Lecture 12

Fundamentals of Physics

Phys 120, Fall 2015

Waves and Light

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Overview

- Light (Optics)
- Waves

Seeing: The nature of light

Much of our perception comes from images that we see. But what is this process that we call seeing?

What is the physical underpinning of this sensation?

If you are interested, you can look at this wikipedia article.

The nature of light

Aristotle: particles coming out from your eye. Lucretius: similar theory about particles emanating from the eye.

Of course this would mean that you should be able to see at night. So there was a recognition that the particles emmanating from your eyes had to combine with other particles coming from the sun (or another light source).

Newton: particle theory of light.

Consider your room at night. Turn the light out and you don't see anything. So something emanates from the lightbulb. If you look at the lightbulb you see the light it emanates.

If you look at an object you see light that comes from the lightbulb, bounces off the object and then reaches your eye.

But what is this stuff that we call light? What are colors?

Corpuscle theory

Newton (and most others) believed that light was made up of little particles.

Thomas Young (1773 - 1829) performed an interesting experiment: But we can do a two-slit experiment and we see and interference patter, just like we did for the waves we just talked about:
Video of interference pattern

This is a phenomenon that we know from waves!

Looking at waves

We are all familiar with waves: ripples traveling across a placid pond, or waves in a slinky or a rope.

But what exactly is traveling?

It is not matter, in the way we have been thinking about it. The atoms in the rope do not move from one end to the other! They just undergo gentle undulations.

But the wave **can transfer energy!**

The medium

The material through which the wave is moving is called the medium.

This can be the rope, it can be the water for surface waves. Most matter can contain waves: even metal or air.

Watch animations at http://www.acs.psu.edu/drussell/demos/waves/wavemotion.html

Another wave example: face waves!

Video of someone being hit in the face with a soccer ball.

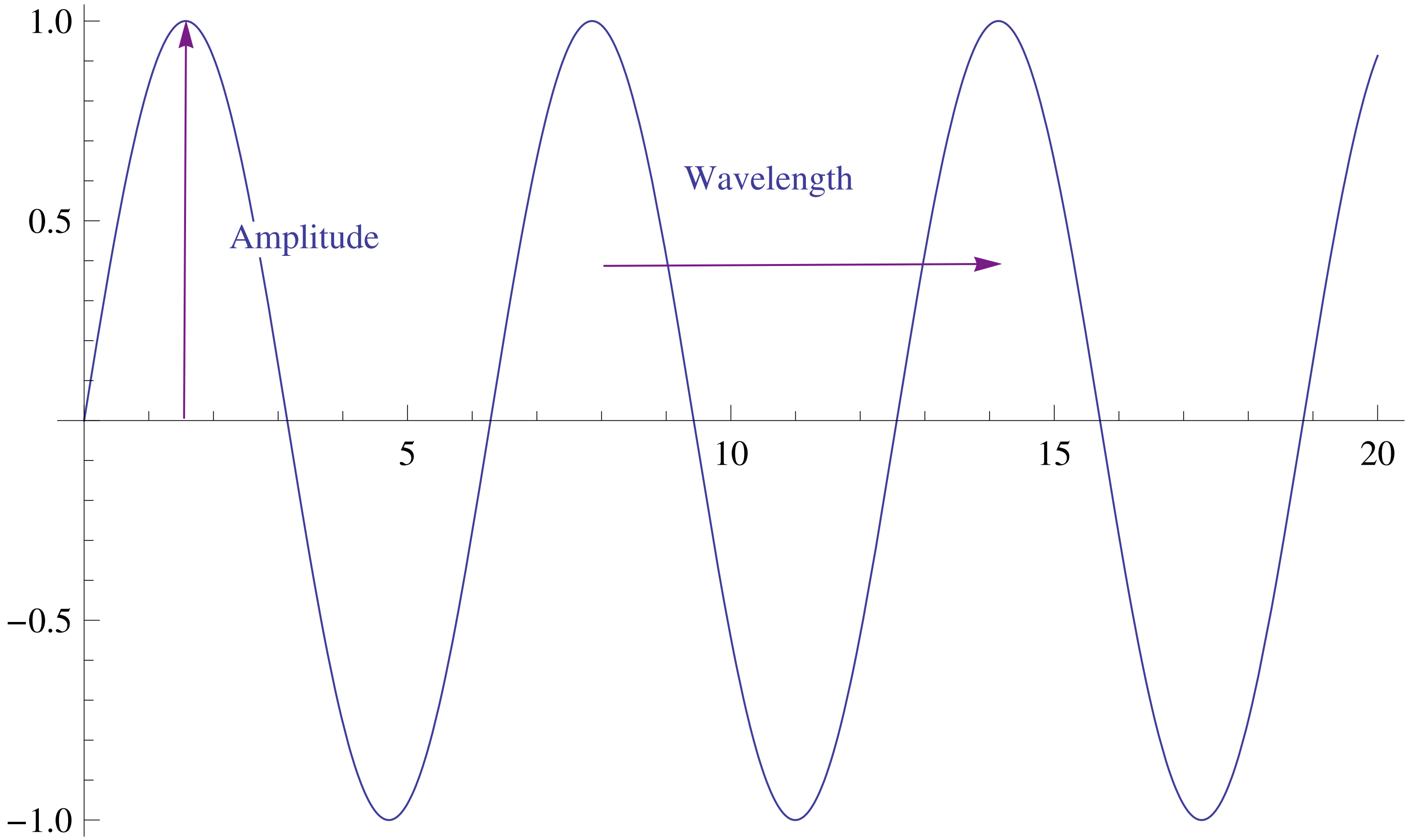
What we see here are waves on the face after the impact. These are quite complex and therfore not easily described. However, even the most complex waves can be described as just a superpostion of simple waves.

