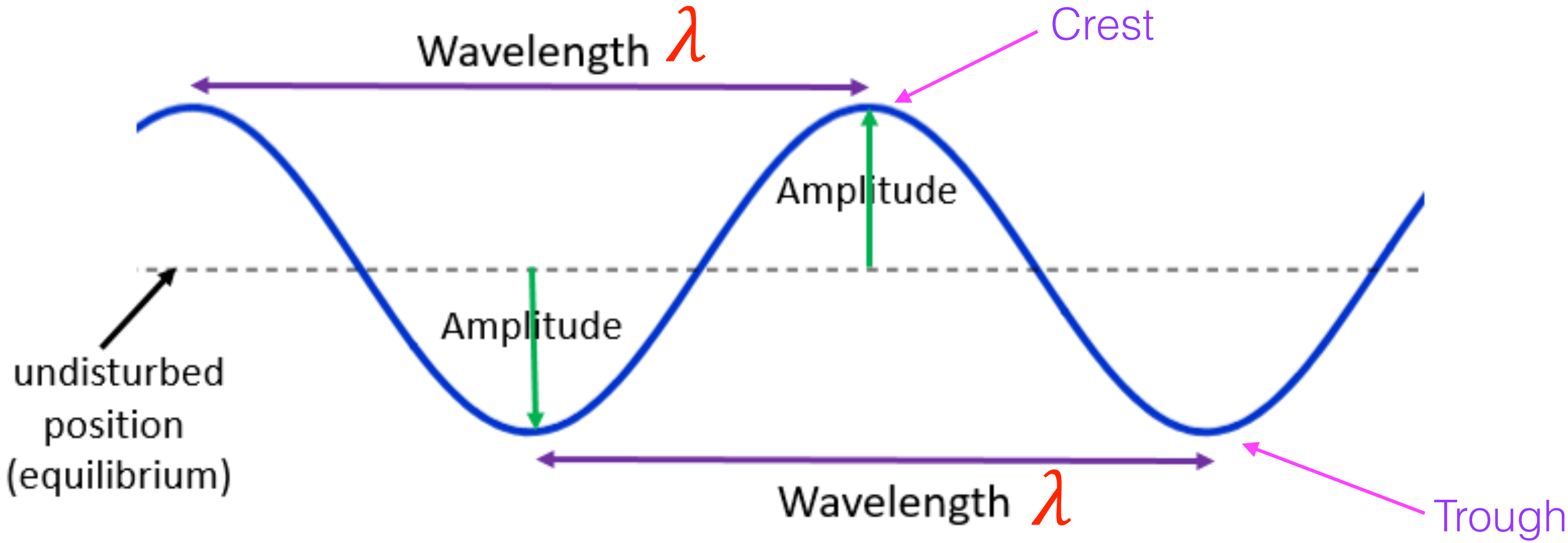
Waves: The concept

Crowd wave in a stadium



Is this a wave ?

Characteristics of wave



Amplitude: maximum displacement of a point on a wave away from its undisturbed position

Wavelength: distance from a point on one wave to the equivalent point on the adjacent wave.

Time period: Time taken of the wave to complete one oscillation

$$v = \frac{\lambda}{T}$$

Classification of Waves

Waves are classified into different types according to their nature

- **Based on medium:** Mechanical, Non-mechanical, Matter waves
- **Based on Vibrations:** Transverse, Longitudinal and Mixed waves
- **Based on Propagation dimension:** 1D, 2D and 3D waves

Classification of Waves: Medium

Waves are classified into two types based on medium

WAVES

Mechanical waves

- Required Medium to travel
- Can not travel in vacuum

Electromagnetic waves

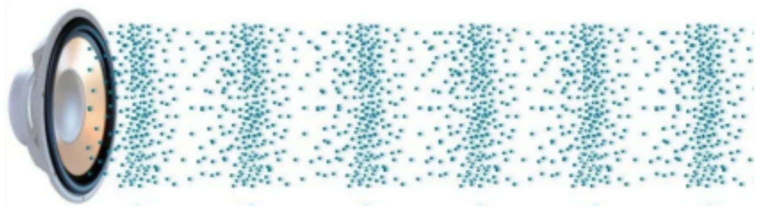
- Do not Required Medium to travel
- Can travel in vacuum

Matter waves: It is a wave associated with each particle. $\lambda = \frac{h}{p}$ [De-Broglie wavelength].These waves can not be understood by classical theories. Quantum Physics is applicable

Classification of Waves by Medium

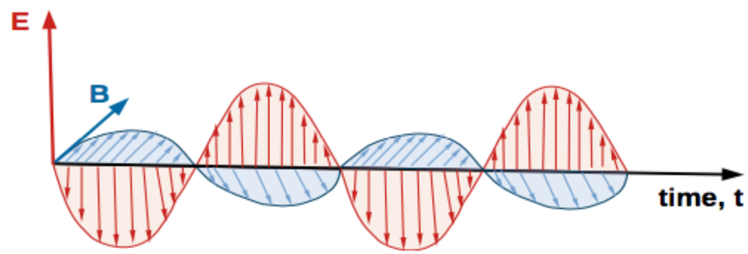
Mechanical Waves:

Sound and water waves are mechanical waves; meaning, they require a medium to travel through.



Non-mechanical Waves:

Electromagnetic wave is an example of non-mechanical wave. In vacuum, electromagnetic waves move with speed of 3 x 10^8 ms^{-1}.



Electromagnetic waves

Microwaves, X-ray, Radio waves, Ultraviolet waves, Light

Classification of Waves: Vibration

WAVES

Mechanical waves

- Required Medium to travel
- Can not travel in vacuum

Transverse waves

Longitudinal waves

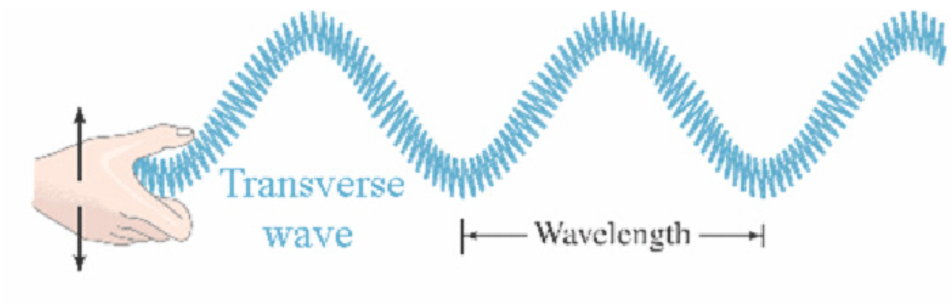
Electromagnetic waves

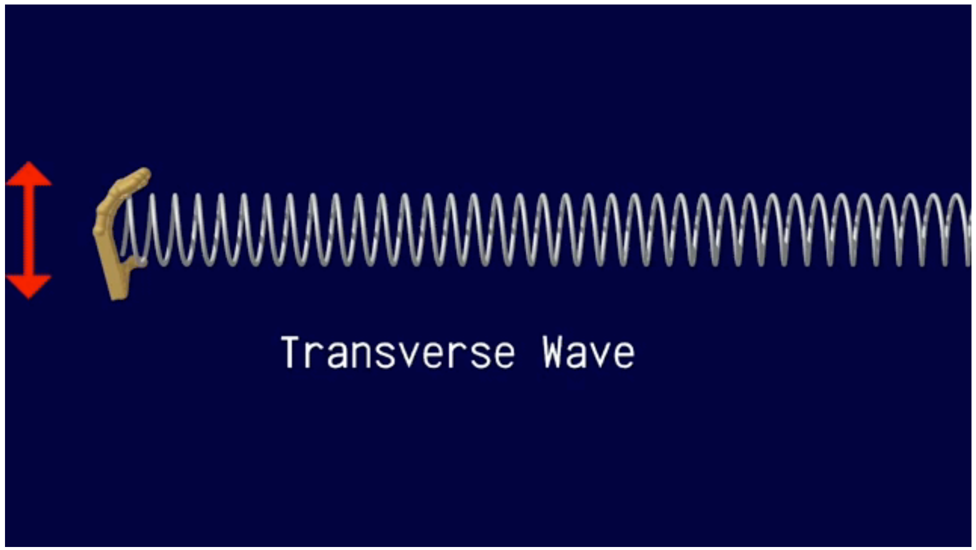
- Do not Required Medium to travel
- Can travel in vacuum

Only Transverse waves

Classification of Waves: Vibration

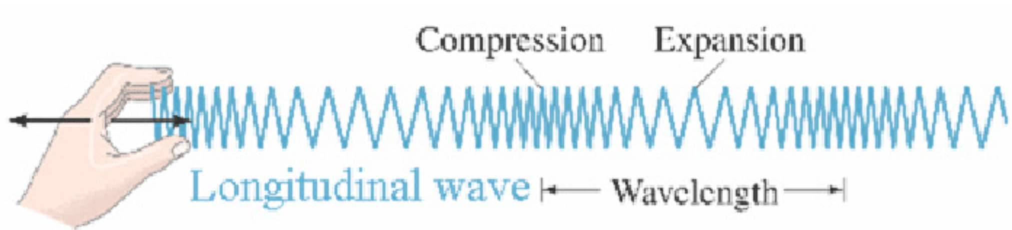
- Based on mode of vibrations
  - ❖ Transverse waves
    - Vibrations perpendicular to the direction of propagation
    - Example: EM waves, Water waves, etc.

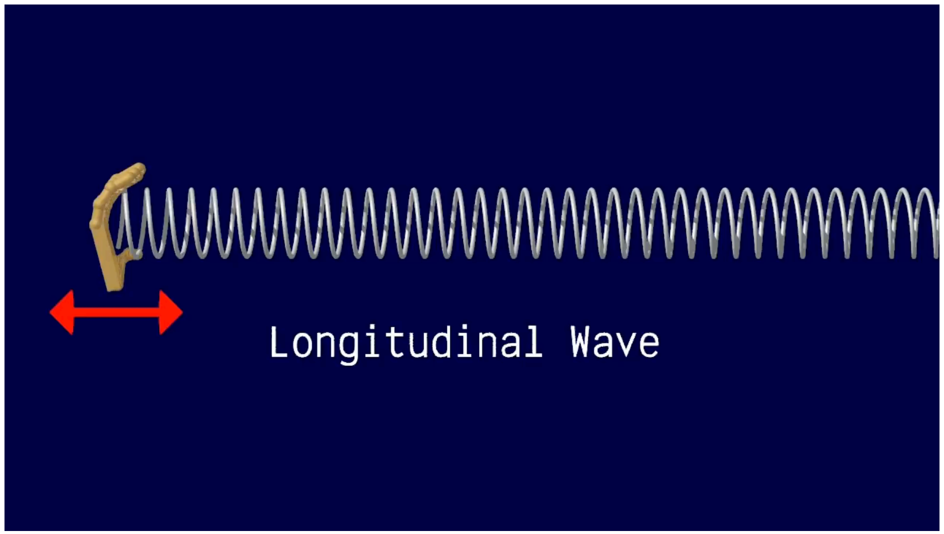




Classification of Waves: Vibration

- Based on mode of vibrations
  - ❖Longitudinal waves
    - Vibrations along the direction of propagation
    - Example: Sound waves

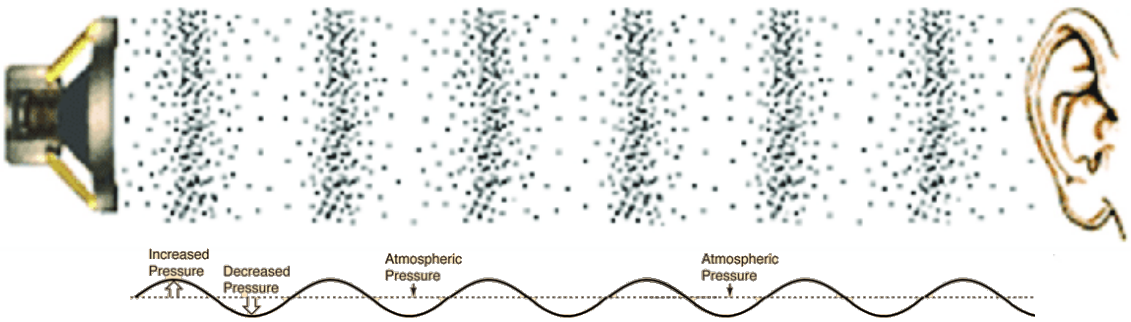


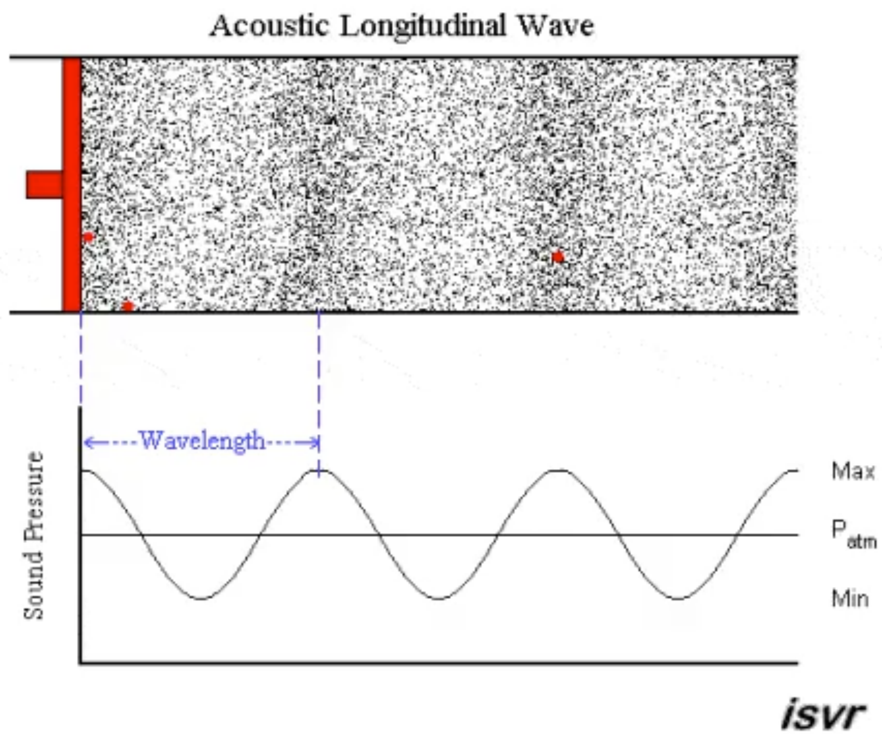


Sound Waves: A Longitudinal wave

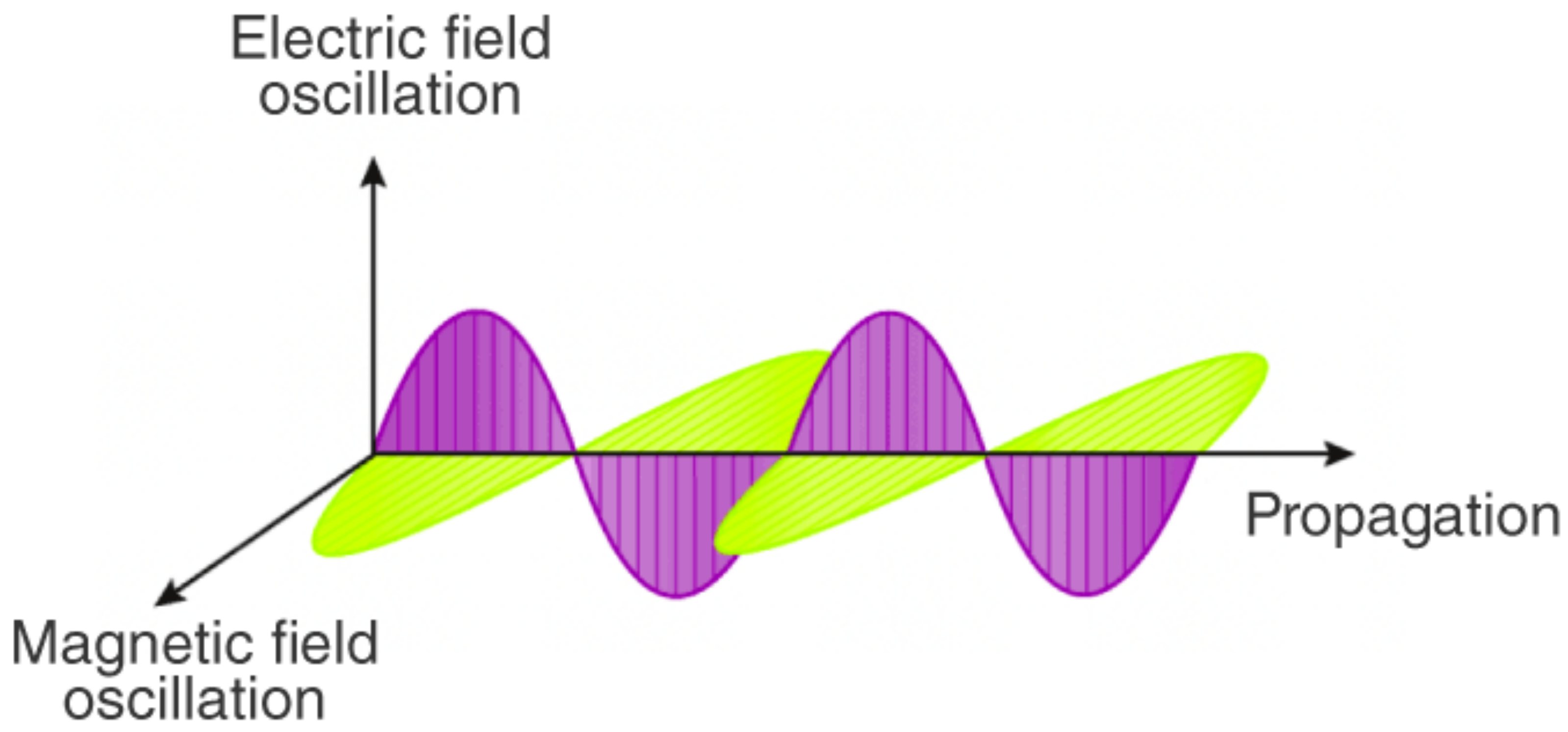
- Example: Sound waves

a wave of compression and rarefaction, by which sound is propagated in an elastic medium such as air.





