Web page: http://www.physics.ucla.edu/class/99F/17_Orgad

Physics 17 – Lecture 1 : Copied from Prof. G. Morales

Preliminaries : * Introduce yourself
* It's a small class - take advantage of that - Names and Background

* Go over the syllabus
* DO YOUR HOMEWORK !
* ASK QUESTIONS !

Overview : Before we get into the technical details of this class I would like to give you an overview of what we are trying to do in this course. The material covers the most significant developments in physics during the period of 1850-1905:

* Electromagnetic Radiation - Light
* Theory of Special Relativity
* Quantum nature of Radiation and Matter
* Wave - Particle Duality

→ (These developments ~~were developed~~ took place outside ~~of~~ the time frame that we consider but are related to the main "wavy" theme of the course).

(We'll concentrate on the first two subject and explore the other two only partially. For a deeper treatment of those take QM classes.)

In particular we will emphasize the prominent role of the concept of "waves" in these theories.

The concept of "mechanical waves" was well established before this period ~~and~~. We will spend some time learning about them in order to acquire the technical tools needed and in order to appreciate the revolutionary nature of EM radiation and special relativity.

Example of mechanical waves are:

* Sound Waves
* Waves on strings
* Vibrations of drums
* Water Waves
* Sesmic Waves – Earthquakes

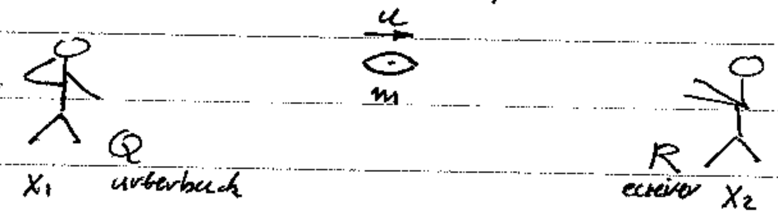
There are also Chemical Waves in chemical reactions.

By now you have heard me use the word "waves" several times but I have not yet defined it for you. Since each of you come across wave phenomena in your daily lives you have a sort of a sense of what it means

In this class you will learn how to generalize your perception of what a wave is and how to analize it using mathematical tools ~~st~~ in order to make quantative predictions. You will also see that the concept of waves appears all over the place in physics and that ~~in some respects~~ it is one of the most fundamental concepts.

So what is a wave?

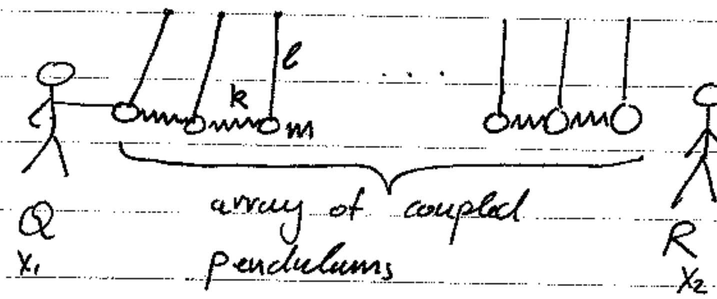
In order to answer this question let me first make you aware of the simple way of transfering energy or information from one place to another.



i.e one can send a material entity, something having a mass from one point to another. The "packet of energy" associated with m can then be used R to do a variety of things, what is important to note is that what R uses is ~~what Q~~ the same thing Q held in his hands earlier!

This method of transfering energy is called "Ballistic" or "Convective" transport

Now let us look at the corresponding process of transfering energy / information using a wave



In this case Q does not send a mass flying to R but rather caus a local displacement from equilibrium of an oscillatory object. In this example the individual entity is a pendulum. As this pendulum oscillates it will interact with the neighboring pendulum through the spring and will cause it to oscillate. The process repeates itself with a net result of transfering energy down the line. R receives the energy whose original source is Q but the mass located at X_1 dose not get transfered to X_2. This proces is said to represent a <u>wave</u>

* A wave transfers energy and momentum across space without having to exchange ~~a~~ material entity between the ~~to~~ two points.

What is needed to generate a Wave?

1. Some sort of "local oscillators" (the pendulums)

2. A way to couple the "local oscillators" (the springs)

* Another fundamental difference between balistic and wave transport is that in the ballistic case Q determines the speed u with which the energy is transfered, But not in the wave case, Here Q select the amplitude - the size of the displacement - the <u>amount</u> of energy that will be transfered but <u>not</u> the <u>speed</u>.

[when m is large the pendulum moves slowly → slow u]

* The speed depends on the * 1. nature of the local oscillators

[strong coupling → replace springs by rods $u \to \infty$] → 2. coupling between them.

⇒ The <u>speed</u> is <u>determined</u> <u>by</u> <u>the medium</u> not the sender!

<u>In what sense then EM waves are different from mechanical waves?</u>

The first obvious difference is that mechanical waves propagate through a medium made of coupled local oscillators while EM waves can propogate in ~~VACUUM~~ EMPTY SPACE!