Some more info on the slinky by the same guys.

Next we discuss simple waves.

Quantitative waves

The simplest kinds of waves for quantitative descriptions are regular waves that move down a line:



Meaning of wavelength and amplitude. The wavespeed is the speed at which a crest or a trough moves down the rope.

Quantitative Waves II

A waves frequency is the number of vibrations that any particular part of the (stationary) medium experiences per second.

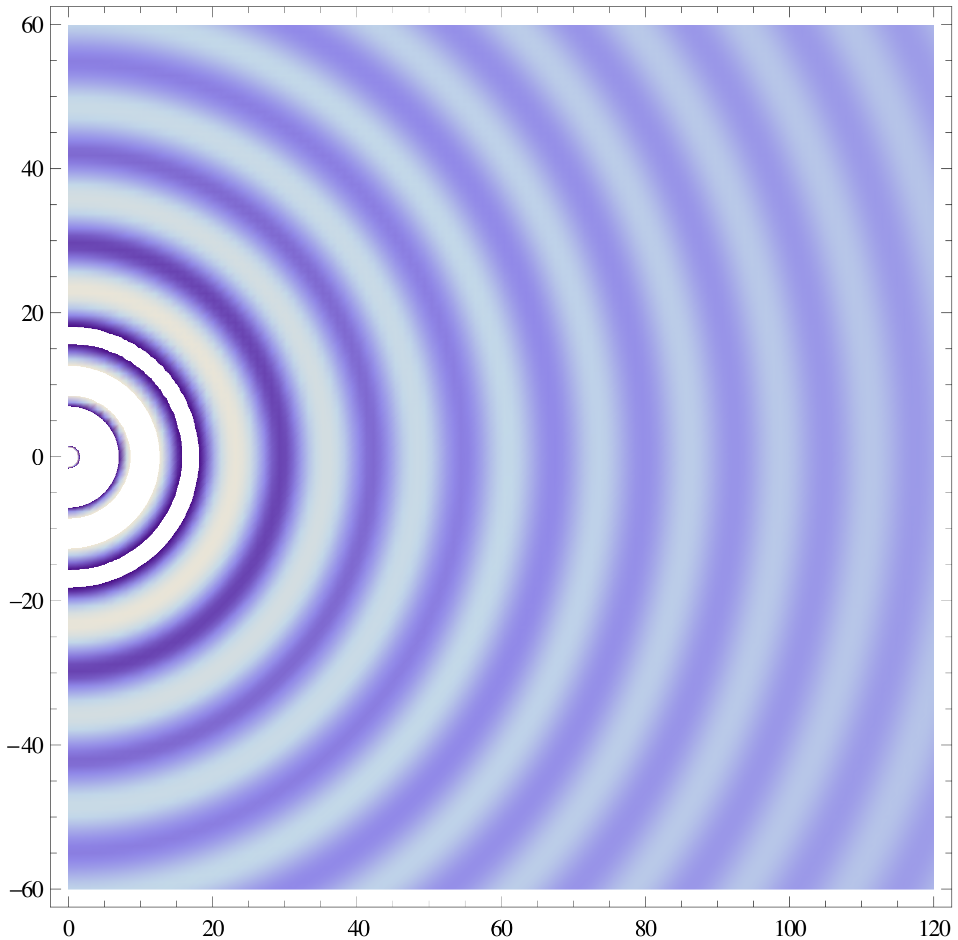
The relation between wavelength, wavespeed and frequency is

