

Lecture-1

Date: 04.01.2016

- Introduction
- Traveling Waves in Lossless and Lossy Medium
- Examples



Fields and Waves (ECE230)

Instructor: Dr. Mohammad S. Hashmi

TAs: Dinesh, Shelly, Vipin, Shreya

Class Timings: Monday (14:30 – 16:00) and Thursday (12:00 – 13:30)

Tutorial: Tuesday (10:00 – 11:30)

Lab Session: Friday (10:00 – 13:00) in RF & Propagation Lab

Office Hours: Monday (16:00 – 17:00)

TA Office Hour: All the TAs will be available in RF Lab on Friday (10:00-13:00)

Pre-requisites: Vector Calculus, Calculus, Complex Variables

Course URL:

Available at: <http://www.iiitd.edu.in/~mshashmi/Teaching.html>

Course Focus:

Foundations of Electromagnetic Field Theory

Course Objectives:

On the completion of this course students should be able to:

- Gain thorough understanding of Time Varying Fields, Maxwell's Equations, Time Harmonic Fields, and Plane Electromagnetic Waves
- Understand the operating principles of resistors, capacitors and inductors
- Analyse simple electronic blocks utilizing electromagnetics concept

Lab Component:

- MATLAB based sessions and possibly some demo

Evaluation:

- Assignments + Lab – 20%
- Surprise Quizzes – 20%
- Exams – mid-sem (25%) & end-sem (25%)
- Project – 10%

Attendance and Classroom Behavior:

- Attendance not mandatory – **however skip classes at your own risk**
- Students will be responsible for any notes, announcements etc. made during the class
- Prompt arrival to the class is requested – **please do not enter the class if you are late by 5 minutes!**
- No eating, drinking, smoking allowed in the class – **definitely no facebooking will be entertained**

Text Book:

- Principles of electromagnetics *6th Edition*, Mathew N. O. Sadiku

Syllabus:

- Chapters 1-10 from Mathew N. O. Sadiku

Other Recommended Books:

- Electromagnetics Fields and Waves *2nd Edition*, David K. Cheng
- Fundamentals of Applied Electromagnetics *6th Edition*, Fawwaz T. Ulaby
- Engineering Electromagnetics *2nd Edition*, Karl E. Lonngrenn et al.

Why Study Electromagnetics?

This course is about electromagnetics (EM), the electrical foundation of Electrical and Computer Engineering, or, how electricity *really* works.

-- Look into the black boxes.

- Linear Circuit is a simple part of EM, so it was taught first.
- However there are an increasing number of cases in ECE where circuit theory fails (e.g. faster computers, higher communications frequencies, power electronics, power system transients,), and therefore EM must supplement circuit theory. *But, don't worry...*
- Also EM is the basis for many devices (machinery, antennas, etc.), and one of the physical foundations of any active electronic device.

Why Study Electromagnetics?

Electrical Engineering is Applied Electromagnetics

- As devices get smaller and smaller, and frequencies get higher and higher, circuit theory is less able to adequately describe the performance or to predict the operation of circuits.
- At very high frequencies, transmission line and guided wave theory must be used in applications such as high speed electronics, micro/nano electronics, integrated circuits.
- Other applications include: Fiber Optics, Microwave Communication Systems, Antennas and Wave Propagation, Optical Computing, Electromagnetic Interference, Electromagnetic Compatibility, Biology and Medicine/Biomedical Imaging.

What is Electromagnetics?

- Electromagnetics is the study of Charges:
 - (i) at rest
 - (ii) in motion
- The subject of electromagnetics may be divided into 3 branches:
 - Electrostatics: charges are at rest (no time-variation)
 - Magnetostatics: charges are in steady-motion (no time-variation)
 - Electrodynamics: charges are in time-varying motion
(give rise to waves that propagate and carry energy and information)

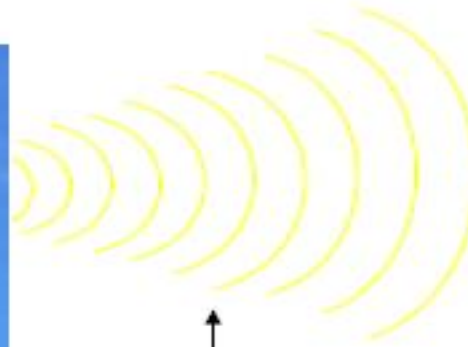
Steps in Studying Electromagnetics

- Define basic quantities (e.g., E-field, H-field)
- Define the rules of operation (mathematics) of these quantities (e.g., Vector Algebra, PDEs)
- Postulate fundamental laws



Examples of Electromagnetic Applications

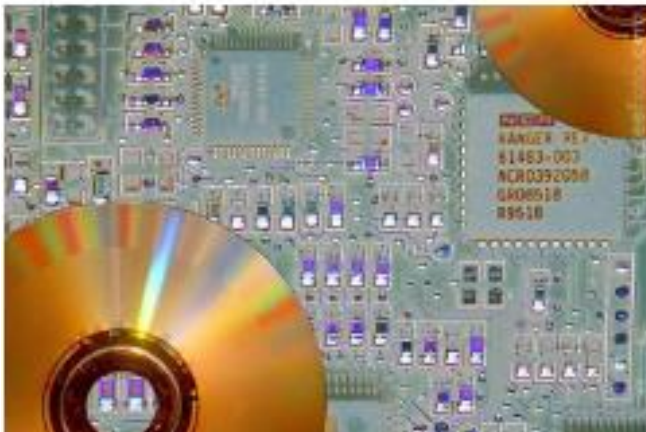
Communication Technology



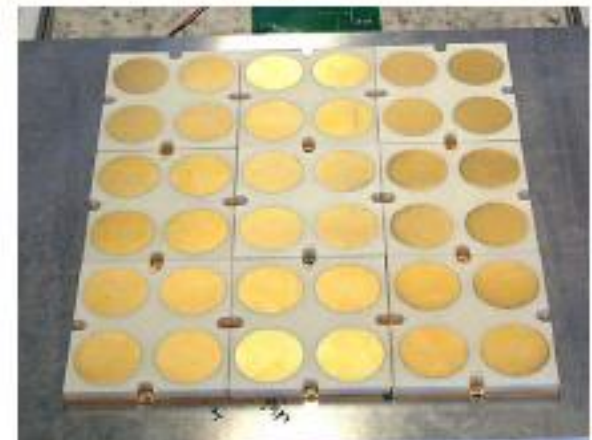
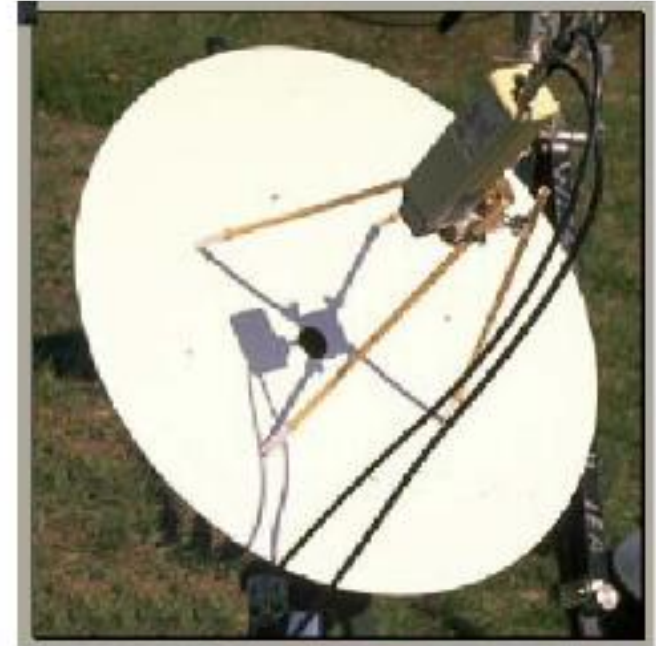
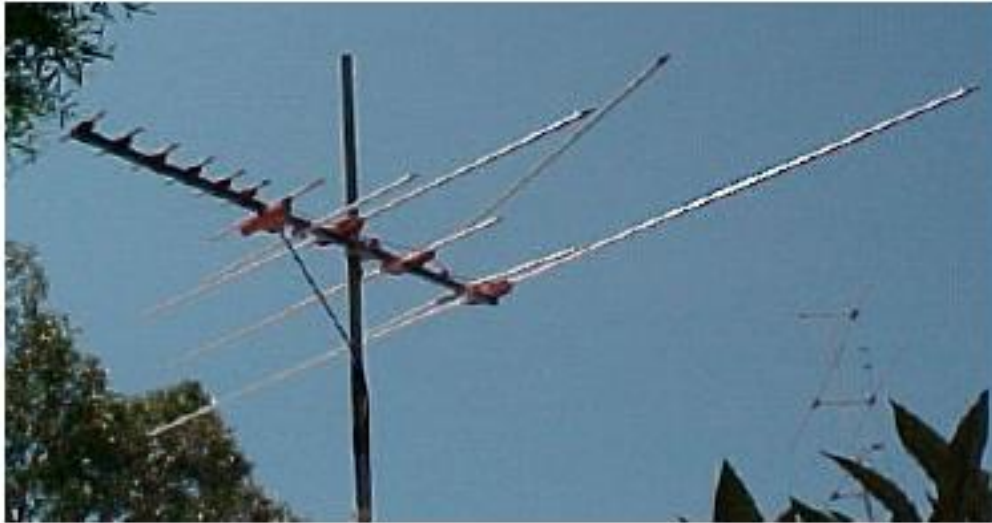
↑
Electromagnetic field