EM Waves: A Transverse wave

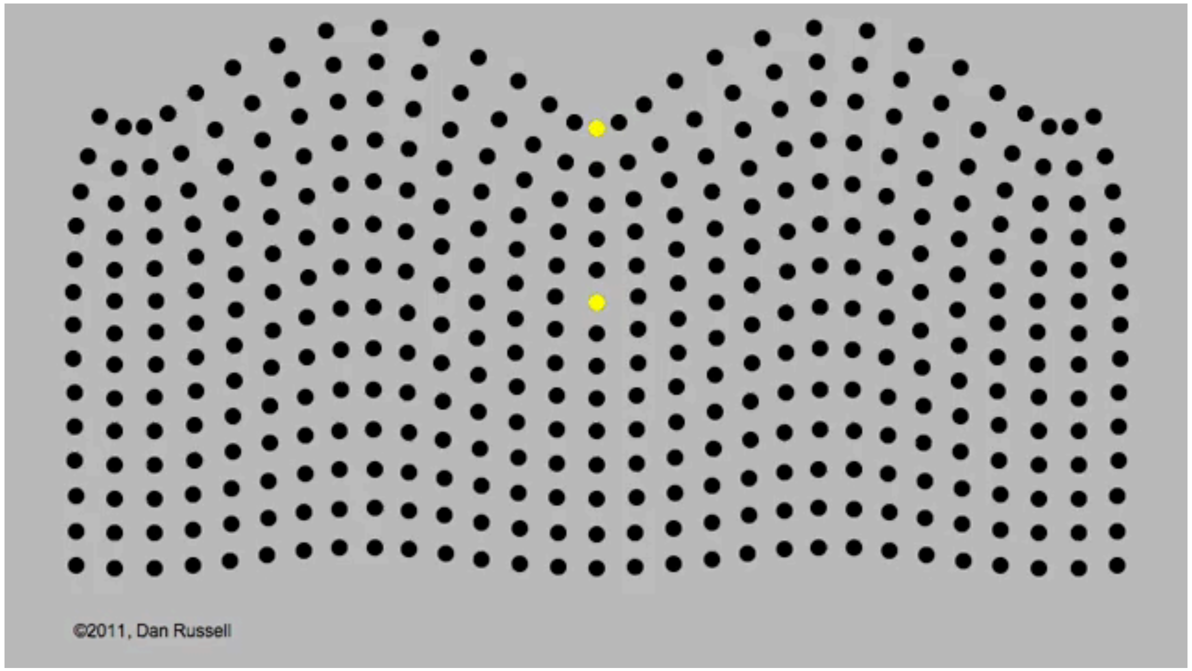


Electromagnetic waves are transverse in nature as they propagate by varying the electric and magnetic fields such that the two fields are perpendicular to each other

Surface Waves

Surface waves : has characteristics of both longitudinal and transverse wave

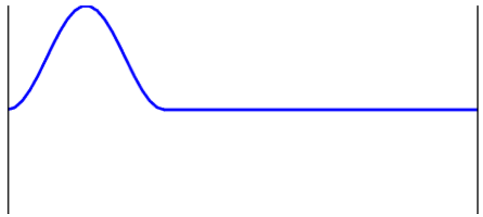
In a surface wave, particles of the medium move up and down as well as back and forth. This gives them an overall circular motion.



1D, 2D & 3D Waves

Based on Dimensionality, waves can be classified as

- 1-Dimensional waves



- 2-Dimensional Waves

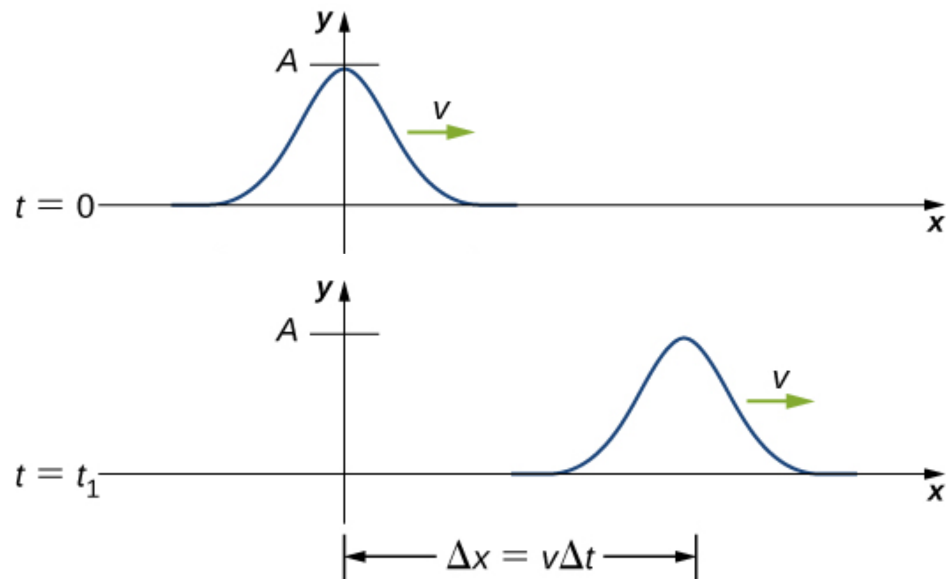
- 3-Dimensional waves

Mathematical interpretation of wave

How to describe a wave ?

A disturbance, moving with a speed, v in the forward direction:
So at t=0,

$$y(x, t=0) = f(x)$$



The same disturbance at the time, $t=t_1$ can be written as:

$$y(x, t_1) = y(x\text{-}vt, 0) = f(x\text{-}vt)$$

Therefore, the general functional form of a wave propagating in either positive or negative x-axis is given be:

$$\mathbf{y\ (x, t) = f(x \pm vt)}$$

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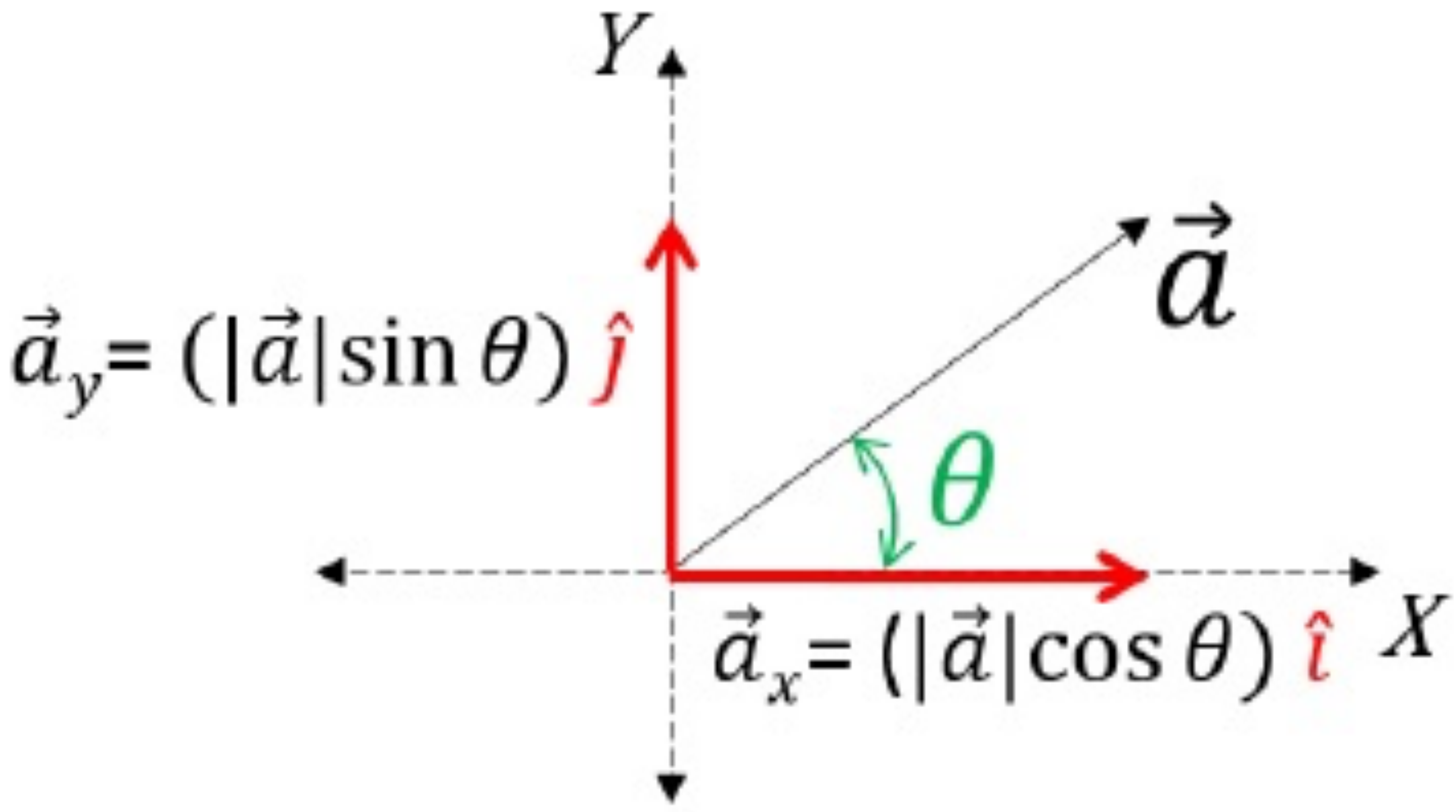
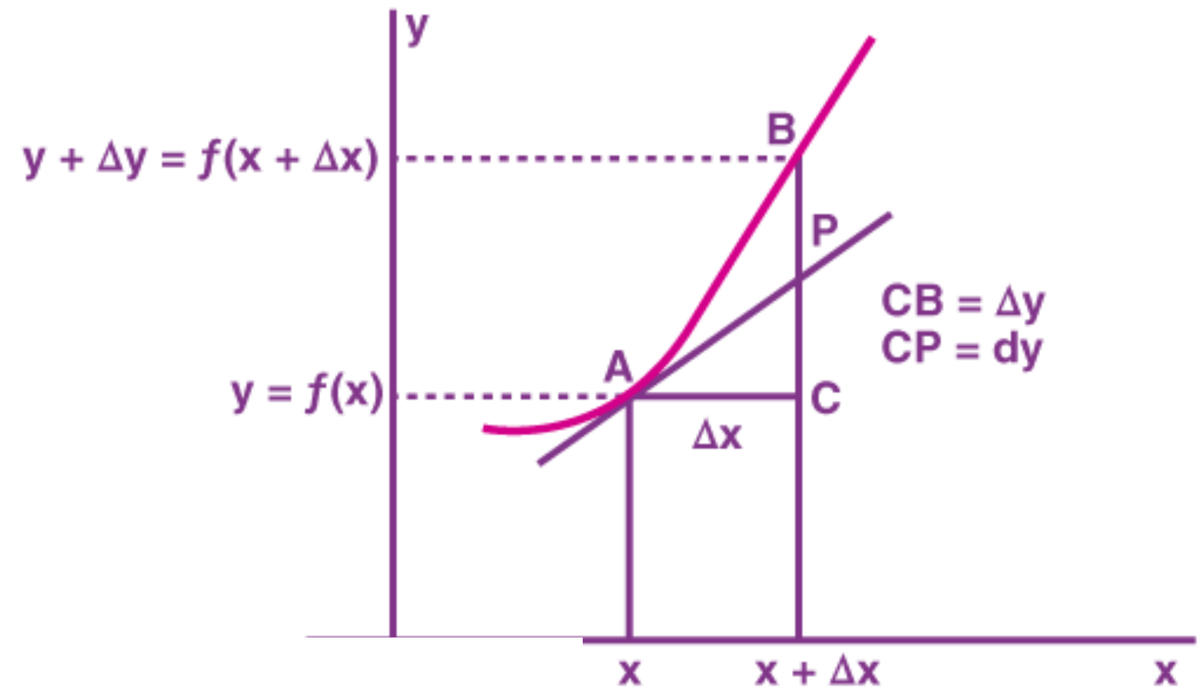
Vector Resolution



Resolution of a vector is **the splitting of a single vector into two or more vectors in different directions which together produce a similar effect as is produced by a single vector itself**. The vectors formed after splitting are called component vectors.

Concept of partial derivative

$$\frac{\partial f}{\partial x} \text{ vs. } \frac{df}{dx}$$



For any function of two independent variables, $g(x,y)$

First order partial derivative

$$\frac{\partial g}{\partial x} = \lim_{\Delta x \to 0} \frac{[g(x+\Delta x, y) - g(x,y)]}{\Delta x} = \tan(\theta)$$

Second order partial derivative

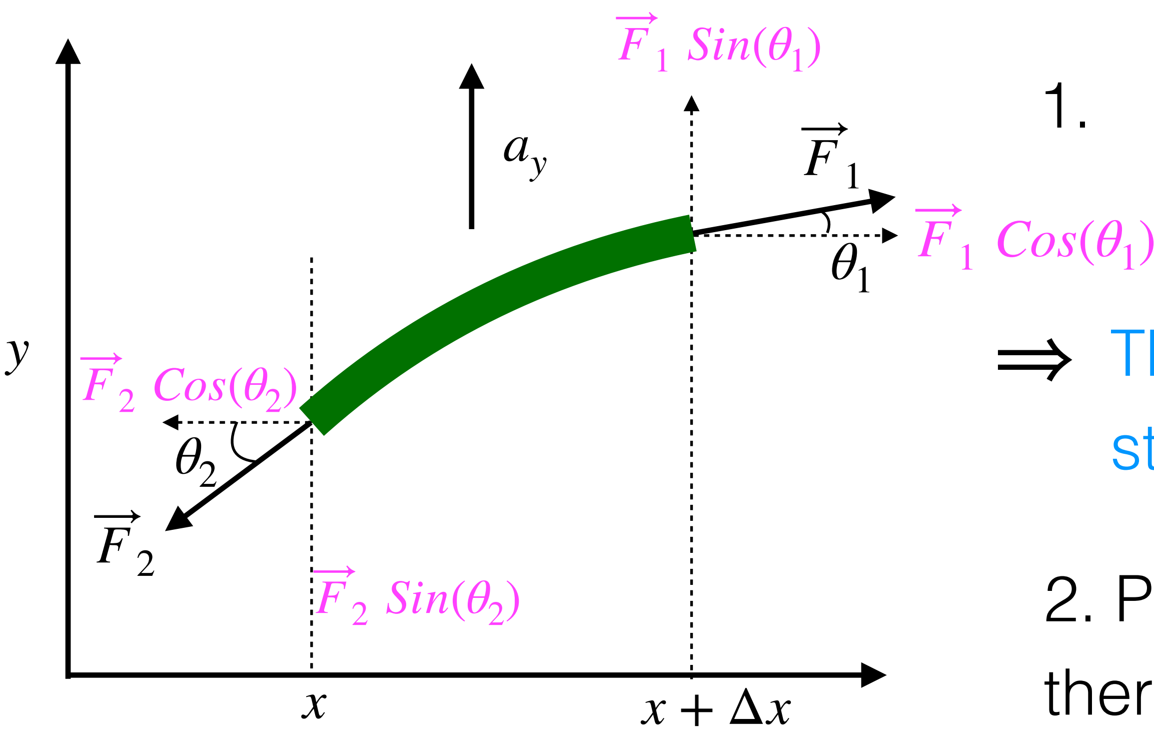
$$\frac{\partial^2 g}{\partial x^2} = \lim_{\Delta x \to 0} \frac{\left[\left(\frac{\partial g}{\partial x}\right)_{x+\Delta x} - \left(\frac{\partial g}{\partial x}\right)_{x}\right]}{\Delta x}$$

Wave equation: 1D

Wave on a string

Wave motion on string follows Newton's Second Law of motion

linear mass density of the string : ρ



Now we shall obtain the equation of motions of string under the following **assumptions**:

1. The string is perfectly flexible and offers no resistance to bending

$\Rightarrow$ The tension in the string is tangential to the curve of the string

2. Points on the string move only in the vertical direction, there is no motion in the horizontal (longitudinal) direction

$\Rightarrow$ Sum of the forces in the horizontal direction be **zero**

3. Gravitational forces on the string is negligible

$\Rightarrow$ Net resultant force (F) = mass $\times$ acceleration

Wave equation: 1D

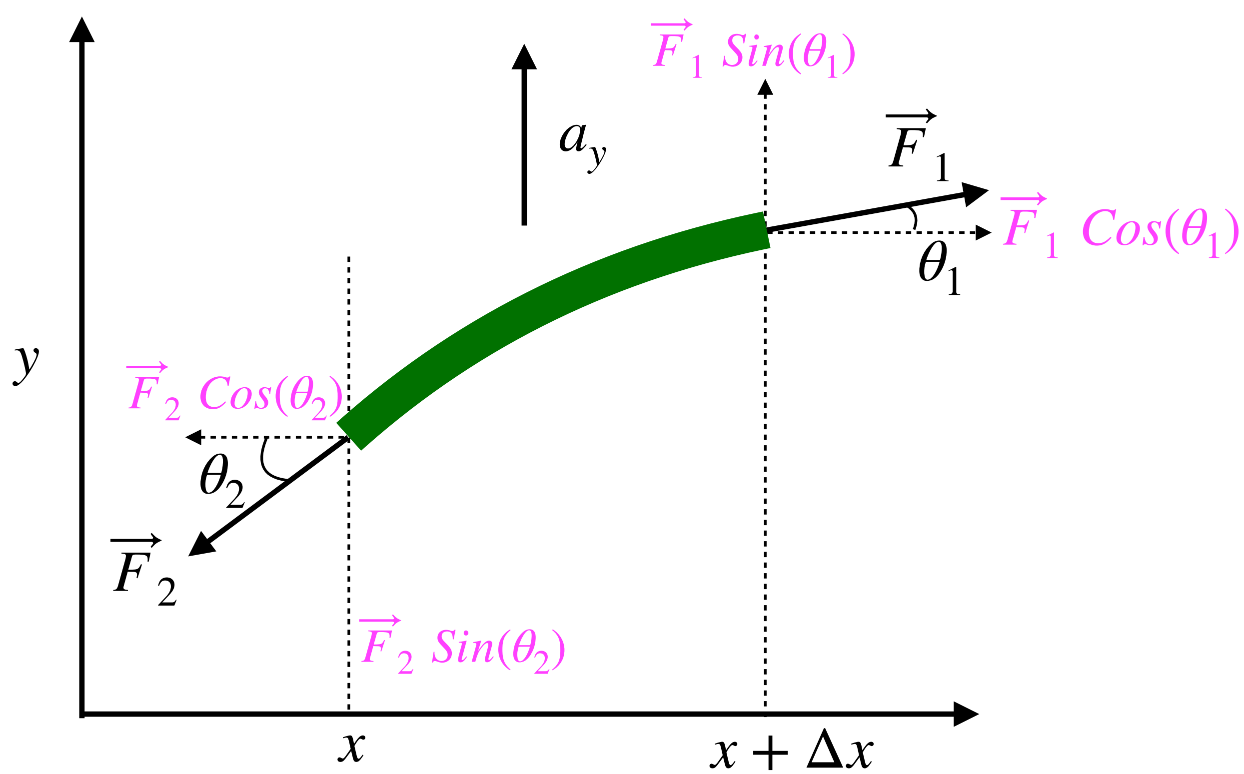
Wave on a string

Wave motion on string follows Newton's Second Law of motion

mass density of the string : ρ

Net force along x direction = 0 $\rightarrow F_1\cos(\theta_1) = F_2\cos(\theta_2) = T$