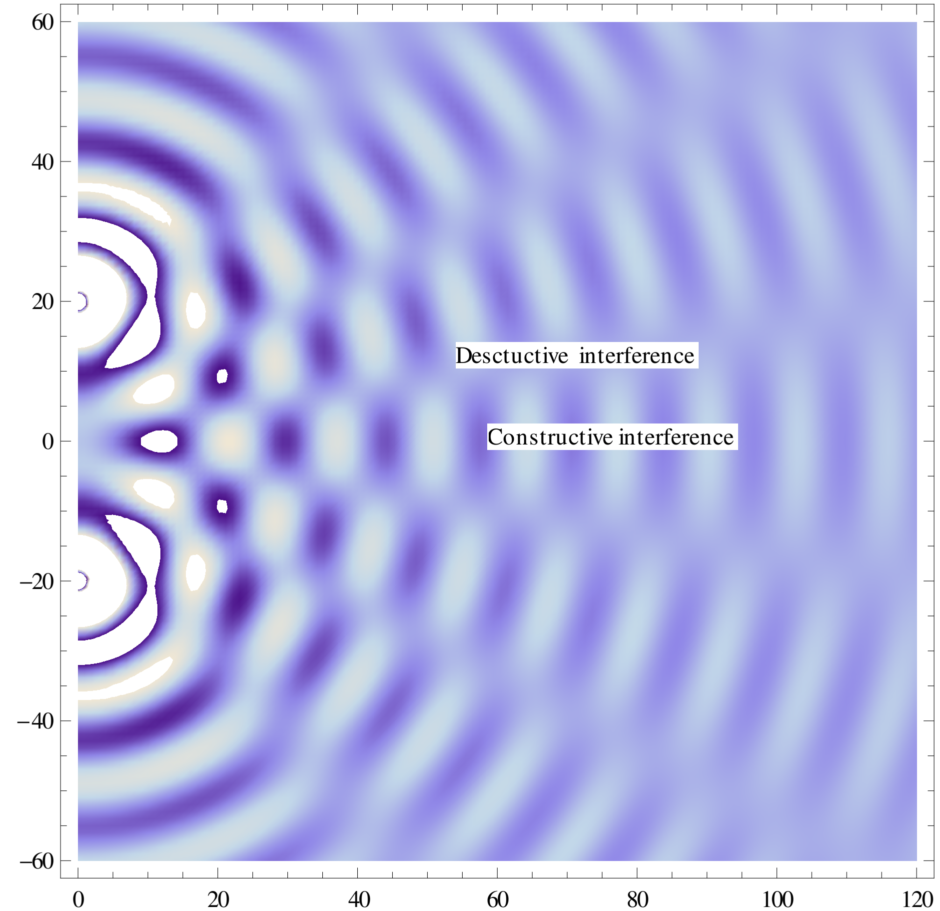
$$\text{speed} = \text{frequency} \ \times \text{wavelength}$$

or

$$s = f\lambda$$

Interference





Overlapping of waves leads to interference. Most waves just add to each other: if valleys hit valleys and hills hit hills in time then the wave will be twice as big, but if valleys hit hills and hills hit valleys then the wave gets extinguished.