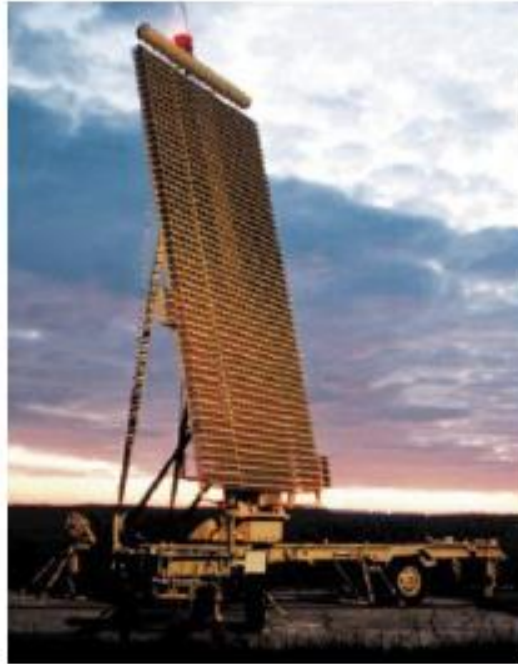
Computer Technology



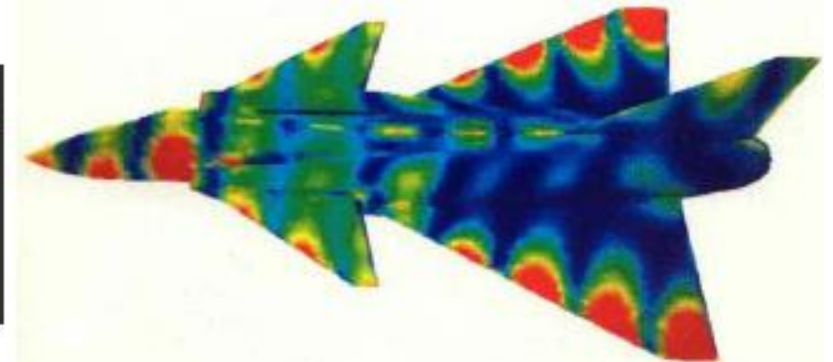
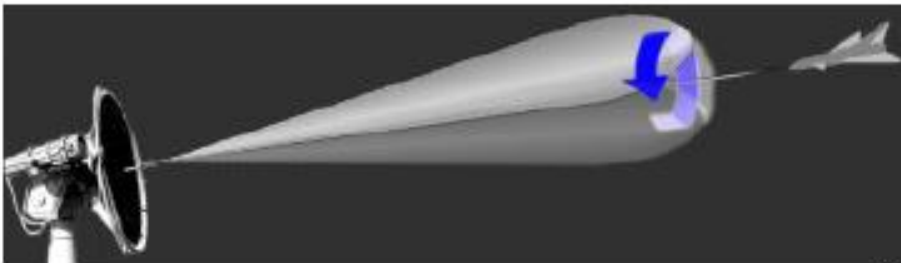
Antenna Technology



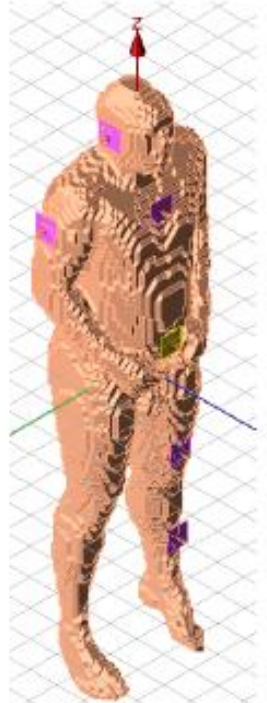
Military and Defense Applications



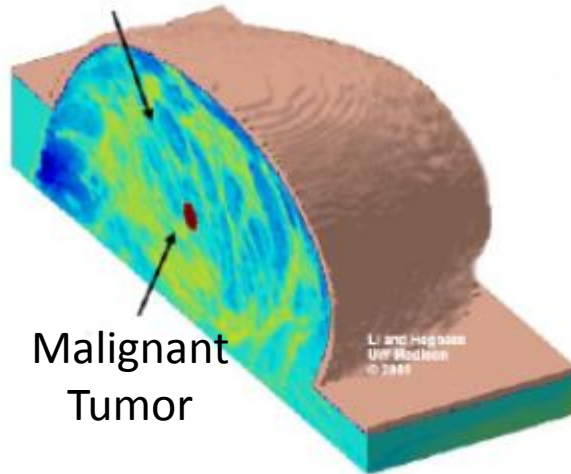
Radars



Biomedical Applications



Fat and Fibrogranular Tissues



Malignant Tumor



Person wearing electrodes for EEG

EEG (Electroencephalography) measures the electrical activity produced by the brain as recorded from electrodes placed on the scalp.

ECG (Electrocardiogram) records the electrical activity of heart over time.