Net force along y direction = $\Delta F = F_1\sin(\theta_1) - F_2\sin(\theta_2) = \rho\Delta x a_y$



$$\Delta F = T[\tan(\theta_1) - \tan(\theta_2)]$$

$$= T\left[\frac{\partial y}{\partial x}\bigg|_{x+\Delta x} - \frac{\partial y}{\partial x}\bigg|_{x}\right]$$

$$\Delta F = T\frac{\partial^2 y}{\partial x^2}\Delta x \qquad = \rho\Delta x\frac{\partial^2 y}{\partial t^2}$$

$$\frac{\partial^2 y}{\partial x^2} = \frac{\rho}{T}\frac{\partial^2 y}{\partial t^2}$$

$$v = \sqrt{\frac{T}{\rho}}$$

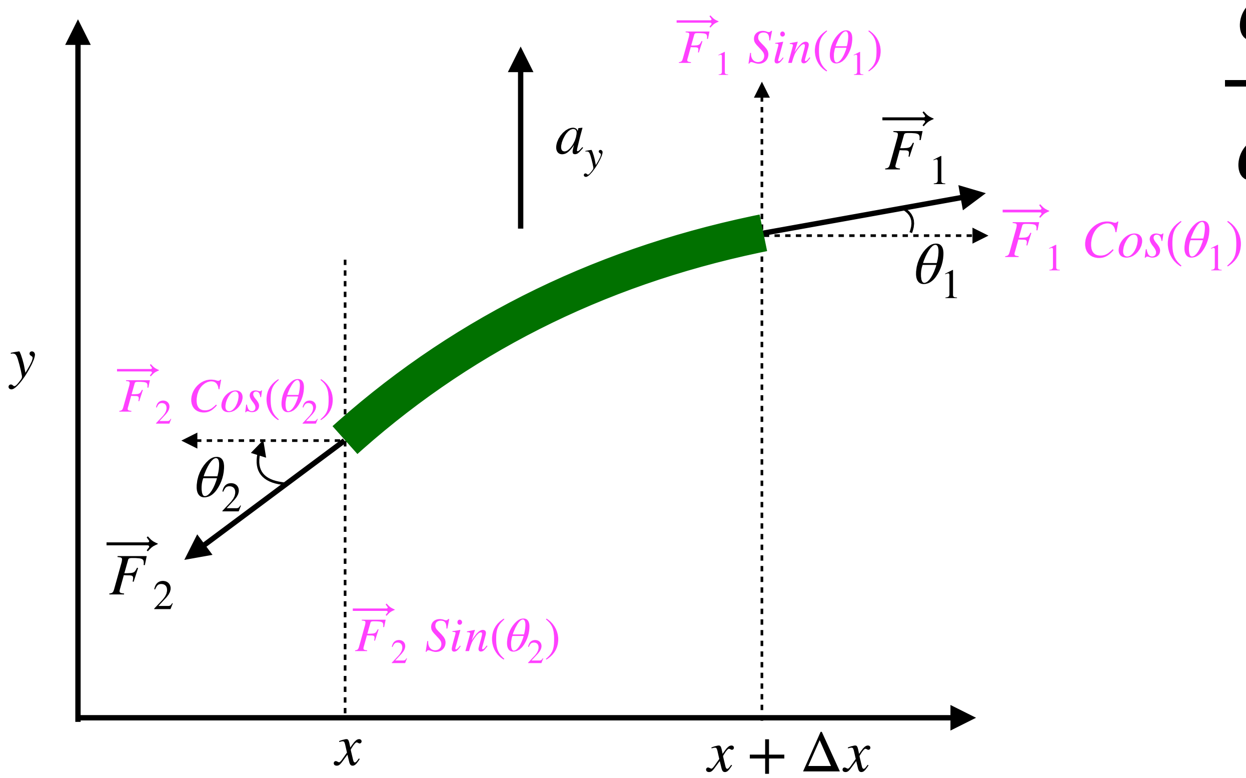
$$\boxed{\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}}$$

Wave equation: 1D

Wave on a string

Wave motion on string follows Newton's Second Law of motion

mass density of the string : ρ



$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2} \qquad v = \sqrt{\frac{T}{\rho}}$$

$$\text{Dim of v } [v] = \sqrt{\frac{[T]}{[\rho]}}$$

$$[T] = [MLT^{-2}] \qquad [\rho] = [ML^{-1}]$$

$[v] = [LT^{-1}]$ Velocity

Wave equation: 1D

The wave equation is a second-order linear partial differential equation for the description of waves

From Newton's second law of motion $F = ma$ $\Rightarrow$ $F = m\dfrac{d^2x}{dt^2}$

We will consider a 1-D infinite string and try to derive the wave equation by following steps:

Vibrations of a String

↓

Vibrations (Displacement) of a mass 'm'

↓

Balanced by the net force

Examples

A copper wire is pulled by using an external tension, T = 0.98 newtons. The density of a copper wire is $\varrho = 9.86 \text{g cm}^{-1}$. Compute the speed of the wave supported by the string.

$$v = \sqrt{\frac{T}{\rho}}$$

Ans: v= 1.01 m/s

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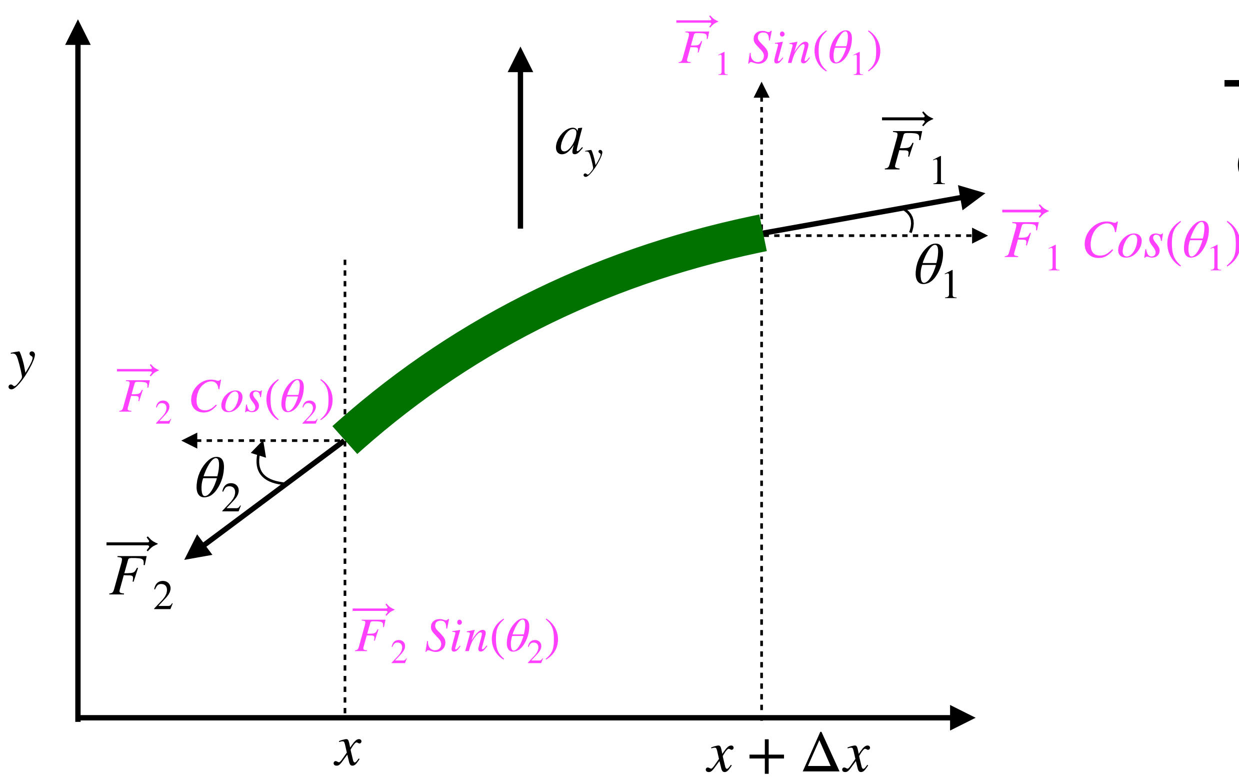
Wave equation: 1D

Wave on a string

Wave motion on string follows Newton's Second Law of motion

mass density of the string : ρ



$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2} \qquad v = \sqrt{\frac{T}{\rho}}$$

Dim of v $[v] = \sqrt{\frac{[T]}{[\rho]}}$

$$[T] = [MLT^{-2}] \qquad [\rho] = [ML^{-1}]$$

$[v] = [LT^{-1}]$ Velocity

Examples

Show that $f(x,t) = A\ Sin\left[B(x - vt)\right]$ satisfies the wave equation

General solution of the wave equation

- Solution to the wave equation $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$ must be a function of x and t.
- General solution can be of the form, $f_1(vt - x)$or $f_2(vt + x)$

$$y = f_1(vt - x) \quad \therefore \frac{\partial y}{\partial x} = -f_1'(vt - x)$$

$$\Rightarrow \frac{\partial^2 y}{\partial x^2} = f_1''(vt - x)$$

$$\frac{\partial y}{\partial t} = v f_1'(vt - x) \Rightarrow \frac{\partial^2 y}{\partial t^2} = v^2 f_1''(vt - x)$$

$$\therefore \frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

Same can also be proved for $f_2(vt + x)$

- Most general solution is the superposition of f_1 and f_2.

$$y = f_1(vt - x) + f_2(vt + x)$$

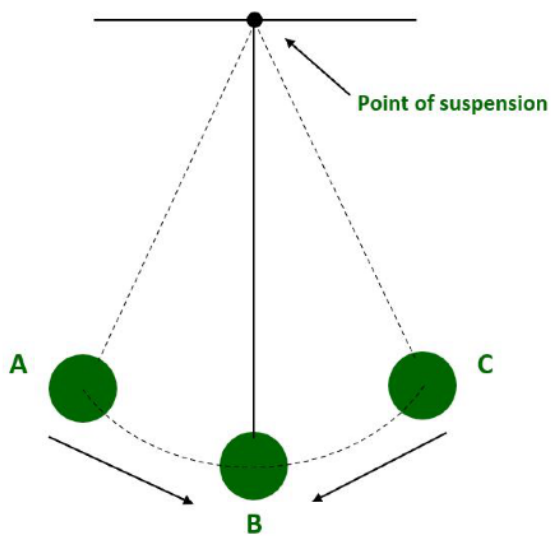
Numerical

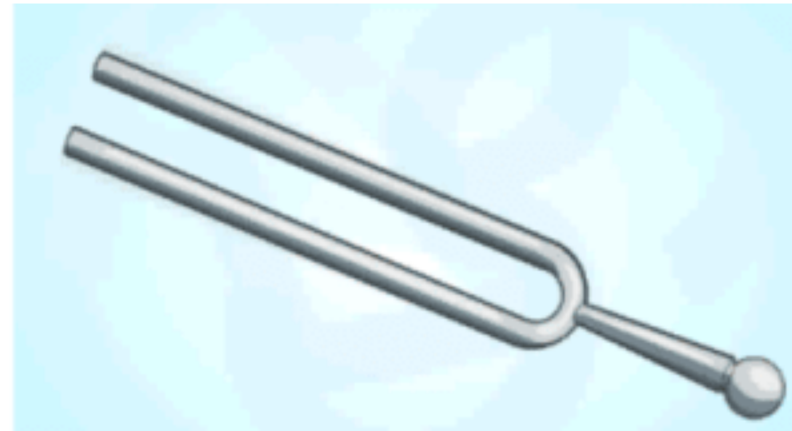
Show that the function $y(x,t)=Ae^{-b(x-vt)^2}$ **satisfies the wave equation.**

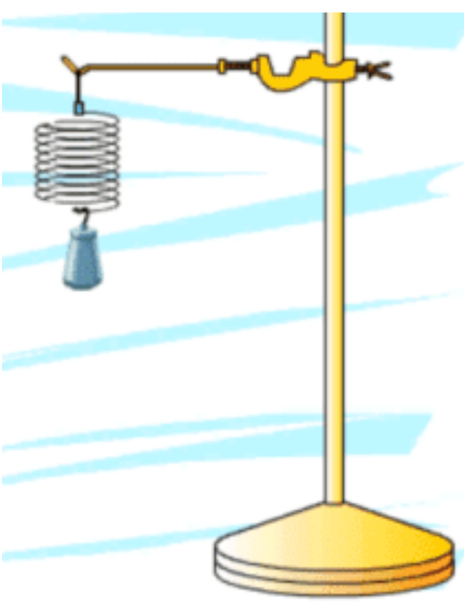
Show that the function $y(x,t)=\dfrac{A}{1+B(x+vt)}$ **satisfies the wave equation.**

What is the direction of the wave in this case?

Simple Harmonic Motions







A motion, in which the restoring force is directly proportional to the displacement of the particle from the mean positions

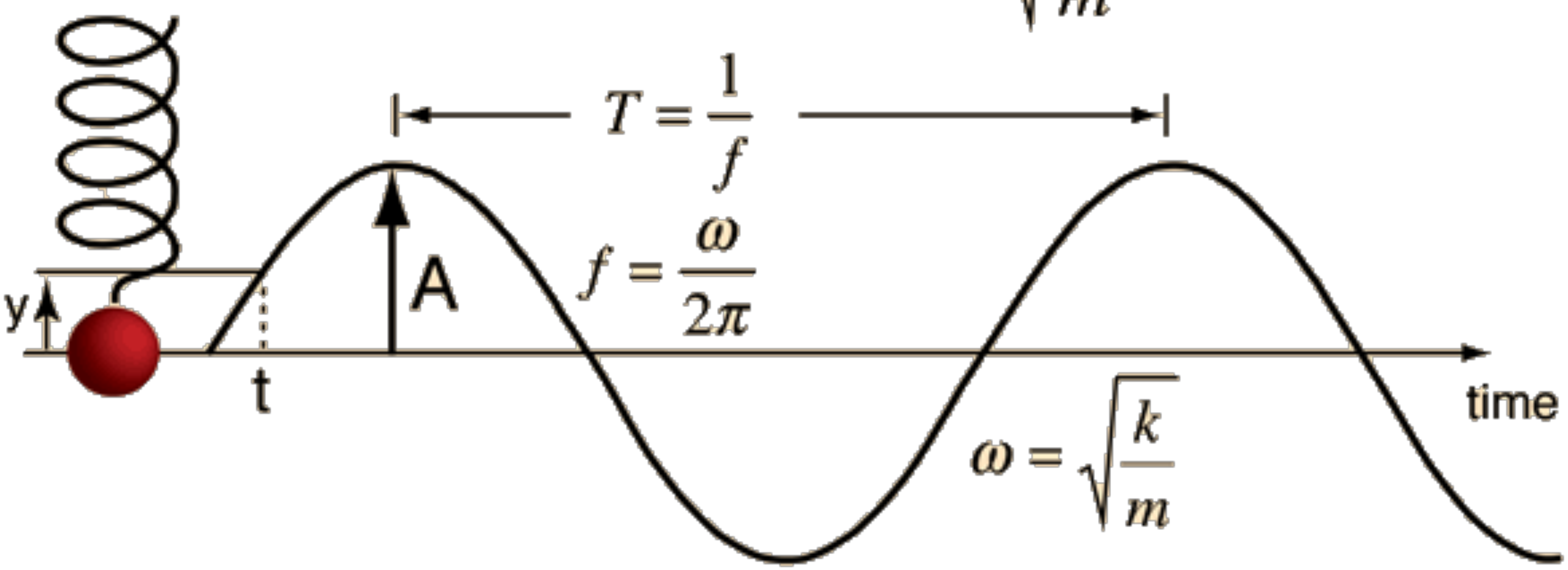
$$F = -ky$$

Simple Harmonic Motions

A motion, in which the restoring force is directly proportional to the displacement of the particle from the mean positions

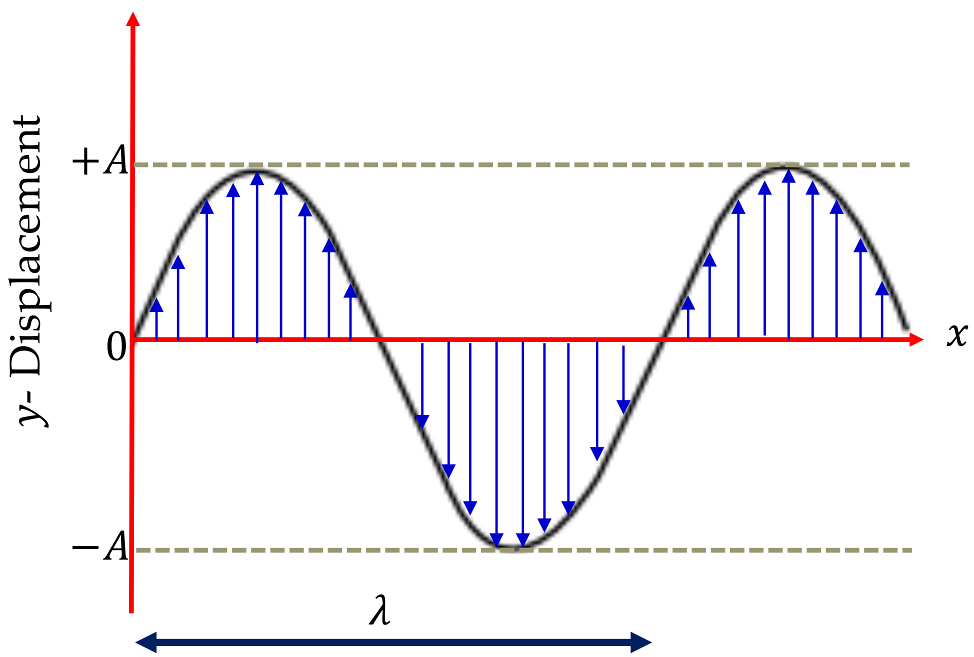
F = -ky

$$y = A\sin\omega t = A\sin\sqrt{\frac{k}{m}}\,t$$



Harmonic waves are completely sinusoidal in character

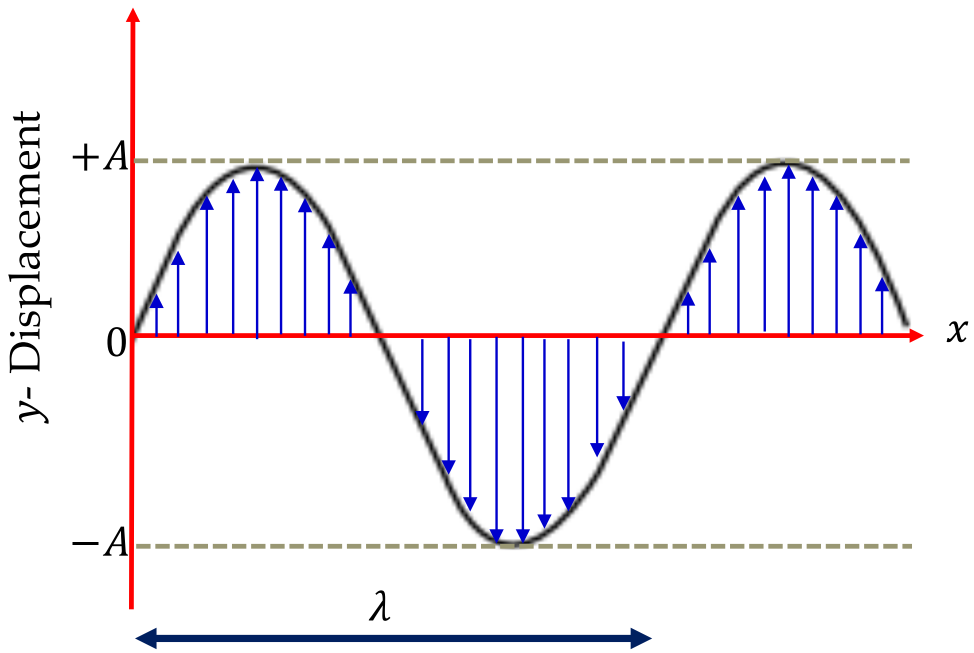
Harmonic Wave



- For harmonic motion, the amplitude can be best modelled by a sine function.
- Harmonic waves propagate down the string one wavelength (λ) along the x axis during one time period (T) along the time axis.
- Wave propagates with a constant speed, $v=\lambda/T$
- Value of Sine function with argument θ varies between -1 and +1.
- Repeats every 2π radians.
- Amplitude of harmonic waves varies between -A to +A.
- Repeats after every wavelength (λ) along x-axis.