More thoughts on the double slit experiment

Now imagine having a single slit: then you would have an even pattern for the intensity of the wave at the screen. However, by letting in **more** light then there are areas where it becomes **darker**.

That is the nature of interference.

For particles (e.g. little golf balls) that could not happen.

Do an experiment with your fingers: hold them close together, look through them at the bright screen and you will see little interference lines appearing!

Medium for light waves?

We saw for all the waves that we looked at that they needed a medium, i.e. some material that moved as the wave passed through.

What is the medium for light waves?

Air?

What kind of wave is light?

Electric waves

Imagine waving a charged object and observing the response of a second charged object.

There is an attraction between the two charges, but if the distance is changed, the force will vary a little bit and you should be able to feel that.

Is that information transferred instantaneously?

Maxwell's laws of Electrodynamics

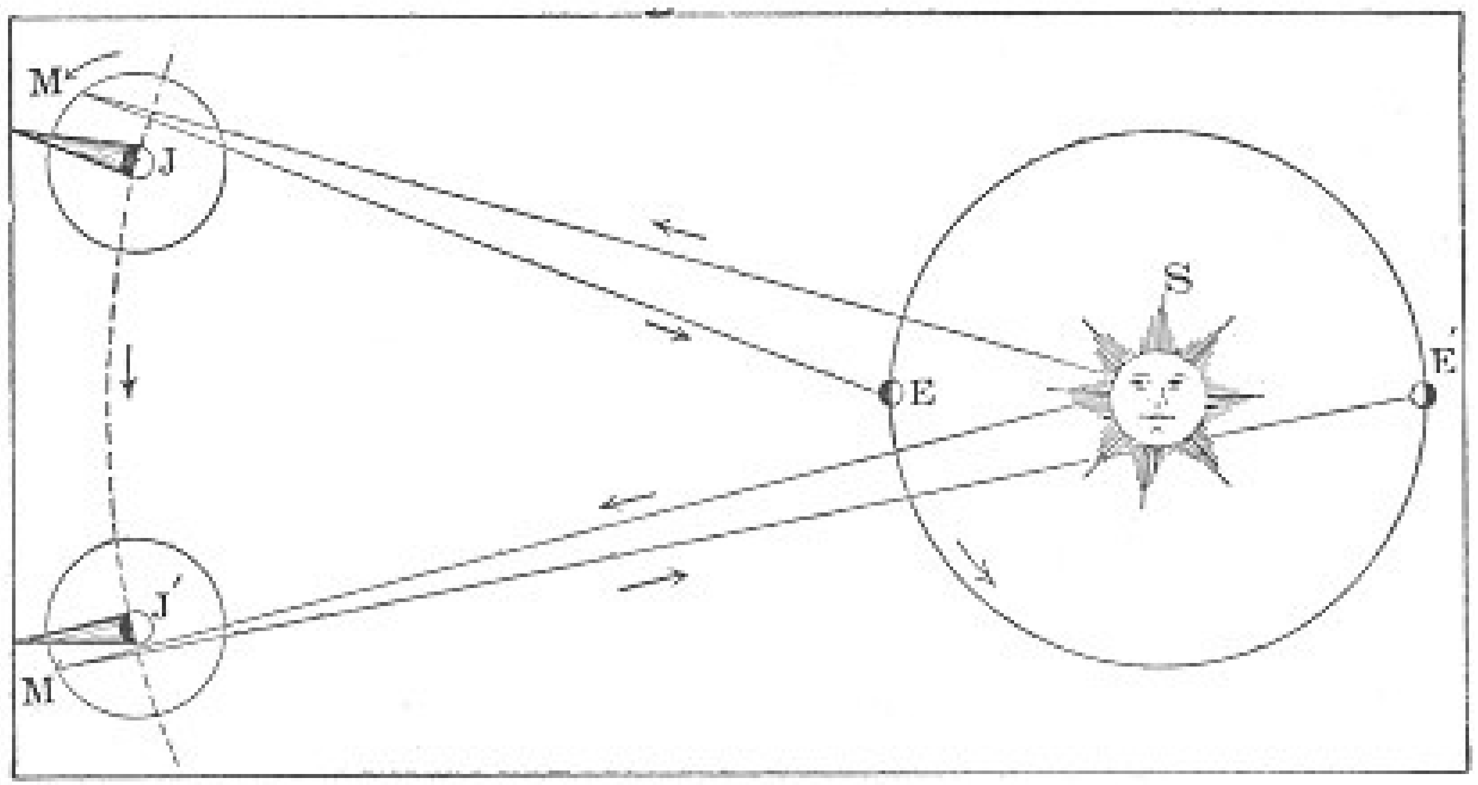
We know that charges cause Electric fields, and that moving charges cause Magnetic fields. Faraday showed that changes in magnetic fields can cause electric fields.