Transportation

- Levitated trains: Maglev prototype



Localization and Sensing

- Localization and Sensing

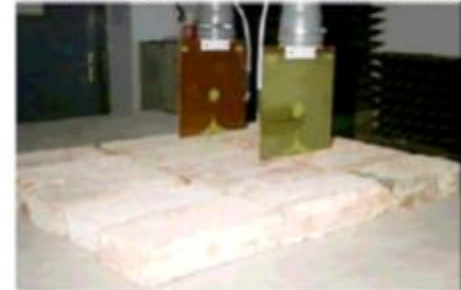
Through wall imaging



GPR



Material science

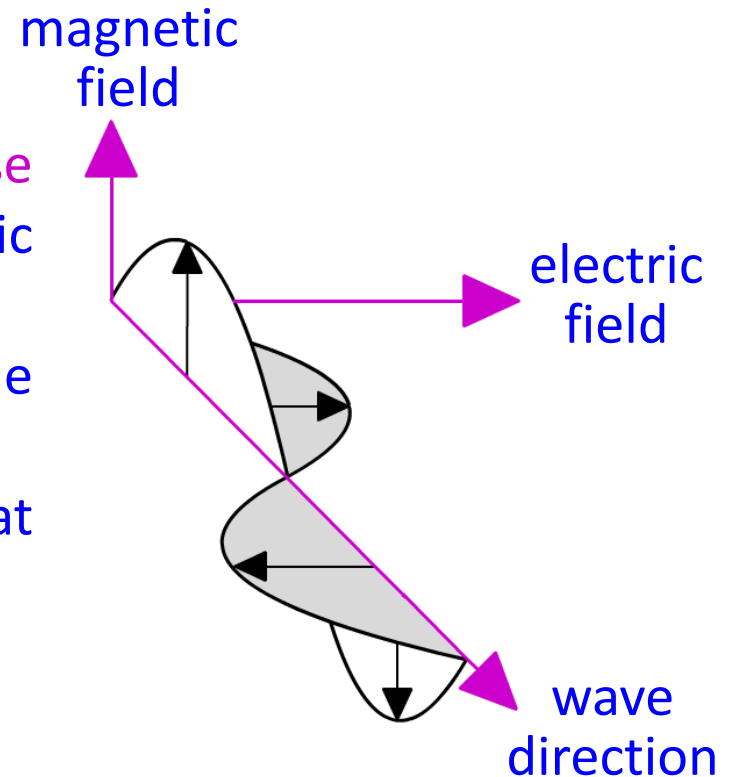


Automotive radar



What are electromagnetic waves?

- Electromagnetic waves are **transverse waves** made up of electric and magnetic fields.
- All electromagnetic waves travel at the same speed.
- In a vacuum (space), they travel at **300,000,000 m/s!**



How do electromagnetic waves differ?

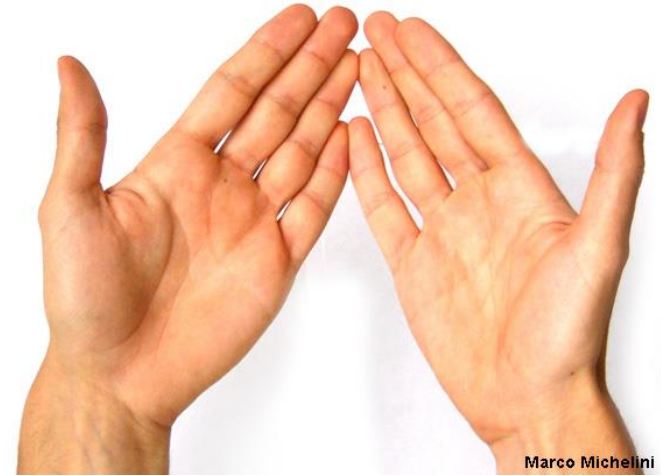
- Different electromagnetic waves carry different amounts of energy.
- For example, microwaves carry less energy than X-rays.
- The amount of energy carried by an electromagnetic wave depends on the wavelength:
 - the shorter the wavelength, the higher its energy.
- Wavelength and frequency are linked properties of a wave: the shorter the wavelength, the higher its frequency.
- So, frequency also tells you about the energy of a wave:
 - the higher its frequency, the higher is energy.



Do microwaves have a shorter wavelength than X-rays?

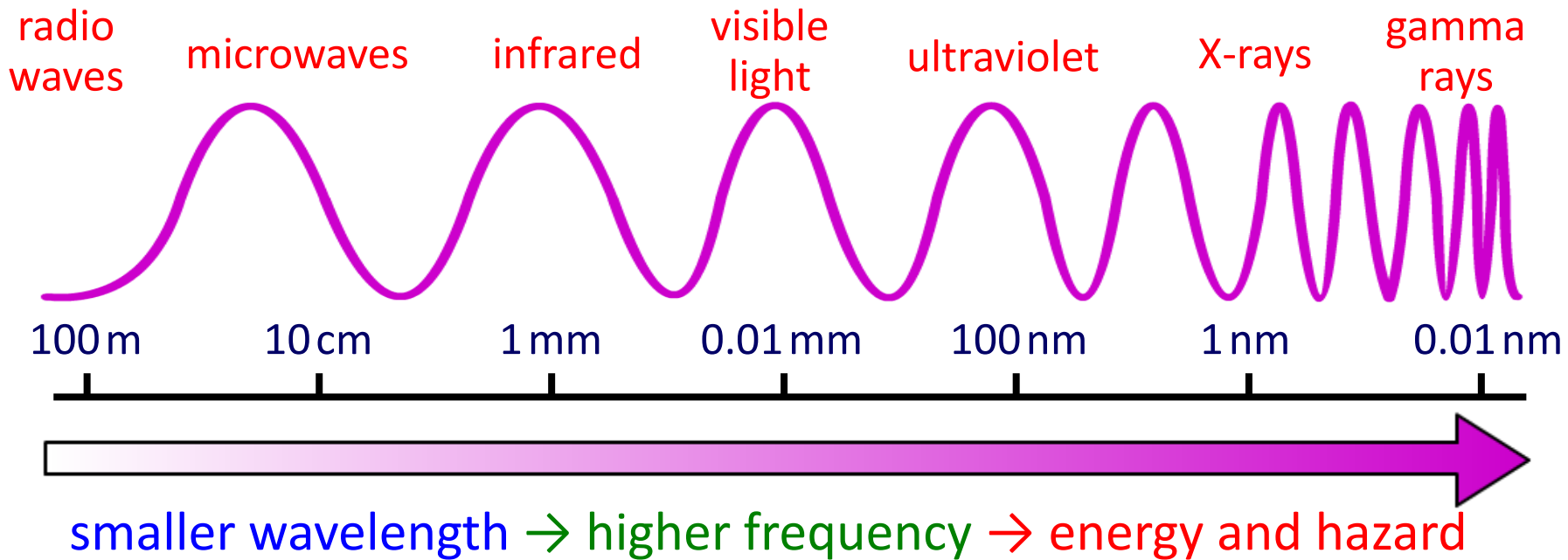
What happens when waves hit a surface?

- When electromagnetic waves hit a surface, they can be **reflected**, **absorbed** or **transmitted**.
- How the waves behave, depends on their energy and the type of material.
- For example, light waves are reflected by skin **but** X-rays pass straight through.
- If electromagnetic waves are absorbed, some of their energy is absorbed by the material. This usually increases the temperature of the material.



What is the electromagnetic spectrum?

- The electromagnetic waves are grouped into types that have similar wavelengths and so have similar properties.



Electromagnetic waves form a continuous series in order of changing wavelength, frequency and energy. This series is called the **electromagnetic spectrum.**

How do radio waves affect humans?

- Radio waves are the longest-wavelength electromagnetic waves and mostly pass through the body.
- They are not strongly absorbed and are thought to have no effect on the health of living tissue.

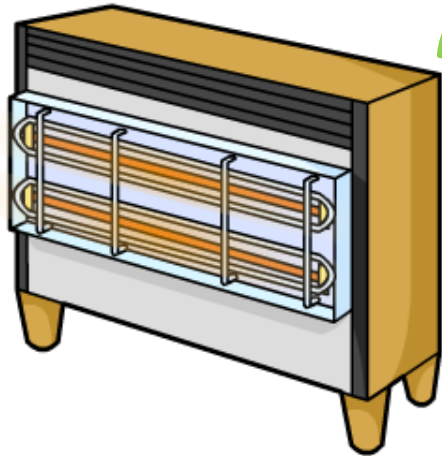


Jupiterimages Corporation

- Microwaves are radio waves with short wavelengths. They are very slightly absorbed by the body and can cause a minor heating effect.
- However, the microwaves produced by mobile phones have not yet been proved to cause health problems.

