

# Lecture 10 Maxwell and Electromagnetic Waves


## The Electromagnetic Field is Real Moves at speed of light!

$\vec{E}$  &  $\vec{B}$

speed of light?

Ether?

Action at a Distance?



Maxwell

$v = f \lambda$

## Announcements

- **Today:** Electricity and Magnetism Continued  
Homework 5 given out; due October 15
- **Speed of light measured**
- **Maxwell and his equations**
- **Maxwell showed electromagnetic waves move at speed of light - light is electromagnetic wave!**
  - March( Ch 6 ), Lightman( Ch 3)
- **Next Time: Waves and Light - Interference**
  - March (Ch 7)
- **Next Week: Einstein and the birth of relativity**
  - Lightman( Ch 3 ), March (Ch 8)

## Light

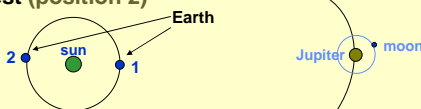
- At first sight there is **NO** connection between light and electricity and magnetism.
  - Light is not affected by magnets or electric forces, etc.
- **Light is generated by electric discharges, but this appears to be just a conversion of energy from one form to another**
- **One of the great triumphs of science** - to show that two things that appear so different are in fact described by the same simple laws!

## What was known about the Speed of Light by the 1800's?

- **The first measurement.**
- Ole Roemer (1644-1710), a Danish astronomer, found in 1675 that the observed orbital period of Jupiter's moons varied with time.
- **Newton's theory predicts the orbital period to be a constant.**
- **Should we conclude Newton's theory is wrong?**
- **No. Instead the evidence for Newton theory is so strong that Roemer's observation was used to say something about light!**

## The Speed of Light

- Ole Roemer found that Jupiter's moons are eclipsed by the planet about **16 minutes earlier** when the Earth is closest to Jupiter (position 1) than when it is furthest (position 2)

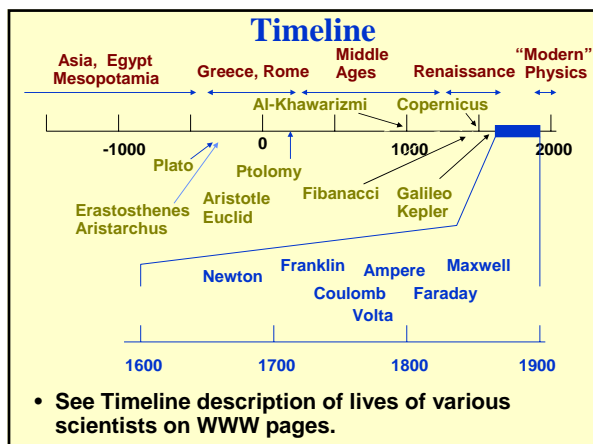


- **Explanation? Newton's laws wrong?**
  - **No.** Light has a finite speed. When Jupiter is further from the Earth, it takes a longer time for the information about the eclipse to reach the Earth.
  - **Quantitative estimate:**
    - $c = \text{Speed of light} = (\text{diameter of Earth's orbit} / 16 \text{ minutes})$
    - $= 190,000 \text{ miles/second.}$
- Impressive! --- the accepted value now is 186,000 miles/sec

## The Speed of Light

- **Later measurements**
  - **Careful measurement in the laboratory on earth (Fizeau) around 1850 gave a more accurate value**
  - **By the time Maxwell published his equations (1873) the speed of light was rather well established**
- Accepted value now**
- $c = 299,792,500 \text{ m/s}$
- or  $c = \text{about } 300,000,000 \text{ m/s} = 3 \times 10^8 \text{ m/s}$
- $= \text{about } 186,000 \text{ miles/sec}$

# Lecture 10 Maxwell and Electromagnetic Waves



### Electricity and Magnetism

- In the last lecture we reviewed the Newtonian **paradigm** of particles and forces.
  - We discussed **electric and magnetic forces**
- Recall electric forces are between charged bodies; magnetic forces act on moving charged bodies
- **Question 1: What “carries” the forces between the bodies**
  - Faraday proposed that a “field” due to a charged body #1 extends throughout space
- The force on body #2 is determined by the field at the position of that body (the field is due to body #1)
- **Question 2: Do electric and magnetic forces act instantaneously between two bodies? Are there fields that travel at a finite speed?**

### Electricity, Magnetism, Gravity

- Recall electric forces are similar to gravitational forces
- **Electrostatic Law**  $F_E = K q_1 q_2 / R^2$  (**Coulomb's Law**)
- **Gravity:**  $F_G = G m_1 m_2 / R^2$  (**Newtons Law**)
- **The same questions apply to gravity: Do gravitational forces act instantaneously between two bodies?**
  - This was a problem for Newton!
- Are there gravitational fields?