$$\frac{\theta}{x} = \frac{2\pi}{\lambda} \Rightarrow \theta = \frac{2\pi}{\lambda}x \quad \Rightarrow \quad \therefore y = A\sin\left(\frac{2\pi}{\lambda}x\right)$$

Harmonic Wave



$$\frac{\theta}{x} = \frac{2\pi}{\lambda} \Rightarrow \theta = \frac{2\pi}{\lambda}x$$

$$\Rightarrow \therefore y = A\sin\left(\frac{2\pi}{\lambda}x\right)$$

Correlating this with the most general solution of wave equation

$$y(x,t) = A\sin\left(\frac{2\pi}{\lambda}(x \pm vt)\right)$$

$$\Rightarrow y(x,t) = A\sin\left(\frac{2\pi}{\lambda}x \pm \frac{2\pi}{\lambda}vt\right)$$

$$\therefore y(x,t) = A\sin(kx \pm \omega t)$$

$$v = \frac{\lambda}{T} \Rightarrow \frac{2\pi}{\lambda}vt = \frac{2\pi}{\lambda}\frac{\lambda}{T}t = \frac{2\pi}{T}t = \omega t$$

$+$ sign → $-x$ direction of propagation
$-$ sign → $+x$ direction of propagation

Concept of Phase

$$y(x,t) = A\sin(kx \pm \omega t)$$

A= Amplitude
k= wavenumber
ω=angular frequency

PHASE

Temporal term ωt gives phase of the wave w.r.t. the reference oscillator

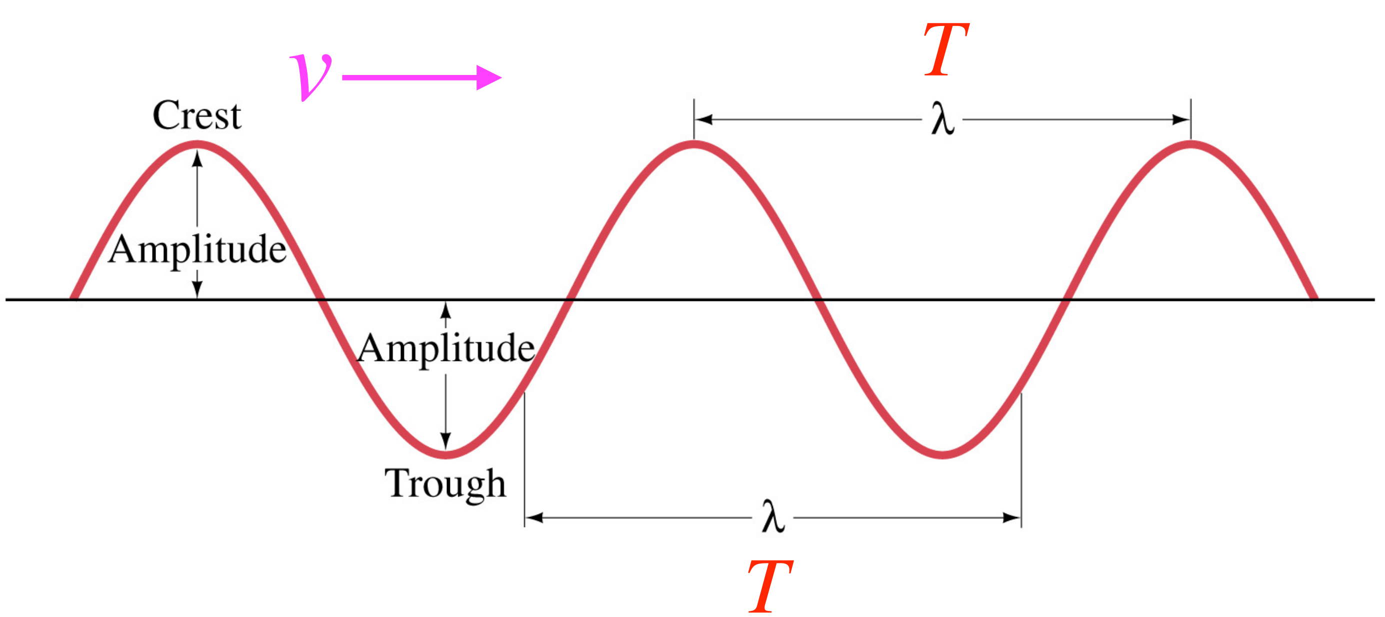
Spatial term kx gives the displacement of the oscillator

For an initial phase, ϕ, the wave can be represent as:

$$y(x,t) = A\sin(kx \pm \omega t + \phi)$$

Properties of SH Waves

1. **Amplitude (A)**: maximum displacement of a point on a wave away from the undistributed position
2. **Wavelength/Wavenumber**: Wavelength is the distance between successive crests/troughs of the disturbance. The general notation we use in this course is **λ**. When describing a wave mathematically, it is convenient to use wave number k, which is defined as $k = \dfrac{2\pi}{\lambda}$



3. **Period and Frequency**: Period is the time between the arrival of two successive crests or two successive troughs at a point in space. Frequency is the number of crests (or troughs) passing at a given location per unit of time. Period and frequency are inversely related.

$$f = \frac{1}{T} \Rightarrow \omega = \frac{2\pi}{T} = 2\pi f$$

4. **Velocity**: The velocity of a wave relates period and wavelength of oscillations of the wave. If T is the time period, λ is the wavelength, then velocity is

$$v = \frac{\lambda}{T} \Rightarrow v = \frac{\omega}{k}$$

Simple Harmonic Wave representation

For a given wave $y(x,t) = 0.02Sin(\frac{x}{0.01} + \frac{t}{0.05})$

Find

1. **Amplitude**
2. **Wavelength**
3. **Frequency**
4. **Velocity**

Amplitude=0.02, $\boldsymbol{\lambda}$=$\boldsymbol{\pi}$/50, f=10/$\boldsymbol{\pi}$, v=0.02 m/sec

Simple Harmonic Wave representation

There are several equivalent expressions for $y(x,t) = f(x \pm vt)$

$$\Rightarrow \; y(x,t) = A sin\frac{2\pi}{\lambda}\left(x \pm vt\right)$$

$$\Rightarrow \; y(x,t) = A sin 2\pi\left(\frac{x}{\lambda} \pm \nu t\right)$$

$$\Rightarrow y(x,t) = A sin \omega\left(\frac{x}{v} \pm t\right)$$

$$\Rightarrow \; y(x,t) = A sin\left(kx \pm \omega t\right)$$

$$\Rightarrow \; y(x,t) = A sin\left(kx \pm \omega t + \phi\right)$$

Mathematically convenient was to represent the wave is:

$$y(x,t) = Ae^{i(kx \pm \omega t + \phi)}$$

Simple Harmonic Wave: Wave velocity & Particle velocity

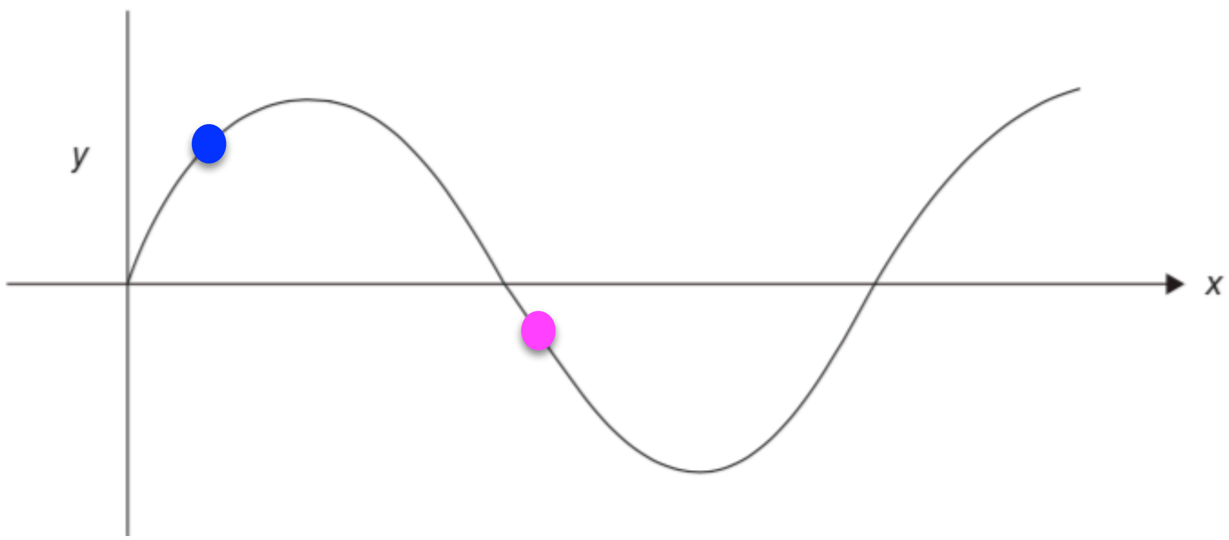
There are several equivalent expressions for $y(x,t) = f(x \pm vt)$

For a right-moving wave: $$\frac{\partial y}{\partial t} = -v\frac{\partial y}{\partial x}$$

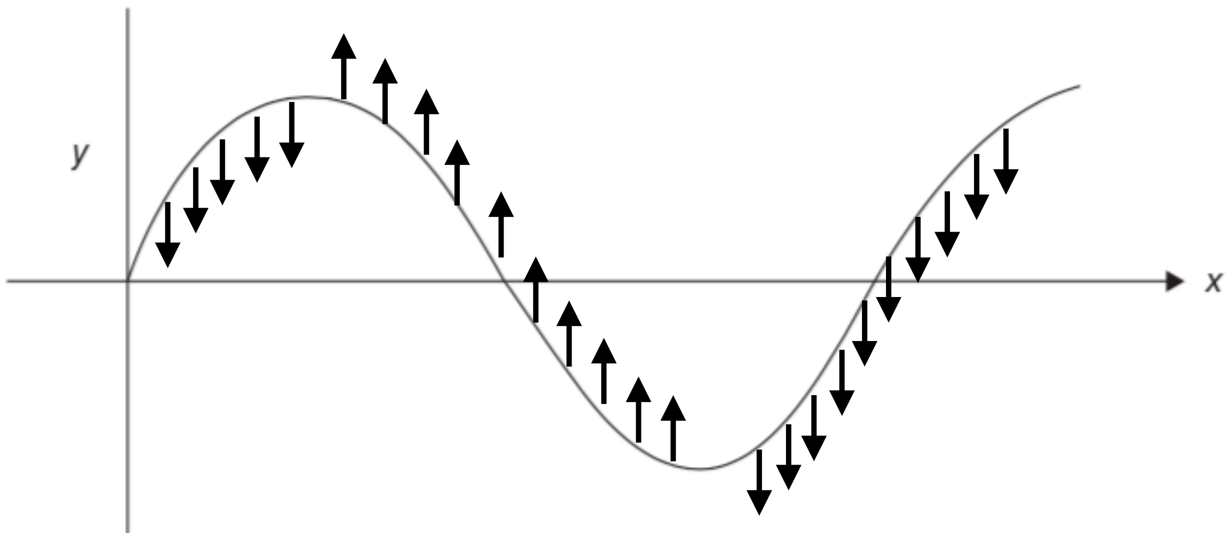
For a left-moving wave: $$\frac{\partial y}{\partial t} = v\frac{\partial y}{\partial x}$$

particle velocity=direction × wave velocity × slope

Simple Harmonic Wave: particle motion



Which particle moves
Up and which is
moving down?



Engineering Physics

Course Code: BPHY101L; Course Type: Theory Only (TH)

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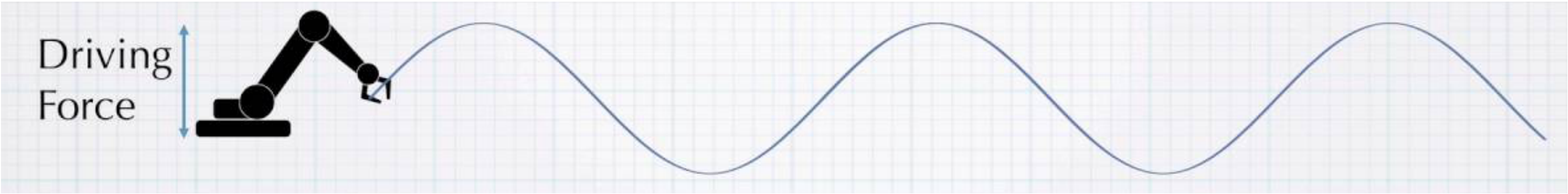
Characteristic Impedance of a String

What is Impedance ?

The opposition to the wave motion offered by a medium when a wave propagates through it. The impedance offered by the string to the transverse wave traveling through it is called the characteristics impedance. It is denoted by **Z**

$$Z = \frac{Transverse\ \ Force}{Transverese\ \ Velocity} = \frac{F_y}{v_y} = \frac{F_y}{\frac{\partial y}{\partial t}}$$



Characteristic Impedance of a String

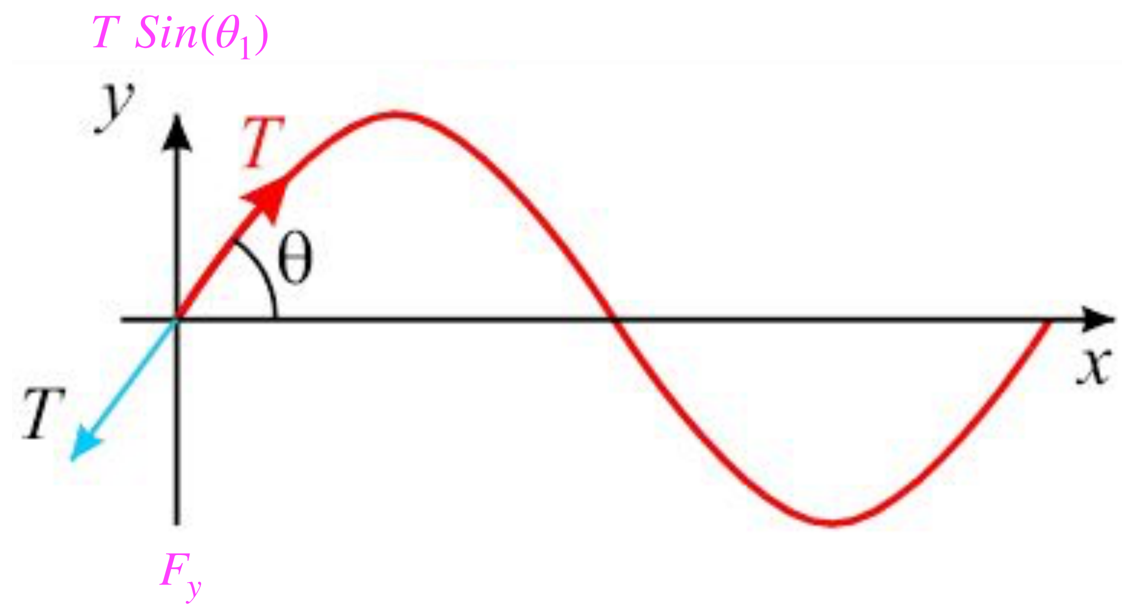
The magnitude of the transverse force is

$$\Rightarrow F_y = -T\, sin\theta$$

For smaller values of θ

$$\Rightarrow F_y = -T\, sin\theta \approx -T\, tan\theta$$

$$\Rightarrow F_y = -T\left(\frac{\partial y}{\partial x}\right)$$



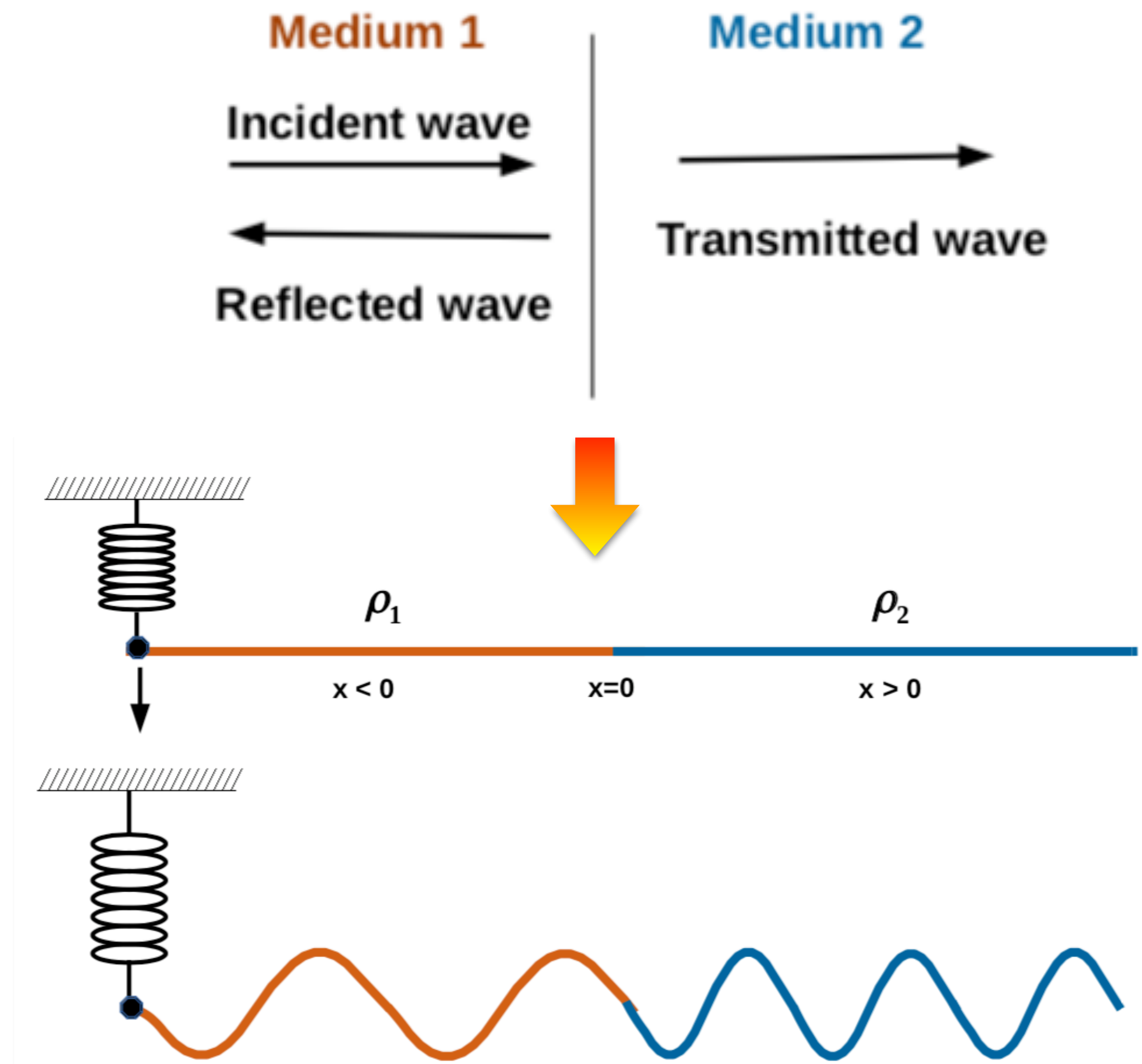
we know that, for a right moving wave $\frac{\partial y}{\partial t} = -v\frac{\partial y}{\partial x}$

particle velocity=direction × wave velocity × slope

$$\Rightarrow Z = \frac{F_y}{v_y} = \frac{F_y}{\frac{\partial y}{\partial t}} \Rightarrow = \frac{-T\frac{\partial y}{\partial x}}{-v\frac{\partial y}{\partial x}} \Rightarrow \frac{T}{v} \Rightarrow \sqrt{T\rho}$$

Wave travel in different medium

Lets understand the properties of the wave travelling in two different medium. We will try to understand its properties in terms of impedance



Wave travel in different medium

Medium-1

$Z_1,\ \rho_1,\ v_1,\ k_1,\ \lambda_1$

Medium-2

$Z_2,\ \rho_2,\ v_2,\ k_2,\ \lambda_2$

$$y_i(x,t) = A\sin(k_1 x - \omega t)$$

$$y_r(x,t) = B\sin(-k_1 x - \omega t)$$

$$y_t(x,t) = C\sin(k_2 x - \omega t)$$

x=0

At the boundary, x=0, it must satisfy the boundary conditions:

- Displacements must be the same immediately to the left and right of x=0 at all times.
- No discontinuity of displacement at the boundaryTransverse force; $F_y = -T\left(\frac{\partial y}{\partial x}\right)$ must be continuous at x = 0.