How do infrared waves affect humans?

- Infrared waves are absorbed by skin to a limited depth. They transfer their energy to the skin tissue warming it up.
- This heating effect is detected by temperature-sensitive nerve endings in the skin.



Infrared waves from this grill heat the surface of the meat. If the meat absorbs too much energy, it will be burnt.



If skin is exposed to too many high-energy infrared waves, it will be burnt.

How do visible light affect humans?

- Your eyes detect visible light, which does not normally pose any health risk.
- However, very bright light can damage your eyes and may even make you blind. This is why you should not look at the Sun through a telescope or binoculars.



- Lasers are very intense sources of visible light. The lasers used in light shows are not powerful enough to cause harm but must be used safely.
- Some very powerful lasers can cut through materials such as metal.
- These would also be able to burn through living tissue.

Project Themes

1. Microwave/THz Imaging
2. Automotive Radar
3. Mobile Phone Technology
4. RF Circuits and Systems
5. RF Sensors for Measurement Applications

Minimal requirement: thorough reading and understanding the concept by going through various papers, book chapters, white papers etc.. You are expected to explore (such as simulation or test setup development) as much as possible if you want to get the optimum marks and bonus marks.



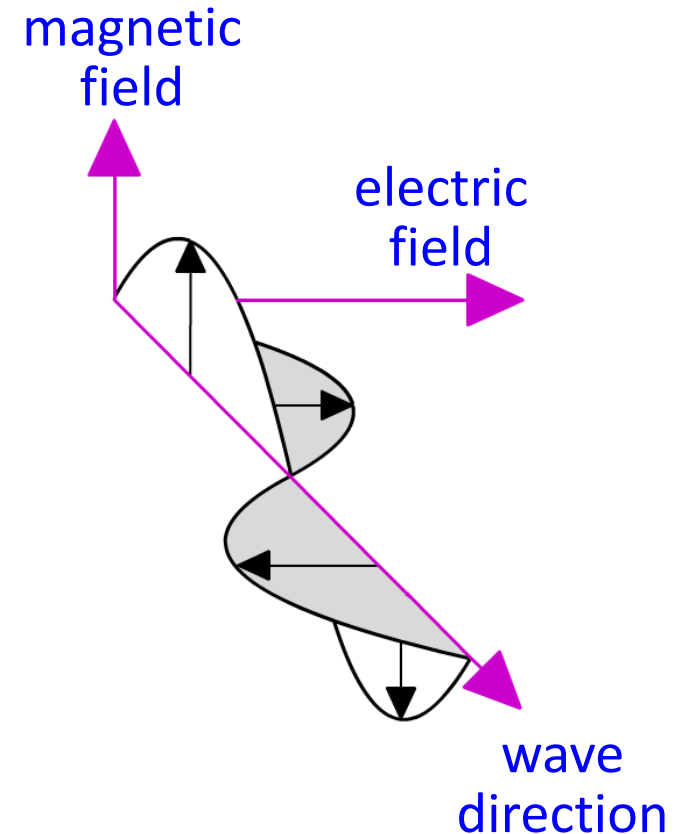
Preliminaries on Fields and Waves

Traveling Waves

- Electromagnetic waves are **transverse waves** made up of electric and magnetic fields.
- All electromagnetic waves travel at the same speed.
- In a vacuum (space), they travel at **300,000,000 m/s!**

- Moving waves carry energy
- Waves have velocity

Many waves exhibit a property called **linearity** → EM waves are linear

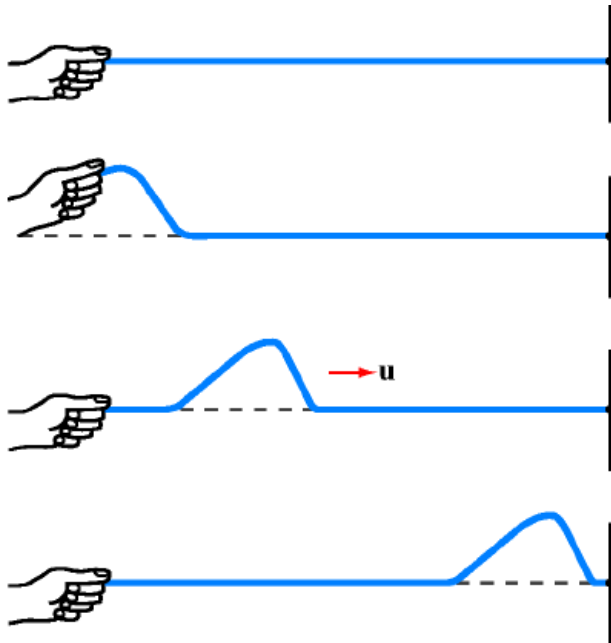


Traveling Waves (contd.)

Two types

- Transient Waves: caused by sudden disturbance
- Continuous Periodic Waves: generated by a repetitive source

An essential feature of a propagating wave is that it is a self-sustaining disturbance of the medium through which it travels

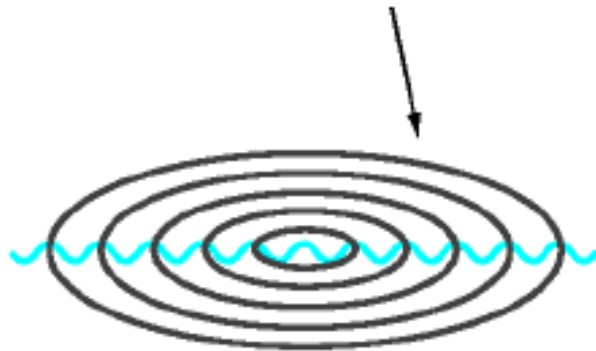


Disturbance varies as a function
of one space variable

Here, the vertical displacement varies
with time and with the location along
the length of the string

Traveling Waves (contd.)

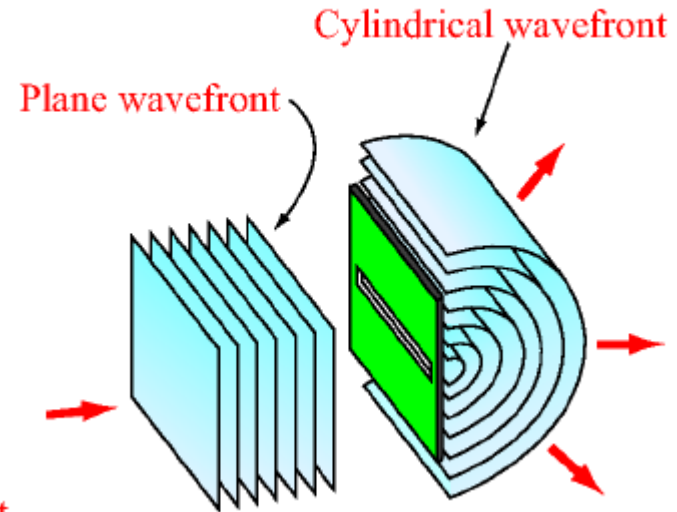
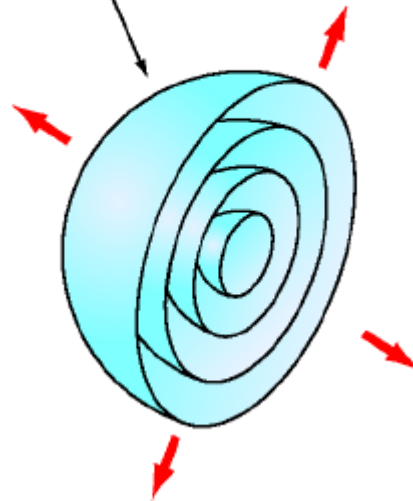
Two-dimensional wave



2D wave
propagates
out across a
surface

For now we will
consider 1D
sinusoidally varying
wave

Spherical wavefront




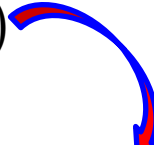
3D wave
propagates
through a volume
and its disturbance
may be a function
of all three space
variables

Sinusoidal Waves in Lossless Medium

- All linear waves can be described mathematically.
- A medium is lossless if it doesn't attenuate the amplitude of the wave traveling within it or on its surface.