Maxwell discovered that the theory, written down mathematically, is not as symmetric as it could be. He decided the theory would be much more beautiful if there were also a term that corresponds to a changing electric field causing a magnetic field. No one had observed this (yet), but Maxwell proposed this on purely mathematical grounds.

If this was correct, then there would be electromagnetic waves, and one could also calculate the speed of such a wave which would be about 3×10^8m/s. This speed had been observed before!

The speed of light

Galileo had tried to determine if light had a finite speed by bouncing light off a faraway mountain, but he could measure no delay.



By looking at the apparent orbital speed of Jupiter's moon Io, we can see that there is a small but visible difference depending on Jupiter's and earth's relative position. This can be attributed to a finite speed of light if the speed of light is about $3 \times 10^8 m/s$.

Maxwell's theory

Maxwell (1831–1879) completed the equations for electromagnetic phenomena (deducing that changing electric fields also cause magnetic fields).

Electromagnetic waves and light are one and the same thing!

Electromagnetic Wave Theory of Light
Every vibrating charged object creates a disturbance (wave) in its own electromagnetic field. This disturbance spreads outward through the field at **light-speed**, 300,000 km/s or 3×10^8 m/s. Light is just such an electromagnetic wave.

Fields are real

Since fields contain energy, they are physical objects.

This is a significant change from Newtonian Physics where the Physical reality was thought to be completely described by particles!

Einstein:
We may say that, before Maxwell, Physical Reality, in so far as it was to represent the processes of nature, was thought of as consisting in material particles. . . . Since Maxwell's time, Physical Reality has been thought of as represented by continuous fields, . . . and not capable of any mechanical interpretation. This change in the conception of Reality is the most profound and the most fruitful that physics has experienced since the time of Newton.