### Fields

- Today we will continue our study with a discussion of the fields.
  - Faraday argued that there are **electric and magnetic fields** that extend throughout space that carry the forces. **Fields are created by charges and the fields cause forces on other charges.**
- How do we know the fields are real, not just mathematical tricks?
- **Maxwell's work is what puts it together – the fields are real!**

### Electric and Magnetic Fields

- **Demonstrations - Interpretations**
  - **Fields are created by charges and the fields cause forces on other charges.**
  - 1. **Coulomb's law** - relates electric field to charges
  - 2. **Ampere's law (Generalized)**- moving charge or changing electric field generates a magnetic field
  - 3. **Faraday's law:** changing magnetic field generates an electric field
- **Demonstrations show the effects – but can you “see” the fields**

### James Clerk Maxwell

- **Born Nov. 13, 1831, in Edinburgh, Scotland**
  - the year that Samuel F.B. Morse first conceived the telegraph
- **Died Nov. 5, 1879, in Cambridge England**
  - the year that Thomas Edison was doing his first early work to invent the light bulb.
- **Life**
  - Child of wealthy family
  - Attended Edinburgh Academy, Edinburgh University and Cambridge University
  - Wrote first paper at age of 14
  - Cavendish Professor 1871-1879
- **Great physicist**
  - Revolutionary work in electromagnetism and theory of gases.
  - Wrote the final chapter of classical physics

# Lecture 10 Maxwell and Electromagnetic Waves

## Maxwell - Electricity & Magnetism

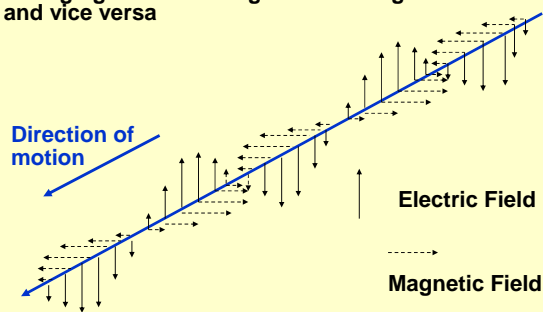
- James Clerk Maxwell: **Treatise on Electricity & Magnetism (1873)** is the last word on classical E&M
  - Ranks with Newton's work as one of the great accomplishments of physics
- Maxwell's Equations
- Four equations that completely describe all of electricity and magnetism
  1. **Coulomb's law** - relates electric field to charges
  2. **Ampere's law (Generalized)**- moving charge or changing electric field generates a magnetic field
  3. **Faraday's law**: changing magnetic field generates an electric field
  4. **Absence of free magnetic "charges"** (only pairs of north-south poles)
- You are NOT responsible for the equations!

## Maxwell - Electricity & Magnetism

- Maxwell's equations show that electric and magnetic forces **travel at a definite predicted speed** - **NOT instantaneous "action at a distance"**
- Travel as **electromagnetic waves** - recall that a **changing electric field generates a magnetic field and vice versa**
- Travel in free space (vacuum) at a speed determined by the constants in Coulomb's law and Faraday's law
- Using values for the constants measured in the laboratory, speed predicted to be equal to the speed of light!
 
$$c = 3.0 \times 10^8 \text{ m/s}$$

## Electromagnetic Wave

- Electromagnetic wave in vacuum (free space)
- Changing electric field generates magnetic field and vice versa



## Maxwell – Electromagnetic fields

- No problem now with "action at a distance". Fields are **real** and they **transmit forces at finite speed!**
  - Very fast but finite speed!
- The waves are real because you can detect them long after the source has changed – e.g., you can see light from galaxies emitted billions of years ago
- Electrical and magnetic forces transmitted by waves that move at speed  $c$  in through space

## How can light travel through space?

- Light is an **electromagnetic wave** - also radio waves, infrared radiation that we feel as heat
- But what is waving?
  - **Maxwell's answer**: Light is a wave in the "ether" .. an invisible, massless substance which permeates all space.
  - Is this a "scientific" proposition?
  - Science pursues the details relentlessly! All propositions must be **tested** and shown to be consistent or inconsistent with observations.
  - **More on this later** - this is the beginning of the downfall of Newtonian physics

Ether?



Maxwell

## Summary

- Until the work of Maxwell light appeared to have no connection to electricity or magnetism
  - Travels at speed  $c$  about 300,000,000 m/s (known before Maxwell)
- Maxwell's (1873) theory of electricity & magnetism
  - Four equations that completely determine all of E & M
  - You are NOT responsible for the equations!
  - Newton's and Maxwell's equations describe all "classical physics"
- Maxwell's equations lead to electromagnetic waves
  - Electric and magnetic forces are NOT instantaneous "action at a distance forces"
  - Move as electromagnetic fields that travel at a velocity determined from E&M constants =  $c$  = speed of light !
- Light is an electromagnetic wave!
  - What is a wave? (Next lecture) What is waving?
  - How can light go through free space (vacuum)?
  - What does light travel through?
  - The "Ether" ?? -- a massless substance invented to carry light??