Example: a wave traveling on a lake surface. Ignore the frictional forces (essentially, in this scenario the wave on water surface can travel indefinitely with no loss in energy).

$$y(x,t) = A \cos \left(\frac{2\pi t}{T} - \frac{2\pi x}{\lambda} + \varphi_0 \right)$$


$$y(x,t) = A \cos \varphi(x,t)$$


$$\varphi(x,t) = \left(\frac{2\pi t}{T} - \frac{2\pi x}{\lambda} + \varphi_0 \right)$$

$\varphi(x, t)$: phase of the wave

A: amplitude

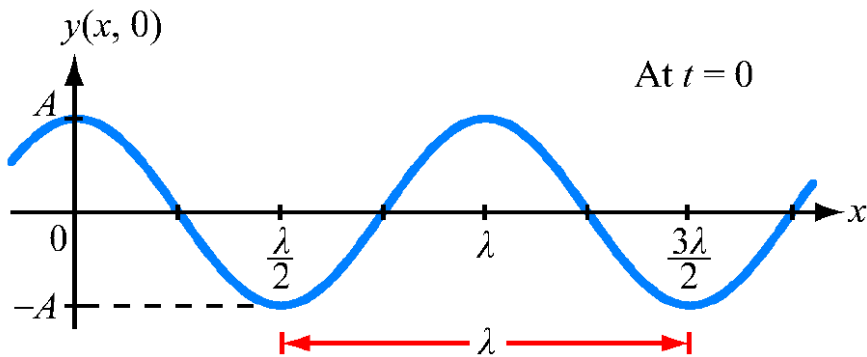
T: time period

λ : spatial wavelength

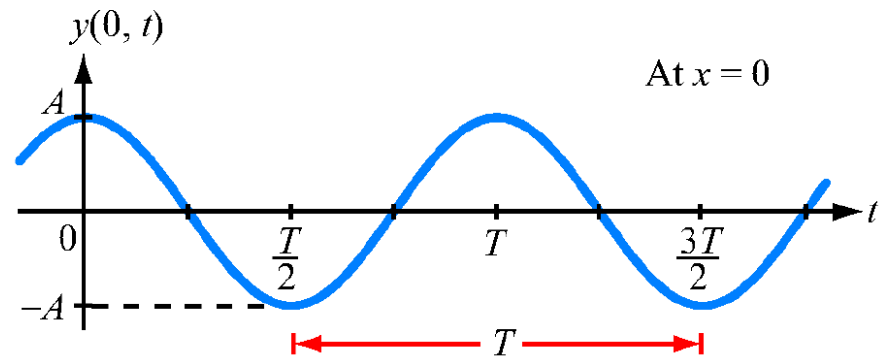
φ_0 : reference phase

Sinusoidal Waves in Lossless Medium (contd.)

$$y(x, t) = A \cos\left(\frac{2\pi t}{T} - \frac{2\pi x}{\lambda}\right) \quad \varphi_0 = 0$$

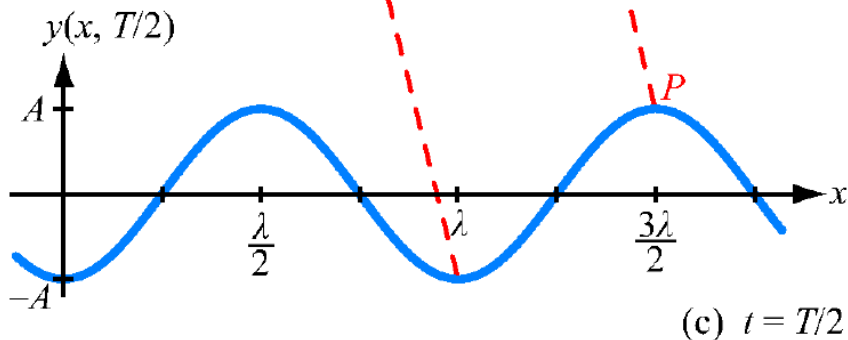
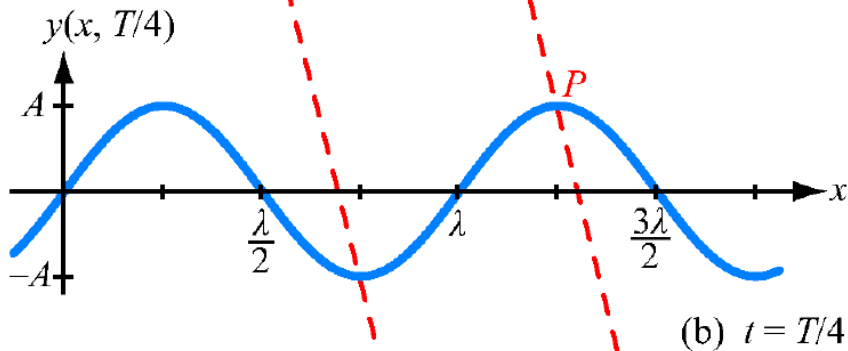
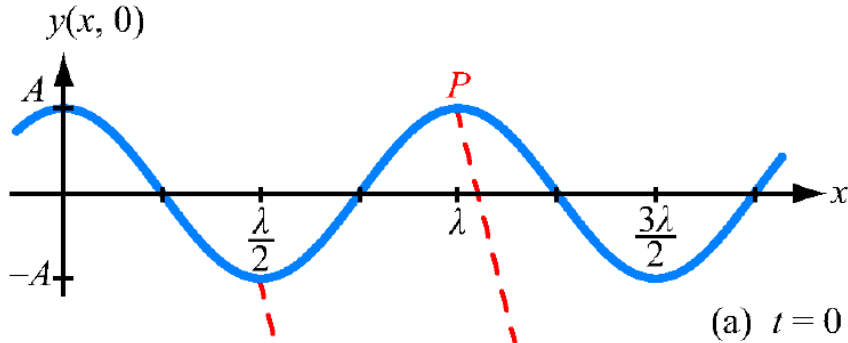


(a) $y(x, t)$ versus x at $t = 0$




(b) $y(x, t)$ versus t at $x = 0$

Sinusoidal Waves in Lossless Medium (contd.)



- $y(x, t)$ at three time instances.
- Spacing between the peaks remain λ .
- Patterns are shifted relative to one another.

Track point P and it gives the info about phase velocity.