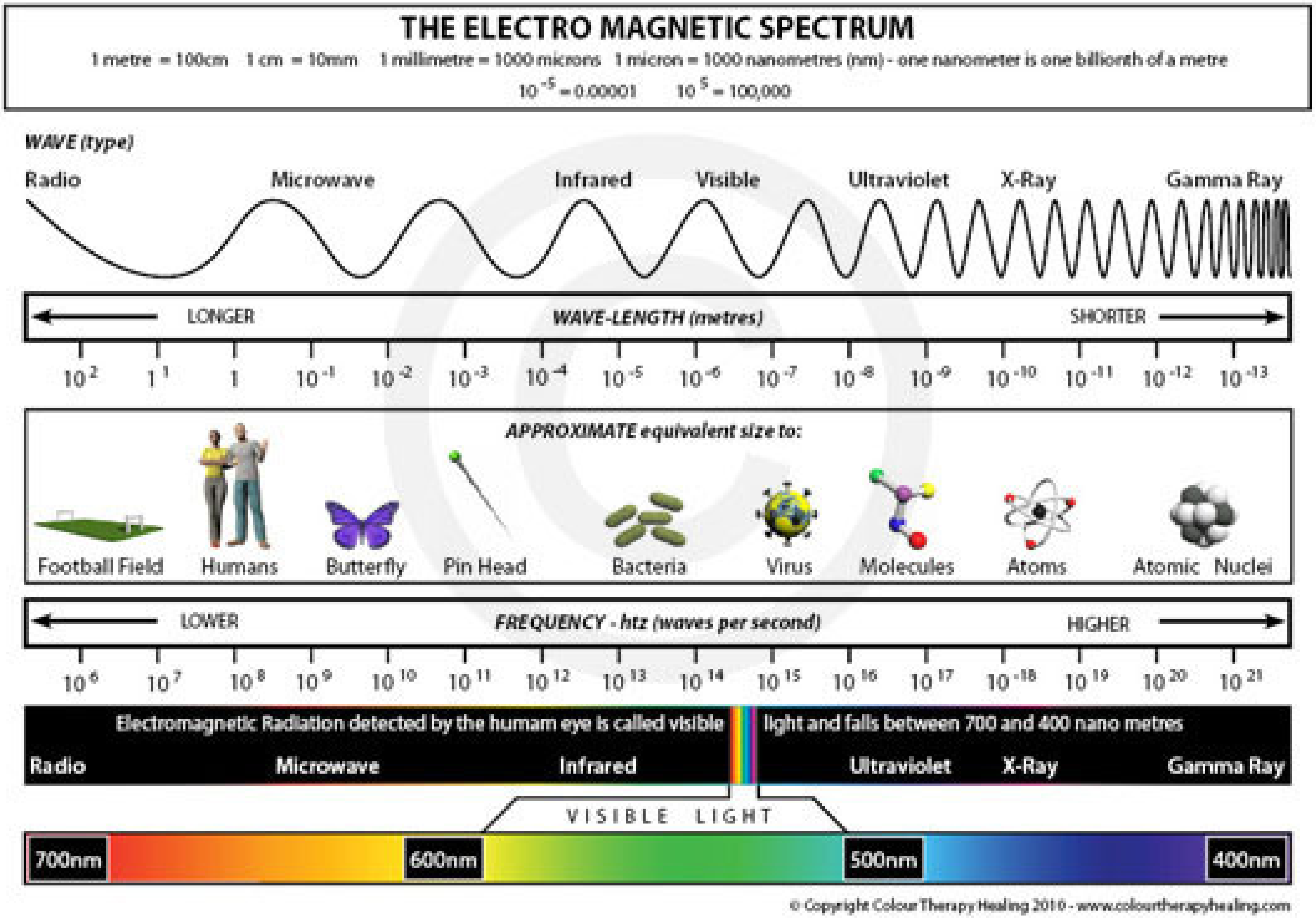
Electromagnetic waves

As charged objects can be wiggled with different frequencies, we can generate electromagnetic waves with different frequencies f. All of these frequencies correspond to different wave length according to our formula