What is going on here?

Let's look at Maxwell's equations in vacuum

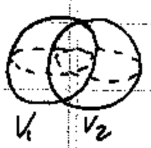
In differential form: $\vec{\nabla}\times\vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}$ c: velocity of light

$\vec{\nabla}\times\vec{B} = \frac{1}{c}\frac{\partial \vec{E}}{\partial t}$ the first hint that light has to do with Electromagnetism.

Or in integral form:

2. change in B causes change in E on neighboring points

$$\oint \vec{E}\cdot d\vec{l} = -\frac{1}{c}\frac{\partial}{\partial t}\int \vec{B}\cdot d\vec{a}$$



$$\oint \vec{B}\cdot d\vec{l} = \frac{1}{c}\frac{\partial}{\partial t}\int \vec{E}\cdot d\vec{a}$$

1. change E inside V_1 creates a change of B in neighboring points

3. repeat the process to get a propagating disturbance.

The local oscillators are the Electric and Magnetic Fields
Their coupling is described by Maxwell's equations.

Can show with $\nabla\cdot\vec{E} = \nabla\cdot\vec{B} = 0$ and no y, z dependence of the fields ~~in one dimension~~.

The z component of the first equation → $\frac{\partial E_y}{\partial x} = -\frac{1}{c}\frac{\partial B_z}{\partial t}$

The y component of the second eq. → $-\frac{\partial B_z}{\partial x} = \frac{1}{c}\frac{\partial E_y}{\partial t}$

explain how ⟹

$$\begin{cases} \frac{\partial^2 E_y}{\partial t^2} - c^2\frac{\partial^2 E_y}{\partial x^2} = 0 \\ \frac{\partial^2 B_z}{\partial t^2} - c^2\frac{\partial^2 B_z}{\partial x^2} = 0 \end{cases}$$

Thus both $\vec{E}$ and $\vec{B}$ satisfy the "wave equation":

$$\frac{\partial^2 \psi(x,t)}{\partial t^2} - u^2 \frac{\partial^2 \psi(x,t)}{\partial x^2} = 0$$

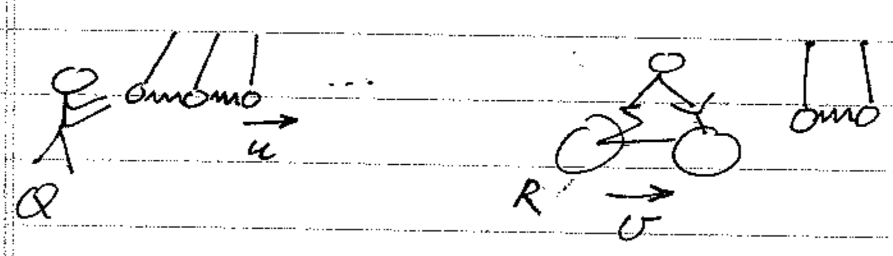
which is the unifying way of describing different wave phenomena.

* $\psi(x,t)$ is the quantity which is associated with the wave (E, B or the displacement of the pendulums in the mechanical example)
* u : the velocity of the wave. - depends on the properties of the medium.

This is a Partial Differential Equation. We will show how it can be solved. In real life for most systems there are further terms and complications that appear here - Subject of other courses

The other main difference between mechanical and EM waves is the following

Consider a receiver who is moving with respect to the medium - the pendulums



our experience tells us that R will ~~experience~~ observe the wave to move with velocity $v-u=u'$

People's intuition througout the 19th century told them that a similar thing should happen with EM waves. Accordingly they postulated the existance of a rest frame of the EM oscillators : the <u>ether</u>.

Numerous experiments have ~~sho~~ demonstrated by now that for EM waves

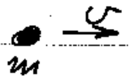
$$c = c'$$

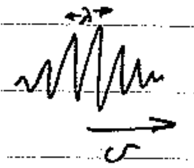
The velocity of light is the same for all ~~mov~~ uniformly moving observers. There is No ~~rest fram~~ absolute rest frame for the EM field!

This radical change is at the heart of the special theory of relativity. The seemingly inosent equation $c=c'$ leads to remarkable consequences which we will explore.

Finally I want to briefly mention the concept of <u>matter</u> waves. In our current understanding of the world matter (on the microscopic scales) is described by wave propagation through matter fields - the analog of the EM field

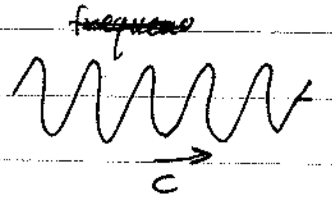
~~Particles are lumps~~

The localized particle  is actually a super position of waves:



$\lambda = \frac{h}{mv}$ ← planck's constant

Similarly The electromagnetic wave can be described as a collection of individual "particle like" ~~part~~ photons



of energy $= h\frac{c}{\lambda}$

We'll talk about this "Particle-Wave Duality" towards the end of the course.