 $\phi(x, t) = \frac{2\pi t}{T} - \frac{2\pi x}{\lambda} = 2n\pi$

- Say, the height of the wave at point P is y_0

$$y(x, t) = y_0 = A \cos\left(\frac{2\pi t}{T} - \frac{2\pi x}{\lambda}\right)$$

Sinusoidal Waves in Lossless Medium (contd.)

$$\xrightarrow{\text{blue arrow}} \frac{2\pi t}{T} - \frac{2\pi x}{\lambda} = \cos^{-1}\left(\frac{y_0}{\lambda}\right) \xrightarrow{\text{orange arrow}} \text{constant}$$

- The velocity of the fixed height y_0 can be obtained by taking the time derivative as:

$$\frac{2\pi}{T} - \frac{2\pi}{\lambda} \frac{dx}{dt} = 0$$

$$\frac{dx}{dt} = v_p = \frac{\lambda}{T}$$

phase
velocity

- Compact expression for wave is:

$$y(x,t) = A \cos\left(2\pi ft - \frac{2\pi}{\lambda} x\right) = A \cos(\omega t - \beta x)$$

$\omega = 2\pi f$: angular velocity
 $\beta = \frac{2\pi}{\lambda}$: phase constant

- Wave in $-x$ direction:

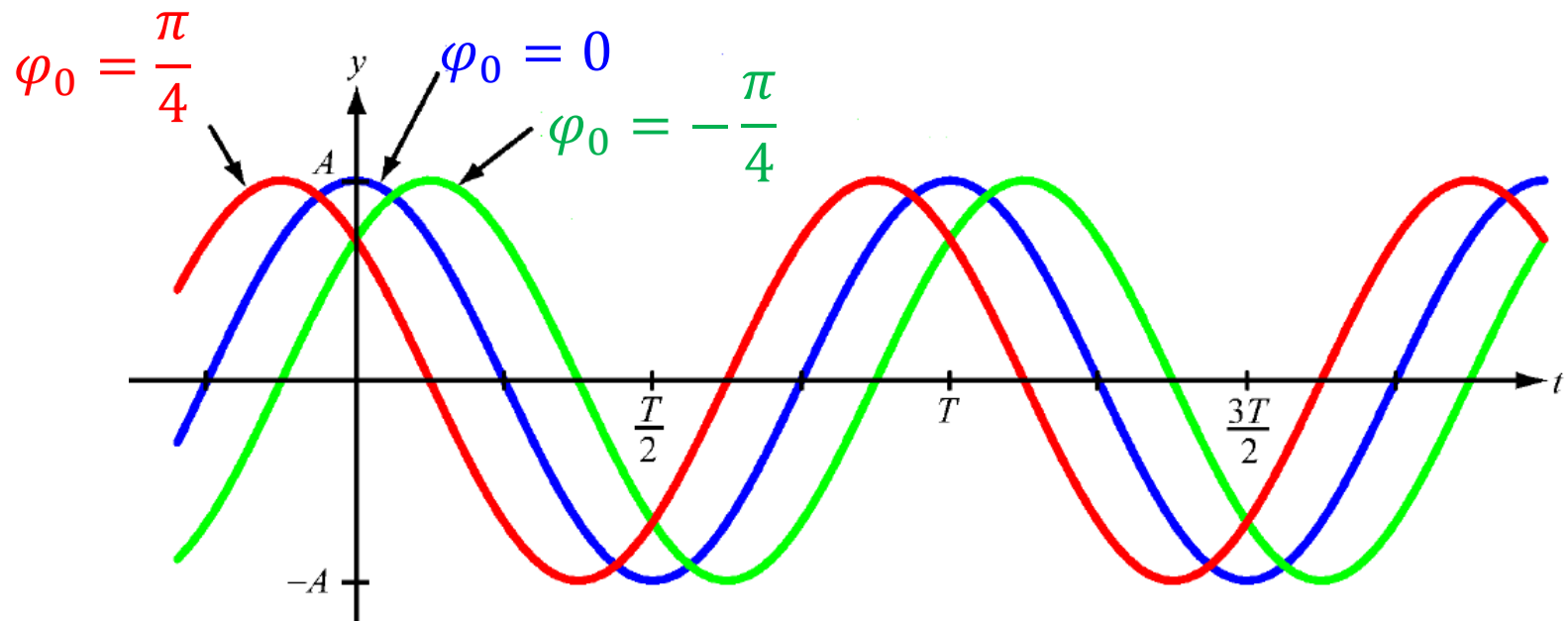
$$y(x,t) = A \cos\left(2\pi ft + \frac{2\pi}{\lambda} x\right) = A \cos(\omega t + \beta x)$$

Sinusoidal Waves in Lossless Medium (contd.)

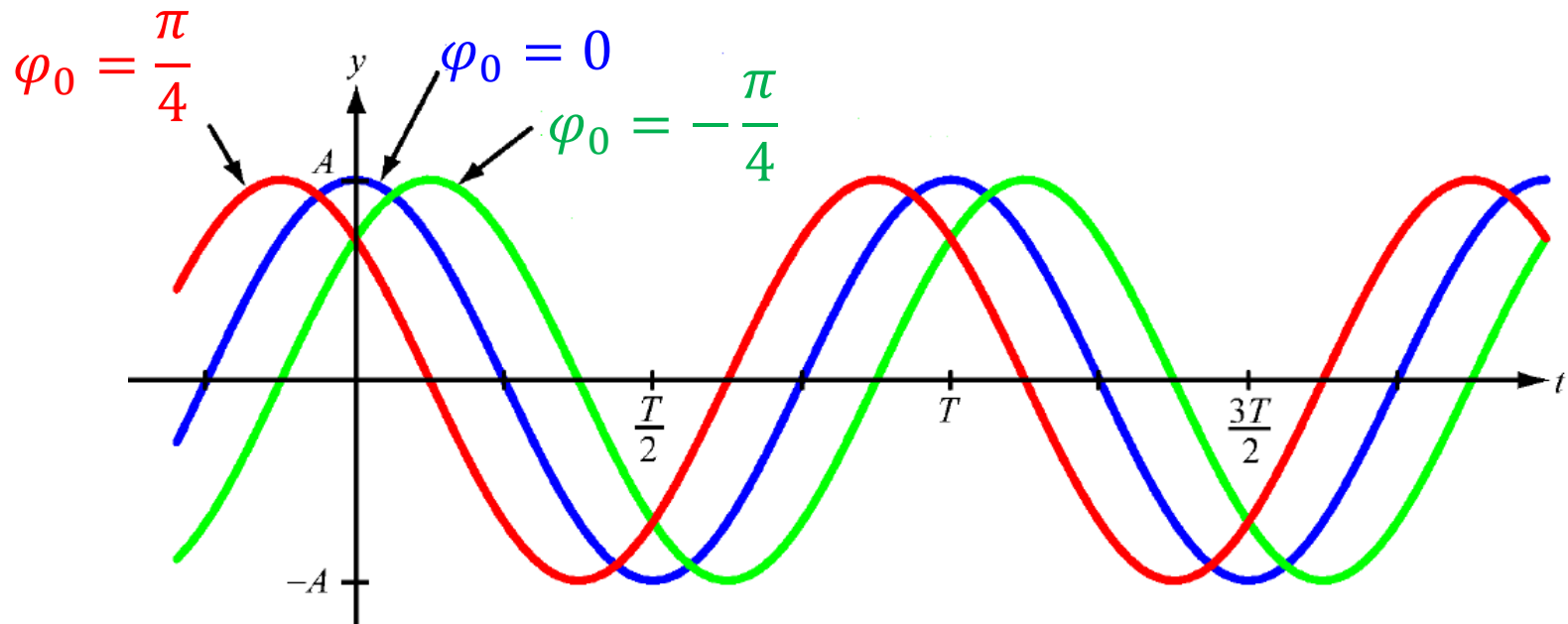
- The role of phase reference φ_0 : $y(x, t) = A \cos(\omega t - \beta x + \varphi_0)$

Essentially the plot of $y(x, t)$ will be shifted when it is plotted as a function of x or function of t .

- Plots of $y(0, t) = A \cos[(2\pi t/T) + \varphi_0]$ for three different values of the reference phase φ_0 .