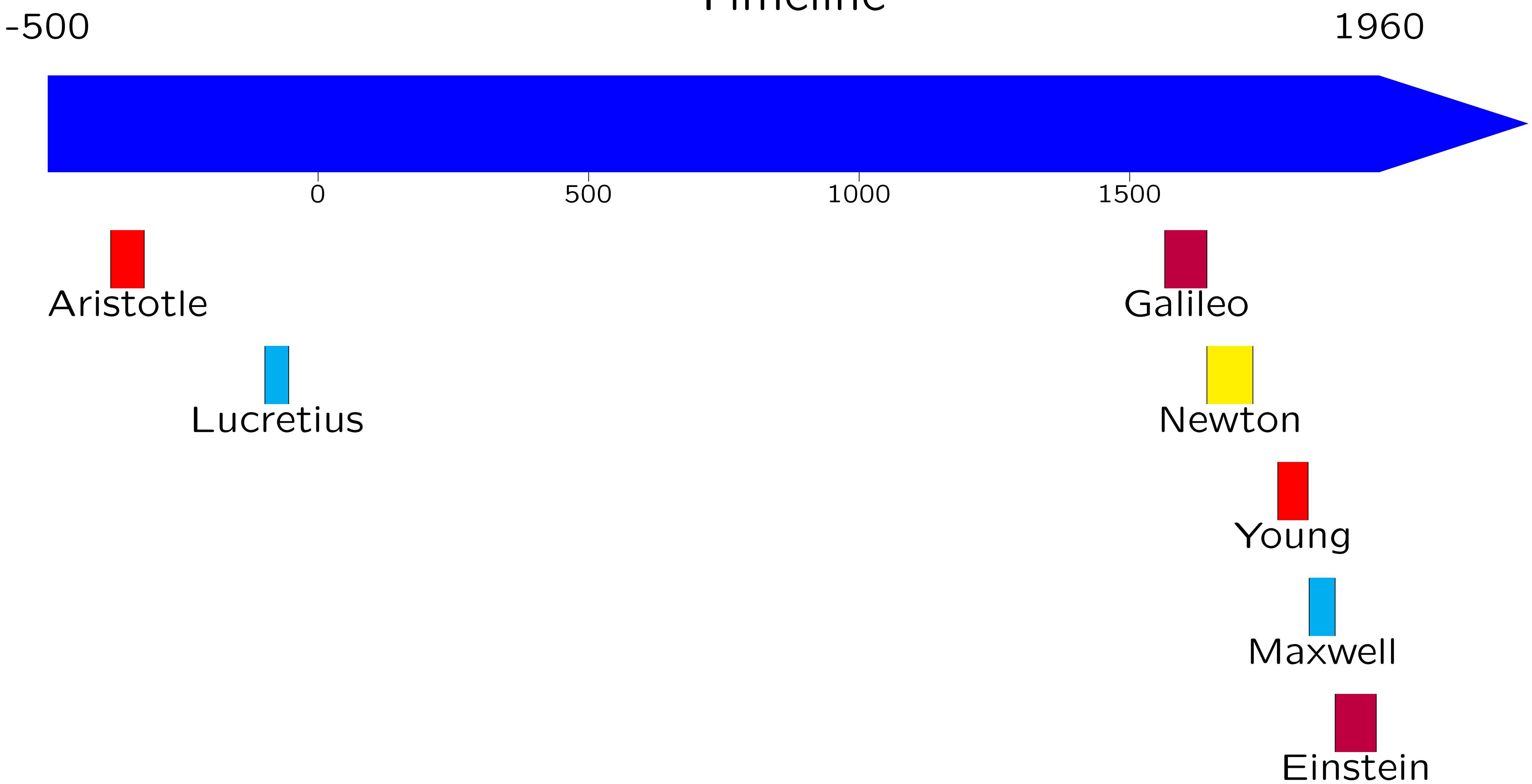
$$\lambda = c/f$$

where $c = 3\ 10^8$ is the speed of light.

Electromagnetic Spectrum



Timeline



-500
1960
0
500
1000
1500
Aristotle
Galileo
Lucretius
Newton
Young
Maxwell
Einstein

Summary

- waves are everywhere.

- simple plane waves have a well defined wavelength λ and frequency f, and their speed is given by $c = \lambda f$.

- Maxwell discovered that changing electric fields induce magnetic fields, which meant that electromagnetic waves should exist, moving with a speed of 3 $10^8 m/s$.

- That is the speed of light, and it turns out that light is just an electromagnetic wave.

- There appears to be no medium for electromagnetic waves. Initially a medium, the *ether* was postulated, but experimentally it did not appear to exist.

- The spectrum of electromagnetic waves contains many important phenomena from radio waves over visible light to x-rays!