Lecture 6

Phy 100. Electromagnetism, Waves

- Posted Presentation Topics: Let me know if you have a topic I should include, by Feb. 15.

- Groups with assigned topics should be decided by March 1st.

- Exam 1 will be on Wed. Feb 17 (two weeks!)

- Next Tuesday Feb 9 at 8pm, Gleason 318
Public Lecture on Wave-Particle Duality.
RECAP: SPECIAL THEORY OF RELATIVITY RELATES OBSERVATIONS OF ANYTHING BETWEEN INERTIAL REFERENCE FRAMES

SPACE & TIME GET MIXED UP → SPACETIME

OTHER PHYSICAL QUANTITIES: ENERGY, MOMENTUM, ELECTRIC FIELD...

ALSO TRANSFORM AND CAN GET MIXED TOGETHER:

ENERGY + MASS: $$E = mc^2$$

ELECTRIC + MAGNETIC FIELD
Q. Observer sees force between static charges \( \Rightarrow \) electric

Q. Now if the observer is moving by, the charges will look like they are moving (currents) \( \Rightarrow \) the force is now seen to be magnetic (in part)

What we perceive as electric or magnetic field is relative!
REMEMBER RELATIONSHIP BETWEEN E AND M FIELDS:

Moving electric charge creates a magnetic field.

Magnetic field exerts a force on moving charge.
RELATIONSHIP BETWEEN ELECTRIC AND MAGNETIC FIELD IS VERY DEEP.

**MAXWELL'S EQUATIONS (1864)**

\[ F = q E = \frac{q}{c^2} \frac{\mathbf{Q}}{d^2} \]

1. \[ \oint \mathbf{E} \cdot d\mathbf{a} = \frac{Q_{\text{enclosed}}}{\varepsilon_0} \]
   - **GAUSS LAW**
   - FLUX OF E THROUGH A CLOSED SURFACE S
   - ELECTRIC CONSTANT

2. \[ \oint \mathbf{B} \cdot d\mathbf{a} = 0 \]
   - **GAUSS LAW OF MAGNETISM**
   - NORTH POLES AND SOUTH POLES COME IN PAIRS.
   - MAGNETIC FIELD LINES COME IN LOOPS.

CHARGED OBJECTS CREATE E FIELDS
3) \[ \oint_C \vec{E} \cdot d\vec{l} = - \frac{d}{dt} \oint_S \vec{B} \cdot d\vec{a} \]  
**FARADAY LAW OF INDUCTION**

A CHANGING MAGNETIC FIELD INDUCES AN ELECTRIC FIELD

4) \[ \oint_C \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}} + \mu_0 \epsilon_0 \frac{d}{dt} \oint_S \vec{E} \cdot d\vec{a} \]  
**AMPERE'S LAW WITH MAXWELL'S CORRECTION**

MAGNETIC FIELDS CAN BE CREATED BY ELECTRICAL CURRENT AND BY CHANGING ELECTRIC FIELDS.

MAXWELL UNIFIED ELECTRICAL AND MAGNETIC FORCES INTO ELECTROMAGNETISM
At point P, as fist swoops by there is a changing electric field.

Maxwell’s eqns tell us that this creates (or induces) a changing magnetic field in the vicinity of P...

And this produces a changing E field.... etc....

The cycle of E and B field creation propagates outward at the speed of light.

Light is a wave.
INTRO TO WAVES

WAVES ARE A WELL KNOWN MECHANICAL PHENOMENON.

1) WAVE PULSE TRAVELING ON A STRING
2) SOUND WAVES TRAVELING IN AIR
3) WATER WAVES IN THE OCEAN
4) "MEXICAN" WAVE IN A SPORTS STADIUM
5) LIGHT

ABSTRACTION: A WAVE IS A DISTURBANCE CARRYING ENERGY IN A MEDIUM.
Ex: IMAGINE A WAVE TRAVELING ON THE SURFACE OF WATER

AS WAVE MOVES PAST, THE CORD BOBS UP AND DOWN WITHOUT MOVING LEFT OR RIGHT.
CHARACTERIZING A WAVE

1) DIRECTION OF MOTION
2) AMPLITUDE: MEASURE OF ENERGY AND INTENSITY.
3) WAVELENGTH: $\lambda$ LENGTH WITH WHICH WAVE REPEATS
4) PERIOD: THE AMOUNT OF TIME IT TAKES FOR THE cork to bob THROUGH A FULL CYCLE.
   \[ T = \frac{\lambda}{\text{the wave moves a distance } \lambda \text{ in a time } T \text{ (one period)}} \]
5) FREQUENCY: $f = \frac{1}{T} = \frac{1}{\text{seconds}} \equiv \text{Hz} \text{ (HERTZ)}$
Freq corresponds to pitch in sound waves.

- Sound with high $f$ → You perceive it as having high pitch
- Low $f$ → Low pitch

Freq. corresponds to color in light waves

- High $f$ → More blue
- Low $f$ → More red

Velocity of a wave: $v = \frac{\lambda}{T} = \lambda f$ because $f = \frac{1}{T}$

Light in vacuum: $c = \lambda f$

Speed is a property of the medium
Maxwell realized that E and B spread outwards from moving charged fist at some finite speed $c = 3 \times 10^8$ m/s. "His" $c$ coincided with the numerical value known for the speed of light! Light is an electromagnetic wave.