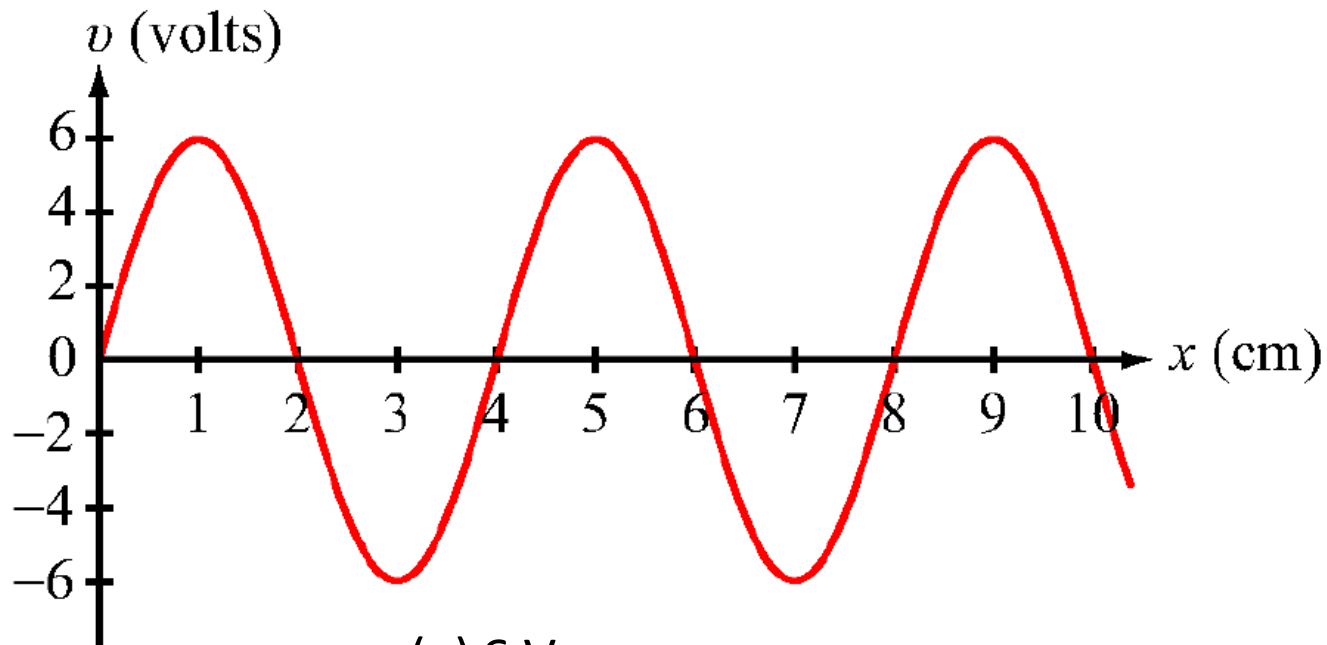
Sinusoidal Waves in Lossless Medium (contd.)



- It can be observed that for $\varphi_0 = \frac{\pi}{4}$, $y(t)$ reaches peak or any other value sooner than when $\varphi_0 = 0$. Therefore, wave with $\varphi_0 = \frac{\pi}{4}$ is said to lead the wave with $\varphi_0 = 0$ by a *phase lead* of $\frac{\pi}{4}$.

Example – 1

In the following wave, what is the wave's (a) amplitude, (b) wavelength, and (c) frequency, given that its phase velocity is 6 m/s?



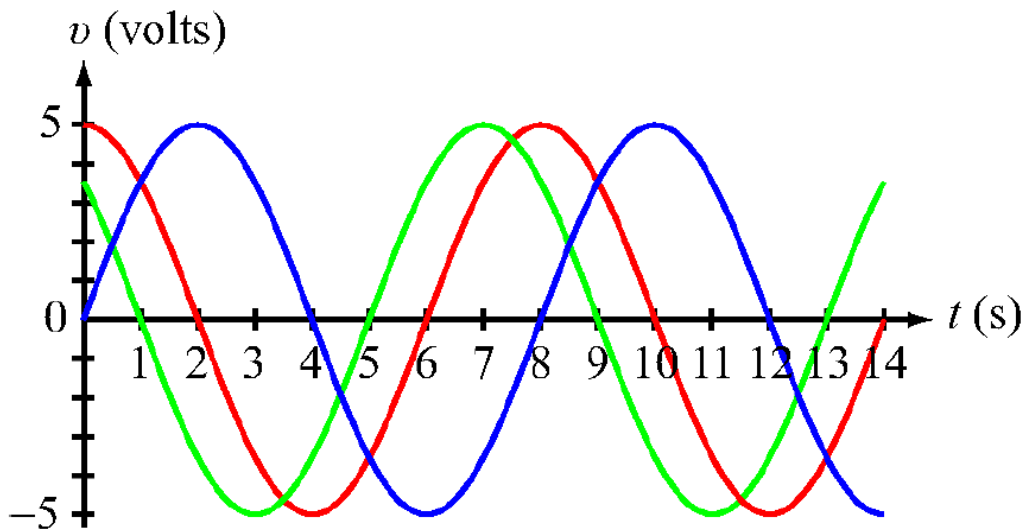
(a) 6 V.

(b) $\lambda = 4$ cm.

(c) $f = \frac{v_p}{\lambda} = \frac{6}{4 \times 10^{-2}} = 150$ Hz

Example – 2

- Red is the reference wave in the following and is expressed by $v = 5\cos(2\pi t/8)$.



- Of the following which equation applies to green wave which equation to blue wave.

$$v = 5\cos(2\pi t/8 - \pi/4)$$

$$v = 5\cos(2\pi t/8 + \pi/4)$$

$$v = -5\cos(2\pi t/8 - \pi/4)$$

$$v = 5\sin(2\pi t/8)$$

Example – 3

- The electric field of a traveling electromagnetic wave is given by:

$$\vec{E}(z, t) = 10 \cos\left(\pi \times 10^7 t + \frac{\pi z}{15} + \frac{\pi}{6}\right) \quad \text{V/m}$$

Determine: (a) the direction of wave propagation, (b) the wave frequency f , (c) the wavelength λ , and (d) its phase velocity

- a) The direction of the wave is in $-z$ – *direction* because the signs of the coefficients of t and z are both positive.
- b) $\omega = \pi \times 10^7 \quad \therefore f = 5\text{MHz}$
- c) $\frac{2\pi}{\lambda} = \frac{\pi}{15} \quad \therefore \lambda = 30\text{m}$
- d) $v_p = f\lambda$

Example – 4

- An acoustic wave traveling in x -direction in a fluid is characterized by a differential pressure $p(x, t)$. The unit for pressure is N/m^2 . Find an expression for $p(x, t)$ for a sinusoidal sound wave traveling in the positive x -direction in water, given that the wave frequency is 1 kHz , the velocity of sound in water is 1.5 Km/s , the wave amplitude is 10 N/m^2 , and $p(x, t)$ was observed to be at its maximum at $t = 0$ and $x = 0.25\text{ m}$. Treat water as a lossless medium.