Wave travel in different medium

Medium-1

$Z_1,\ \rho_1,\ v_1,\ k_1,\ \lambda_1$

Medium-2

$Z_2,\ \rho_2,\ v_2,\ k_2,\ \lambda_2$

$$y_i(x,t) = A\sin(k_1 x - \omega t)$$

$$y_r(x,t) = B\sin(-k_1 x - \omega t)$$

$$y_t(x,t) = C\sin(k_2 x - \omega t)$$

x=0

At the boundary, x=0, it must satisfy the boundary conditions: **Displacement is Continuous**

$$y_i(x,t) + y_r(x,t) = y_t(x,t)$$

$$\Rightarrow A + B = C$$

Wave travel in different medium

Medium-1

$Z_1,\ \rho_1,\ v_1,\ k_1,\ \lambda_1$

Medium-2

$Z_2,\ \rho_2,\ v_2,\ k_2,\ \lambda_2$

$$y_i(x,t) = A \sin(k_1 x - \omega t)$$

$$y_t(x,t) = C \sin(k_2 x - \omega t)$$

$$y_r(x,t) = B \sin(-k_1 x - \omega t)$$

x=0

At the boundary, x=0, it must satisfy the boundary conditions:**Tension is same**

$$T\left(\frac{\partial y}{\partial x}\right)_i + T\left(\frac{\partial y}{\partial x}\right)_r = T\left(\frac{\partial y}{\partial x}\right)_t$$

$$\Rightarrow \quad A - B = \frac{k_2}{k_1} C$$

Wave travel in different medium

$$A + B = C \qquad A - B = \frac{k_2}{k_1}C$$

Reflection coefficient:

$$\Rightarrow \frac{B}{A} = \frac{k_1 - k_2}{k_1 + k_2}$$

$$\Rightarrow \quad = \frac{v_2 - v_1}{v_2 + v_1} \quad \left(k_1 = \frac{\omega}{v1} \ \& \ k_2 = \frac{\omega}{v2}\right)$$

$$\Rightarrow \frac{B}{A} = \frac{Z_1 - Z_2}{Z_1 + Z_2} \quad \left(T = Z_1 v_1 \ \& \ T = Z_2 v_2\right)$$

Transmission coefficient:

$$\Rightarrow \frac{C}{A} = \frac{2k_1}{k_1 + k_2}$$

$$\Rightarrow \quad = \frac{2v_2}{v_1 + v_2}$$

$$\Rightarrow \frac{C}{A} = \frac{2Z_1}{Z_1 + Z_2}$$

Independent of ω

Wave travel in different medium

$$A + B = C \qquad A - B = \frac{k_1}{k_2}C$$

Reflection coefficient:

$$\Rightarrow \frac{B}{A} = \frac{k_1 - k_2}{k_1 + k_2}$$

$$\Rightarrow = \frac{v_2 - v_1}{v_2 + v_1} \quad \left(k_1 = \frac{\omega}{v1} \ \& \ k_2 = \frac{\omega}{v2}\right)$$

$$\Rightarrow \frac{B}{A} = \frac{Z_1 - Z_2}{Z_1 + Z_2} \quad \left(T = Z_1 v_1 \ \& \ T = Z_2 v_2\right)$$

Transmission coefficient:

$$\Rightarrow \frac{C}{A} = \frac{2k_1}{k_1 + k_2}$$

$$\Rightarrow = \frac{2v_2}{v_1 + v_2}$$

$$\Rightarrow \frac{C}{A} = \frac{2Z_1}{Z_1 + Z_2}$$

Independent of ω

Wave travel in different medium:Rigid End

Transmission coefficient:

$$\frac{C}{A} = \frac{2Z_1}{Z_1 + Z_2}$$

Reflection coefficient:

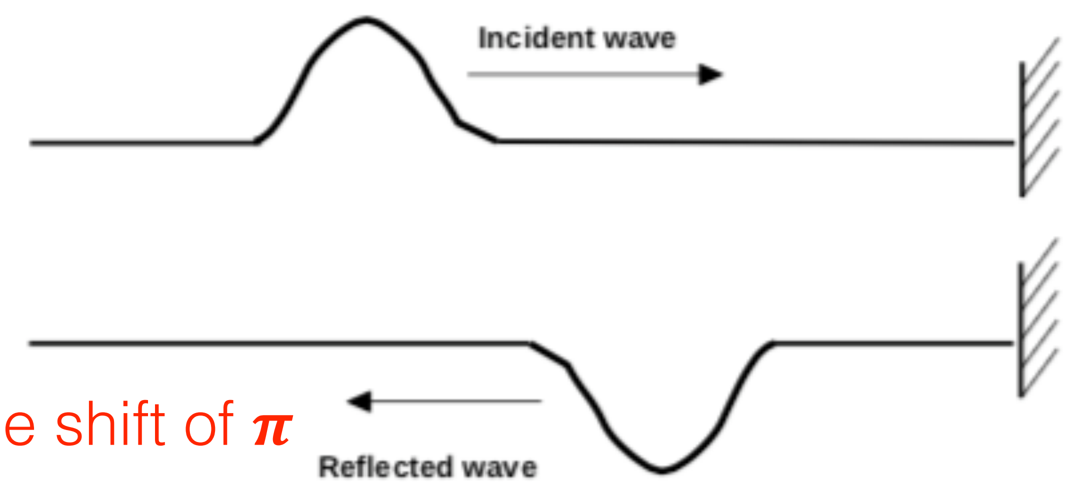
$$\frac{B}{A} = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

let's consider two cases:

1. If the boundary has **infinite impedance**

$$\Rightarrow \; Z_2 \to \infty$$

$$\Rightarrow \frac{C}{A} = 0, \; \& \; \frac{B}{A} = -1$$



phase shift of π

Qualitatively, The amplitude of the transmitted wave goes to zero, so the amount of energy it can carry will also go to zero. the transmitted wave will returned back with a phase shift of 180 degree

Wave travel in different medium: Free End

Transmission coefficient:

$$\frac{C}{A} = \frac{2Z_1}{Z_1 + Z_2}$$

Reflection coefficient:

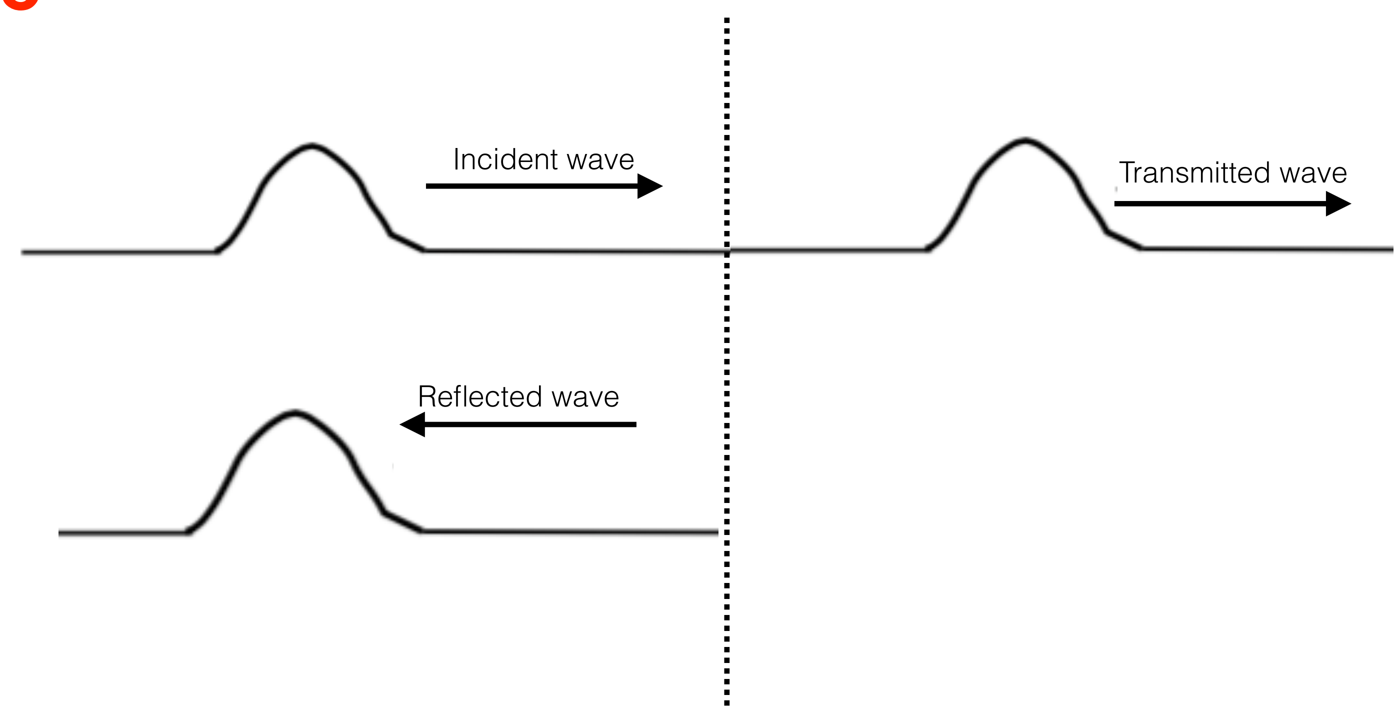
$$\frac{B}{A} = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

let's consider two cases:

1. If the boundary has **low impedance**

$$\Rightarrow \quad Z_2 \to 0$$

$$\Rightarrow \frac{C}{A} = 2, \ \& \ \frac{B}{A} = 1$$



Qualitatively, the the coefficient of the transmitted wave will be as large as it can possibly be: TWICE the size of the incident wave

Boundary with same medium

Transmission coefficient:

$$\frac{C}{A} = \frac{2Z_1}{Z_1 + Z_2}$$

Reflection coefficient:

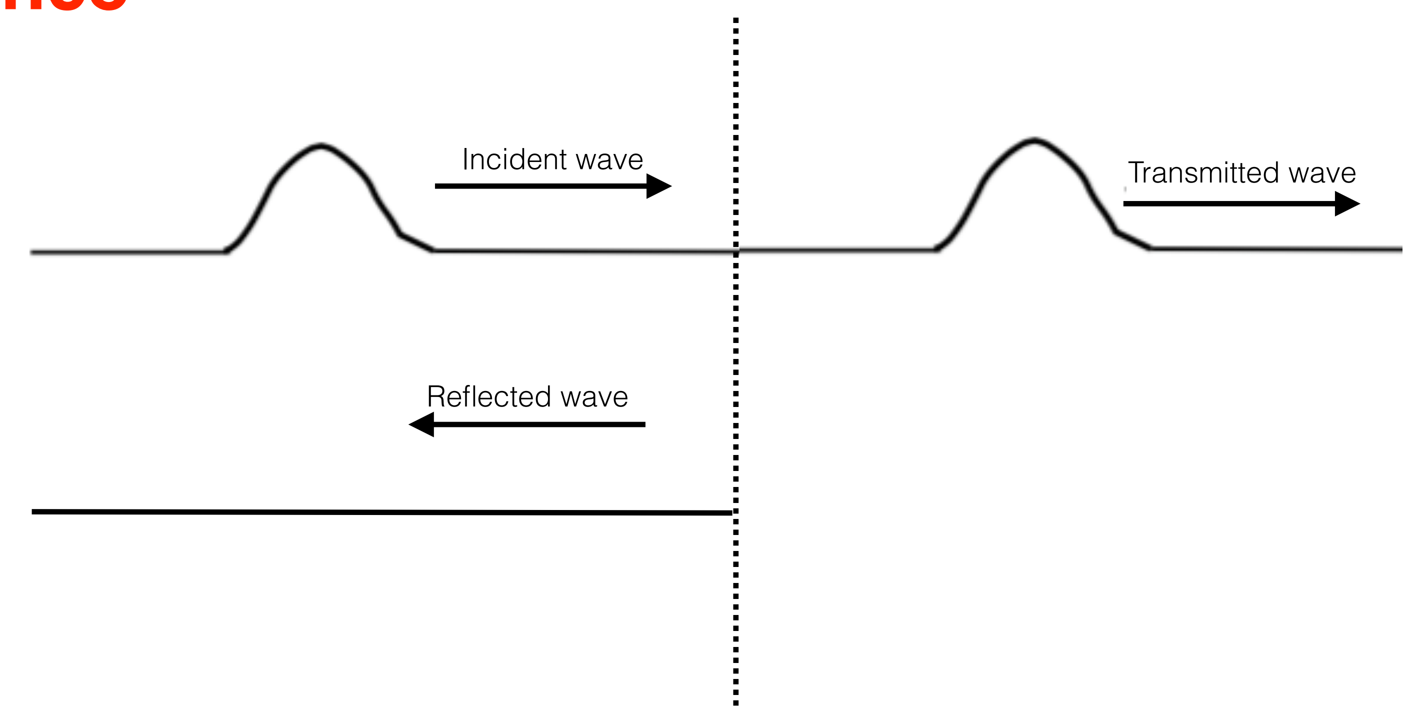
$$\frac{B}{A} = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

let's consider two cases:

1. If the boundary has **Equal impedance**

$$\Rightarrow \; Z_1 = Z_2$$

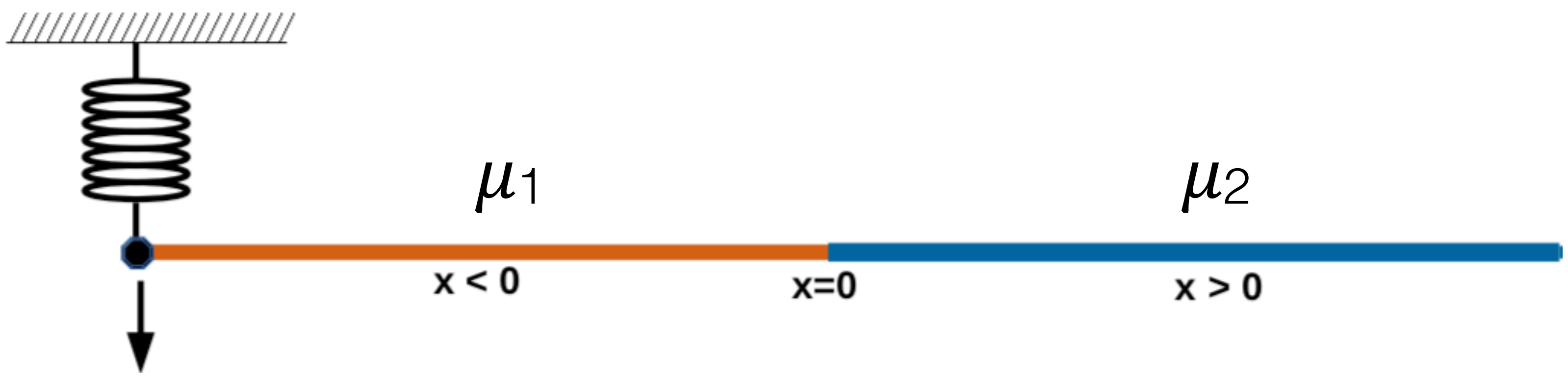
$$\Rightarrow \frac{C}{A} = 1, \; \& \; \frac{B}{A} = 0$$



Qualitatively, the string doesn't change at all at the boundary, so there is no boundary. The incident wave just keeps travelling to the right, into Region II, carrying all its energy

Reflection and Transmission of Wave in String: Free End

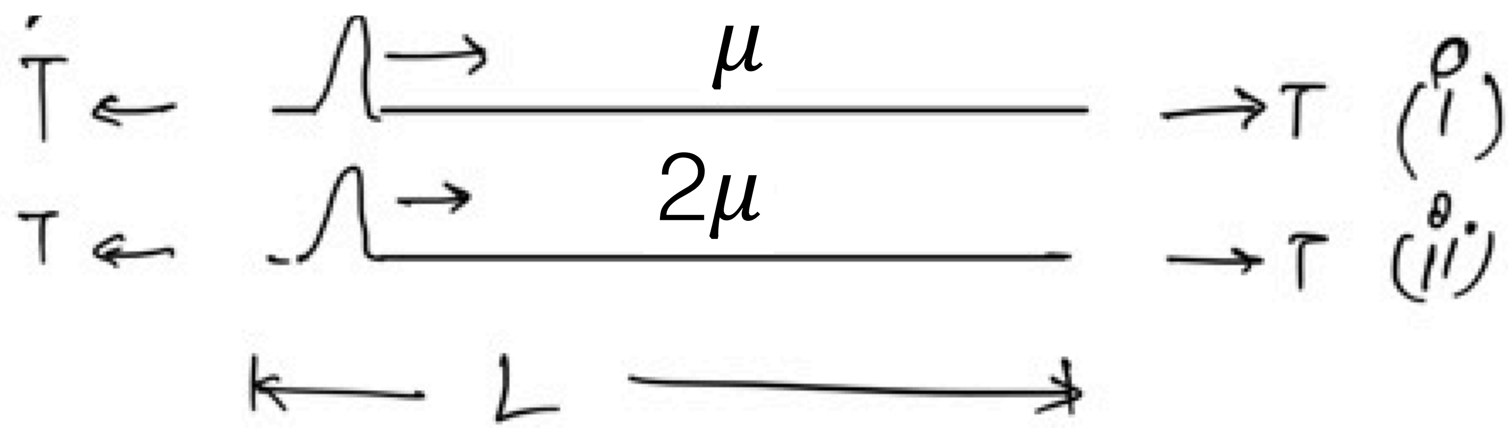
Properties of the wave changes when move from one medium to another medium



Properties	Reflection	Transmission
Velocity (v)	Same	**Change**
Frequency (f), $\omega=2\pi f$	Same	Same
Wavelength (λ), $k=2\pi/\lambda$	Same	**Change**
Phase (ϕ)	$\phi=0$; $Z_{High} \Rightarrow Z_{low}$ **$\phi=\pi$; $Z_{low} \Rightarrow Z_{High}$**	$\phi=0$; $Z_{High} \Rightarrow Z_{low}$; $Z_{low} \Rightarrow Z_{High}$

Numerical Problems-1

Q.1 Consider two strings (given below i & ii) with linear mass density, μ and **2**μ**,** respectively. The strings are isolated and kept under the same tension T and have a length of L.



(a) Calculate the wave velocity in both strings?

(b) Wave on which string will reach the other end faster? Calculate the time difference between the two waves at the end of the string ?

(c) How much tension should be increased in the string-2, so that both the waves will reach other ends on the same time ?

Numerical Problems-2

Q.2 A transverse harmonic wave on a string under the tension of **100 N** is given as:

$$y(x,t) = (0.1mm)\,.\,Sin(12.56\ cm^{-1}x - 1.57\ s^{-1}t)$$

Then find the:

(a) Amplitude

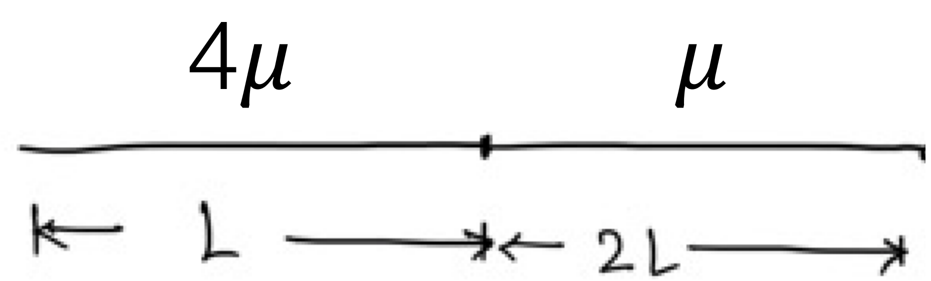
(b) Wavenumber and Wavelength

(c) and the Velocity of the harmonic wave

(d) If the string is attached to a rigid end, then write down the harmonic wave function for the reflected wave

Numerical Problems-3

Q.3 A string, under tension **T**, is formed by combining two strings of different mass densities (as shown in the below figure)



Then:

(a) Calculate the reflection and transmission coefficients

(b) For an incident wave of the form (displacement)

$y(x, t) = (3m) \,.\, Cos(x - 10\ ms^{-1} \,.\, t)$, write down the waveform of the reflected and transmitted waves

Engineering Physics

Course Code: BPHY101L; Course Type: Theory Only (TH)

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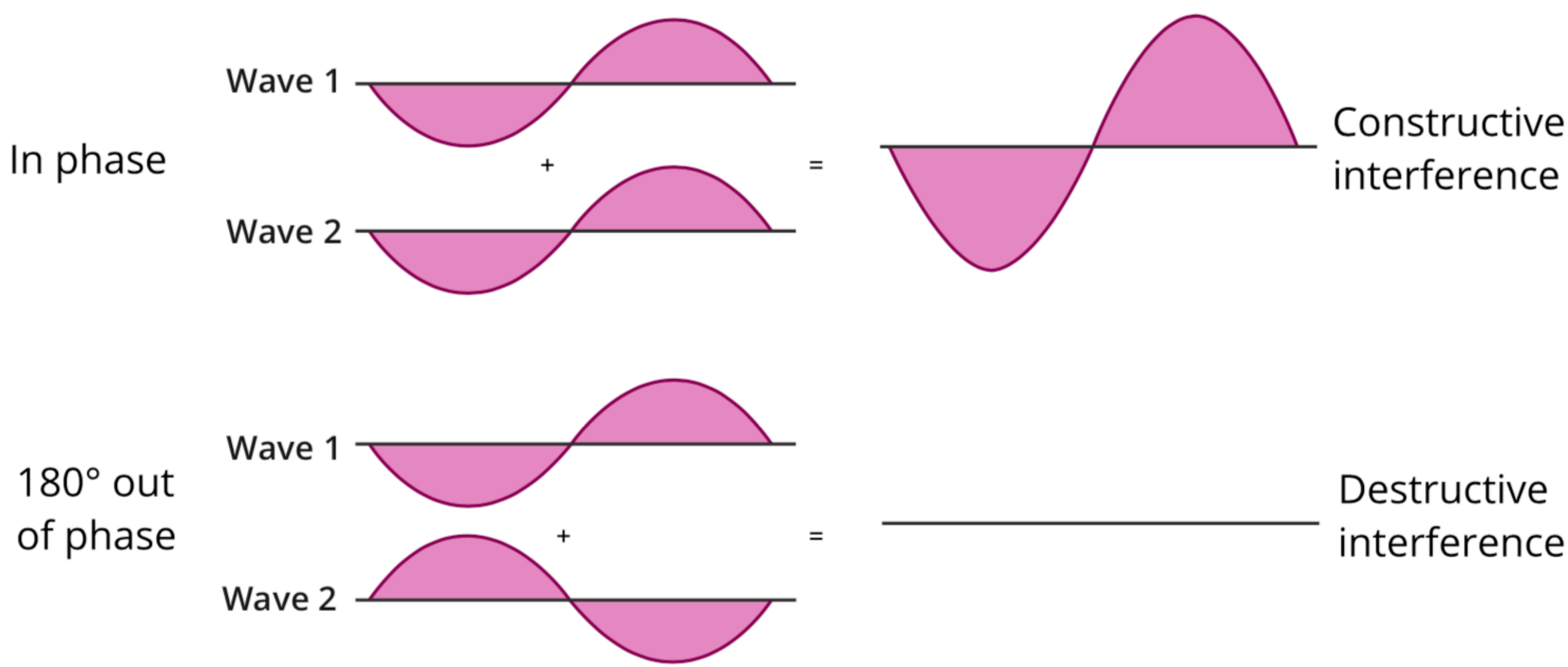
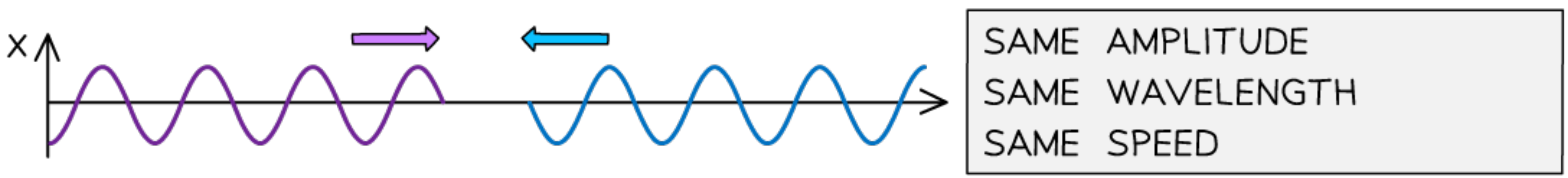
Superposition Principle

- "When two or more wave with constant phase difference, same intensity and same amplitude travelling from medium each wave produces its own displacement irrespective of each other. The resultant of these waves is the vector sum of the amplitude of each wave".
- "The modification or the redistribution of intensity of resultant wave due to superposition of two or more waves is known as interference".

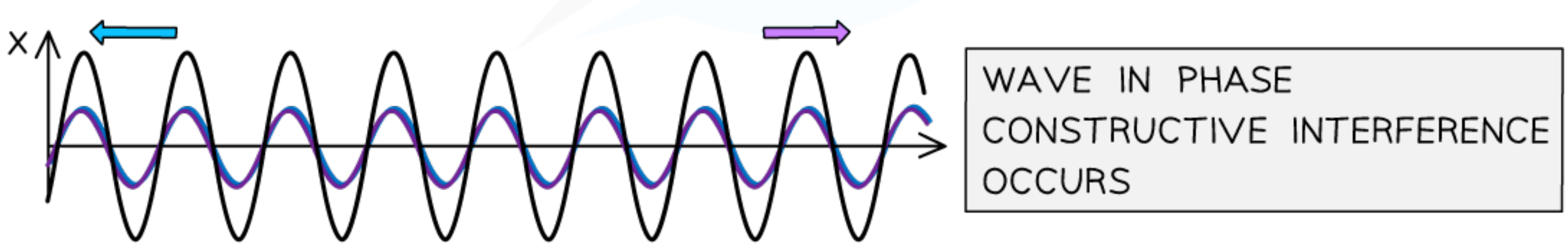


Standing Wave

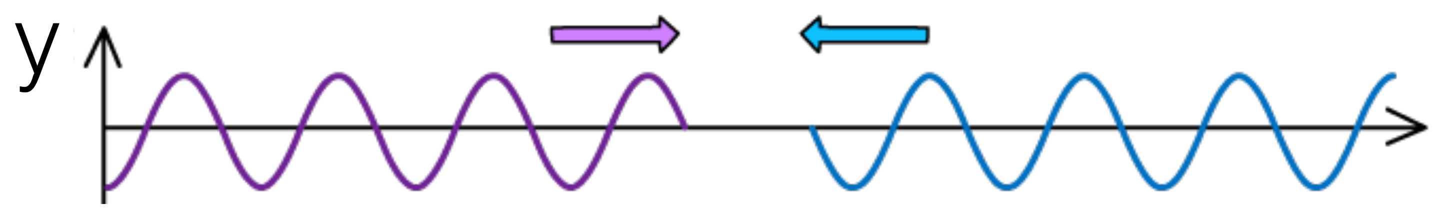
When two identical progressive waves (i.e. waves having same amplitude, wavelength & speed) travelling through medium along same path in opposite direction, interfere with each other, by superposition of waves, the resultant wave obtained in the form of loops, is called a stationary wave or standing wave



Why they are called Standing/stationary ?



Why Standing Wave ?



Right travelling wave:

$$y_l(x,t) = ASin(kx + \omega t)$$

Left travelling wave:

$$y_r(x,t) = ASin(kx - \omega t)$$

Resultant wave will be: $y(x,t) = y_r(x,t) + y_l(x,t)$

$$\Rightarrow \; = Asin(kx - \omega t) + Asin(kx + \omega t)$$

$$\Rightarrow \; y(x,t) = 2Asin(kx)cos(\omega t)$$

Not in form of the

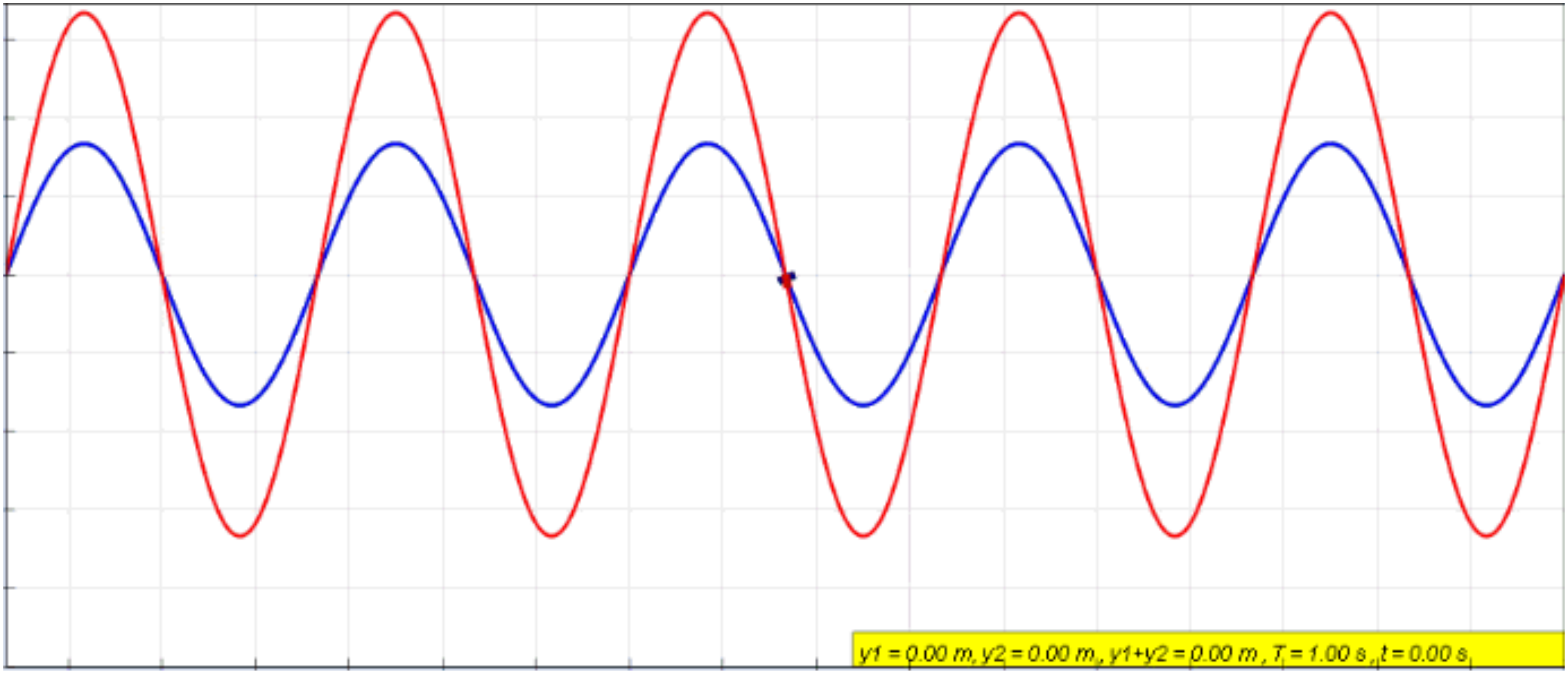
$$f(x - vt) \;/\; f(x + vt)$$

But satisfy

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

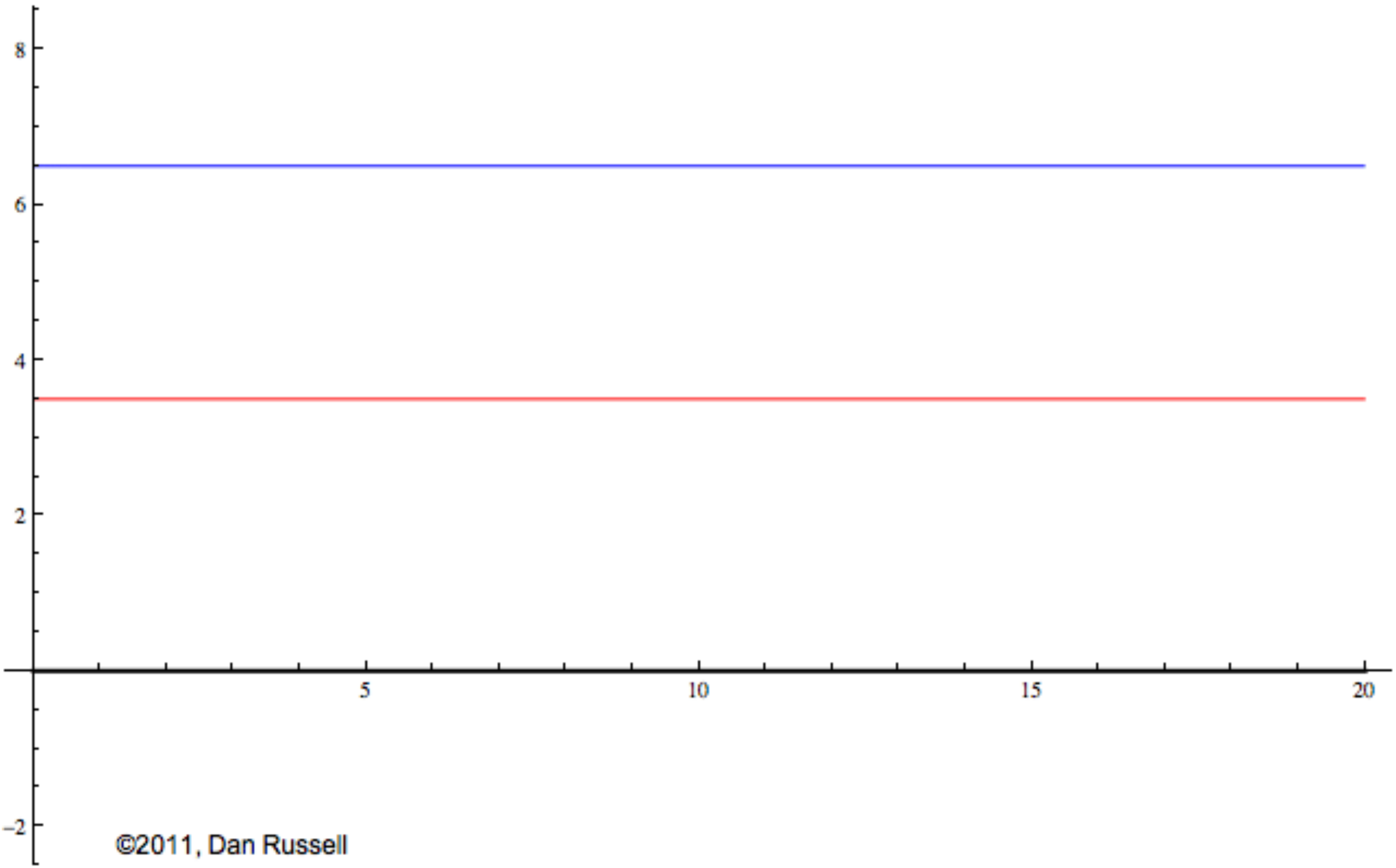
It is a wave but not progressive/traveling, hence standing wave

Why Standing Wave ?