- Wave in positive x – direction:
$$p(x, t) = A \cos\left(\frac{2\pi}{T}t - \frac{2\pi}{\lambda}x + \varphi_0\right)$$

Sinusoidal Waves in Lossy Medium

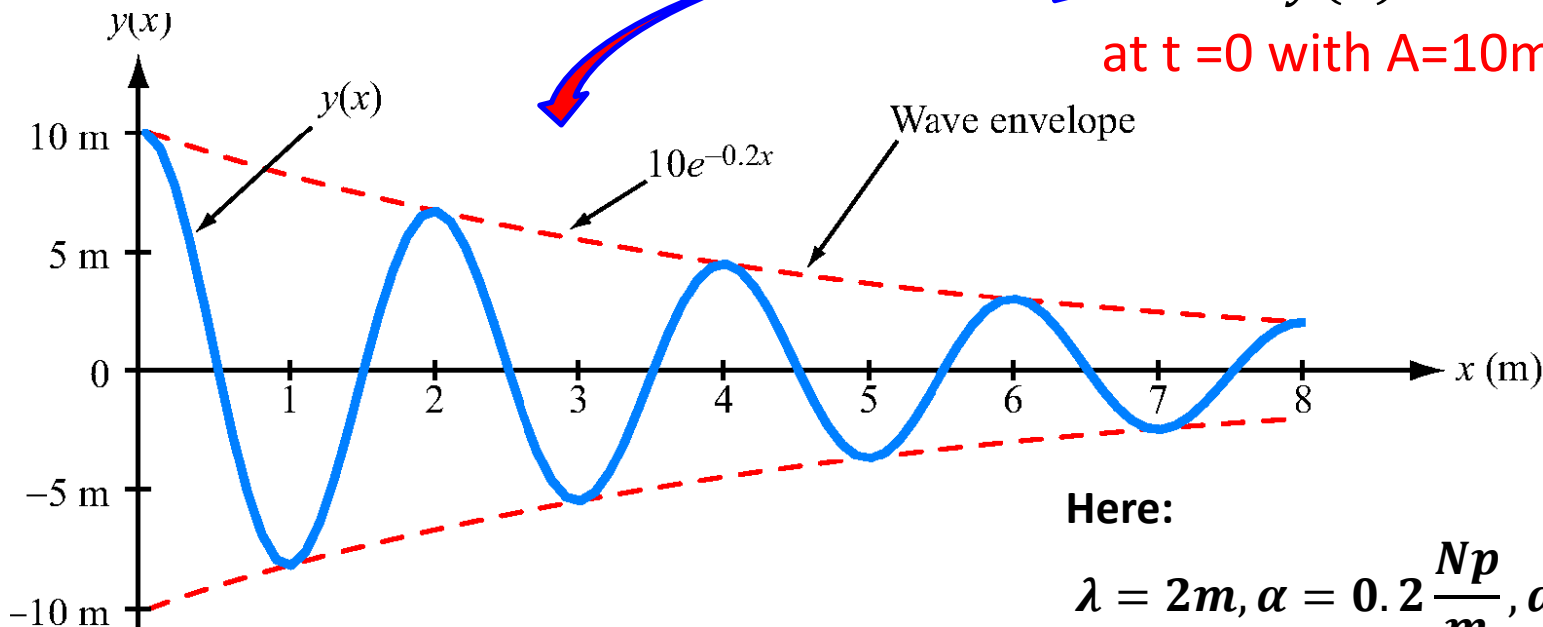
- A wave propagating in x-direction in a lossy medium is given by:

$$y(x,t) = Ae^{-\alpha x} \cos(\omega t - \beta x + \phi_0)$$

$e^{-\alpha x}$ is called the attenuation factor in NP/m.

The amplitude is now $Ae^{-\alpha x}$ and not **A**

Plot of $y(x) = 10e^{-0.2x} \cos \pi x$ at $t = 0$ with $A = 10\text{m}$.



Here:

$$\lambda = 2\text{m}, \alpha = 0.2 \frac{\text{Np}}{\text{m}}, \text{ and } \phi_0 = 0$$

Example – 5

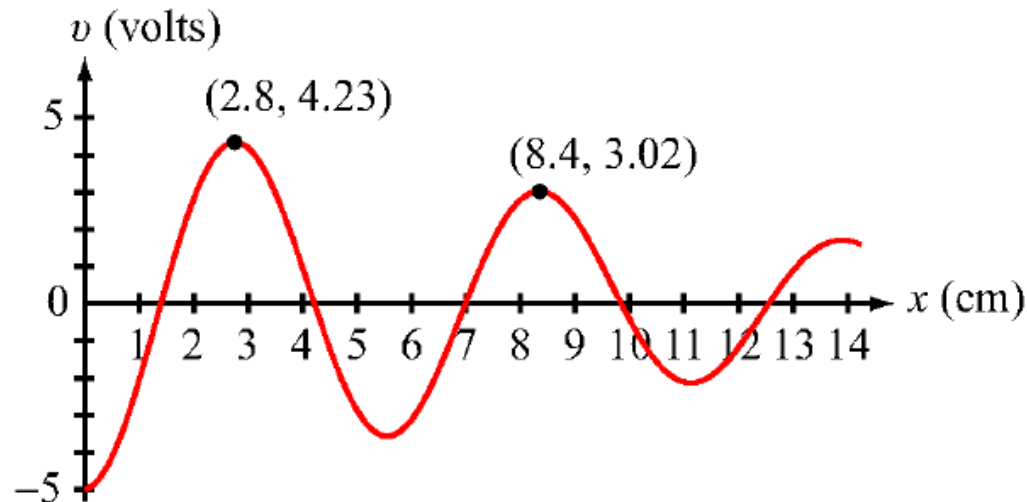
- A laser beam of light propagating through the atmosphere is characterized by an electric field given by:

$$\vec{E}(z, t) = 150e^{-0.03x} \cos(3 \times 10^{15}t - 10^7x) \quad V/m$$

Where x is the distance from the source in meters. The attenuation is due to absorption by atmospheric gases. Determine: (a) the direction of wave travel, (b) the wave velocity, (c) the wave amplitude at a distance of 200m.

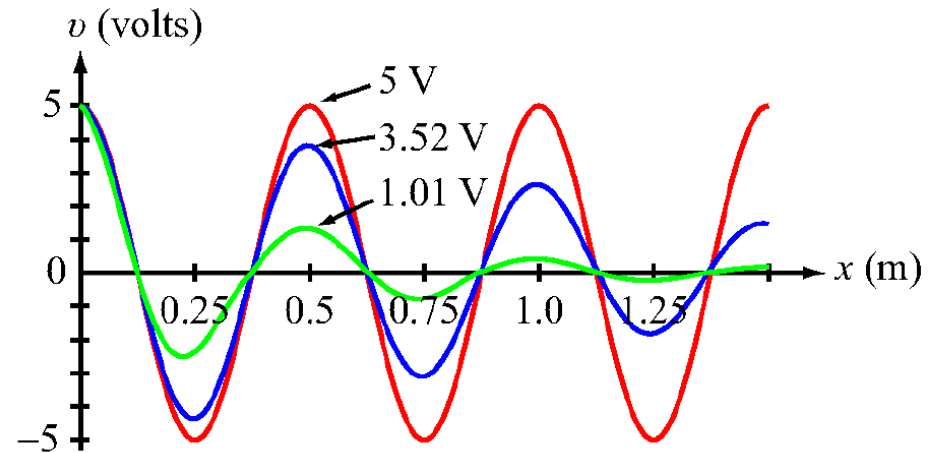
Tutorial – 1

1. A reference wave is given by $y = 5 \cos 4\pi ft$. Plot this using MATLAB. Now generate another wave $y = 5 \cos(2\pi ft + \varphi_0)$ and superimpose it on the first wave. Your MATLAB code should be flexible enough with regards to choice of φ_0 .
2. Consider the following wave. What is the wave's (a) amplitude (at $x = 0$), (b) wavelength, and (c) attenuation constant?



Tutorial – 1 (contd.)

3. The red wave shown in the figure is given by $v = 5\cos 4\pi x$. What expression is applicable to (a) the blue wave, and (b) the green wave?



4. Using MATLAB, plot a wave $y = 5\cos(\pi t - \pi x)$ volts. Now superimpose another wave given by $y = 5e^{-\alpha x}\cos(2\pi f t - \frac{2\pi x}{\lambda})$ volts. For this lossy wave, choose $f = 0.5 \text{ Hz}$, $\lambda = 2 \text{ m}$, $\alpha = 0.20 \frac{\text{Np}}{\text{m}}$.