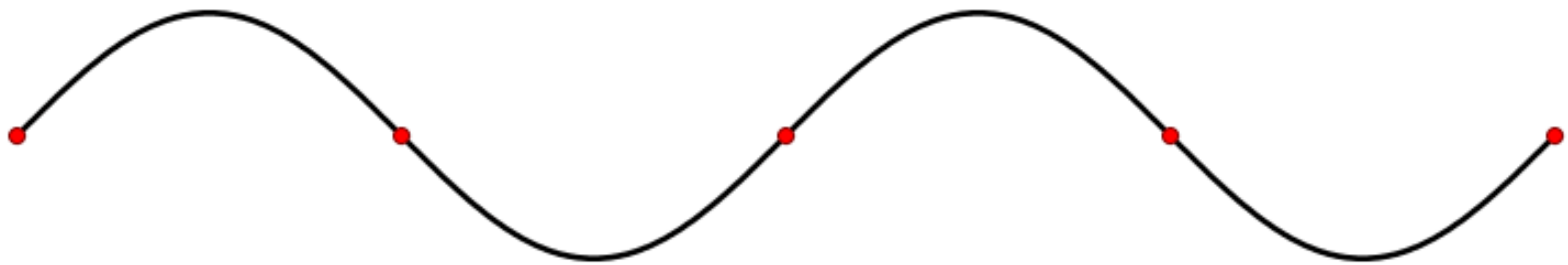
https://upload.wikimedia.org/wikipedia/commons/5/5d/Waventerference.gif

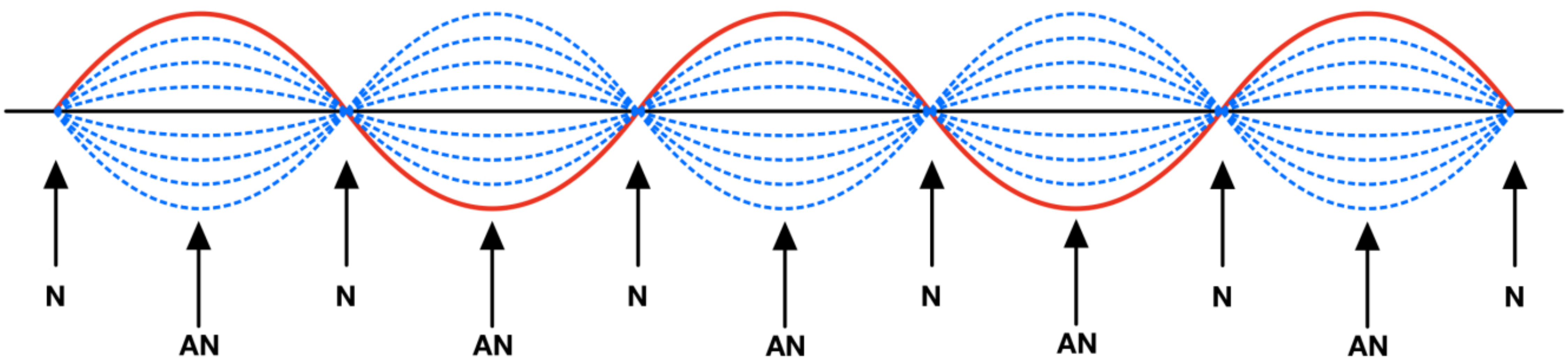
Standing Wave



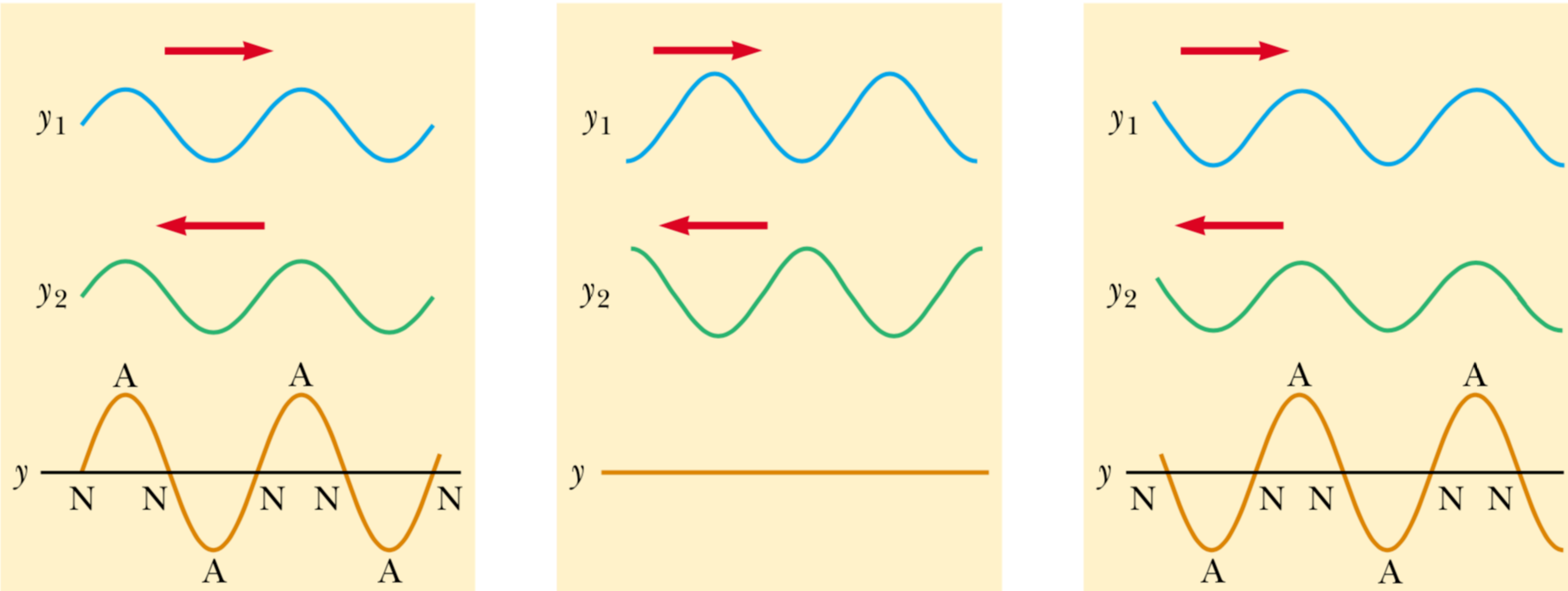
https://www.acs.psu.edu/drussell/Demos/SWR/SWR.html

Why Standing Wave ?



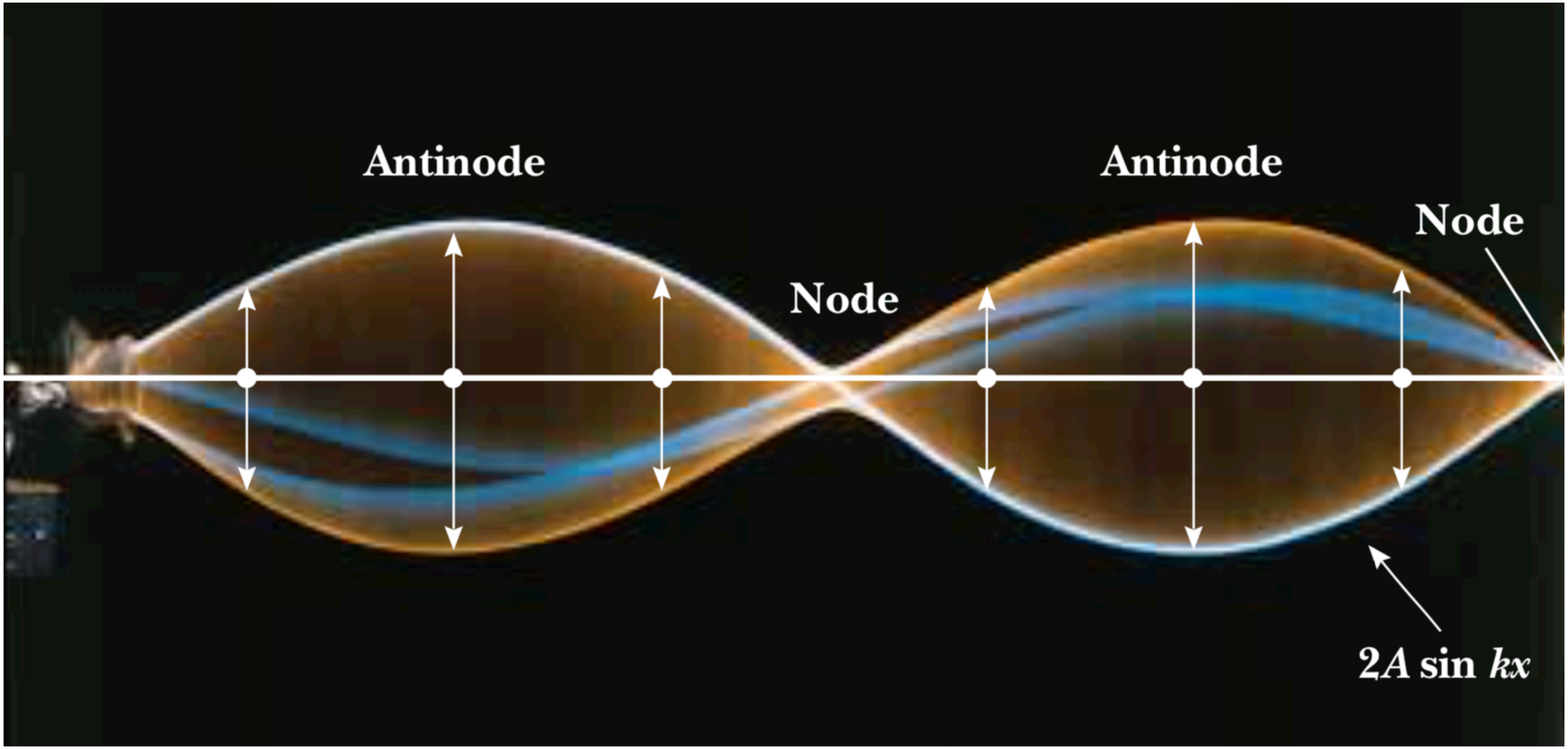


Standing Wave: Time Frame



(a) $t = 0$ (b) $t = T/4$ (c) $t = T/2$

Standing Wave



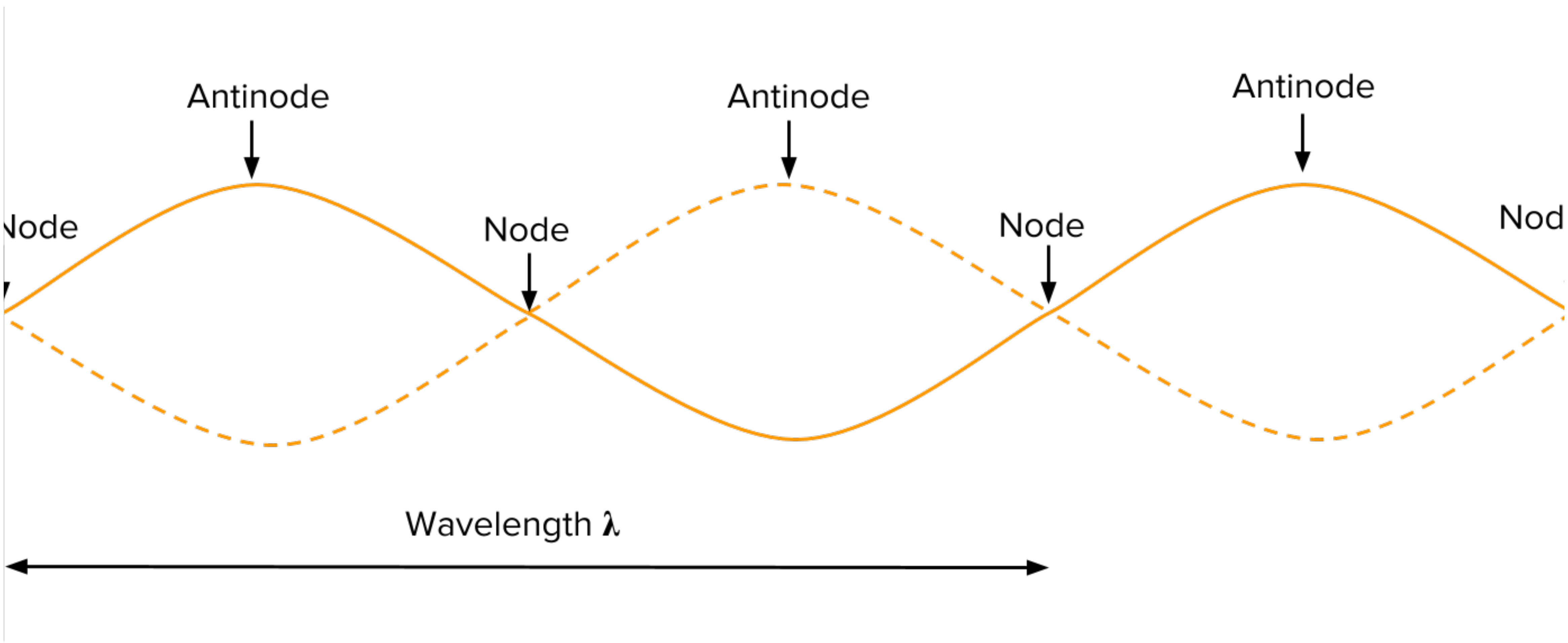
Standing Wave

https://www.youtube.com/watch?v=De1J2V0Cta4

Standing Wave: Nodes/Antinodes

Resultant wave will be: $y(x,t) = 2A sin(kx) cos(\omega t)$

$$= 2A[sin(kx)]cos(\omega t)$$



Standing Wave: Nodes/Antinodes

Resultant wave will be: $y(x,t) = 2Asin(kx)cos(\omega t)$

$$= 2A[sin(kx)]cos(\omega t)$$

Nodes (least amplitude) :

$$sin(kx) = 0$$

$$\Rightarrow kx = n\pi$$

$$\Rightarrow \frac{2\pi}{\lambda}x = n\pi$$

$$\Rightarrow x = \frac{n\lambda}{2}$$

$$x = 0, \frac{\lambda}{2}, \lambda, \frac{3\lambda}{2}, 2\lambda, \frac{5\lambda}{2} \ldots\ldots$$

Anti nodes (maximum amplitude) :

$$sin(kx) = \pm 1$$

$$\Rightarrow kx = \left(n + \frac{1}{2}\right)\pi$$

$$\Rightarrow \frac{2\pi}{\lambda}x = \left(n + \frac{1}{2}\right)\pi$$

$$\Rightarrow x = \left(2n + 1\right)\frac{\lambda}{4}$$

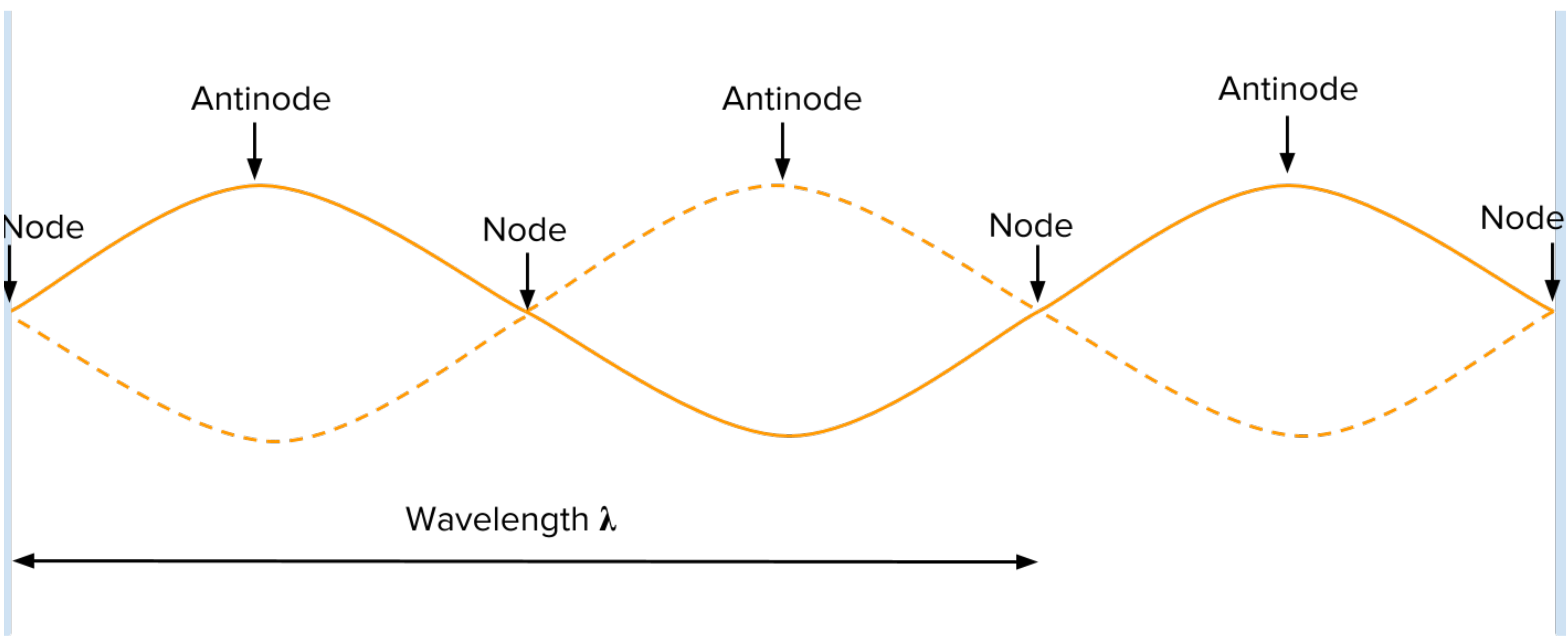
$$x = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \frac{7\lambda}{4} \ldots\ldots$$

Standing Wave: Nodes/Antinodes

Resultant wave will be: $y(x,t) = 2Asin(kx)cos(\omega t) = 2A[sin(kx)]cos(\omega t)$

Nodes (least amplitude) : $x = 0, \frac{\lambda}{2}, \frac{3\lambda}{2}, 2\lambda, \frac{5\lambda}{2} \ldots\ldots$

Anti nodes (maximum amplitude) : $x = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \frac{7\lambda}{4} \ldots\ldots$



Standing Wave in a String with Fixed End

$$v = \sqrt{\frac{T}{\mu}}$$

Lets consider a string of Length L, which is fixed at two end points, with a tension, T and linear mass density μ

The string of length L. Let x = 0 and x = L be two ends of the strings which are fixed (these ends does not move and so displacement must be zero here).

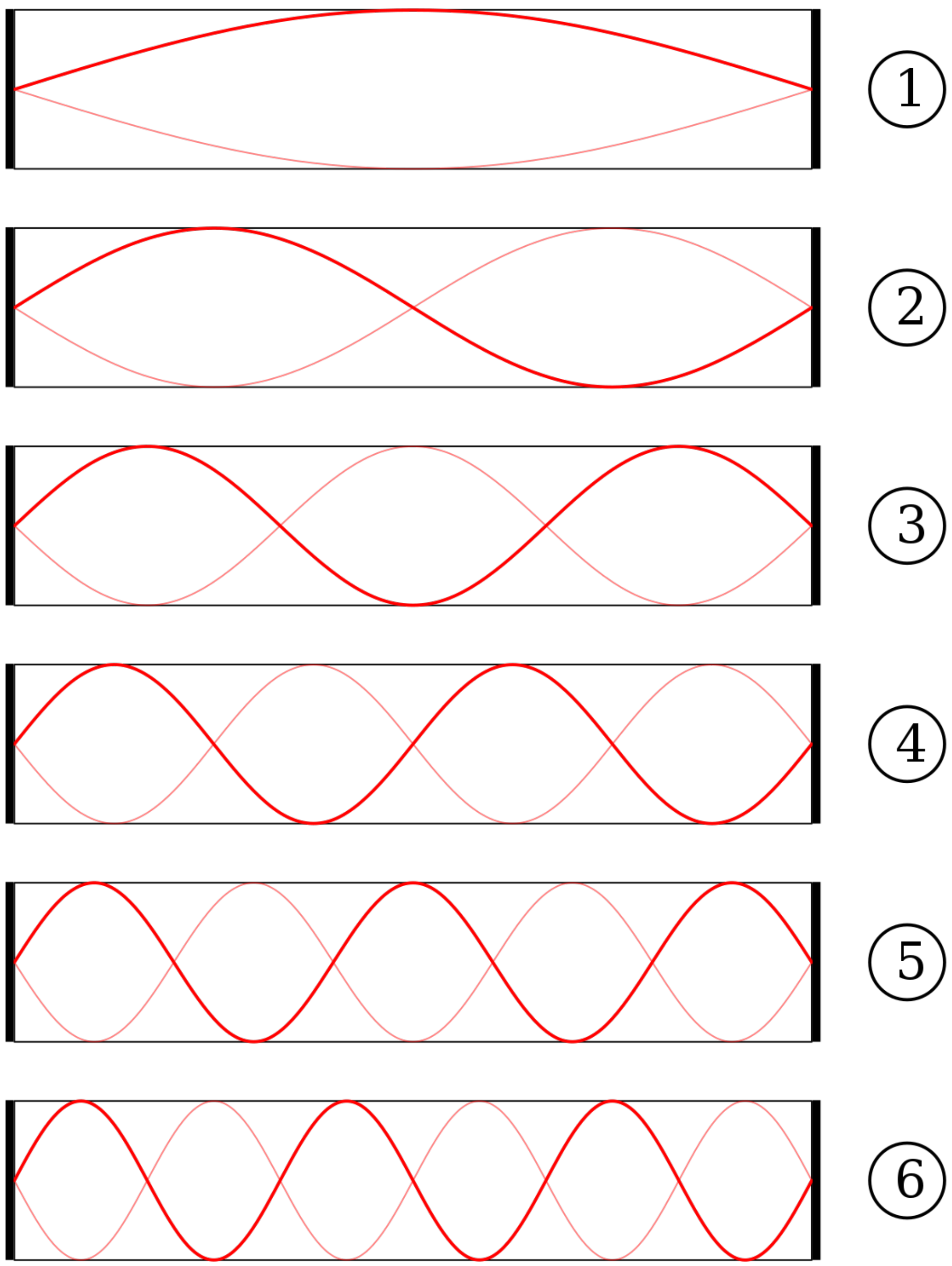
$$y(x,t) = 2A sin(kx) cos(\omega t)$$

Two extreme points in the strings are, x=0 and x=L; y(x,t)=0

$\mathbf{y(x = 0, t) = 0} \implies$ Obvious

$$\mathbf{y(x = L, t) = 0} \implies sin(kL) = 0 \implies k_n = \frac{n\pi}{L} \implies \lambda_n = \frac{2L}{n}$$

Standing Wave in a String: Fundamental Modes



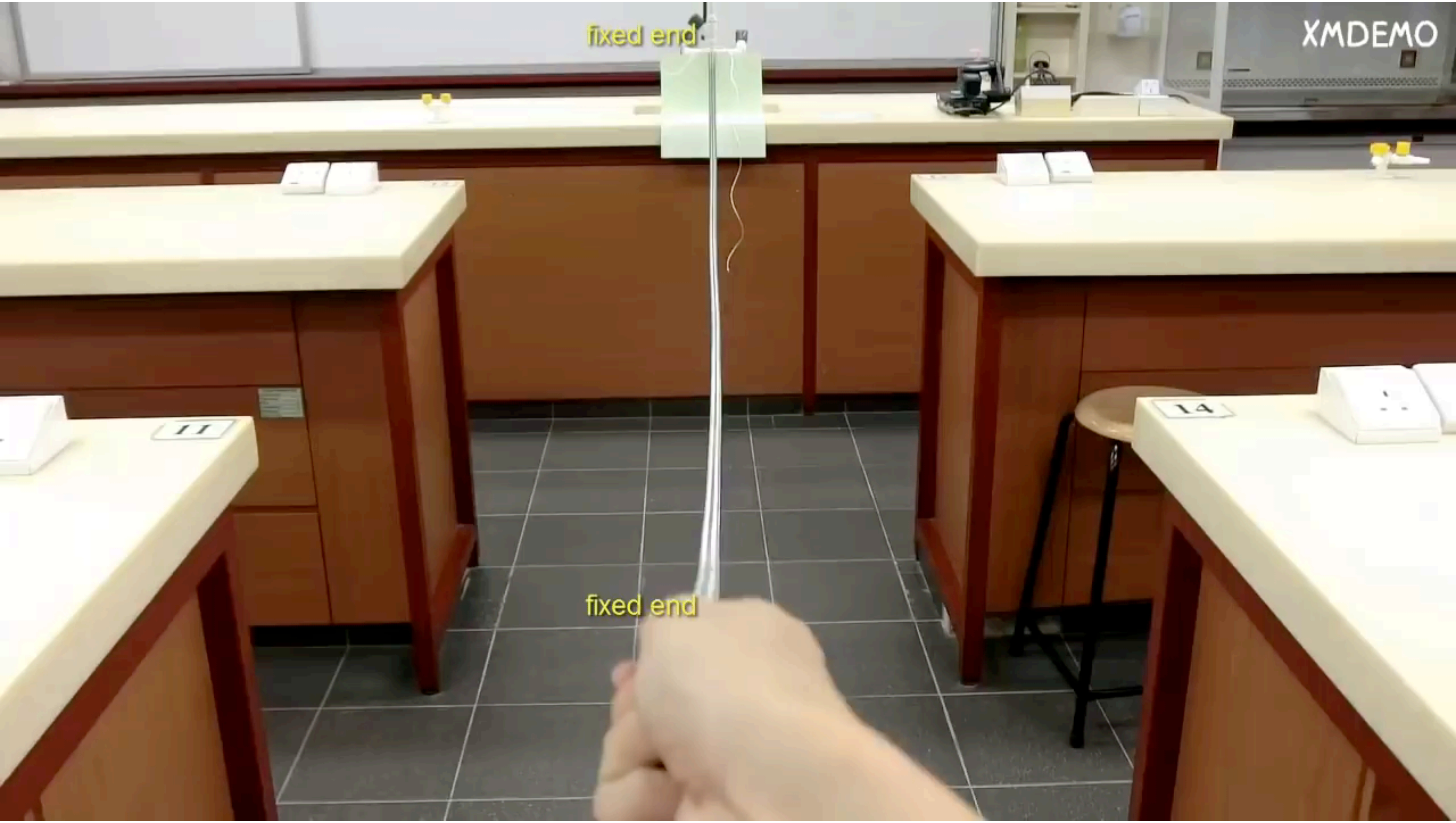
- For a given harmonic $(n > 1)$, there will be $(n-1)$ points on the string which are always at rest.
- These positions of zero motion are called as nodes

$$v = \sqrt{\frac{T}{\rho}} \qquad \lambda_n = \frac{2L}{n}$$

For fundamental mode, n=1, **λ**=2L

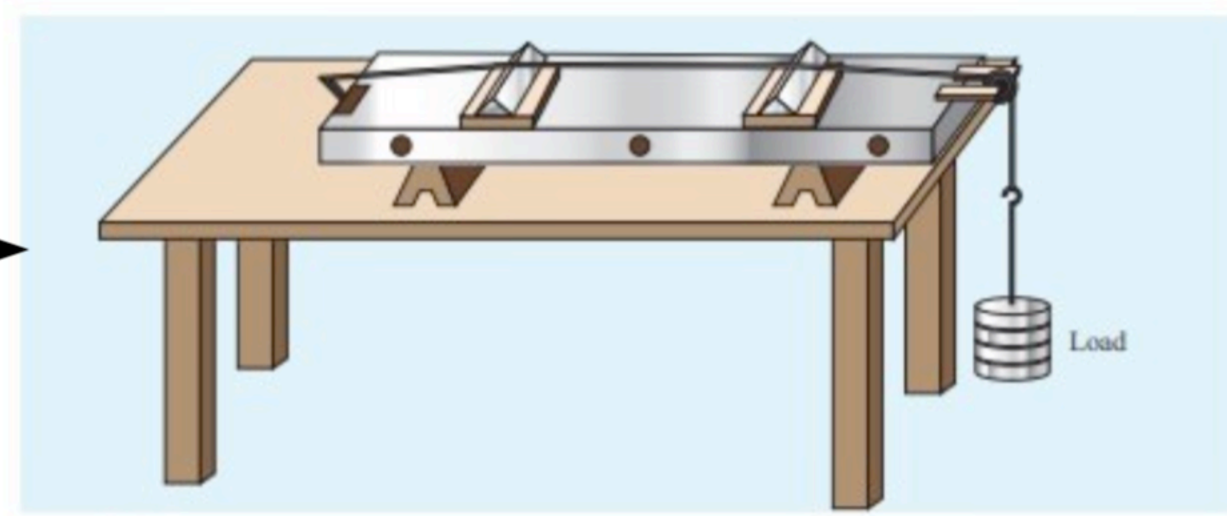
$$f = \frac{v}{\lambda_1} = \frac{1}{\lambda_1}\sqrt{\frac{T}{\rho}} \Rightarrow \boxed{f = \frac{1}{2L}\sqrt{\frac{T}{\rho}}}$$

Standing Wave Example



Standing Wave Example: Sonometer EXP

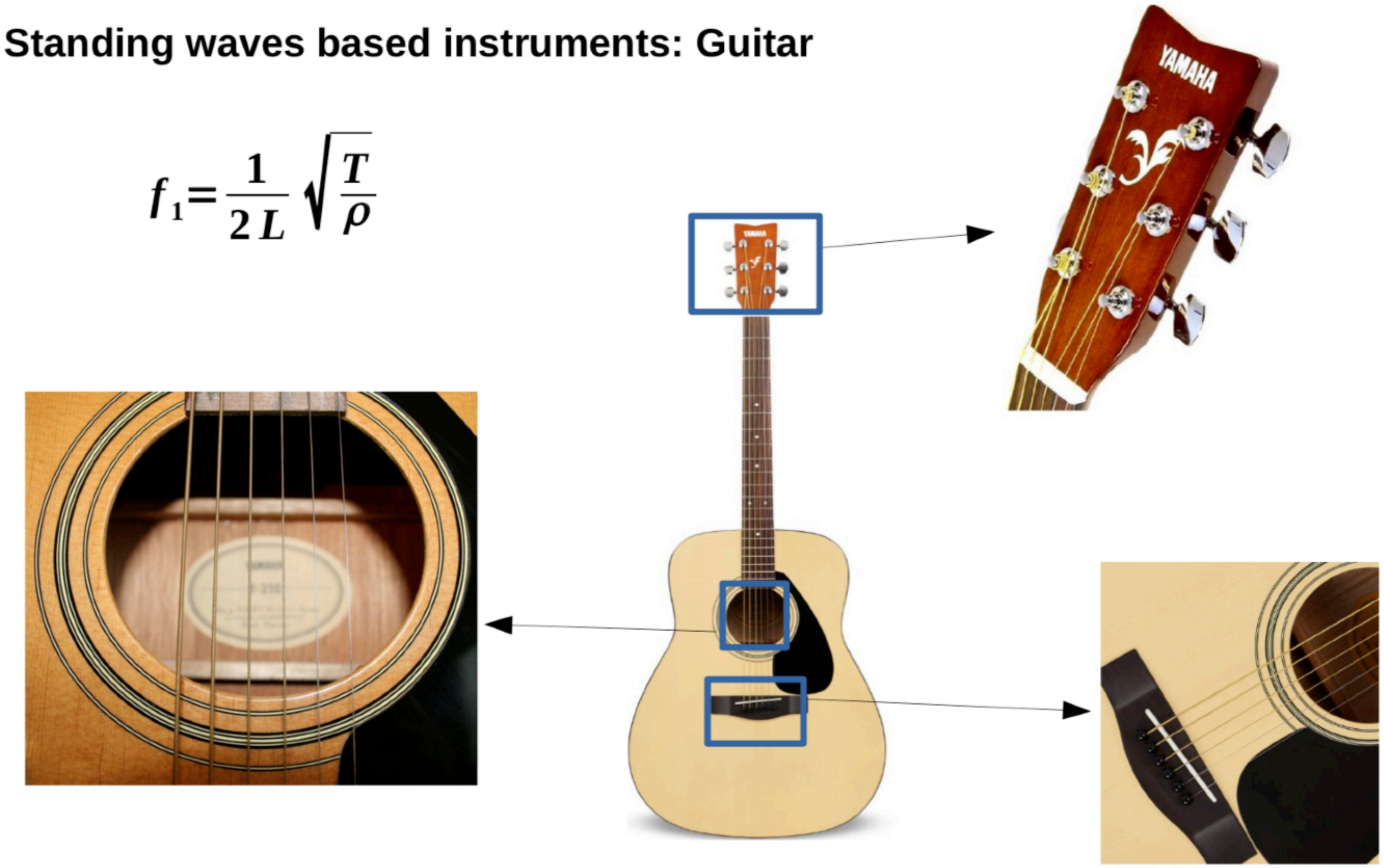
$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{\rho}}$$



Standing Wave Example: Guitar

Standing waves based instruments: Guitar

$$f_1 = \frac{1}{2L}\sqrt{\frac{T}{\rho}}$$



...	**Sa**	**Re**	**Ga**	**Ma**	**Pa**	**Dha**	**Ni**	**Sa**	...	
...	**240**	**270**	**300**	**320**	**360**	**400**	**450**	**480**	...	← Hz

Numerical Problems-1

A transverse harmonic wave on a string under the tension of **100 N** is given as:

$$y(x,t) = (0.1mm)\,.\,Sin(12.56\ cm^{-1}x - 1.57\ s^{-1}t)$$

Then find the:

(a) Amplitude

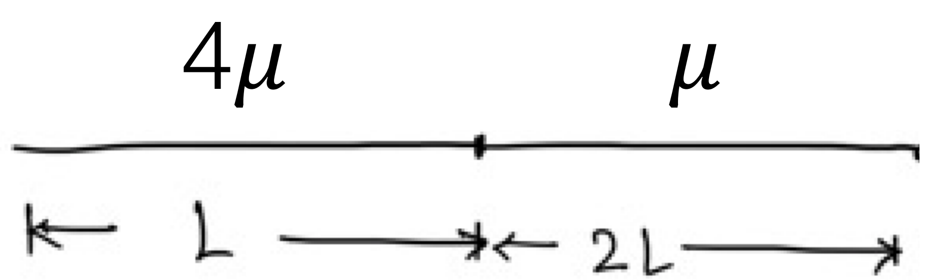
(b) Wavenumber and Wavelength

(c) and the Velocity of the harmonic wave

(d) If the string is attached to a rigid end, then write down the harmonic wave function for the reflected wave

Numerical Problems-2

A string, under tension **T**, is formed by combining two strings of different mass densities (as shown in the below figure)



Then:

(a) Calculate the reflection and transmission coefficients

(b) For an incident wave of the form (displacement)

$y(x,t) = (3m)\,.\,Cos(x - 10\ ms^{-1}\,.\,t)$, write down the waveform of the reflected and transmitted waves

Numerical Problems-3

A uniform string of length 2.5 m and mass 0.1 kg is placed under a tension of 10 N. What is the fundamental mode frequency?

Numerical Problems-4

A string instrument is tuned for fundamental frequency of 81 Hz. Its length is 15 cm, mass is 0.78 g. Find out the required tension.

Numerical Problems-5

A standing wave of amplitude **10 cm** is formed on a string of length **1 m** with both ends fixed.

(a) If three antinodes are formed on the string, then calculate the wavelength of the standing waves.

(b) Calculate the standing wave's velocity and the eigenfrequency of the standing wave if the string tension is **10 N** and the string density is **0.1g/cm**

Exercises-Practice at home

1. A harmonic wave passes through the junction of strings of two different linear mass densities. The velocity of the wave in the first medium is 100 ms^{-1} and that in the second medium is 80 ms^{-1}. Compute the reflection and transmission coefficient of the waves.

2. A string of 0.05 meter is fixed at two ends. It supports wave of speed 100 m/s. Calculate the wavelength and eigenfrequency of first, second and third harmonics

3. A wire is of length 100 m and its total mass is 5kg. The wire is under tension of 100 N. When the wire is periodically driven, a wave of wavelength 0.30 m travels down the string. What is the velocity and frequency of the wave?

Exercises-Practice at home

5. A harmonic wave has a wavelength of 1.70 m. It takes 0.20 s for a portion of the string at a position x to move from a maximum position to the equilibrium position. What is the period, frequency, and velocity of the wave?

6. A string of length 1 meter is fixed on both ends. It can support a wave of speed 100m/s. It is oscillated with an amplitude of 0.05 meter. Write a mathematical form representing the displacement of the string

7. Show that the superimposed wave $y(x,t)= A\,\mathbf{sin}(k\,x-\omega t) + A\,\mathbf{sin}(k\,x+\omega t)$ satisfy wave equation.

Exercises-Practice at home

8. A sinusoidal wave is generated on a wire by moving one end up and down 5 times per sec. The maximum displacement from equilibrium is 0.05 meters and wave travels at a speed of 200 m/s in the positive x-axis direction. Compute (i) wavelength and (ii) angular frequency of the wave. Finally write its mathematical form

Important Question-Mod-1

1. Explain classification of waves with an example in each case.

2. Derive the equation for the propagation of wave on a string. Write all the assumptions and show the relevant diagrams. Show that velocity of the wave is proportional to square of the tension in the string.

3. Write a harmonic wave, explain different components and show that it satisfies the wave equation. From that indentify the velocity of the wave.

4. Show that f(x+vt) and f(x-vt) both satisfy the wave equation.

5. Write the expression for reflection coefficient and transmission coefficient in terms of (a) impedance of the two strings (b) wave velocities

6. What are standing waves. Write the expression for displacement of the standing waves fixed at two ends of a string of length L. From that compute the eigen frequencies and wavelengths of different modes.

Thank You